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FOREWORD

The Global Maritime Congress (GMC'24), which is organized for the fifth time with the partnership of Istanbul Technical University Faculty of Maritime, UCTEA The Chamber of Marine Engineers, Batumi State Maritime Academy, Constanta Maritime University, Strathclyde University, represents a significant milestone in the ongoing dialogue and collaboration across the global maritime sector. This gathering brings together leading academics, researchers, industry professionals, and key stakeholders to explore the latest innovations, developments, and emerging trends in maritime technology and transport.

This year's Congress aims to highlight critical topics that are reshaping the future of maritime transport, including advancements in Maritime Transportation Management and Technologies, Port Operations, Risk Assessment, Maritime Policy, Law & Governance, and Maritime Safety & Security. In addition, discussions will delve into sustainability challenges, climate change impacts, and the role of emerging technologies in enhancing operational efficiency and environmental stewardship across the maritime sector.

With over 140 presentations covering a wide range of topics such as alternative fuels & renewable energy, best practices & new concepts in MET, cyber security at sea, energy efficiency & energy management, human factor, marine environment and technologies, marine risk assessment, maritime policy, law & governance, maritime economy, maritime safety & security, maritime transportation & management, naval architecture & offshore technologies, and seafarers' wellbeing, the Congress provides a unique platform for exchanging knowledge, sharing research, and fostering collaboration among international experts.

We extend our heartfelt thanks to our sponsors, partners, and all participants, whose contributions have been instrumental in bringing this event to life. Special recognition is also due to the organizing committee, whose tireless efforts have ensured the success of this congress.

We are confident that the proceedings of this Congress will serve as a valuable resource for shaping the future of maritime transport, fostering innovation, and driving sustainable solutions for the challenges ahead.

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Section 1

Maritime Safety & Security

Harmonizing Navigation Safety: A Metaheuristic Journey in Ship Steering Control Optimization

Tayfun Uyanık

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Abstract

Amidst the maritime industry's rapid growth, intensified trade, and increased vessel numbers, navigational safety and emissions reduction have become paramount concerns. The International Maritime Organization (IMO) has responded with stringent regulations, prompting the industry to seek cost-effective strategies. This study addresses this challenge by proposing an economical enhancement to ship steering control through the application of the proportional–integral–derivative (PID) method.

The research focuses on the development of a rudder system based on the ship's motion equations, with MATLAB/Simulink software utilized for optimal PID parameter computation. Employing diverse optimization algorithms—genetic algorithms, multi-objective genetic algorithms, particle swarm optimization algorithms, simulated annealing algorithms, and gravitational search algorithms—the study reveals the superior performance of the gravitational search algorithm.

This innovative approach not only aligns with IMO regulations but also underscores the importance of cost-effectiveness in implementation.

Keywords: *Maritime industry, PID control, Optimization, Metaheuristic algorithms.*

1. Introduction

In recent years, the maritime industry has borne the primary responsibility for the transportation of commercial cargo [1]. The proliferation of commercial ships and the consequential strain on the maritime sector have led to a notable increase in marine accidents and ship emissions. This circumstance prompted the establishment of the International Maritime Organization (IMO), tasked with formulating laws and regulations governing the maritime domain [2]–[4]. To adhere to IMO norms, enhance voyage safety, mitigate ship-related emissions and energy consumption, and prevent pollution, maritime enterprises find themselves compelled to make extensive modifications to their vessels [5]. Some of these enhancements pose a considerable financial burden on transportation businesses. In response to the heightened expenses imposed by regulations, maritime enterprises have engaged in research and development, seeking cost-effective approaches [6].

The acquisition of new ships and the integration of new technologies into existing vessels have become increasingly costly, as evidenced by research focusing on predictive maintenance for ships as a cost-effective application. While maintenance serves to prolong a ship's service life, associated costs continue to escalate, particularly towards the end of the ship's life cycle due to factors such as corrosion and wear and tear [7]. Efficient utilization of the electrical system on board ships is identified as a cost-effective and emission-reducing application, with coastal power and electrical propulsion systems being environmentally benign. The Particle Swarm Optimization (PSO) technique has been employed for optimizing the management of a ship's electrical power system, resulting in potential reductions in operational expenses [8].

Research underscores that a ship's energy management strategy can be determined through accurate estimations, even in the absence of prior knowledge about power demand in ships, employing reinforcement learning methods. This highlights the significance of establishing an energy management strategy to contend with energy costs [9]. Machine learning algorithms have been applied to estimate ship fuel consumption, evaluating cost-effective methods to enhance energy efficiency. Anticipating fuel consumption accurately is proposed as a means to reduce the quantity of fuel consumed during a voyage [10].

In recent years, the scholarly discourse pertaining to the control of motion systems on ships has experienced a notable surge in research endeavours. A particularly noteworthy study in this field implemented a decision-making algorithm designed to modify the course and speed of a ship, thereby mitigating the risk of collision [11]. The PID (Proportional-Integral-Derivative) controller has emerged as a particularly effective technique for addressing structural constraints and complexities inherent in a ship's steering system. It is proposed that surmounting these challenges holds the potential for achieving cost-effective navigation safety and enhancing energy efficiency [12].

Research has demonstrated that the adept management of a ship's rudder system contributes to enhanced cruise safety [13] and heightened energy efficiency, particularly during scenarios requiring precision manoeuvring [14]. The PID controller, as affirmed by reviewed studies [15]–[17], exhibits successful regulation of the ship's steering system, necessitating a meticulous determination of steering system features and the acquisition of transfer functions for successful control [18].

Heuristic optimization algorithms have emerged as successful tools for controlling complex and nonlinear systems, particularly in the optimization of PID controller coefficients for ship steering systems [19]. In light of the challenges associated with traditional PID calculation approaches, this study employed heuristic optimization algorithms, including the genetic algorithm (GA) [20], Multi-Objective Genetic Algorithm (MOGA) [21], Particle Swarm Optimization Algorithm

(PSO) [22], Simulated Annealing Algorithm (SA) [23], and Gravitational Search Algorithm (GSA) [24]. These algorithms were employed to optimize the linear PID controller coefficients for the ship steering system. This study contributes to the literature in the following ways:

- A comparative analysis of the performance of five different metaheuristic algorithms based on the ship steering system PID controller optimization problem.
- The application and successful results of GSA, SAA, and PSO algorithms for the first time in the ship steering system PID controller optimization problem.
- Investigation of the effects of external factors such as wind, waves, and currents on the ship's steering system controller in addition to stagnant water conditions.

The subsequent sections of this paper are organized as follows: Section 2 provides a description of the ship steering system and the methodologies employed. In Section 3, a case study is presented. Simulations are conducted in Section 4, and the results are discussed. Finally, Section 5 offers conclusions and addresses the implications of the study.

2. Material and Methods

2.1. Ship Steering System Principle

The steering and rudder systems play a pivotal role in ensuring the marine vessel's precise directional control during both cruising and manoeuvring. The ship's movement is orchestrated within the $X_0 - Y_0$ coordinate system, and the force components of this motion are illustrated in Figure 1 [17].

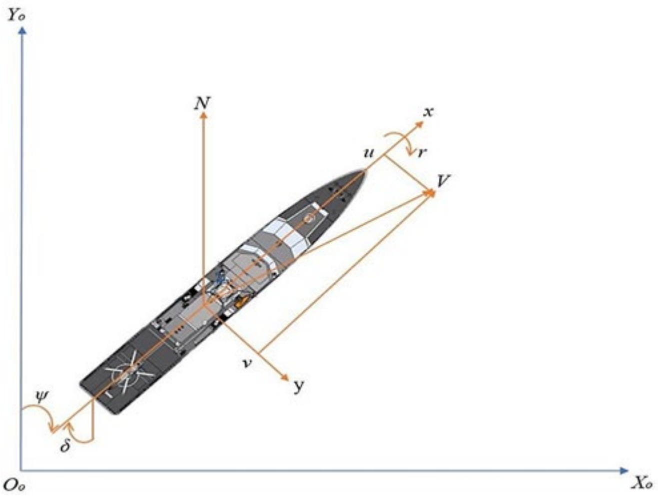

Figure 1. Ship motion components.

In Figure 1, the ship's directional coordinates are presented in the *x-y* coordinate system, incorporating the yaw angle (ψ), rudder angle (δ), total velocity (V), roll motion (u), pitch motion (v), and yawing rate (r). The transfer function governing the relationship between the rudder angle and yawing rate is expressed as Eq. 1, based on Nomoto's model [26], specifically for rudder angles less than 5°.

$$\frac{r(s)}{\delta(s)} = \frac{K(1+T_3 s)}{(1+T_1 s)(1+T_2 s)} \tag{1}$$

Here, '*s*' denotes the Laplace operator, and 'K' represents the gain constant. Time constants are denoted by T_i ($i=1, 2, 3$). The connection between yaw angle (ψ) and yawing rate (r) is defined by Eq. 2.

$$\psi'(t)=r(t) \tag{2}$$

The calculation of Laplace operator (K) and time constant (T) parameters is conducted in accordance with Eq. 3 and Eq. 4, respectively.

$$K=K^*(U/L) \tag{3}$$

$$T_{1,2,3}=T^*_{1,2,3}(L/U) \tag{4}$$

where and are representing dimensionless gain constraint and time constant [16], respectively. The ship's forward speed is shown with U and length is presented as L. In this paper, $U = 5$ *m/s*, $L = 350$ *m*, $K^* = 0.83$, $T_1^* = -2.88$, $T_2^* = 0.38$, $T_3^* = 1.07$ used and for the calculation of $T = T_1^* + T_2^* - T_3^*$ used [17]. With these calculations, eq. 1 is converted to eq. 5 as follows.

$$\frac{\psi(s)}{\delta(s)} = \frac{K}{(1+Ts)s} \tag{5}$$

The block diagram of the ship steering system and steering machine are shown together in Figure 2.

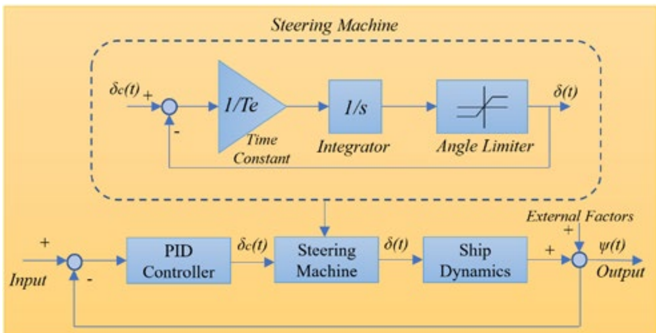

Figure 2. Block diagram of the steering system and machine.

Figure 2 depicts the commander rudder angle, actual rudder angle, and yaw angle as , , and , respectively. The time constant of the steering machine is shown as which is 2.5 seconds. Angle limiter is ranged from −35° to +35° which is determined according to the international standard for the ship steering system [27]. Variables such as wave, wind, and current affecting the motion of the ship are expressed by external factors.

2.2. Control Principle

Control systems are architectural frameworks designed to regulate the behaviours of devices or systems. These systems typically oversee a variety of devices based on signals received from sensors and other data sources. Depending on the intended application, control systems come in various types, including fuzzy logic, on-off control, and PID control [28].

The fuzzy logic method exhibits efficacy in poorly defined nonlinear and complex control systems, providing notable advantages. However, the design process in the fuzzy logic method requires expert opinions, and determining membership functions can be a time-consuming endeavour. Consequently, if the system is well-defined, resorting to fuzzy logic solutions may be unnecessary. On-off control, a straightforward method, finds common application in heating systems and the control of non-vital industrial systems. Despite its simplicity, this control method is often avoided due to its unsuitability for multipurpose use, limited effectiveness, and propensity to induce oscillations.

PID controllers stand out as one of the prevalent control systems in industrial applications. This method involves the creation of a control function for the system using proportional, integral, and derivative components. Application of this function to the system results in effective control [29]. The ideal formulation of the PID control function is expressed in Eq. 6.

$$K(s)=Kp\left(1+\frac{1}{K_i s}+K_d s\right) \tag{6}$$

In the presented equation, represents the control function, wherein denotes the proportional coefficient, and and signify the integral and derivative coefficients of the function, respectively [30]. In the context of this study, the selection of the ideal PID controller is motivated by the objective of mitigating the adverse effects associated with the controller, notably the introduction of noise signals into the system due to the presence of the derivative coefficient.

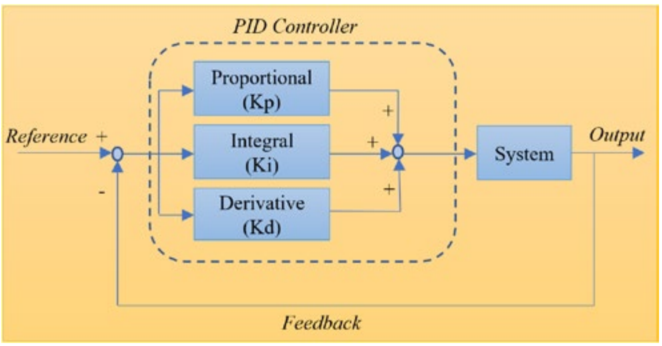

Figure 3. Basic concept of the PID controller

2.3. Metaheuristic Optimization Algorithms

As a result, metaheuristic optimization methods are extensively applied to address a diverse array of optimization challenges. Numerous studies have underscored their pronounced efficacy, particularly in the computation of PID controller coefficients for the control of nonlinear systems [14], [18], [31]. In the context of this study, the determination of coefficients for the ship steering system's PID controller is carried out through the employment of metaheuristic optimization methods, including Genetic Algorithms, Multi-Objective Genetic Algorithms, Particle Swarm Optimization Algorithms, Simulated Annealing Algorithm, and Gravitational Search Algorithm. The ensuing sections provide detailed descriptions of the algorithms employed in this research.

2.3.1. Genetic Algorithms

Genetic Algorithms (GAs) represent a metaheuristic optimization methodology rooted in the principles of evolution and drawing inspiration from human biology [21]. The algorithm is structured to assess the fitness adequacy of solutions generated through stochastic rules, seeking and diversifying potential treatments. This process unfolds within the realm of probabilistic principles, mirroring the mutation of genes in evolutionary theory. Notably, this alteration transpires in binary format throughout the optimization process of the Genetic Algorithm, as illustrated in Figure 4, depicting the flowchart of the Genetic Algorithm.

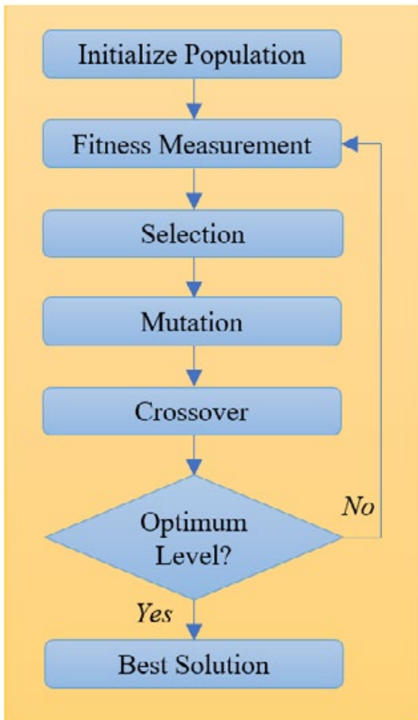

Figure 4. Flowchart of the Genetic Algorithm

2.3.2. Multi-Objective Genetic Algorithms

Multi-objective optimization methods, commonly referred to as Pareto optimization, constitute decision-making systems designed to propose solutions for more than one problem concurrently. Employing GA optimization enables the exploration of multiple segments within a problem's solution space, facilitating the effective resolution of discontinuous, multi-mode challenges. Consequently, the use of GA to address problems across multiple unmapped Pareto solution spaces proves advantageous. Thus, Multi-Objective Genetic Algorithm (MOGA) stands out as a formidable metaheuristic approach for tackling multi-objective problems [22].

2.3.3. Particle Swarm Optimization Algorithms

Particle Swarm Optimization (PSO) adopts an optimization methodology akin to the collective behaviour observed in populations, such as swarming birds. Introduced initially in 1995 [23], PSO has found application in a diverse array of investigations [32], [33]. In comparison to other computer-based approaches, the PSO algorithm is recognized for its computational efficiency [32]. The optimization process commences by generating a random number of particles. Through iterative assessments of each particle's accuracy using the objective function, the process continues until the most accurate particle is identified, achieving the optimization goal upon reaching the correct answer. Figure 5 depicts the flowchart illustrating the Particle Swarm Optimization Algorithm.

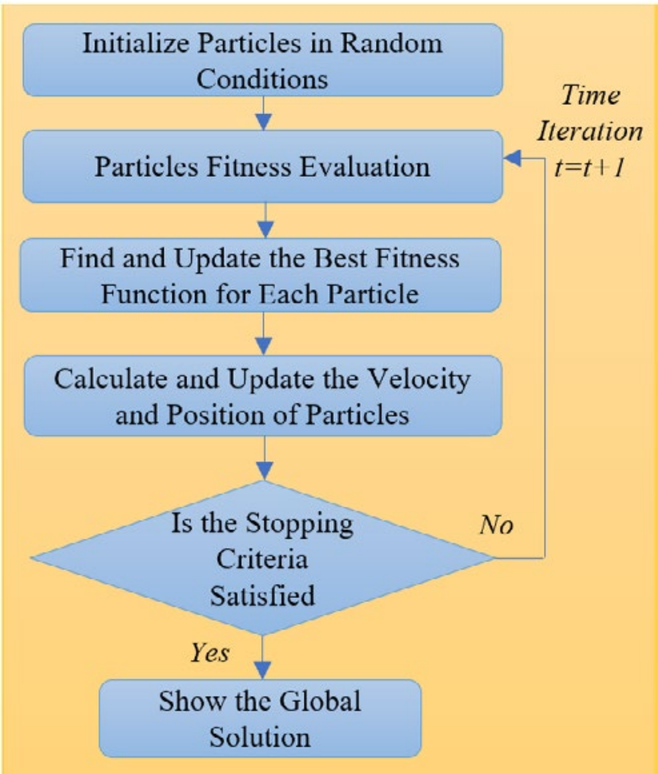

Figure 5. Flowchart of the Particle Swarm Optimization Algorithm

2.3.4. Simulated Annealing Algorithm

The simulated annealing technique is an algorithm inspired by the structural transformations observed in metals as they achieve optimal atomic order during the cooling process. Named for its resemblance to the annealing process, this algorithm proves particularly valuable for addressing complex problems that resist resolution through conventional mathematical models [24]. The optimization phase of the algorithm involves perturbing the design and observing the resultant changes. The algorithm identifies the optimal solution as the deviations in these changes diminish, yielding superior results [34]. Figure 6 provides a visual representation of the Simulated Annealing Algorithm through a flowchart.

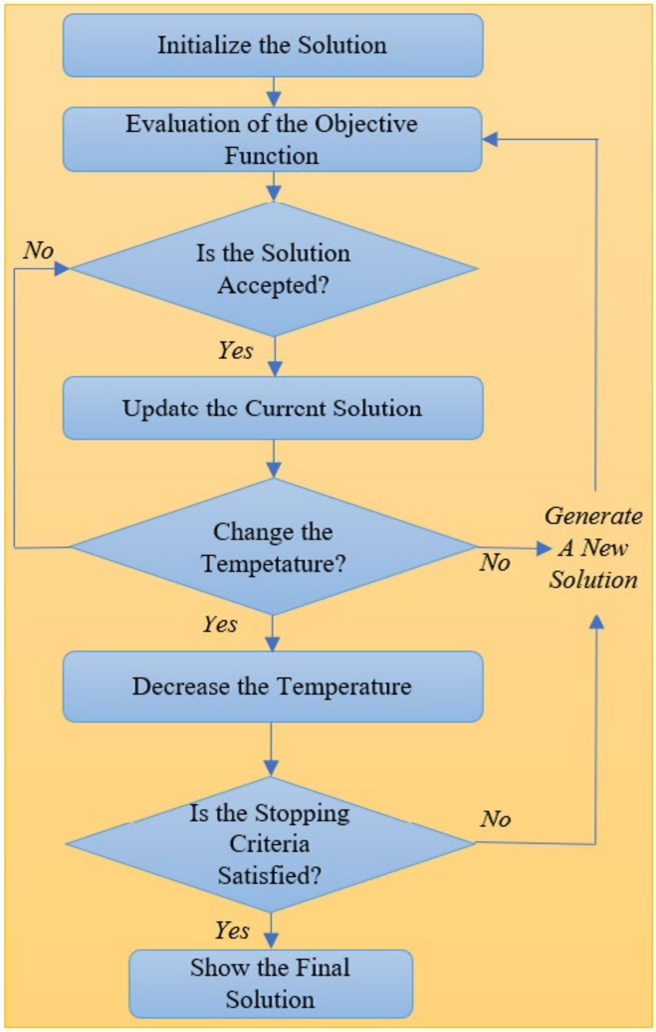

Figure 6. Flowchart of the Simulated Annealing Algorithm

2.3.5. Gravitational Search Algorithm

The Gravitational Search Algorithm (GSA) is a pioneering metaheuristic algorithm devised in 2009, grounded in the principles of Newton's law of gravity [25]. Within the algorithm, individual elements possess a mass corresponding to a performance metric, and entities with lower mass are attracted to those with greater mass, adhering to the principles of gravitational attraction. The fundamental attributes of each element include passive gravity, mass, inertial mass, active gravitational mass, and location. Each element in the algorithm proposes a solution, and as the movement of elements is orchestrated towards the one with the highest mass, the algorithm deduces the optimal solution based on mass values. Figure 7 delineates the flowchart illustrating the Gravitational Search Algorithm.

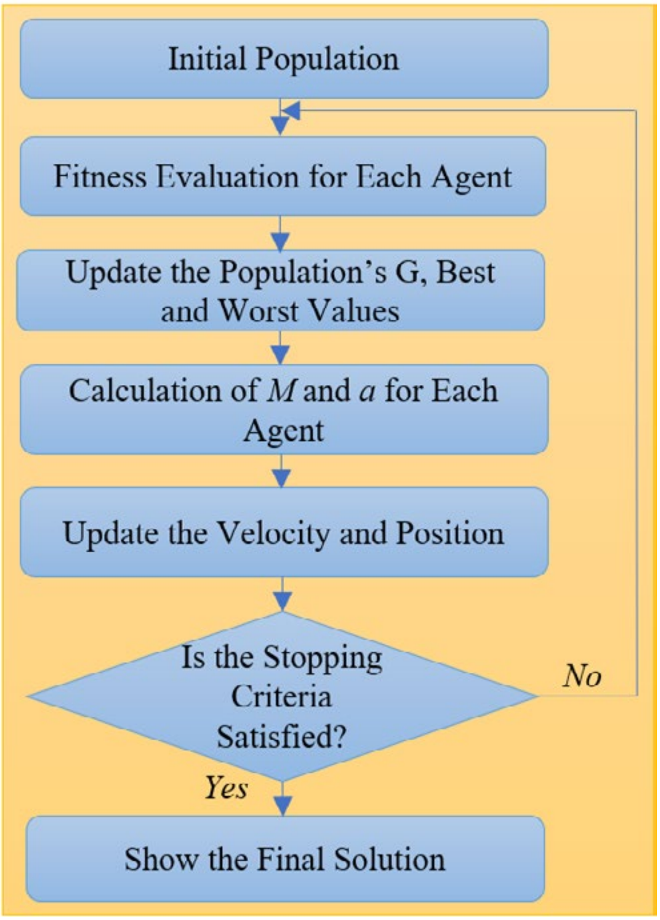

Figure 7. Flowchart of the Gravitational Search Algorithm

3. Case Study

The PID methodology was applied for the control of a ship's steering system, which served as the model in this study. Metaheuristic algorithms were employed to govern the ship's steering system. The initial step involved the construction of the system's transfer function by modelling the dynamics of the ship, accounting for external elements such as wind, waves, currents, etc., and incorporating system limitations. Subsequently, the system was subjected to metaheuristic algorithms, tasking them with the optimization of the PID coefficients for the system controller.

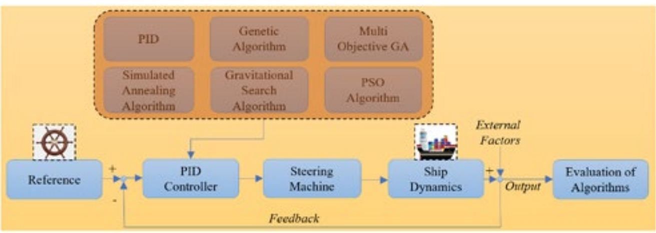

Figure 8. The methodology of the ship steering system PID coefficients' optimization process.

The PID controller values were derived through consecutive execution of the algorithms. Subsequently, a simulation was conducted using MATLAB/Simulink software, and the system was regulated using the PID coefficients generated by the algorithms. The controllers, featuring the PID coefficients developed by the algorithms, evaluated whether each system achieved the specified reference angle in the final step of the simulation. Subsequent to this, the settling time, rising time, overshoot, and undershoot values were assessed. The simulation phase of the study utilized a computing environment equipped with 32 GB DDR4 memory and a 2.6 GHz i7-9750H mobile CPU.

Figure 8 provides an overview of the study's methodology. Figure 9-A presents the control schematic for the ship's steering system, wherein PID controllers, rudder machines, and ship dynamics collectively form the subsystem. Figure 9-B illustrates the simulation approach for this subsystem, while Figure 9-C delineates the system operating under the steering machine system.

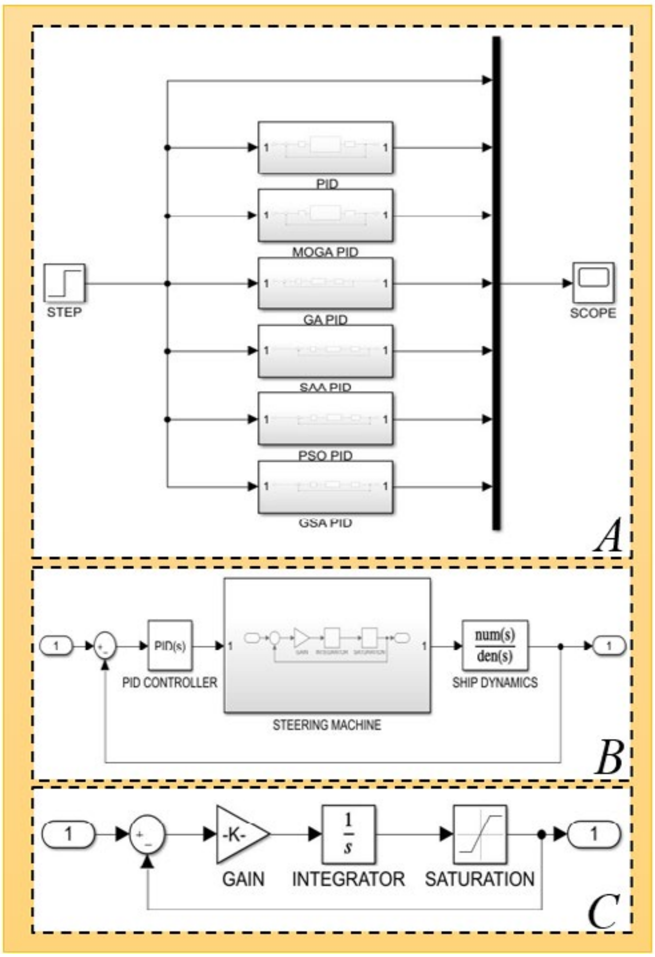

Figure 9. MATLAB/Simulink scheme of ship steering control system (A), MATLAB/Simulink scheme of ship steering control subsystem (B), MATLAB/Simulink scheme of ship steering machine subsystem (C).

4. Simulation Results

The simulation results of the study are detailed below. Figure 10-A provides an illustration of the system's responses when PID controllers, optimized using algorithms, are subjected to a step function as the system's reference input. The introduction of external elements, such as wind, waves, and sea currents, slightly affects the performance of the controllers, as depicted in Figure 10-B, albeit the controllers still exhibit functionality. The parameter bounds for the PID controller coefficients in this specific case study are presented in Table 1. Detailed PID controller coefficients and the corresponding performance metrics developed by the algorithms for the control system are systematically presented in Tables 2 and 3, respectively.

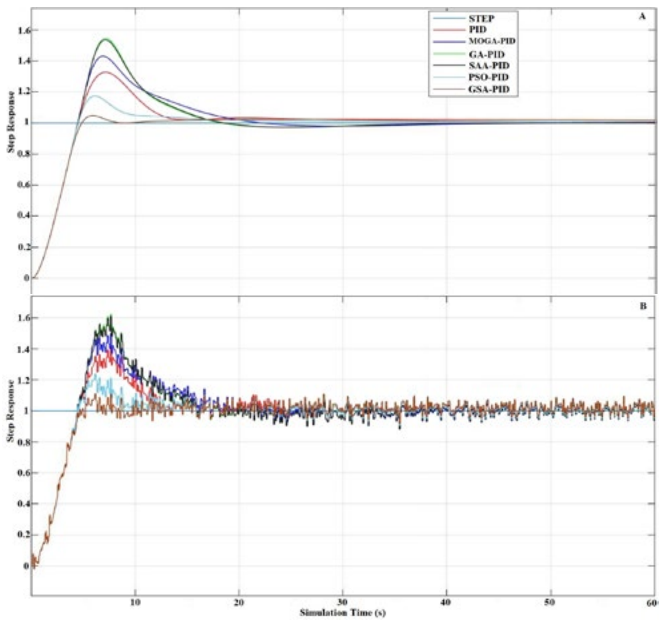

Figure 10. The simulation results of the study: step response of controllers (A), under the external factor effects (B).

In the conducted investigation, the simulation time was specified as 60 seconds, during which system performance metrics were systematically computed. The reference input employed for the assessment was exclusively the step function, and the ensuing system performance metrics were documented. Subsequently, external influences, including wind, waves, and sea currents, were introduced to gauge the system's response and assess potential degradation. Remarkably, the findings indicated that the system-maintained functionality even under disruptive external influences.

The parameter space of the system was determined utilizing the optimization tool integrated into MATLAB/Simulink, allowing for a comprehensive exploration of the system's operational boundaries.

Table 1. Space bounds of PID controller parameter values for algorithms

Controller Parameter	Upper bound	Lower bound
Proportional	1	-300
Integral	1	-50
Derivative	1	-500

Table 1. PID controller parameters proposed by algorithms

Algorithm	Proportional	Integral	Derivative
PID	-71.669	-2.631	-124.267
MOGA	-84.225	-8.049	-299.981
GA	-99.998	-9.999	-299.999
SAA	-97.966	-9.882	-299.967
PSO	-66.744	-0.438	-295.462
GSA	-45.400	-0.510	-290.100

Table 2. Controller performance values

Algorithm	Overshoot (%)	Undershoot (%)	Rise Time (s)	Settling Time (s)
PID	30.921	1.175	3.134	12.404
MOGA	44.203	1.169	3.074	17.675
GA	55.469	1.527	3.080	15.430
SAA	53.077	1.194	3.102	15.588
PSO	17.059	1.884	3.108	10.192
GSA	4.737	1.807	3.192	5.871

5. Conclusions and Discussions

The computation of PID coefficients using conventional methods is acknowledged for its time-consuming nature. To address this challenge, this study employs metaheuristic algorithms for the optimization of PID coefficients within the ship steering system. The initial phase involved instructing the metaheuristic algorithms on the system specifications, followed by the optimization of PID coefficients using the MATLAB/Simulink software. Simulations were then concluded, and the resultant PID coefficients were used to assess system performance metrics.

Several notable observations emerged from the simulations. Metaheuristic methods proved effective in optimizing PID coefficients for the ship steering system. Notably, the GSA method exhibited superior performance by minimizing overshoot values. This is particularly advantageous during challenging manoeuvres, as a minimal overshoot ensures the ship accurately reaches the desired route angle without excessive deviation, thereby reducing fuel consumption. This contributes to enhanced ship energy efficiency and reduced emissions.

Evaluation of undershoot values indicated that they ranged between approximately 1% and 2%, affirming the positive impact of the PID coefficients on the system. Rise time values, calculated in response to the algorithms' PID coefficients, were approximately 3 seconds. Additionally, a review of settling time data in the performance table highlighted that the GSA technique achieved the desired reference angle significantly faster than other methods.

Based on simulation data, the GSA technique outperformed other tested metaheuristic algorithms in the optimization of ship steering system PID coefficients. This underscores the efficacy of the GSA method in enhancing the performance of the ship's steering system and contributes to the broader goal of improving energy efficiency and reducing emissions in maritime operations.

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Improving Maritime Safety: Analyzing PSC Deficiencies with Deep Learning Approach to Prevent Ship Detention

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Abstract

This academic study explores the maritime safety environment through a rigorous review of ship inspection findings conducted by Port State Control Officers (PSCOs) under memorandums of understanding (MoUs). Drawing on a dataset covering a high number of inspection findings from 2020 to 2023 for different ship types and PSC organizations under different MoUs, our study focuses on specific deficiencies, denoted by PSC action code 17, which indicates issues that need to be corrected before departure. The reason for choosing this PSC action code is that action code 17 was heavily detected before action code 30 when it was decided to detain the vessel. The subset generated by filtering PSC action code 17 was rigorously analyzed using a Support Vector Classifier (SVC) based deep learning algorithm and natural language processing techniques to interpret and categorize the port state control officer comments. These processed comments were then integrated into the fault tree analysis method and aligned with the cause categories specified by the American Bureau of Shipping (ABS). The auditor comments were then labelled according to the appropriate cause categories, revealing the causations of the identified deficiencies. The expanded dataset was then used in a statistical learning model to gain insights into the causations of PSC action code 17 findings and their frequency across variables such as PSC organization, vessel type and finding category. The study not only reveals the underlying causes of the deficiencies, but also provides a valuable resource for maritime stakeholders to effectively understand and address these issues. By eliminating the causations of deficiencies, the study argues that the number of deficiencies identified can be reduced and, as a consequence, the inspection performance of both the inspected vessel and the Flag State can be improved and aligned with the objectives of the MoU.

Keywords: *PSC inspections, deep learning approach, ship detention, root cause of deficiencies*

1. Introduction

The maritime industry plays a pivotal role in global trade and commerce, with the safety of vessels being of paramount importance to ensure the smooth functioning of maritime operations. Within this context, Port State Control (PSC) inspections serve as a critical mechanism for upholding safety standards and regulatory compliance in the shipping sector [1], [2]. These inspections, conducted by designated authorities under Memorandums of Understanding (MoUs), aim to identify and rectify deficiencies that pose risks to vessel safety and environmental protection [3], [4].

Despite the widespread practice of PSC inspections, there exists a significant gap in the literature regarding the detailed analysis of inspection findings and the underlying causes of identified deficiencies [5]. This research seeks to address this gap by conducting a rigorous examination of ship inspection data collected by PSC officers (PSCO) over the period from 2020 to 2023.

The primary focus of the study revolves around deficiencies identified during inspections, specifically those denoted by PSC action code 17, which signify issues requiring correction before vessel departure. The rationale behind selecting PSC action code 17 lies in its significance as a precursor to more severe actions such as vessel detention, thus highlighting its pivotal role in maintaining maritime safety standards [6].

To analyze the dataset effectively, the study employs advanced analytical techniques, including Support Vector Classifier (SVC)-based deep learning algorithms and natural language processing (NLP) techniques [7], [8], [9], [10]. By integrating these methodologies, the study aims to interpret PSCO comments, categorize deficiencies, and uncover causations through fault tree analysis aligned with the American Bureau of Shipping (ABS) cause categories.

Through a systematic analysis of inspection data and the identification of causations, this research aims to contribute to the enhancement of maritime safety practices and the optimization of inspection performance. By illuminating the underlying factors contributing to deficiencies, stakeholders can devise targeted interventions to address systemic issues, thereby fostering a safer and more resilient maritime environment [11], [12].

The ultimate goal of this academic effort is twofold: first, to unveil the underlying causes of deficiencies identified during PSC inspections, and second, to provide a valuable resource for maritime stakeholders to address these issues effectively [13], [14]. By elucidating the causations of deficiencies, the study advocates for proactive measures aimed at improving inspection performance, enhancing regulatory compliance, and ultimately fostering a safer maritime environment aligned with the objectives of MoUs and international maritime regulations.

Furthermore, the study aims to contribute to the body of knowledge within maritime safety by providing actionable insights derived from rigorous data analysis and advanced modeling techniques. By delving into the intricacies of ship inspection findings and uncovering the systemic issues and causations underlying deficiencies, the study seeks to inform evidence-based decision-making processes and facilitate targeted interventions to address safety concerns effectively.

2. Literature Review

Port State Control (PSC) inspections serve as a critical mechanism for ensuring maritime safety, security, and environmental protection by examining vessels' compliance with international maritime regulations [15]. The effectiveness of PSC inspections hinges not only on the thoroughness of scrutiny but also on the depth of analysis, particularly concerning root cause analysis (RCA) methods utilized in assessing deficiencies and detentions post-inspections [16], [17].

Root cause analysis (RCA) methods play a fundamental role in determining the underlying causes of deficiencies identified during PSC inspections [18]. Traditional RCA methodologies such as fishbone diagrams, Fault Tree Analysis (FTA) and the 5 Whys technique have been extensively researched for their applications and adaptations in maritime as well as in other industries [19], [20]. These methods facilitate the systematic examination of various factors that contribute to noncompliance, including human error, equipment failure, and organizational deficiencies [21]. However, these analysis methods have remained far from innovative since they contain subjective judgments and are suitable for event-based analysis [18], [22], [23].

Additionally, there is a notable dearth of academic literature focusing on the application and effectiveness of RCA methods, particularly those supplemented with innovative approaches, in the analysis of inspection findings and detentions after PSC inspections. Further research is needed to elucidate the challenges and opportunities associated with applying RCA techniques in a maritime context [15], [24].

On the other hand, in recent years, there has been a growing interest in exploring innovative approaches to enhance the analysis of PSC inspection findings and detentions [22]. Despite this, the academic literature documenting such innovative approaches remains sparse. There is a need for research exploring how emerging technologies such as artificial intelligence (AI), machine learning (ML), and big data analytics can be leveraged to analyze PSC inspection data more effectively [16], [24], [25], [26], [27], [28].

Artificial intelligence and machine learning algorithms can examine large datasets containing inspection findings, identify patterns of non-compliance, and prioritize ships for inspection based on risk assessment models. Additionally, the integration of blockchain technology could be promising for increasing transparency and accountability in PSC audits by providing immutable records of audit results and compliance status [22], [27], [28].

Despite the potential benefits of these innovative approaches, their adoption and implementation in PSC inspections have been relatively slow. The literature gap highlights the need for further research and collaboration between academia, industry stakeholders, and regulatory agencies to explore and apply innovative methodologies for analyzing PSC audit findings and detentions [29], [30], [31].

In conclusion, while causation analysis methods are fundamental to understanding the underlying factors contributing to deficiencies in PSC inspections, there is a considerable body of academic literature on their application and effectiveness in the maritime domain. However, innovative approaches for analyzing PSC inspection findings and detentions, such as AI, ML, and blockchain, remain largely unexplored in academic research. Bridging this gap through empirical studies and collaborative efforts is essential for enhancing the effectiveness and efficiency of PSC inspections and promoting maritime safety and compliance.

3. Methodology

This study focuses on streamlining the analysis of inspections within the maritime sector through a machine learning approach based on natural language processing (NLP). The emphasis lies in deciphering comments made by PSCOs during ship inspections and identifying causal factors. The study relies on NLP techniques and machine learning algorithms. A crucial variable for both NLP and machine learning algorithms is the inclusion of reasons mentioned in the comments within the dataset.

The methodology of the study comprises two primary components: the natural language processing method and the machine learning algorithm. The natural language processing method involves initial data preprocessing. Following standardization through data preprocessing, PSCO comments are fed into the machine learning algorithm. Given that verbal data is utilized for the machine learning process, the SVM (Support Vector Machine) classification algorithm is chosen for its efficacy.

The steps of this study can be outlined as illustrated in Figure 1.

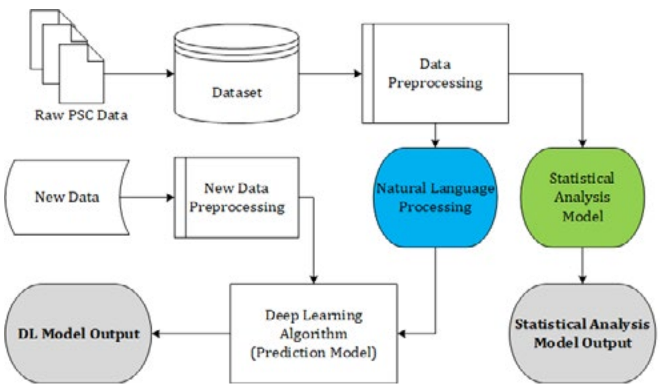

Figure 1. Flowchart of this study.

3.1. Data Collection

The data collection process constitutes a foundational aspect of this study, serving as the cornerstone upon which subsequent analyses are built. A meticulous approach was adopted to gather comprehensive and reliable data pertaining to ship inspection findings conducted by Port State Control Officers

(PSCOs) under various Memorandums of Understanding (MoUs) from 2020 to 2023.

The primary sources of data include official records and reports generated by PSC organizations operating under different MoUs. These records encompass a diverse range of vessel types and inspection outcomes, providing a rich dataset for in-depth analysis. Additionally, supplementary data sources, such as inspection databases and regulatory compliance records, were consulted to augment the dataset and ensure its comprehensiveness. The data collection process adhered to established protocols and guidelines to maintain data integrity and consistency. Rigorous quality control measures were implemented to verify the accuracy and completeness of the collected data, thereby minimizing the risk of errors and discrepancies.

The selection criteria for inclusion in the dataset were based on predefined parameters, including the relevance of inspection findings to the research objectives and the availability of comprehensive data for analysis. Information such as type, port, country, deficiency code, deficiency comment and action code is meticulously documented to facilitate subsequent analyses and comparisons.

3.2. Data Preprocessing

Data preprocessing is a critical phase in the research process, aimed at ensuring the quality, consistency, and compatibility of the dataset for subsequent analysis. In this study, a systematic approach was employed to preprocess the collected ship inspection data, encompassing various stages of data cleaning, transformation, and normalization.

The first step in data preprocessing involved the identification and handling of missing or incomplete values within the dataset. Missing data points were carefully assessed, and appropriate strategies, such as imputation or deletion, were employed to address missing values while preserving the integrity of the dataset. In the analysis of categorical variables, preprocessing is essential to ensure data suitability. Categorical variables must be encoded into numerical format, typically achieved through techniques like one-hot encoding or label encoding.

3.3. Support Vector Classifier (SVC)

The Support Vector Classifier (SVC) is a powerful machine learning algorithm employed in this study to classify and analyze ship inspection findings based on predefined criteria and patterns. SVC operates by constructing a hyperplane in a high-dimensional space that separates different classes or categories of data points with maximum margin, thereby facilitating effective classification and prediction tasks.

The implementation of SVC involves several key steps, beginning with the selection of appropriate features and the preparation of the dataset for model training. Features extracted from the preprocessed dataset are carefully selected based on their relevance to the classification task and their ability to discriminate between different classes of ship inspection findings.

Following model training, the performance of the SVC classifier is evaluated using metrics such as accuracy, precision, recall and F1 score. These metrics provide insights into the effectiveness and robustness of the classifier in accurately predicting ship inspection findings and classifying them into predefined categories.

3.4. Natural Language Processing Techniques

Natural Language Processing (NLP) techniques play a crucial role in this study's analytical framework, facilitating the interpretation and analysis of textual data extracted from PSCO comments associated with ship inspection findings. NLP techniques enable the algorithm to extract meaningful insights from unstructured text data, thereby augmenting the understanding of causations and underlying factors contributing to identified deficiencies. The application of NLP techniques involves several key steps, beginning with the preprocessing of textual data to standardize and enhance its quality for subsequent analysis. Text preprocessing encompasses tasks such as tokenization, sentence segmentation, stop word removal, and stemming or lemmatization, aimed at transforming raw text data into a structured format suitable for analysis.

3.5. Fault Tree Analysis Method

The Fault Tree Analysis (FTA) method is a systematic approach used to identify, analyze, and visualize potential causes and factors contributing to failures. FTA is commonly employed in reliability engineering and safety analysis to assess the probability of system failures and pinpoint critical paths leading to undesirable events.

Applying FTA to analyze ship inspection findings aims to provide a structured framework for understanding maritime safety complexities, identifying critical failure modes and developing interventions to improve safety performance in the maritime industry. For this purpose, the MARCAT chart categories developed by the American Bureau of Shipping (ABS) will be used in the FTA application.

3.6. Deep Learning Model

In this study, a deep learning model is employed to gain insights into the causations of This study employs a deep learning model to understand the causes of deficiencies identified during Port State Control (PSC) inspections, particularly focusing on those indicated by PSC action code 17. The model uses advanced neural network architectures and training techniques to analyze the collected dataset.

The application of the deep learning model involves several key components and methodologies. Firstly, data preparation ensures the dataset's quality, consistency, and compatibility before model training. Techniques include handling missing values, outlier detection, normalization, feature selection, and categorical variable encoding. The dataset is then split into training and testing subsets.

Selecting an appropriate deep learning model architecture depends on data complexity and analysis objectives. Considerations include the sequential nature of the data, spatial patterns, and network depth required to capture complex relationships.

Model training involves using the training subset to extract features and make predictions. Optimization includes adjusting parameters and hyperparameters using techniques like adaptive learning rate and regularization to prevent overfitting.

After training, the model's performance is evaluated using metrics such as accuracy, precision, recall, and F1 score. This evaluation provides insights into predictive accuracy, robustness, and generalization capabilities on unseen data.

Finally, post-training, learned representations and model weights are analyzed to interpret relationships between input features and target variables, offering valuable insights into underlying factors contributing to deficiencies identified during PSC inspections.

4. Analysis and Results

This section provides a comprehensive overview of the ship inspection findings derived from Port State Control (PSC) inspections conducted under various Memorandums of Understanding (MoUs) from 2020 to 2023. It outlines the scope of the inspection data, the types of deficiencies identified, and the key trends observed across different vessel types, PSC organizations, and MoUs. The inspection dataset encompasses a wide range of vessel types, including cargo ships, passenger vessels, tankers, and bulk carriers, subjected to PSC inspections at various ports worldwide.

4.1. Focus on PSC Action Code 17

The section explores the causations and contributing factors underlying deficiencies identified under PSC Action Code 17. Through qualitative analysis of PSCO comments, historical data trends, and case studies, insights are gleaned into the systemic issues, human errors, equipment failures, and procedural lapses that lead to the identification of Action Code 17 deficiencies.

4.2. MARCAT with Fault Tree Analysis

This section explores the integration of ship inspection findings, particularly those identified under PSC Action Code 17, with Fault Tree Analysis (FTA) methodologies. FTA provides a systematic framework for analyzing the causations and contributing factors underlying identified deficiencies, offering insights into the complex interactions and dependencies within the maritime safety environment.

MARCAT is a hierarchical map devised within the FTA framework, extensively utilized in the maritime sector for scrutinizing the origins of observations. It is structured into five hierarchical tiers, each delineating varying levels of detail.

4.3. Causation Identification

The MARCAT map was utilized for examining the deficiency comments. The experts listed in Table 1 evaluated the PSCO's deficiency observations during a brainstorming session and categorized each observation under the relevant MARCAT cause groups. The expert team, detailed in Table 1, convened as a brainstorming unit, selecting five hierarchical categories for each observation through the fault tree analysis method using the MARCAT map.

Table 1. Expert team details.

Expert No.	Position	Educational Level	Experience
1	Master	Bachelor's Degree	17 years
2	DPA	Master's Degree	21 years
3	Chief Engineer	Bachelor's Degree	16 years
4	Superintendent	Bachelor's Degree	14 years
5	Superintendent	Bachelor's Degree	18 years

Table 2. Dataset sample.

Ship_ Type	PSC	Port	Def Code	Observation	Act Code
Bulk Carrier	Colombia	Barranquilla	10119	Bridge and hold swing indicators have 2 deg. Difference with main indicator in different positions rudder. (ISM)	17
Bulk Carrier	Colombia	Barranquilla	10101	Unique pilot ladder in service has 3 rubbers steps damaged. _xOO0D_ record of periodical inspections have not remarks about this condition. (ISM)	17
Bulk Carrier	Colombia	Barranquilla	13102	Bamstel and VSCO pumps alarms sirens are out of order. (ISM)	17
Bulk Carrier	Colombia	Barranquilla	3103	Port side five sections are broken on missed. *ISM	17
Bulk Carrier	Colombia	Barranquilla	1299	Master, Bosun lack of familiarization with UMS – Water ingress alarm - BNWAS	17

4.4. Statistical Analysis Method

This section delves into the insights gleaned from the application of a statistical analysis model to analyze ship inspection findings, specifically focusing on deficiencies identified under PSC Action Code 17. Leveraging advanced neural network architectures and training techniques, the statistical analysis model offers valuable insights into the underlying patterns, trends, and relationships within the inspection data.

The statistical analysis model uncovers underlying factors and causations contributing to the occurrence of deficiencies flagged under PSC Action Code 17. Through feature extraction and analysis, the model identifies critical variables, procedural lapses, equipment failures, and systemic vulnerabilities that increase the likelihood of non-compliance during ship inspections. Figure 2 shows the distribution of the findings in the dataset according to cause categories at five levels.

Figure 2. Target variable distributions.

In summary, the insights derived from the statistical analysis model offer valuable perspectives into the complexities of ship inspection findings and regulatory compliance within the maritime industry. By harnessing the power of data analytics, stakeholders can enhance decision-making, optimize resource allocation, and foster a culture of safety and compliance to ensure the integrity and sustainability of maritime operations in a dynamic global environment. Figure 3 contains examples of causation densities of PSC officers' findings.

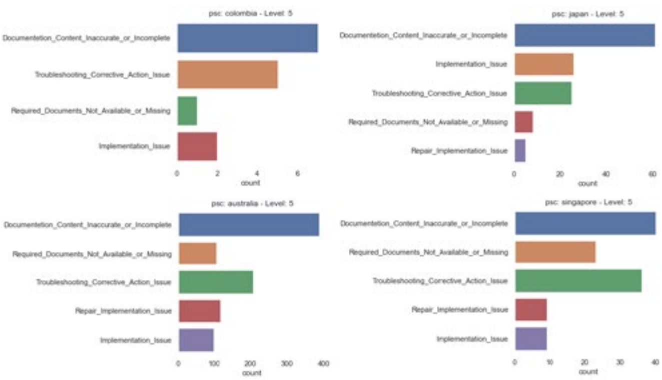

Figure 3. Category based target variable analysis.

4.5. Data Preprocessing

Once consistency is confirmed, the dataset undergoes text preprocessing using an algorithm. Missing data were eliminated. The textual data undergo several steps including "tokenization", "lowercasing", "removing stop words", "removing punctuations", "stemming", and "lemmatization".

4.6. Prediction Model with Deep Learning

This study involves the transformation of verbal expressions within the dataset through the target encoding process. Verbal data will be digitized, analyzed, and then verbalized again. Target encoding is a machine learning technique used to encode categorical features by replacing them with numeric representations based on the target variable. It's commonly employed in classification tasks. The underlying principle of target encoding is to compute the average value of the target variable for each category within the feature, utilizing that value as the encoded representation. This approach enables the model to effectively capture the relationship between the feature and the target variable.

For assessing the performance of machine learning models, it's crucial to split the dataset into training and test data. This division aids in determining the model's performance on real-world data, independent of the data used for training. In this study, the dataset is partitioned into 80% training data and 20% test data.

Text document representation plays a pivotal role in various natural language processing tasks such as text classification, information retrieval, and text mining. In recent years, the TF-IDF (Term Frequency-Inverse Document Frequency) vectorizer has emerged as a potent technique for converting textual data into numerical representations suitable for machine learning algorithms.

The TF-IDF vectorizer is a widely used technique for converting text documents into numerical representations suitable for machine learning algorithms. It considers both the frequency of a term in a document (term frequency) and the rarity of the term across the entire document collection (inverse document frequency).

Following the processing of the dataset, the support vector classifiers was employed to generate prediction results for each level. The results showed that the NLP-based SVC classification algorithm achieved an overall F1 score of 0.92 to 0.78, indicating a high level of accuracy in predicting causations. The precision and recall for each cause category were also calculated, and the results showed that the algorithm performed well for all cause categories. Evaluation metrics values of SVC classification algorithm can be seen in Table 3.

Table 3. Evaluation metrics values of SVC classification algorithm.

Cause Categories	Precision	Recall	F1-score	Accuracy
Level 1 Cause Categories	0.92	0.92	0.92	0.92
Level 2 Cause Categories	0.93	0.95	0.93	0.95
Level 3 Cause Categories	0.91	0.91	0.90	0.91
Level 4 Cause Categories	0.87	0.88	0.87	0.88
Level 5 Cause Categories	0.81	0.80	0.78	0.80

Figures 4 and 5 contain sample confusion matrices for level 1 and level 5. These graphs are visualizations of the values used to calculate algorithm accuracy.

Figure 4 and 5. Confusion matrix of level 1 cause and level 5 cause.

5. Discussion

The research contributes to the existing literature on causation analysis within the maritime sector by introducing and assessing a novel NLP-based SVC classification deep learning algorithm tailored for post-inspection analysis. Additionally, it offers insights into the distribution of cause categories for pre-inspection analysis. These findings can guide future research endeavors in causation analysis within ship inspections and aid ongoing endeavors to enhance safety and efficiency in the maritime domain.

While prior studies have primarily explored statistical analysis methods to discern trends and patterns in data, this research focuses on the application of NLP-based SVC classification algorithms for post-inspection analysis. This methodology offers the advantage of automatically identifying cause categories for new deficiencies based on reviewer comments and categorized causes.

However, certain limitations must be acknowledged. Firstly, the dataset utilized in this study comprised only 5326 rows, potentially lacking full representation of all ship inspections in the maritime industry. A more extensive dataset would have yielded more robust outcomes and enhanced the generalizability of the findings. Secondly, while the MARCAT framework employed for categorizing deficiencies is widely accepted within the maritime industry, it may not encompass all potential causes of deficiencies. Thus, alternative frameworks or methodologies could be explored in future investigations. Finally, the efficacy of the NLP-based SVC classification algorithm developed for post-inspection analysis hinges on the accuracy and comprehensiveness of the provided reviewer comments and cause categories. Inaccurate or incomplete data may impede the algorithm's performance and lead to erroneous predictions.

Despite these limitations, the study offers valuable insights into the advancement and application of NLP-based SVC classification algorithms for causation analysis in ship inspections, with implications extending beyond the maritime industry.

6. Conclusion

The principal discoveries of this study are as follows:

- The NLP-based SVC algorithm devised in this study offers a streamlined and accurate method for forecasting causations in new inspection reports based on previous PSCO observations and categorized causes.
- The deep learning model presents a comprehensive and efficient approach for scrutinizing ship inspection reports and identifying the causations of observations.
- The implications of this study's outcomes extend significantly beyond the maritime sector, potentially enhancing safety and operational efficiency across industries reliant on inspections and causation analysis.

In summary, this study contributes to the ongoing efforts to bolster safety and efficiency in the maritime industry through the application of data science methodologies, providing a flexible framework adaptable to other industries.

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Digital Waves in Maritime Safety: A Systematic Analysis of Industry Transformation

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Abstract

Maritime safety is a paramount issue, considering the inherent risks at maritime environment. Hence, there is a need to continuously improve safety protocols. The maritime industry is experiencing a significant digital transformation, by adopting the new technologies. However, the integration of digitalization into maritime safety protocols is an underexplored area, which poses a critical research opportunity. Traditional safety measures largely overlook the potential benefits of digitalization, such as efficiency and real-time capabilities. However, the literature lacks comprehensive studies on how digital tools can reduce risks, improve emergency response and prevent accidents in maritime operations. This research aims to address this gap by providing an insight on the integration of digital technologies to maritime safety. In this paper, a systematic literature review (SLR) was conducted to identify studies on digitalization in maritime safety by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Furthermore, limited results were reviewed and a basis for future research was established. Overall, it contributed to a better understanding of how digitalization can enhance safety standards in maritime operations.

Keywords: *Digital transformation, Maritime, Systematic literature review, Maritime safety*

1. Introduction

Maritime safety is an essential concern in the maritime industry, given the risks inherent in the maritime environment [1], [2]. The evolving dynamics of the maritime industry with the emergence of new technologies such as big data, virtual reality (VR)[3], artificial intelligence (AI)[4], [5], augmented reality (AR)[6], Internet of Things (IoT)[7], [8] and blockchain[9], [10] offers hopeful paths for enhancing safety protocols [11]. The maritime industry is experiencing a significant digital transformation in various areas by following these technologies. As a result of this transformation, crewless ships, autonomous ships, smart ships, and intelligent global logistics are emerging [12], [13]. However, despite the significant progress witnessed in the field of digital transformation, the integration of digitalization into maritime safety remains an under-explored area. Accordingly, this presents a significant research opportunity.

Traditionally, maritime safety measures have mostly relied on established protocols, often overlooking the potential benefits of digitalization, such as higher efficiency and real-time capabilities. In the newly developing literature in this field, there is a noticeable absence of comprehensive studies explaining how digital tools can serve to mitigate risks, strengthen emergency response mechanisms, and prevent accidents in maritime operations proactively.

Thus, this research aims to address this gap by providing valuable insights into the integration of digital technologies into maritime safety protocols. The paper conducts a systematic literature review (SLR) on digitalization in maritime safety guided by the PRISMA framework.

Furthermore, this paper goes beyond a simple review of the existing literature by attempting to distill the limited findings and outline a solid framework for future research efforts. Moreover, by revealing the various impacts of digitalization on maritime safety, this research aims to provide maritime stakeholders with a refined understanding of how digital technologies can act as a potential catalyst for improving safety standards. In brief, this paper contributes to highlight the intersection of digitalization and maritime safety. It is not only to enrich the academic literature, but also to serve as a holistic perspective that points to pragmatic interventions aiming to enhance safety protocols in maritime operations.

The study consists of five main sections. The first section introduces the motivation of the study. The second section presents the research methodology. In the third section, a systematic literature review is conducted. The fourth section analyzes the findings. The last section concludes the study and provides recommendations for future research.

2. Research Methodology

A Systematic Literature Review (SLR) is a method used to review and analyze research studies on a particular subject. Its purpose is to combine evidence from sources in a transparent manner. The PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta Analyses) is a widely accepted methodology for conducting systematic literature reviews.

The PRISMA framework provides a structured approach for conducting reviews and meta-analyses, promoting transparency and reproducibility in the review process [14]. It includes a checklist and explanation that assists researchers throughout the stages of conducting a systematic review, including identification, screening, eligibility, and study inclusion [15]. By following the PRISMA guidelines, researchers can conduct their literature review in a methodical and transparent manner, enhancing the quality and dependability of the review process [16].

The use of the PRISMA framework in systematic literature reviews contributes to a robust and grounded understanding of the relationships being studied [17]. The PRISMA framework assists in identifying research gaps and new research directions, guiding future research endeavors [18]. It also enhances the quality of literature reviews by providing a process flow diagram that aids in better understanding the overall review process and its boundaries [19].

Table 1. Review Protocol

Item	Description
Database	Scopus; Web of Science
Keywords	(maritime) AND ("digit*" OR "maritime 4.0" OR "Digital Technolog*" OR "Digital* transformation" OR "Internet of thing*" OR iot OR "Internet of service*" OR "artificial intelligence" OR "Big Data" OR "Cloud comput*" OR "blockchain" OR "virtual reality" OR "Augmented Reality") NOT (port OR offshore OR military)
Boolean Operators	AND; OR; NOT
Search Fields	Title; Abstract; Keywords
Exclusion Criteria	Papers that are not directly related with the maritime safety
Language	English
Publication Type	Article; Review; Book; Book Chapter
Research Area	Engineering
Time Window	2013-2023

In the context of SLRs, the adoption of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework ensures that the review is conducted in an auditable way, producing repeatable results and contributing to the synthesis of evidence from different studies [20]. Additionally, the PRISMA framework is widely recognized and established as a method for guiding the systematic review of scholarly literature, ensuring that the review process is rigorous and comprehensive [15].

In this study, the first step was to establish a literature review protocol (**Table 1**). Next, searches were conducted on Scopus and Web of Science, which are recognized as the most reliable and comprehensive databases in the literature [21], [22], [23]. Appropriate keywords were identified to reveal studies related to the digitalization of the maritime industry. Exclusion criteria were implemented to identify papers related to digitalization in the onboard maritime safety. Additionally, areas such as ports, offshore structures, underwater systems, military applications, education, and others were also excluded. The filtering process was refined to include only peer-reviewed publications, articles, reviews, books, and book chapters in the English language. The analysis focused on engineering publications. In order to assess current research, recent studies that were conducted within the last 10 years were examined.

3. Literature Search

A compilation of related publications from the most well-known academic databases, Web of Science (WoS) and Scopus, served as the basis for our review. In November 2023, a keyword search in the WoS and Scopus databases was conducted to gather relevant bibliography data. The detailed keyword search process with the Boolean functions and the filtering process of the results has shown in **Table 2**.

Table 2. Keyword search in WoS and Scopus databases

Step	Keyword Search	Publications	
		Scopus	WoS
1	(maritime) AND ("digit*" OR "maritime 4.0" OR "Digital Technolog*" OR "Digital* transformation" OR "Internet of thing*" OR iot OR "Internet of service*" OR "artificial intelligence" OR "Big Data" OR "Cloud comput*" OR "blockchain" OR "virtual reality" OR "Augmented Reality")	3836	1942
2	(maritime) AND ("digit*" OR "maritime 4.0" OR "Digital Technolog*" OR "Digital* transformation" OR "Internet of thing*" OR iot OR "Internet of service*" OR "artificial intelligence" OR "Big Data" OR "Cloud comput*" OR "blockchain" OR "virtual reality" OR "Augmented Reality") NOT (port OR offshore OR military)	2956	1492
3	Filtered by year: 2014-2023	2456	1315
4	Filtered by language: English	2391	1264
5	Filtered by document type: Article; Review; Book; Book Chapter	1049	865
6	Filtered by research area: Engineering	595	407

Since the main purpose of the search was to identify studies on digitalization in the maritime industry, "maritime industry" and "digitalization" were identified as the two main keywords. In order to avoid any overlooked publications, the keywords were expanded and "maritime", "shipping", "vessel" were used to cover the "maritime industry". However, it was observed that "vessel" is also used in other fields such as medicine and "shipping" is used in many sectors related to logistics. These keywords were removed as they distracted from the main purpose of the search. Similarly, the keywords “digit*”, “maritime 4.0”, “digital technolog*”, “digital* transformation”, “internet of thing*”, “iot”, “internet of service*”, “artificial intelligence”, “big data”, “cloud comput*”, “blockchain”, “virtual reality”, “augmented reality” were used to cover all publications related to “digitalization”. Among the results, there were a lot of digitalization publications related to ports, offshore structures and military. As the main focus of the study was on commercial vessels, publications containing “port”, “offshore”, “military” were not included in the search. Once all these keywords were identified, a detailed literature search was completed in both databases using the Boolean function. In order to see the current situation regarding the research topic, studies that were not conducted between 2014 and 2023 were excluded. Only “english” language publications in the field of “engineering” in the document type of “article”, “review”, “book”, “book chapter” were filtered.

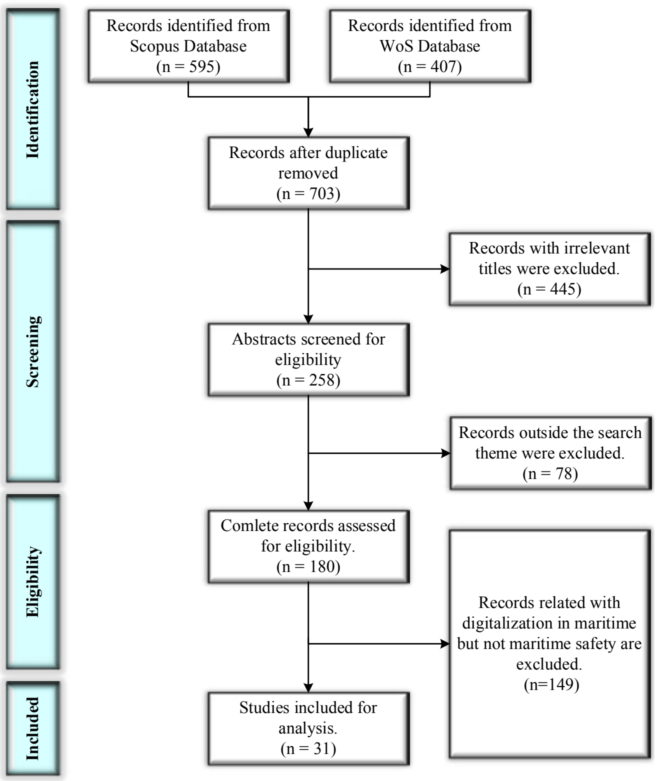

Figure 1: PRISMA Flowchart

Subsequently, the PRISMA flowchart consisting of 4 stages was used in the literature search (**Figure 1**). These stages are Identification, Screening, Eligibility, and Inclusion. In the Identification stage, the results from two separate databases were combined and duplicate records were extracted. Afterwards, titles and abstracts of 703 publications were screened. In the eligibility stage, publications were reviewed and evaluated completely. Eventually, the inclusion stage resulted in 31 publications that were ready to be analyzed.

4. Analysis and Findings

4.1. Main information

Figure 2: Main information

This study only examines academic publications on digital transformation in the maritime safety between 2013 and 2023. After a deep literature search, 31 relevant publications were identified. When these publications were analyzed as the annual growth in the publication numbers, we came across a rate of 35.59%. On the other hand, the average age of publications in the last 10 years is only 1.58. These metrics show that digital transformation in the maritime safety is not only a very timely, trending and popular topic, but also in its infancy. The main information about the relevant publications is shown in **Figure 2**.

4.2. Annual scientific publication and time trend

The general trend of annual publications has shown in **Figure 3**. It is evident that the number of publications on digital transformation in the maritime safety has risen significantly, especially since 2021 as new technologies like blockchain, augmented reality (AR), artificial intelligence (AI), and the internet of things (IoT) have developed with greater velocity. The rapid increase in the number of publications per year is a sign of the growing interest in the digital transformation of the maritime safety day by day.

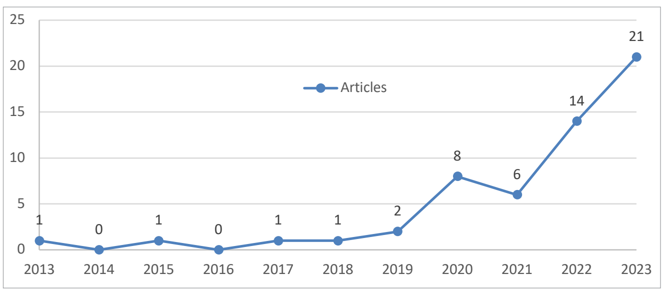

Figure 3: Annual scientific publication

4.3. Most relevant keywords

The keywords selected by the authors offer valuable clues regarding the thematic areas of research addressed in their papers and the methodological approaches employed. Analyzing the relationships between these keywords provides an inside to the dominant research trends within the field and the popular topics deemed most relevant by the academic community. An analysis of the most frequently used keywords reveals a prominent focus on rapidly developing technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) in maritime safety. This suggests a strong trend towards incorporating these technologies into the maritime safety. Further exploration of keyword co-occurrence networks provides valuable insights into the specific applications of these technologies **(Figure 4)**.

Five distinct clusters emerge from the network analysis, with AI and IoT technologies displaying particular prominence. Examining the keyword connections within the blue cluster reveals a strong focus on AI and deep learning applications in "trajectory prediction," "safety," and "predictive models." In contrast, the red cluster highlights a closer association between IoT and blockchain technologies with "sensor systems," "authentication," and "monitoring." Additionally, the purple cluster supports the use of "big data analytics" and "machine learning" for "ship safety" systems.

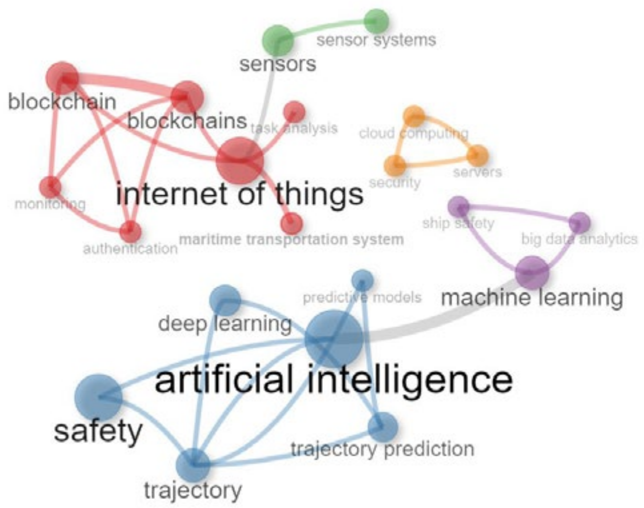

Figure 4: Author's keywords occurrence

4.4.Analysis of studies in maritime safety

The existing literature on maritime safety has made significant strides in addressing various aspects of the maritime sector. However, despite the general trend towards digitalization in the maritime sector, there remains a noticeable gap in the literature on the incorporation of digitalization into maritime safety practices in particular. The dominant focus in maritime safety literature has traditionally been on traditional safety measures, standardized procedures, and resilient physical infrastructure. While these aspects are undeniably important, the increasing trend of digitalization across the maritime industry has not been adequately reflected in the field of safety protocols.

In a comprehensive literature review on digitalization in the maritime industry, 180 publications were included in the analysis. However, only 31 of these publications were directly related to maritime safety. All publications related to digitalization in maritime safety were examined in detail and the digitalization technology, application area, and safety category proposed in the publication were identified (**Table 3**).

The provided table presents the intersection of various technological applications within distinct application areas and safety categories in the maritime domain. A comprehensive analysis reveals a diverse spectrum of safety-related applications. It is very clear that the most of the publications were focused on enhancing the navigational safety (**Figure 5**).

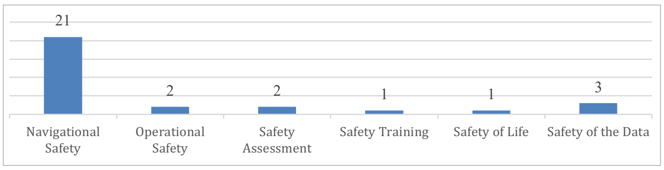

Figure 5. Number of publications by safety categories

Furthermore, data-driven prediction emerges as a prominent application area for digital technologies, encompassing diverse domains such as maintenance prediction, trajectory optimization, traffic condition analysis, and maritime accident prevention.

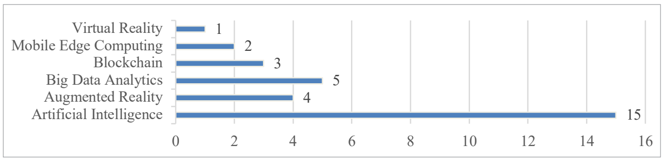

Figure 6. Number of publications by technology

Among the technological solutions suggested in the literature for enhancing maritime safety, artificial intelligence (AI) stands out as a particularly prominent technology (**Figure 6**). Within the AI domain, the focus on navigational safety is evident, encompassing tasks like Maritime Surveillance, Trajectory Prediction, Grounding Risk Evaluation, Failure Detection, Unsupervised Route Planning, Ship Speed Prediction, Traffic Condition Prediction, Maritime Accident Prediction, Search and Rescue Operations, Visibility of Marine Lanterns, and Object Detection for Ship Safety Plans. Accordingly, Big Data Analytics emerges as a prominent technology, addressing navigational safety through collision avoidance, trajectory compression, and trajectory prediction. The repetition of these applications indicates the significance of data analytics in mitigating collision risks and optimizing trajectory planning. Additionally, augmented reality (AR) applications mainly contribute to navigational safety. The integration of AR technologies underlines their potential impact on real-time decision making and enhancing situational awareness. Moreover, blockchain technology is featured in the context of safety of the data, specifically related to securing data in IoT-enabled maritime transportation systems and facilitating secured ship-to-ship communication. Lastly, Virtual Reality is showcasing its role in immersive and practical safety training.

Table 3: Publications related to digitalization in maritime safety

Pub.	Technology	Application Area	Safety Category
[24]	Artificial Intelligence	Maritime Surveillance	Navigational Safety
[25]	Artificial Intelligence	Trajectory Prediction	Navigational Safety
[26]	Artificial Intelligence	Grounding Risk Evaluation	Navigational Safety
[27]	Artificial Intelligence	Failure Detection	Operational Safety
[28]	Artificial Intelligence	Unsupervised Route Planning	Navigational Safety
[29]	Artificial Intelligence	Ship Speed Prediction	Navigational Safety
[30]	Artificial Intelligence	Traffic Condition Prediction	Navigational Safety
[31]	Artificial Intelligence	Maritime Accident Prediction	Navigational Safety
[4]	Artificial Intelligence	Search and Rescue Operations	Safety of Life
[32]	Artificial Intelligence	Reliability Centered Maintenance	Operational Safety
[33]	Artificial Intelligence	Maritime Accident Prediction	Navigational Safety
[5]	Artificial Intelligence	Visibility of Marine Lanterns	Navigational Safety
[34]	Artificial Intelligence	Object Detection for Ship Safety Plans	Safety Assessment
[35]	Artificial Intelligence	Maritime Risk Assessment	Safety Assessment
[36]	Artificial Intelligence	Maritime Awareness Systems	Navigational Safety
[37]	Augmented Reality	Ship Piloting	Navigational Safety
[38]	Augmented Reality	Lights for Restricted Visibility Navigation	Navigational Safety
[6]	Augmented Reality	Bridge Watchkeeping	Navigational Safety
[39]	Augmented Reality	Operators in a Safety-Critical System	Navigational Safety
[40]	Big Data Analytics	Collision Avoidance	Navigational Safety
[41]	Big Data Analytics	Trajectory Compression	Navigational Safety
[42]	Big Data Analytics	Trajectory Prediction	Navigational Safety
[43]	Big Data Analytics	Collision Avoidance	Navigational Safety
[44]	Big Data Analytics	Trajectory Prediction	Navigational Safety
[45]	Blockchain	Data of IoT-Enabled Maritime Transportation Systems	Safety of the Data
[46]	Blockchain	Data of IoT-Enabled Maritime Transportation Systems	Safety of the Data
[47]	Blockchain	Secured Ship-to-Ship Communication	Navigational Safety
[48]	Mobile Edge Computing	Trajectory Prediction	Navigational Safety
[7]	Mobile Edge Computing	Data of IoT-Enabled Maritime Transportation Systems	Safety of the Data
[3]	Virtual Reality	FF and Evacuation Training	Safety Education

4.5. Discussion and future directions

The literature review reveals the absence of comprehensive studies examining the integration of digital technologies into maritime safety procedures. Digitalization, characterized by transformative technologies like IoT, AI, AR, VR, blockchain, and big data analytics, has permeated various maritime sectors, from navigation to logistics. However, its potential to enhance safety protocols through innovative applications remains under-investigated. This presents a crucial research opportunity to bridge this gap and leverage the power of digital solutions for safer maritime operations.

The gap becomes more pronounced when considering the potential benefits of digitalization for enhancing maritime safety. The efficiency, accuracy, and real-time capabilities offered by digital technologies remain largely untapped in the context of safety management. The literature gaps in-depth investigations into how digital technologies can mitigate risks, improve emergency response, and proactively prevent incidents in maritime operations.

In conclusion, the existing literature on maritime safety does not adequately reflect the transformative wave of digitalization sweeping the maritime industry. Addressing this gap is crucial for a holistic understanding of how digital technologies can be leveraged to enhance safety standards in maritime operations. Future research efforts should focus on unlocking the untapped potential of digitalization to ensure the safety of maritime operations.

5. Conclusion

In conclusion, this systematic analysis of digitalization in maritime safety highlights a significant gap in the current literature. Despite the rising wave of digital transformation in the maritime industry, there is a notable lack of comprehensive studies addressing the integration of digital technologies into maritime safety protocols.

The findings underline the urgent need for further research to realize the potential benefits of digitalization for enhancing safety standards in maritime operations. While traditional safety measures still exist, the transformative power of digital technologies remains largely untapped in safety management practices.

In this context, the study not only identifies key technology applications within various safety categories, but also highlights the critical importance of navigational safety enhancements. From AI-driven predictive models to data analytics for collision avoidance, the potential for digital solutions to revolutionize maritime safety practices is evident.

Looking forward, future research efforts should prioritize bridging the gap between digital innovation and maritime safety. In particular, digitalization of daily operations on board is a topic that needs to be explored. By exploring innovative applications and encouraging collaboration between industry stakeholders and academia, we can exploit the full potential of digitalization to ensure the safety of maritime operations in the digital age.

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Statistical Research on Crew Members Who Have Disappeared Without a Trace from Onboard Ships

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Abstract

Seafarers working aboard ships not only face risks associated with maritime accidents but also experience unexplained disappearances from vessels. Due to limited coverage in the media, awareness surrounding this issue remains low. The primary objective of this study is to highlight the plight of crew members who fall outside existing accident categorisations and vanish under inexplicable circumstances, aiming to classify such incidents as a distinct category of accidents. Furthermore, the study seeks to advocate for the incorporation of these incidents into international laws and regulations or the establishment of separate regulations specifically addressing this issue. This study utilised the PRISMA 2020 method, a systematic and standardised approach to literature analysis, to offer a transparent and comprehensive examination of incidents involving missing crew members from onboard ships. The study exclusively focused on crew members lost while onboard ships. Correlation analysis was employed to investigate the relationship between data extracted from missing reports and news sources. The analysis revealed a statistically significant correlation between various data points, with the exception of age and rank. Notably, upon scrutinising loss statistics reported on crew embarkation dates, it was found that 61% of missing crew members disappeared within a period spanning two days to two weeks after joining the ship. Furthermore, recommendations were proposed to mitigate such losses in the future.

Keywords: *Maritime accidents, Disappeared crew, Seafarers*

1. Introduction

The disappearance of seafarers without a trace from aboard ships is a serious and concerning issue in the maritime industry. As these losses receive limited coverage in the media, awareness of the issue is correspondingly low. This situation has multiple reasons, including the hope of finding the disappeared person, the desire of maritime companies to conceal the incident, and the lack of clear accident categories associated with such incidents, leading to a deficiency in reporting.

As a result of the literature review, a dearth of studies pertaining to the subject has been encountered. In the study conducted on work-related deaths in British merchant shipping between 1976 and 2002 [1], out of 835 deaths investigated, 87 were attributed to individuals who went missing. While deaths at sea are classified in [2], one of the causes of death is categorized as individuals disappears at sea. Out of the 123 incidents examined, 7.3% consisted of disappeared individuals. In [3], the causes of 147 incidents of death on Danish commercial ships from 1986 to 1993 have been examined, with six of them reported as individuals going missing from the vessel. The focus on disappearances from cruise ships is a relatively recent development. Despite the reporting of 47 disappearances from cruise ships between 1995 and 2004 [4], the matter did not capture public interest until 2005. In [5], the author, who statistically examines the reasons behind passenger disappearances on cruise ships, has arrived at the conclusion that "During the last years more passengers went missing due to more cruising at the sea".

Such incidents can have various causes, including accidents, foul play, piracy, mental health issues, homicide, suicide or intentional disappearance. In the most comprehensive study on individuals missing from ships [6], it was mentioned that there could be 17 distinct reasons for disappearances. It is noteworthy that many social scientists examining the deaths of seafarers posit that approximately 50% of those who disappear at sea are likely victims of suicide [7]. In [8], a study of the United Kingdom fleet spanning from 1976 to 2005 revealed 57 suicides out of a total of 1,515 deaths (3.8%). Additionally, 90 seafarers were reported as having gone missing at sea. Between 2005 and 2008, an additional 66 passengers and crew members disappeared from cruise ships. In some instances, the individual was successfully rescued, while in others, the disappearance was explicitly attributed to suicide or resulted from an accident. However, many cases remained enigmatic.

It has been previously observed that alcohol is implicated in numerous unexplained disappearances. Furthermore, alcohol is linked to sexual assaults and other criminal activities [9]. Alcohol played a role in a significant number of suicides and accidents, with substantial gambling losses identified as a contributing factor in some instances. Notably, there was a singular case where one passenger was observed throwing another overboard. In September 2001, during an 11-day cruise of Norway's fjords, a 69-year-old woman was pushed overboard in the presence of her husband by a fellow passenger, who was revealed to be a former mental patient [10]. Notably, following the tragic death of Dianne Brimble, who succumbed to a drink spiked with GHB (also known as fantasy, often associated with date rape) during a P&O Australia cruise in 2002, the cruise line faced pressure to enhance the training of crew members in responsible alcohol service. Additionally, there were calls to eliminate economic incentives for bartenders and waiters to serve excessive alcoholic drinks. Similar demands emerged in North America and Europe after the demise of Lynsey O'Brien, a 15-year-old girl who disappeared on January 5, 2006, from Costa Magica. It was reported that she had been served over ten alcoholic drinks within a brief period, leading to such intoxication that she fell overboard while vomiting over a balcony railing [11,12].

In a more recent incident, a crew member on the Nieuw Amsterdam, a vessel operated by Holland America Line, brutally assaulted and raped a 31-year-old woman in her cabin late at night in February 2014. The woman managed to escape, severely injured and barely alive, and was subsequently airlifted to shore for urgent medical attention. The crew member revealed that his intention had been to dispose of the woman's body by throwing her overboard from the balcony of her cabin [13]. Undoubtedly, had he succeeded, the incident might have been classified as a fall or an intentional fall (suicide). Similarly, individuals responsible for the death of Diane Brimble on a cruise ship off Australia confessed to contemplating throwing her body overboard but were unable to find a means to bring her up on deck [11].

In contrast to assertions that incidents involving passengers overboard are categorized as falls or jumps, data spanning from 1995 to mid-2013 indicates that 16.7% of individuals overboard are successfully rescued. Of these incidents, 6.2% involve alcohol intoxication, 11% are identified as suicides, 3.3% as murders, 9.5% as falls, 2.4% follow a substantial casino loss, 7.1% occur after a domestic altercation, and approximately 30% remain unexplained, lacking a clear rationale. The data further reveals that 73.8% of individuals overboard are male, with 75% being passengers. On average, males are younger than females (38.85 vs. 42.11), though the age range for males is considerably broader than that for females [14]. The challenges in working conditions on cruise ships create pressure on the personnel.

Over a three-year span from 2009 to 2012, a minimum of thirteen crew members reportedly disappeared from Royal Caribbean and Celebrity ships. These incidents involved various vessels, including the Majesty of the Seas, Monarch of the Seas (on two separate occasions), Radiance of the Seas, Explorer of the Seas, Oasis of the Seas, Grandeur of the Seas, Celebrity Constellation, Celebrity Eclipse, Celebrity Summit, and Monarch of the Seas, as well as Serenade of the Seas (twice). Regrettably, the majority of these cases were purportedly not subjected to investigation by the respective flag state, indicating a lack of concern or attention to these occurrences.

The financial losses resulting from disappearances at sea are substantial, as are their underlying causes. In 2011, the disappearance of a master in the waters off Australia may have incurred a cost between US$50,000–US$100,000 for the ship owner due to the diversion and delay of the voyage. When a ship's journey is halted or rerouted due to a mentally ill seafarer or a seafarer going missing at sea, the financial impact on the ship owner or charterer can be substantial. In 2012, the daily operational cost of a 3,500 TEU container ship, built in 2000, was anticipated to be US$7,825 (information on container ship operating costs provided with permission from Drewry Maritime Research, London). This cost does not encompass fuel oil expenses and is based on various categories, including manning, insurance, stores, spares, lubricating oil, repair and maintenance, and management administration. It also incorporates a daily cost over five years for dry-docking at US$551,000.

Similarly, in 2012, the expected daily cost of operating a 10,000 TEU container ship, built in 2000, was projected to be US$10,944. This figure considers yearly costs across the same expense categories, with a dry-docking cost of US$750,000. Notably, the daily cost of fuel oil can surpass all other operational expenses for container ships. Fuel oil costs may reach as high as US$30,000 per day, contingent on the Singapore price of fuel oil. Additionally, the ship owner may incur mortgage insurance and capital repayment costs [7]. It is highlighted that in cases involving high-value perishable cargo, its loss could further contribute to the overall expenses for the ship owner.

Legal and social measures are taken concerning both passengers and personnel disappeared from the ship. The disappearances from ships gained attention with the disappearance of George Allen Smith during his honeymoon aboard Royal Caribbean's Brilliance of the Seas cruise ship on a Mediterranean trip. His disappearance prompted congressional hearings in December 2005 [15] and led to the establishment of the International Cruise Victims Association in early 2006 [16]. Barack Obama introduced the Cruise Vessel Safety and Security Act in 2010, which became effective in January 2014. This legislation compels cruise lines to report crimes on board cruise ships involving U.S. citizens or sailing in U.S. waters. Crimes involving non-U.S. citizens are not mandated to be reported. This circumstance has led to the assumption that the actual number of reported incidents is underestimated, especially for overboard incidents involving individuals from different nations, as they carry a high risk of going unreported. Additionally, media outlets may not publish every incident, often due to lack of awareness. In a confidential meeting between CLIA (Cruise Lines International Association) and the ICV (International Cruise Victims) in 2007, the former CLIA President stated that "they will not report any person overboard unless the media already knows about it" [17].

A significant concern revolves around how cruise ships become aware when a passenger goes overboard. An issue at hand is whether cruise ships adhere to the Cruise Vessel Safety and Security Act of 2010, which mandates the presence of technology for detecting persons overboard. The International Cruise Victims Association argues that cruise ships are not in compliance with the law and suggests several systems. In contrast, the cruise industry contends that there are no systems approved by the U.S. Coast Guard, rendering the law ineffective [18]. In spite of international acts, we are not aware of any cruise ships that are equipped with automatic man overboard systems, which promptly alert the bridge when an individual goes over the rails. Furthermore, these systems should be capable of tracking the person in the water, even during nighttime, using infrared, heat sensor, motion detection, or radar technology.

In 2015, the global initial step in this matter was undertaken with the establishment of a registry by Human Rights at Sea. The primary objective of this register is to construct a precise international database elucidating the status of seafarers and fishers who are reported missing at sea on a global scale. Its goal is to enhance international awareness regarding those individuals who have gone missing by profiling specific cases for maritime authorities, flag states, governments, ship owners/managers, civil society organizations, and the general public. Before the establishment of the register in 2015, there were no recorded statistics concerning the number of individuals missing among the 1.5 million registered seafarers worldwide, or among the substantial population of unregistered, trafficked, or abused individuals entangled in illegal and unregulated maritime activities, such as fishing. Presently, the register includes approximately 240 individuals who are listed as missing.

2. Method

Data sourced from the Human Rights at Sea database, along with information from media reports and maritime accident investigation reports from various countries, was systematically examined and classified using the Prism 2000 method (Figure 1).

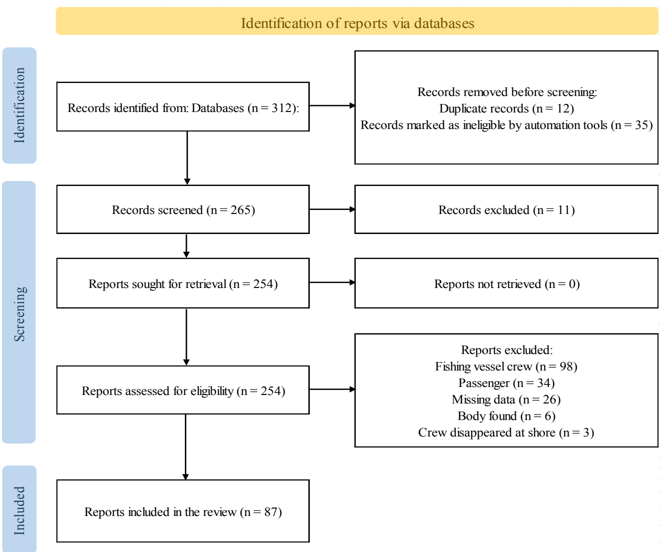

Figure 1. PRISMA flow diagram of missing crew report selection.

The study exclusively considers crew who go missing on merchant vessels. Individuals who are ship crew members but go missing outside the vessel are excluded. Those whose bodies cannot be found, cases with a known reason for disappearance (such as those resulting from accidents), individuals missing on fishing vessels, and passengers are not included in the study. Furthermore, incidents involving ships and their personnel/passengers going missing as a result of accident have not been considered within the scope of the study. This is because such events are typically classified as sinking accidents. With advancing technology, the wrecks of these missing vessels are being located each day.

The statistical data of the classified disappearance incidents are explained and presented in detail below. Although the examined reports contained data such as the date of the accident, the embarkation date of the missing crew, the time period when the personnel went missing, the location of the accident at sea, whether it occurred at night or during the day, the rank, age, nationality of the crew, possible causes of the disappearance incident, the flag, navigation status, type and tonnage of the ships, the specific location of the incident onboard, as well as sea and wind condition data, many of these details were not recorded in most of the accidents. Therefore, the data groups shown in the following figures and tables represent the substantial number of known data.

When considering disappearance incidents in terms of time periods, it is observed that the majority of incidents occur during the period from midnight to dawn (Table 1). We anticipate two different reasons for this. Firstly, on ships other than cruise ships, the majority of the crew is likely to be in a resting or sleeping state during this time period. Secondly, on cruise vessels, this time period may coincide with the peak of alcohol consumption and the minimum presence of sober individuals.

Table 1. Time period of disappearance incidents on merchant ships.

Time Period of Incident	No of Incident	Percentage
Between 00:00-06:00	22	25.3 %
Between 06:00-12:00	13	14.9 %
Between 12:00-18:00	7	8 %
Between 18:00-00:00	11	12.6 %
No Data	34	39 %

Examining accidents based on the rank of the personnel, as expected, it is observed that ordinary and able-seaman facing the greatest risks have the highest number of disappearances. Additionally, crew such as stewards, entertainment staff, and galley personnel, who are relatively inconspicuous on cruise vessels, experience a significant number of disappearance accidents. Remarkably, the rate of chief engineers being victims of disappearance accidents is found to be high (Figure 2).

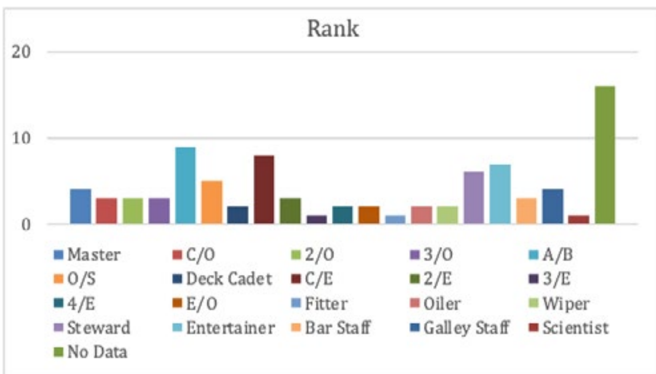

Figure 2. Rank of disappeared crew.

Analysing accidents based on the nationality of the missing personnel, it is observed that proportional values emerge as expected, corresponding to the number of employed seafarers (Figure 3).

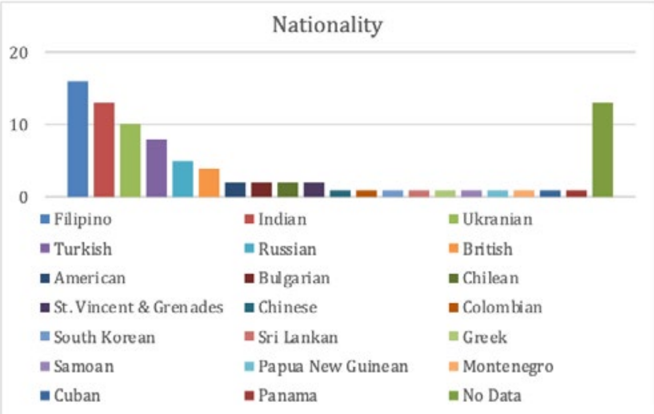

Figure 3. Nationality of disappeared crew.

When examining the types of ships involved in disappearance accidents, cruise ships and tankers stand out as the most common (Figure 4). The high number of individuals on cruise ships naturally has a significant impact on this situation.

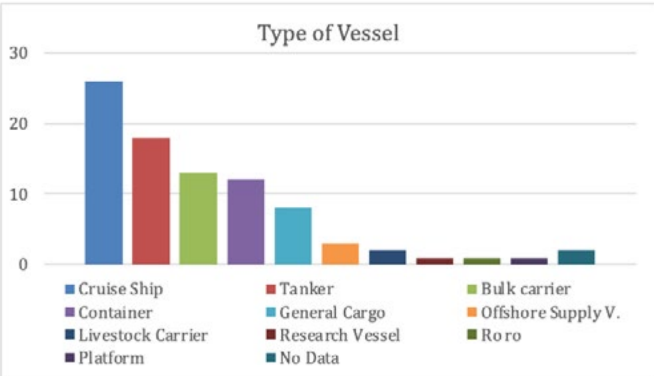

Figure 4. The type of ship where disappearance incidents occurred.

Considering the situation of whether it was night or day, it is observed that the majority of disappearance accidents occur during the night hours. The darkness and the lower number of individuals awake are the main reasons for this trend (Figure 5). In the examination based on the navigation status of ships, it is natural that vessels underway stand out as the ones where disappearance accidents most frequently occur (Figure 6). The higher likelihood of individuals surviving or being detected in the event of falling from a moored or anchored ship significantly contributes to this pattern.

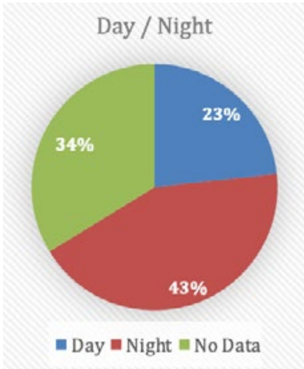

Figure 5. The situation of whether it was night or day.

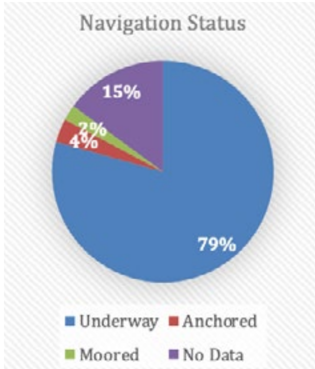

Figure 6. The navigation status of the ships during the incidents.

The examination of the age distribution of the missing personnel reveals that there is no distinct pattern (Figure 7).

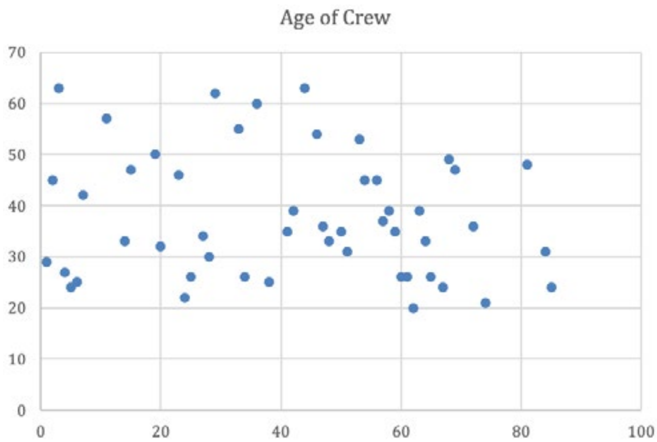

Figure 7. The age distribution graph of the crew who disappeared from the ships.

The data acquired from the considered accidents underwent an initial descriptive statistics test within the SPSS program to ascertain whether they exhibited a normal distribution. It was noted that the data displayed a normal distribution, and subsequent correlation analysis was conducted to assess if there existed a significant relationship between the variables (Table 2). Following the correlation analysis, it was found that a positive significant relationship existed between the date of the accident (DoI) and the date of the crew's embarkation (DoE), the flag of the ship (SF) and the age of the missing crew (Age), as well as the flag and type of the ship (ST). Based on the same analysis, it was established that there was a negative significant relationship between the age and rank of the crew (Rank), the type of ship and the rank of the crew, and the flag of the ship and the rank of the crew.

Table 2. The correlation analysis results of the disappeared crew data.

		DoI	DoE	D_N	Rank	Age	Nat	NS	ST	SF
DoI	Pearson Correlation	1								
	Sig. (2-tailed)									
	N	87								
DoE	Pearson Correlation	.999**	1							
	Sig. (2-tailed)	.000								
	N	18	18							
D_N	Pearson Correlation	-.233	-.461	1						
	Sig. (2-tailed)	.082	.113							
	N	57	13	57						
Rank	Pearson Correlation	-.093	-.157	.186	1					
	Sig. (2-tailed)	.443	.562	.215						
	N	71	16	46	71					
Age	Pearson Correlation	-.125	-.465	-.090	-.390*	1				
	Sig. (2-tailed)	.388	.128	.587	.011					
	N	50	12	39	42	50				
Nat	Pearson Correlation	-.103	.163	.045	.044	.074	1			
	Sig. (2-tailed)	.383	.533	.764	.732	.630				
	N	74	17	48	63	45	74			
NS	Pearson Correlation	.043	.[a]	-.252	-.035	.[a]	-.143	1		
	Sig. (2-tailed)	.719	.000	.064	.791	.000	.258			
	N	74	16	55	60	44	64	74		
ST	Pearson Correlation	.006	.087	-.216	-.422**	.233	-.055	.036	1	
	Sig. (2-tailed)	.959	.732	.109	.000	.106	.645	.761		
	N	85	18	56	69	49	72	73	85	
SF	Pearson Correlation	-.053	.199	-.138	-.251*	.398**	.157	.001	.255*	1
	Sig. (2-tailed)	.641	.429	.320	.040	.005	.187	.992	.021	
	N	81	18	54	67	48	72	71	81	81

a. Cannot be computed because at least one of the variables is constant.
DoI: date of incident, DoE: date of embarkation, D_N: day/night, Nat: nationality, NS: navigation status, ST: ship type, SF: ship flag

3. Result and Discussion

Upon examining the data in this study, it is evident that disappearance accidents predominantly occur during the night, particularly between the hours of 00:00 and 06:00, marking this period as the most hazardous. Additionally, it is notable that approximately two-thirds of the missing seafarers vanish between the 2nd and 20th day after joining the ship. The research also reveals that passenger ships, even when excluding passengers, experience the highest number of accidents, followed by tankers. The prevalence of these two ship types in such incidents can be attributed to the higher levels of work-related stress compared to other types of vessels. Reviewing the literature, it becomes apparent that the primary causes of disappearance accidents are murder, loss of cognitive control due to alcohol consumption, and suicide.

While disappearance accidents may not be receiving significant attention in the media compared to other types of accidents, numerous studies have highlighted the substantial economic losses they incur. Particularly concerning is the loss of personnel such as captains, chief engineers, and chief officers, which not only leads to the loss of time but also imposes significant financial burdens on maritime companies, placing them in challenging circumstances. The primary measure to prevent disappearance accidents is to equip ships with technology that can promptly detect if crew have fallen into the sea. The occurrence of crew members "disappearing" without a trace from cruise ships suggests that the majority of cruise companies have yet to prioritize the installation of an automatic man overboard system on their vessels. Auto-MOB systems, such as those found here or here, have the capability to detect a person going over the rails and promptly transmit a signal to the bridge. This enables the ship to initiate an immediate search and rescue operation. Such systems are equipped with advanced motion detection sensors, thermal imaging, and radar technology. When comparing the cost of such equipment with the expenses incurred due to the loss of key personnel from the ship, it becomes evident that the prices of the equipment are reasonable. In addition to these systems, smartwatch features can also be integrated, which measure body functions and temperature, providing instant reports and raising alarms when abnormal values are detected.

The maritime community and relevant authorities will address disappearance cases with thorough investigations, cooperation, and efforts to enhance safety and security measures on vessels.

It's important for shipping companies to prioritize the well-being of their crews, implement safety protocols, and provide adequate support systems for seafarers. Additionally, international organizations and maritime authorities may work collaboratively to establish guidelines and regulations to prevent and respond to missing seafarer incidents, ensuring the safety and security of those working at sea. The main challenge faced in this study was the insufficiency or absence of data in the reports and news sources. Consequently, doubts arise regarding the accuracy of the steps to be taken for in-depth examination of accidents, speculation on their causes, and prevention. To address this issue, it would be highly beneficial to recognize disappearance accidents as a distinct category of accidents, establish a standardized report format, and report them accordingly in this format.

The effort to comprehensively document missing seafarers, fishermen and passengers has been a gradual process, dependent on voluntary support from international partners, the availability of open-source information, and direct communication through the website with the family members of the missing. The urgent need for additional funds to further advance the work in this area, refine the online platform to support multiple languages, and widely disseminate awareness about the existence of such a valuable platform.

4. Conclusion

The aim of this study was to draw attention to personnel who go missing from ships and to share statistical data by focusing on the reasons for these disappearances. Based on the comprehensive analysis presented in this study, several key insights emerge regarding disappearance accidents at sea. The findings from this study provide various recommendations for preventing disappearance accidents at sea and coping with such incidents. Firstly, deck personnel need to be more vigilant during night shifts, particularly between 00:00 and 06:00. Additionally, special supervision and attention are required for newly joined personnel during their first few weeks. Specific training programmes and stress management measures should be developed for passenger ships and tankers, which experience the highest number of disappearance cases among ship types. Furthermore, it is essential for ship companies to equip their vessels with automatic man overboard systems and promote the widespread adoption of such technologies. Increasing awareness of disappearance incidents in the media and within society is also necessary. Lastly, establishing a standard reporting format for collecting and reporting accurate data and allocating more research and resources to ship safety are crucial. Implementing these recommendations could help reduce disappearance incidents at sea and enable more effective intervention in such tragedies.

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Latest Ship's Threat while Transiting Red Sea and Gulf of Aden

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Abstract

Since end of October 2023, a new threat to world's merchant ships appeared as drone and missile airstrikes launched by Houthi rebels, as well as transferring of terrorists from Yemen by helicopters followed by hijacking of ships with their crews. The threat of air attacks on ships is present along the coast of Yemen in Gulf of Aden, Red Sea and during transit of „Bab-el-Mandeb" [1]. Red Sea and Gulf of Aden is not only one of the most commonly used trading routes in the world, but it is also the quickest and shortest sea route between Asia and Europe what emphasizes the importance of the affected area. Recent incidents have raised tensions in this area and increased the risk for safe passage of world's merchant fleet, added significant costs and delays to shipments which are mostly coming from the Far East to Europe, and influencing on the other regions in that area which rely on Suez Canal. This article reviews recent maritime incidents involving Houthi missile and drone attacks on merchant ships and warships and discusses the escalating maritime security challenges in these regions, which weren't neglected even before due to Somali pirate's activity, impacting on global shipping and trade routes.

Keywords: *Maritime security threat, Air attacks, Houthi rebels, Red Sea, Gulf of Aden*

1. Introduction

One of the world's most important shipping routes passes in the vicinity of Yemen, which is located in the south of the Arabian Peninsula, all the way to the Suez Canal in Egypt, which connects the Mediterranean Sea with the Red Sea. That is also the shortest sea route from Asia to Europe and about 15% of all world trade takes place through the Red Sea, including oil, liquid gas and 30% of global container trade [2]. This area, the sea west of Yemen (southern part of Red Sea) and sea south of Yemen (Gulf of Aden), in the maritime industry is also known as High Risk Area (HRA). It includes narrow choke points such as the strait of Bab el-Mandeb (*eng. Gate of Grief/Gate of Tears*), the strait between Yemen on the Arabian Peninsula and Djibouti and Eritrea in the Horn of Africa. A High Risk Area (HRA) is an industry-defined area where it is considered that a higher risk of piracy attack exists, and additional security requirements may be necessary [3]. Ships should be prepared to deviate from their planned route at short notice to avoid threats highlighted by navigation warnings or by military forces. During the past years, the main threat in this area were the Somali pirates who were attacking and hijacking the ships from pure economic interests. The intention of Somali pirates was to hijack the ship and hold the crew for ransom. The usual practice was to keep the crew onboard as negotiations progress, keeping both the crew and the ship together until they receive the ransom, when they released the hostages together with the ship. Nowadays, when the Somali pirate's activity is decreasing, the main threat becomes the Houthi rebels and their politically motivated attacks and hijacking of the ships. The greater part of the western coast of Yemen is controlled by the Houthis, and the location of Yemen enables them to control part of the Red Sea, the Babel-Mandeb Strait, and the Gulf of Aden [4]. Due to recent activities, the situation in the Red Sea and the Gulf of Aden is more than worrying so this article reviews recent maritime incidents including Houthi missile and drone attacks on merchant ships and foreign warships and discusses the escalating maritime security challenges in these regions, as well as human rights and commercial issues.

2. Maritime Incidents

Several merchant ships have been attacked by drones or missiles during the recent months, but luckily without any human casualties. It could be noticed that the number of ship hijackings increased again in the months before the Hamas terrorist attack on Israel 7th of October, 2023. Several vessels were seized in the Persian Gulf, the Strait of Hormuz and the Gulf of Oman which were already, a few years ago, considered as part of a high risk area. The attacks are most likely the result of tensions between the US and Iran and restrictions on the trade of Iranian oil, as well as the situation between Israel and Palestine. They are part of Iran's retaliatory strike against the US and the UK. It is already quite clear that Iran is supporting the Houthi rebels and that incidents like this will continue to happen and ships connected to Israel will be the main target but it should be known that is not always the case [8]. The risk of an attack depends particularly on the development of the situation in Gaza. An escalation of Israeli operations against the Palestinians would increase the risk of attacks on Israeli ships and even if they are not sailing under the Israeli flag, they are anyhow connected to Israel [5]. After the initial Hamas attack 7th of October, Iranian-backed Houthi rebels in Yemen have increased the frequency of their attacks on merchant ships and foreign warships located in the Red Sea and the Gulf of Aden. On the 19th of October, the USS Carney warship intercepted four missiles and fifteen unmanned aerial vehicles (UAV), also known as drones, in international airspace in the Red Sea. The missiles were most probably launched by Houthi rebels to attack targets in Israel. 15th of November, the USS Hudner warship shot down a drone in international airspace over the Red Sea that had been launched from Yemen and headed towards the U.S. warship. A week later, US warships destroyed several more "one-way attack drones" in international airspace over the Red Sea that originated from Houthi-controlled areas in Yemen. On November 19, 2023, Houthi rebels carried out an attack by helicopter on the M/V Galaxy Leader while the Bahamian-flagged merchant ship was transiting the Red Sea. The vehicle carrier is British-owned and Japanese-operated (NYK line), but the British owners are associated with Ray Car Carriers, a company founded by a wealthy Israeli businessman. The ship and its twenty-five crewmembers are still being held hostage in Yemen. Japan condemned the act of piracy as “a flagrant violation of international law” and demanded the immediate release of the ship and crew [5]. Numerous attacks on merchant vessels have been carried out in the affected area, listed below in “Table 1.”, but the most significant attack happened on March 06, 2024, with several serious casualties and three fatalities on M/V True Confidence, caused by missile hit.

Table 1. Merchant ships attacked near Yemen since Nov. 19

Ship	Date	Location	Type of attack	Attacked ship type
Galaxy Leader	19-Nov-23	Red Sea	Hijacked	Car carrier
Central Park	27-Nov-23	Gulf of Aden	Hijacked, Rescued, Missile miss	Chemical tanker
Unity Explorer	03-Dec-23	Red Sea	Missile hit	Bulk carrier
Number 9	03-Dec-23	Red Sea	Missile hit	Container ship
Sophie II	03-Dec-23	Red Sea	Missile hit	Bulk carrier
Centaurus Leader	10-Dec-23	Red Sea	Drone miss	Car carrier
Strinda	11-Dec-23	Red Sea	Missile hit	Oil/Chemical
Ardmore Encounter	13-Dec-23	Gulf of Aden	Missile miss	Oil/Chemical
Maersk Gibraltar	14-Dec-23	Bab el-Mandeb	Missile miss	Container ship
Al Jasrah	15-Dec-23	Red Sea	Missile miss, Drone hit	Container ship
Palatium III	15-Dec-23	Red Sea	Drone miss, Missile hit	Container ship
Magic Vela	18-Dec-23	Bab el-Mandeb	Attempted Hijack	Bulk carrier
Swan Atlantic	18-Dec-23	Red Sea	Missile hit, Drone hit	Oil/Chemical
MSC Clara	18-Dec-23	Bab el-Mandeb	Drone miss	Container ship
Blaamanen	23-Dec-23	Red Sea	Drone miss	Oil/Chemical
Sai Baba	23-Dec-23	Red Sea	Drone hit	Oil tanker
Navig8 Montiel	25-Dec-23	Red Sea	Drone miss	Oil tanker
MSC United VIII	25-Dec-23	Gulf of Aden	Drone miss	Container ship
Maersk Hangzhou	31-Dec-23	Red Sea	Missile hit	Container ship
CMA CGM TAGE	02-Jan-24	Red Sea	Missile miss	Container ship
Federal Masamune	09-Jan-24	Red Sea	Missile miss	Bulk carrier
Khalissa	12-Jan-24	Gulf of Aden	Missile miss	Oil tanker
Gibraltar Eagle	15-Jan-24	Gulf of Aden	Missile hit	Bulk carrier
Zografia	16-Jan-24	Red Sea	Missile hit	Bulk carrier
Genco Picardy	17-Jan-24	Gulf of Aden	Drone hit	Bulk carrier
Chem Ranger	18-Jan-24	Red Sea	Drone miss	Chemical tanker
Tomahawk	24-Jan-24	Red Sea	Drone miss	Bulk carrier
Maersk Detroit	24-Jan-24	Gulf of Aden	Missile miss	Container ship
Maersk Chesapeak	24-Jan-24	Gulf of Aden	Missile miss	Container ship
Marlin Luanda	26-Jan-24	Gulf of Aden	Missile hit	Oil tanker
Daffodil	02-Feb-24	Red Sea	Drone miss	Oil tanker
Morning Tide	06-Feb-24	Red Sea	Missile miss	General cargo
Star Nasia	06-Feb-24	Gulf of Aden	Missile miss	Bulk carrier
Star Iris	12-Feb-24	Bab el-Mandeb	Missile hit	Bulk carrier
Lycavitos	15-Feb-24	Gulf of Aden	Missile miss	Bulk carrier
Pollux	16-Feb-24	Red Sea	Missile hit	Oil tanker
Rubymar	18-Feb-24	Gulf of Aden	Missile hit	Bulk carrier
Sea Champion	19-Feb-24	Bab el-Mandeb	Missile hit	Bulk carrier
Navis Fortuna	19-Feb-24	Red Sea	Missile hit	Bulk carrier
Islander	22-Feb-24	Gulf of Aden	Missile hit	General cargo
Torm Thor	24-Feb-24	Gulf of Aden	Missile hit	Oil/Chemical
Jolly Vanadio	27-Feb-24	Red Sea	Missile miss	Container ship
MSC Sky II	04-Mar-24	Gulf of Aden	Missile hit	Container ship
True Confidence	06-Mar-24	Gulf of Aden	Missile hit	Bulk carrier

3. Influences and Consequences on Global Trade

Attacks on vessels by Yemen’s Houthi rebels in the Red Sea have disrupted international trade on the shortest shipping route between Europe and Asia. The air strikes, which came in solidarity and close connection with Palestinians who are facing Israeli bombardments in Gaza, are targeting a route that takes for about 15 percent of the world’s shipping traffic, forcing shipping companies to reroute their vessels. The Houthi attacks have forced a lot of merchant vessels passing through the Suez Canal and the Bab el-Mandeb Strait to take an alternative and longer route around South Africa which causes delays and additional delivery time and unavoidable extra costs. The recent attacks forced several major European shipping companies like MSC (Switzerland), Hapag-Lloyd (Germany), Maersk (Denmark) and another European giant CMA CGM (France) to suspend their shipments through the Red Sea. Together these companies represent approximately 54 per cent of the global vessel market. They have rerouted vessels to navigate around the Cape of Good Hope increasing the voyage distance by about 40 per cent compared with the route via the Suez Canal. It is anticipated that this increased voyage would hike the container charges by $500-1000 per container. This has the potential to choke the global supply chains and hike the prices of export-import goods, trigger further inflation, and increase the Current Account Deficit (CAD) of nations that are already grappling with post-COVID recovery and the Russia-Ukraine situation. War risk insurance, which is crucial for vessels sailing through high-risk areas, has substantially increased. There are growing concerns in the maritime industry regarding the increase in war risk insurance related to shipping in certain areas, particularly in the Red Sea. Initially, the war risk premium was around 0.07% of the total shipping value, but it gradually escalated to almost 0.1% from the second week of December 2023 [6]. While this may not seem like a substantial amount in the context of overall shipping value, the rising frequency of attacks and their indiscriminate nature suggests that these costs could continue to rise.

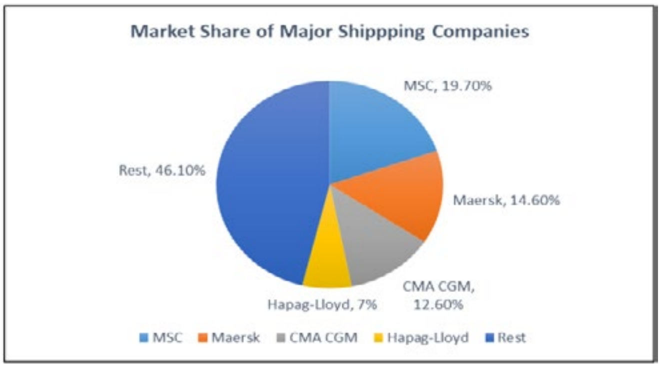

Figure 1: Market share of major Shipping companies [6]

Houthi attacks on merchant ships have significantly increased fuel costs and that affected about 10% of global oil and 8% of liquefied natural gas (LNG) transits through key routes like Suez. European Union have increased their oil and gas imports following Ukraine-related sanctions on Russia's oil industry and it will be difficult to satisfy the needs of the EU with practically blockade of routes through the Suez Canal. Additionally, about 30% of global container shipping passes through Suez, affecting various shipments and causing delays of previously agreed deliveries by adding more than 3,000 nautical miles in route deviation via Cape Town, leading to extended shipment time and additional expenses [6]. Major global companies in the auto industry, energy sector, logistics, retailers and others were impacted by this anomaly in commercial shipping. Michelin, Suzuki, Tesla, Volvo, BP, Equinor, Qatar Energy, Shell, DHL, FedEx, Adidas, Danone, Ikea, Pepco, Primark, BHP Group, Evonik, GechemGmbH & Co KG, Levi Strauss & Co, Logitech [7], they are just some of the companies which are affected by disruption of waterways which results in delays of deliveries and seeking alternative delivery methods and routes.

4. Shipping Company's Role and Responsibility

The escalated security situation in the southern Red Sea and Gulf of Aden is alarming in the global and maritime industry and recent attacks on merchant ships pose a significant threat to the safety and lives of seafarers, ships as property of the owners, the environment, reputation of shipping companies, as well as the functionality of global trade. Shipping companies must monitor the situation constantly and dispose with all available intelligence information on the security situation in the area. Ensuring the safety of seafarers is of the utmost importance and must remain the number one priority in the global and maritime industry, especially during struggling in this challenging situation. A shipping company's understanding of the potential impact on global customer's supply chain and taking the necessary steps to minimize the impact on customers is also very important but all decisions must be carefully considered and only implemented to ensure the safety of vessels, crew, cargo and environment. Ship owners, operators, managers, charterers and crew should regularly evaluate the risks to their ships and plan routes accordingly, taking all relevant facts, risks, previous incidents as experience exchange and all available information into consideration. The majority of leading shipping companies, as mentioned previously in the article, have already suspended their shipments through the Red Sea due to risk determination as high and not acceptable from safety and security aspects. Qatar Energy, the world's second-largest exporter of liquefied natural gas, stopped sending tankers via the Red Sea due to security concerns [7]. Ship operators who have called, or plan to call, at Israeli ports should limit information access which could be used by Houthi rebels. Ship owners and operators who have recently acquired a vessel from an Israeli-associated company should ensure vessel systems, like AIS (Automatic Identification System), properly reflect updated information. Outdated information has caused vessels to be attacked. Ships planning a passage through the Southern Red Sea and Gulf of Aden should conduct a thorough ship and voyage-specific threat and risk assessment considering any additional advice or guidelines from their Flag State. These assessments should include input from official sources, such as UKMTO (United Kingdom Maritime Trade Operations), and relevant information such as operation specifics, shipping associations guidance, ownership details, and trading history of the ship in the last 3 years that could impact decision making. Ships with AIS powered on, as well as powered off, have been attacked. Turning off AIS makes it marginally more difficult to track a ship but may also prevent the ability of the military to provide support or direct contact. The consequences of turning off equipment and aids such as AIS (Automatic Identification System), LRIT (Long Range Tracking and Identification), and especially radars should be carefully assessed [1]. There has been a significant decline, approximately 50%, in maritime traffic in the southern Red Sea and Bab el-Mandeb area between November and late January. Notably, there has been a slight increase in the number of ships passing through Bab el-Mandeb without broadcasting an AIS signal. Only around 10% of merchant ships passing through Bab el- Mandeb have turned off their AIS. Due to the current situation in affected areas caused by Houthi rebels, maritime industry associations have revised and released the security guidance applicable to navigating in the Southern Red Sea and Gulf of Aden, and all vessels transiting this area should comply with it [10]. Guidance (Updated security guidelines for Southern Red Sea and Gulf of Aden) is revised and issued by shipping associations BIMCO (Baltic and International Maritime Council), CLIA (Cruise Lines International Association), ICS (International Chamber of Shipping), IMCA (International Marine Contractors Association), INTERCARGO (International Association of Dry Cargo Shipowners), INTERTANKO (International Association of Independent Tanker Owners) and OCIMF (Oil Companies International Marine Forum) [6]. Company Security Officers, Masters and Ship Security Officers of vessels transiting or preparing to transit this area should take into consideration the following in their voyage-specific risk assessment:

1. Analyze the commercial affiliation of the vessel to assess the threat level for the planned type of operation.
2. Constant monitoring of the security situation, enabling vessels to avoid locations with recent or ongoing incidents.
3. Introduction/update of contingency plans on the company level to address the possibility of seafarers being injured, killed or kidnapped during a security incident. Drills should also be carried out involving shore management.
4. Crew briefings and scenario drills based on a valid and relevant anti-attack plan to ensure that incidents are reported and alarm is raised without delay when required. Drills should include scenarios with major damage and casualties.

5. Enhancement of firefighting, evacuation and damage control procedures, taking into account the possibility of significant damage as a result of direct targeting or collateral damage.
6. Enhancement of medical equipment to deal with multiple casualties.
7. Emergency contacts placed readily available on the bridge.
8. Briefing of the bridge team on hailing/harassment via VHF, prepared responses and immediate contact with naval forces in the respective area. (Local authorities calls on VHF may be an act of spoofing or even targeting, underlined by several incidents in recent days which involved self-proclaimed 'Yemeni authorities' or the 'Yemeni navy' ordering merchant ships to alter course). Combined Maritime Forces also recommend ignoring VHF calls by the "Yemeni navy" with instructions to alter the course to Hudaydah or other locations in Yemen. When merchant ships are contacted, masters are advised to continue the voyage and call for a coalition warship on VHF Channel 16, stating the current location, situation and intentions.
9. Preparation of citadel with emergency provisions and functioning satellite phone.
10. Depending on individual circumstances, the embarkation of armed guards may be useful to mitigate specific risks, specifically concerning the threat of boardings from small boats (e.g. Houthi forces, Somali piracy). However, the threat of direct targeting by missiles, aerial or naval drones used by Houthi forces in Yemen (southern Red Sea / Gulf of Aden) cannot be mitigated by the embarkation of armed guards.
11. Existing BMP5 recommendations have been developed to deter piracy. While the guidance included in BMP5 is relevant to deter illegal boardings, it offers virtually no mitigation against current threats such as attacks by missiles, drones or – potentially – waterborne IEDs (drone boats).
12. Ship operators should also consider issuing specific voyage guidance for transits through the Red Sea and the Gulf of Aden. This guidance should consider specific scenarios (e.g. aerial or waterborne threats, hailing on VHF) and include actions for the crew to minimise the impact of any security incident [9].

5. How to Solve the Current Situation in the Affected Area

The data present in this article suggest that the current situation in the Red Sea and the Gulf of Aden, as well as the Bab el-Mandeb Strait must be solved. The main concern is how to, for the sake of peace, legally survey Yemeni territorial waters, the air space above the sea and the coast from where the majority of air attacks originated. Preventive actions which can be taken, as a product of international cooperation and maritime security measures, to ensure safe navigation in the affected area are:

1. Established maritime security sectors and dedicated international, regional or local warships in each sector as security patrol or escort for merchant ships convoys
2. Warships in each sector to maintain continuous maritime and air traffic surveillance using drones, radars and satellite monitoring systems.
3. Implement usage of recommended transit corridors and reporting procedures for all ships transiting the area
4. Experience exchange information from other ships to be taken into consideration for all regularly updated contingency plans and risk assessments for potential security incidents.
5. All parties involved to comply with the United Nations Convention on the Law of the Sea (UNCLOS) to ensure safe transit of the affected area
6. The Yemeni government to take over control of complete Yemeni territory and to bring security, stability and peace to Yemen by settling the situation in the affected area in close cooperation with the international community.
7. If the root cause is war in Palestine, then Israeli forces must stop their aggression and offensive in Gaza.

Notably, there is a wide space for further progress in analyzing the above-mentioned suggestions and the proper way of implementing them to achieve safe waters for navigation and transit of commercial shipping.

6. Conclusion

The current situation in the Red Sea and the Gulf of Aden is very challenging and the main concern and priority are the people, i.e., seafarers who are risking their lives while transiting affected areas where security risk is at a significantly elevated level. Despite seafarer's psychological issues, on board the ships, during the COVID-19 outbreak Somali pirate's activity decreased during the past years, but the current situation is very worrying for seafarers well-being and state of mind. Especially now, when physical victims are present, the psychological influence on the seafarer's state of mind is already significant and their productivity and effectiveness are dropping and becoming unenviable. Therefore, closely monitoring of ship crew condition, thorough risk assessments and proper contingency planning are crucial for all operators in the area. Shipping companies are facing also increased insurance and fuel costs, which makes freight transportation more expensive, which is ultimately paid by consumers (people). The Gulf of Aden is an important sea passage that connects the West with the East via the Red Sea and the Suez Canal, so there is an undoubted need to solve the current situation as soon as possible. With low water levels affecting the Panama Canal and reducing its capacity, together with this situation in the Red Sea and the Gulf of Aden, this could lead to the biggest crisis in maritime and commercial industry.

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Integrating Comprehensive Analysis and Dynamic Adaptability for Safer Maritime Autonomy

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Abstract

The advent of autonomous ship technologies has ushered in a new era in maritime transportation, promising increased efficiency, safety, and sustainability. However, the integration of autonomy into maritime operations brings forth a unique set of challenges, particularly in the realm of risk assessment. This work explores a holistic approach to risk assessment tailored specifically for autonomous ship operations. The assessment framework integrates technical, operational, and environmental factors, emphasizing a systems-thinking perspective. Moreover, this paper is to provide a comprehensive exploration of the intricate risk landscape associated with the integration of autonomous ships in maritime operations. Embracing a holistic approach, the paper seeks to amalgamate insights from technological, operational, human, and regulatory dimensions, fostering a nuanced understanding of the multifaceted challenges inherent in autonomous shipping. With a primary focus on safety enhancement and informed decision-making, the research aims to contribute valuable frameworks and recommendations that resonate across disciplines, facilitating the smooth and secure integration of autonomous vessels into maritime activities.

In conclusion, this study advocates for a holistic risk assessment approach that goes beyond traditional frameworks to address the intricacies of autonomous ship operations. By embracing a comprehensive perspective and leveraging cutting-edge technologies, our proposed methodology aims to enhance the safety and reliability of autonomous maritime transportation systems, paving the way for their widespread adoption in the global shipping industry.

Keywords: *Autonomous ship technologies, Maritime transportation, Holistic approach*

1. Introduction

This conference paper gets to the heart of this paradigm shift by exploring the necessity of a comprehensive approach to risk assessment specifically designed for autonomous ship operations. In the emerging literature, it is noteworthy that there is a lack of comprehensive studies explaining how autonomous ships can serve to reduce risks, strengthen emergency response mechanisms, and prevent unintentional events in maritime operations[1]. In the emerging literature in this field, there is a notable lack of comprehensive studies explaining how digital tools can serve to reduce risks, strengthen emergency response mechanisms, and proactively prevent accidents in maritime operations. The article conducts a systematic literature review (SLR) on digitalization in maritime security guided by the PRISMA framework. Additionally, this article goes beyond a simple review of the existing literature by attempting to distill limited findings and outline a solid framework for future research efforts.

At its core, our approach advocates a holistic examination of risk factors, covering not only traditional maritime risks but also new challenges inherent in autonomous navigation, sensor reliability, cyber threats, and human-machine interactions[2], [3]. Emphasizing a systems thinking perspective, our methodology combines studies on technical, operational and environmental aspects to provide a detailed understanding of the risks involved[4], [5].

In conclusion, this research, which reveals the various impacts of autonomous ships on maritime safety, aims to provide maritime stakeholders with a better understanding of how the technologies that can be developed on autonomous ships can serve as a potential catalyst in improving safety standards. In short, this article contributes to highlighting the level of dynamic adaptability at the intersection of autonomous ships and maritime security. It is intended not only to enrich the academic literature but also to serve as a holistic perspective that points to pragmatic interventions aimed at improving safety protocols in maritime operations. By combining comprehensive analysis and dynamic adaptability, our approach aims to lead to widespread adoption of autonomous ship technologies and enable progress towards a safer and more sustainable future in shipping.

The study consists of five main sections. The first section explains the motivation of the study. The second section presents the research methodology. In the third section, a systematic literature review was conducted. In the fourth section, the findings are analyzed. In the last section, the study is concluded and suggestions for future research are presented.

2. Research Methodology

A research method called a Systematic Literature Review (SLR) is utilized to analyze and evaluate research projects related to a certain subject[6], [7]. The principal objective of this approach is to combine data from several sources in a clear and methodologically sound way[8]. The PRISMA framework, which stands for Preferred Reporting Items for Systematic Reviews and Meta-Analyses, is a widely accepted approach in the academic world that is employed in the execution of systematic literature reviews[9].

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline is widely acknowledged as a standard reference for conducting systematic literature reviews (SLRs)[10], [11]. Its utility extends beyond enhancing the reporting quality for authors, as it aids reviewers and editors in critically assessing SLRs[12]. These tools play a pivotal role in promoting research reproducibility, addressing a prominent concern in modern academic inquiry.

The PRISMA framework comprises a checklist and a flowchart designed to aid researchers in the preparation, execution, and documentation of systematic reviews and meta-analyses. The checklist encompasses multiple facets of the review endeavor, encompassing tasks such as identifying and selecting studies, extracting data, evaluating study quality, synthesizing findings, and interpreting results[13], [14].

Through adherence to the PRISMA guidelines, scholars can ascertain that their systematic reviews and meta-analyses are executed and documented in a systematic and transparent fashion, thereby enhancing the trustworthiness and applicability of the outcomes for informing decisions in research, policy formulation, and practical implementation[15], [16].

Table 1. Review protocol

Item	Description
Database	Scopus; Web of Science
Keywords	(maritime OR ship) AND (autonom* OR "unmanned surface vessel" OR USV OR "autonomous surface vessel" OR ASV) AND (safety OR risk OR safe*) AND NOT (medicine OR health)
Boolean Operators	AND; OR; NOT
Search Fields	Title; Abstract; Keywords
Exclusion Criteria	Papers that are not directly related with the maritime safety
Language	English
Publication Type	Article; Review; Book; Book Chapter
Research Area	Engineering
Time Window	2014-2024

The initial phase of this investigation involved formulating a literature review protocol, as detailed in Table 1. Subsequently, exploration was undertaken utilizing Scopus and Web of Science databases[17], recognized for their reliability and comprehensiveness in scholarly literature[18], [19]. Appropriate keywords were selected to uncover studies addressing the transition to autonomous systems within the maritime domain. Exclusion criteria were applied to pinpoint documents specifically concerning autonomous systems in shipboard maritime safety. Refinement of the filtering process was enacted to encompass solely peer-reviewed publications, articles, reviews, books, and book chapters published in English. The scrutiny primarily centered on engineering literature. To gauge contemporary research, scrutiny was confined to studies conducted within the past decade.

3. Literature Search

Our review was founded upon a collection of pertinent publications sourced from prominent academic databases, namely Web of Science (WoS) and Scopus. In March 2024, an extensive keyword search was performed within the WoS and Scopus databases to procure relevant bibliographic information. The comprehensive keyword search methodology, incorporating Boolean functions, and the subsequent filtration of results are delineated in Table 2.

Table 2. Keyword search in wos and scopus databases

Step	Keyword Search	Publications	
		Scopus	WoS
1	(maritime OR ship) AND (autonom* OR "unmanned surface vessel" OR USV OR "autonomous surface vessel" OR ASV) AND (safety OR risk OR safe*)	1947	1278
2	(maritime OR ship) AND (autonom* OR "unmanned surface vessel" OR USV OR "autonomous surface vessel" OR ASV) AND (safety OR risk OR safe*) AND NOT (medicine OR health)	1878	1229
3	Filtered by year: 2014-2023	1644	1137
4	Filtered by language: English	1586	1110
5	Filtered by document type: Article; Review; Book; Book Chapter	829	779
6	Filtered by research area: Engineering	668	302

The objective of this investigation is to scrutinize endeavors in achieving safer autonomous shipping through a comprehensive lens. Given the focus on maritime autonomy, the primary keyword "maritime, autonom*, and safety" has been selected. Additional keywords, including "ship, unmanned surface vessel, autonomous surface vessel, safe*, risk," were chosen to ensure a thorough exploration of the topic. It was observed that certain studies retrieved through these keywords pertained to the medical and health domains due to lexical similarities, prompting their exclusion from the review scope. Following the determination of these keywords, an exhaustive literature search was conducted across both Scopus and Web of Science (WoS) databases utilizing Boolean functions. To capture the current landscape of research, studies conducted between 2014 and 2024 were considered, while limiting the scope to publications in English within the engineering field, encompassing document types such as articles, reviews, and book chapters.

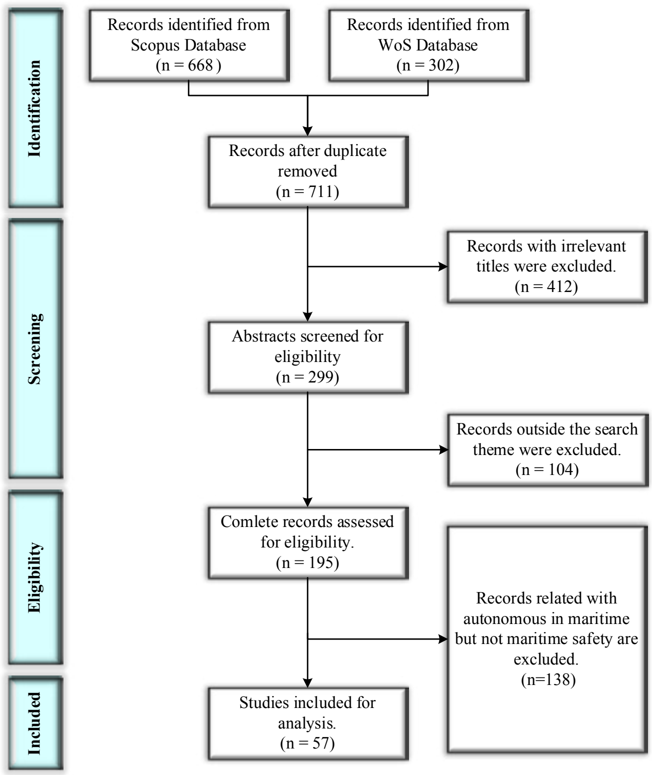

Figure 1. PRISMA flowchart

Following this, the literature search employed the PRISMA flowchart delineated into four sequential stages (depicted in Figure 1): Identification, Screening, Eligibility, and Inclusion. During the Identification phase, outcomes from distinct databases were amalgamated, with duplicate records eliminated. Subsequently, the titles and abstracts of 711 publications underwent screening. In the eligibility phase, publications underwent thorough review and assessment. Ultimately, the inclusion stage yielded 57 publications deemed suitable for further analysis.

4. Analysis and Findings

4.1. Main Information

This study exclusively examines academic literature pertaining to the safety of autonomous ships published between 2014 and 2024. Following an extensive literature review, 57 relevant publications were identified. Analysis of the annual growth rate in publication numbers reveals a rate of 17.46%. Furthermore, the average publication age over the past decade stands at 2.84 years. Examination of the identified publications indicates an average citation count of 29.23, suggesting the significance and impact of studies on autonomous ships as a contemporary and influential topic. Basic information regarding the pertinent publications is presented in Figure 2.

Figure 2. Main information

4.2. Annual Scientific Publication and Time Trend

Table 3 illustrates the overall trend in annual publications. The ongoing evolution of the maritime industry has fueled a growing interest in maritime autonomy. The surge in academic research, particularly evident from 2019 onwards, along with the global pandemic, underscores the growing recognition of the significance of maritime transportation. Based on the observed rise in the table, it is anticipated that the adoption of autonomous systems in the maritime sector will gather further momentum in the forthcoming years.

Table 3. Annual scientific publication

Year	Annual scientific publication
2014	1
2015	1
2016	2
2017	1
2018	1
2019	4
2020	8
2021	9
2022	10
2023	15

4.3. Most Relevant Sources and Words

The most relevant journals are shown in Figure 3 according to the results of the search according to WOS and Scopus database. The journal "Ocean Engineering" has the highest number of publications. Following "Ocean Engineering", "Reliability Engineering and System Safety" is the second most relevant journal. In order of importance, these journals are followed by "Journal of Marine Science and Engineering" and "Safety Science".

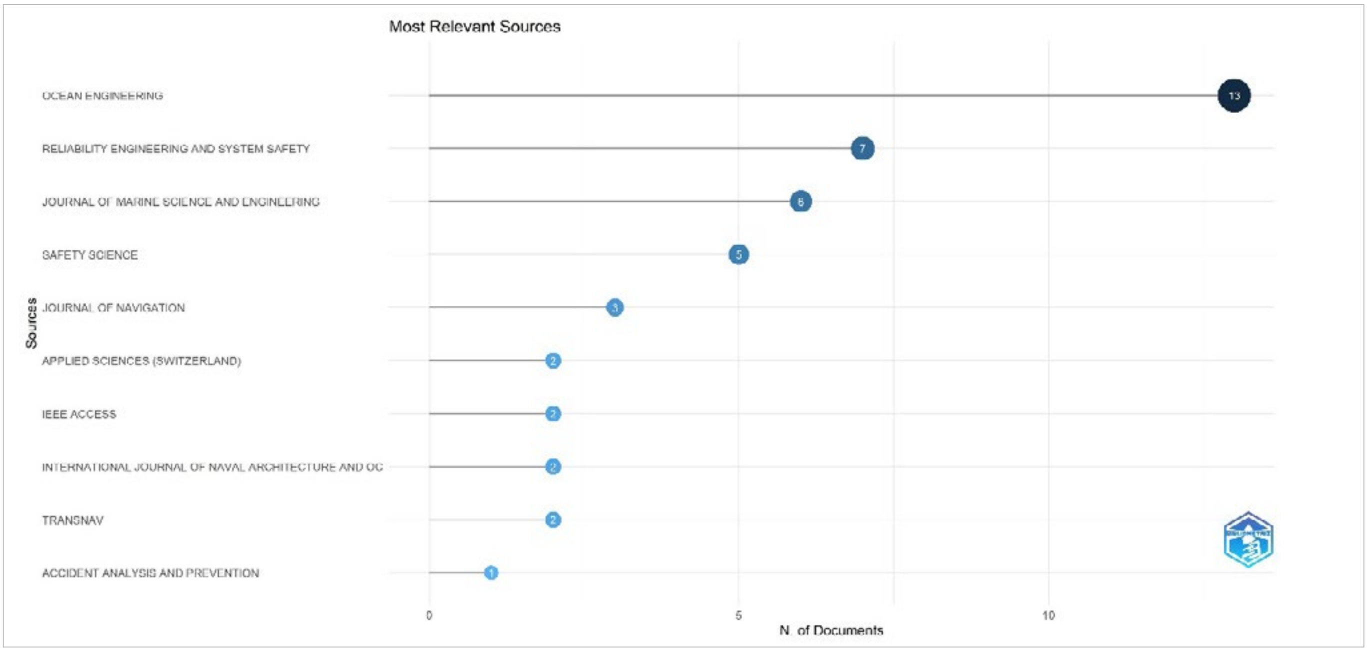

Figure 3. Most relevant sources

The keywords used by the authors contain clues about the topics the articles focus on and the methods they use. The relationship between keywords helps to analyse in which areas the articles are concentrated and accepted. The most frequently used keywords are shown in Figure 4 and the relationships between these words are shown in Figure 5. “Ships”, “Collision Avoidance” and “Risk Assessment” are the most frequently used keywords.

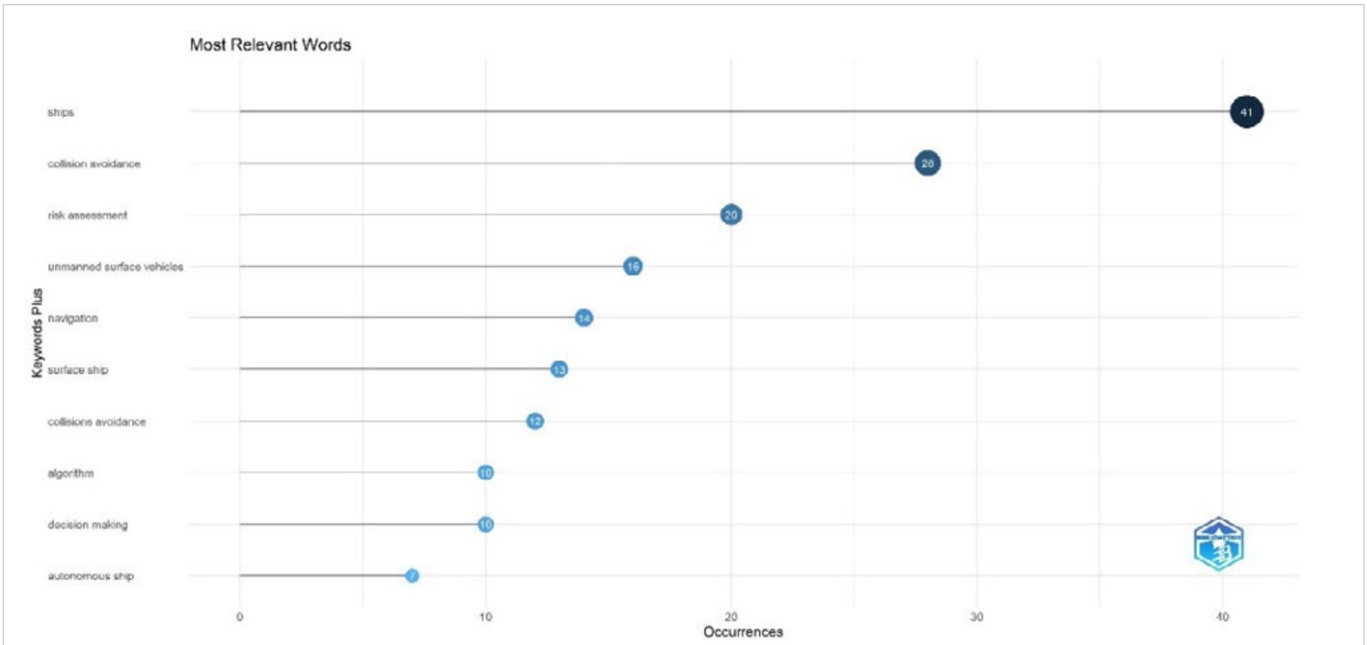

Figure 4: Most relevant words

As a result of the literature review, the most commonly used keywords are concentrated on 3 different networks. The main source of these networks is “ships”, “risk assessment” and “reinforcement learning” depending on this keyword. If the identified network is interpreted, studies on collision and risk in autonomous ships have been carried out with the keyword “ships”. The identified risks are concentrated in the categories of “human error”, “human reliability” and “safety factor”. In these studies, “bayesian network” method was utilised and artificial intelligence was used.

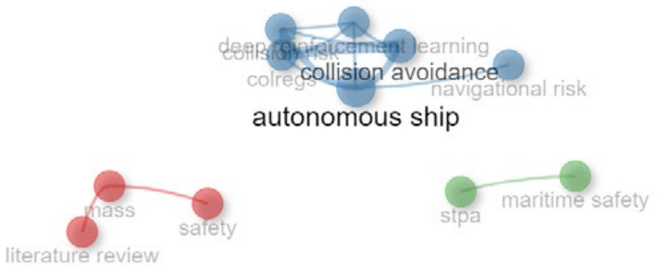

Figure 5: Author's keywords co-occurrence network

4.4. Analysis of Studies in Safer Maritime Autonomy

It is very important for autonomous ships to prioritise safety in maritime operations for several reasons. First of all, ensuring the safety of autonomous ships helps to protect human life and prevent maritime accidents. Since maritime accidents can lead to loss of life, environmental damage and economic losses, safety is of paramount concern.

In this study for safer autonomous ships, we have analysed the studies on autonomous ships so far. The majority of these studies have focused on safety and have generally focused on navigation and collision avoidance. As a result of the keywords determined, 195 studies were analysed. It was seen that only 57 of these studies were carried out on the safety standards determined. It was seen that these articles were made on 3 main keywords and their intersection points on safety.

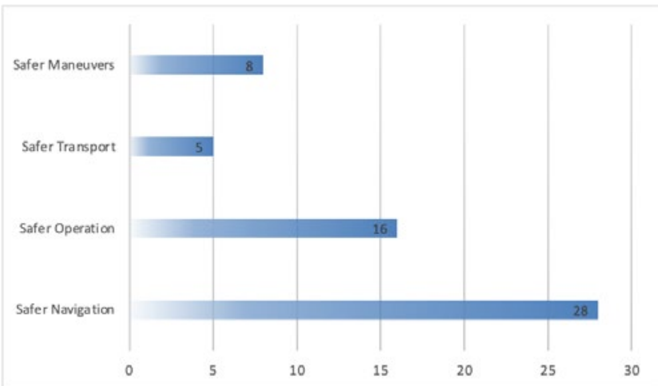

Figure 6. Number of publications by safer categories

The show that figure 6, analysis of the 57 studies categorized under the "Safer" category reveals a distribution across several subfields within maritime autonomy. Among these, 28 studies focused on safer navigation, indicating a predominant emphasis on enhancing navigational safety in autonomous shipping operations. Additionally, 16 studies were conducted in the domain of safer operation, reflecting a substantial interest in optimizing operational safety protocols and practices. Furthermore, 8 studies were dedicated to safer maneuvers, suggesting a targeted investigation into maneuvering safety strategies and techniques. Lastly, 5 studies were centered on safer transport, underscoring a notable attention to safety considerations in the transportation aspect of autonomous maritime operations. These findings highlight a diverse spectrum of research interests and priorities within the broader context of ensuring safety in maritime autonomy, with a discernible emphasis on navigation and operational safety.

4.5. Results and Discussion

An analysis of the existing literature on safer maritime autonomy reveals that significant strides have been made in understanding and addressing safety concerns in autonomous maritime operations. However, it is clear that the existing body of work points to the need for further research and development in several key areas that remain lacking. The lack of studies on the Applicability of Security Measures is noteworthy. While there have been numerous studies examining various aspects of safety in maritime autonomy, there remains a notable gap in the implementation of comprehensive safety measures across the sector. Despite advances in technology and regulatory frameworks, the practical application of safety protocols and guidelines in autonomous maritime operations remains inadequate in some cases due to inconsistent data. These differences underline the need for more emphasis in the maritime sector on translating theoretical knowledge into practical safety applications.

Another topic, which constitutes the majority of the research, is Navigational Safety. These studies have focused on navigational safety with significant attention to collision avoidance systems, route optimization algorithms and sensor technologies. While these advances represent promising steps towards safer navigation on autonomous ships, challenges remain, such as real-time decision making in dynamic environments and unpredictable weather conditions. Further research is required to improve current navigational safety strategies and effectively address emerging challenges. Briefly, while considerable progress has been made in advancing safety measures in maritime autonomy, the current body of work reflects an incomplete understanding of the complexities and challenges inherent in autonomous shipping operations. Addressing these gaps requires interdisciplinary collaboration, industry-wide cooperation, and sustained research efforts to develop and implement comprehensive safety solutions. By prioritizing safety in research, development, and practice, the maritime industry can pave the way for safer and more sustainable autonomous shipping operations in the future.

5. Conclusion

To sum up, the pursuit of safer maritime autonomy represents a multifaceted endeavor that requires continuous innovation, collaboration, and adaptation. While significant progress has been made in understanding and addressing safety concerns within autonomous shipping operations, it is evident that future work is essential to fully realize the potential of maritime autonomy while ensuring the highest standards of safety. Moving forward, several key areas warrant attention and investment in future research and development initiatives.

Firstly, there is a critical need for the implementation of comprehensive safety measures across the maritime industry, translating theoretical knowledge into practical applications to enhance operational safety and mitigate risks effectively.

Additionally, continued advancements in navigational safety, operational protocols, and emergency response mechanisms are imperative to address emerging challenges and evolving regulatory requirements in autonomous shipping. Research efforts should focus on refining existing safety strategies, developing innovative technologies, and establishing standardized training programs to support the safe integration of autonomous systems into maritime operations.

Acknowledgment

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Cargo Liquefaction and Its Effects on Ship Stability

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Abstract

One well-known risk associated with shipping solid bulk freight is cargo liquefaction. Many marine casualties have lost their life due to cargo liquefaction in the past few decades. The process by which a solid material becomes almost fluid is called liquefaction. Numerous common minerals, such as nickel, iron ore, and various mineral concentrates, can liquefy. Solid bulk cargoes are typically loosely packed granular materials. When the cargo is wet during loading it might be susceptible to liquefaction. Liquefaction can be seen in some specific types of dry bulk cargoes where moisture content exceeds their transportable moisture limit. The most hazardous consequence of liquefaction for a vessel is cargo movement, which leads to instability. The main effect is the vessel's loss of stability (decrease or loss of GM) due to the cargo liquefying, as it causes the vessel to list dangerously to one side. In some instances, the angle of heel continues to increase, resulting in the vessel listing heavily, down flooding or even capsizing, leading to the loss of the vessel, its cargo, and its crew.

Keywords: *Maritime transportation, Cargo liquefaction, Ship stability.*

1. Introduction

The maritime industry serves as the lifeblood of global trade, facilitating the movement of diverse goods across vast oceans. Among the various cargo types, the transportation of Liquefied loads poses unique challenges and opportunities. Some solid bulk loads, without any packaging, may liquefy during transportation. Solid bulk cargo refers to any cargo—unlike liquid or gas—that is directly loaded into a ship's cargo compartments without the need for any intermediary containment. This can include grains, particles, or larger chunks of material with a relatively consistent composition. When transporting solid bulk loads, the primary risks are those associated with cargo chemical reactions, loss or decrease in stability during the journey, and structural damage from improper cargo distribution.

Capsizing may result from the interaction of ship motion and cargo displacement. However, scholars have not yet addressed these issues holistically. Organizations including the IMO, Class NK, and Technical Working Group have conducted early investigations and developed some norms and guidance to prevent ship capsizing due to cargo liquefaction [1]. The IMSBC Code [2] was enacted on December 4, 2008, by decision MSC.268(85). It became mandatory on January 1, 2011, by the SOLAS Convention's stipulations. The Code has been updated since then. The IMSBC Code's main goal is to make it easier for solid bulk cargo to be stowed and shipped safely by educating people about the risks involved in shipping specific kinds of bulk cargo and outlining the steps that should be taken when shipping solid bulk cargo.

This study provides thorough information on the phenomenon of bulk cargo liquefaction and its effect on ship stability, as well as a general appraisal of the literature.

2. Literature review

Cargo liquefaction has caused numerous ship catastrophes in the past and present. Due to cargo liquefaction, a growing number of ships have lost their intact stability in recent years. Some of them sadly capsized, while others acquired huge list angles. When the ship Testarosa, carrying iron ore, sank in the Atlantic Ocean in 1987, thirty persons died. Due to cargo liquefaction, the Sea Prospect ship, which was transporting nickel ore from Indonesia to Japan in 1998, sank. In 2010, the ship Nasco Diamond, loaded with 50,150 tons of nickel ore, sank off the coast of western Taiwan due to cargo liquefaction. There are complex factors underlying the liquefaction of solid bulk cargo. Mineral ores transported by ships generally contain moisture. Even when the moisture content of the cargo does not appear to be very high, it is this moisture that increases the risk of liquefaction. Due to their global distribution, iron and nickel ore are the cargoes with this hazard that are most well-known. During the process of ship loading, these cargoes are typically in their solid condition, with particles coming into close touch with one another. As a result, there is a physical resistance to shear forces. Conversely, granular materials found in cargoes like mineral ores, which are loaded into a vessel, are subjected to mechanical agitation and energy input from wave impact, vessel movement, and engine vibrations. The cargo eventually settles and becomes compacted as a result. The pore water pressure between the particles suddenly rises, pushing the particles apart as the gaps between them get narrower and the air is exhausted in the process. When particles lose direct touch and the cargo becomes a viscous fluid—that is, all or some of the cargo has liquefied—internal friction decreases. If there is too much moisture in the mineral cargo it can become muddy slush. Bulk cargo movement begins as soon as the ship's heel angle and the angle of particle internal friction are about equal [3, 4].

One of the most significant macroscopic characteristics that describes the behavior of granular materials is the angle of repose [5]. The angle of repose, or critical angle of repose, of a granular material is the steepest angle of fall or dip about the horizontal plane at which a material can be heaped without collapsing. The moisture content level affects how the angle of repose appears. Cargoes with a high degree of saturation or moisture content have a low friction coefficient, which results in a small angle of repose, according to the liquefaction mechanism. Granular particles may have a significant potential to shift and contribute a significant internal moment to a container or ship hold filled with commodities that have a large angle of repose, particularly when the cargoes have a high moisture content or degree of saturation. Before being loaded onto bulk carriers, liquefaction cargoes may appear "dry" and are usually just slightly saturated. Throughout the voyage, the surface appearance of this cargo will be periodically inspected. During a voyage, if the master notices free water above the cargo or the cargo is in a fluid state, they must take the necessary precautions to prevent the cargo from moving and the ship from capsizing. They might also consider requesting emergency entrance into a place of refuge [6, 7]. Numerous variables can affect the likelihood of cargo shifting and causing liquefaction, including the cargo's characteristics, its capacity to retain water, its initial moisture content, the moisture migration caused by the climate, the loading conditions, and the type of cargo ship. The ship may gradually approach a hazardous heel and capsize if the partially or fully liquefied cargoes flow to one side of the vessel with a roll but do not entirely return with a roll in the opposite direction. During the procedure of liquefaction, the cargo will proceed through phases of solidification, partial liquefaction, and finally full liquefaction [4].

Certain types of dry bulk cargoes with moisture contents above their transportable moisture limit are susceptible to liquefaction [3]. The International Maritime Solid Bulk Cargoes Code, or IMSBC Code, was established by the IMO to regulate the safe transportation of dry bulk cargo. In Chapter VI, the code was approved by the SOLAS convention. Cargoes have been split into three groups under the IMSBC Code: Cargoes in Group A have the potential to liquefy, cargoes in Group B contain chemical dangers, and cargoes in Group C are neither likely to liquefy nor to contain chemical hazards. Managing the safe stowage of dry bulk cargoes is the code's main goal. It can offer comprehensive details regarding the possible risks associated with carrying solid bulk cargoes on ships as well as the essential direction for handling dry bulk cargoes correctly. The IMSBC Code defines the possible risks connected to the transportation of dry bulk cargo, including incorrect cargo distribution, loss or reduction of stability, and cargo chemical reactions. Three categories are used in the code to classify solid bulk shipments. Group A cargoes can be liquefied if the cargoes shipped at a moisture content pass over their Transportable Moisture Limit (TML). There are three main tests for TML. They are the Proctor/Fagerberg Test, the Flow Table Test, and the Penetration Test. Proctor developed the Proctor/Fagerberg test in the 1930s to find the ideal moisture content for compacting granular materials for use in civil engineering applications, such as subgrade for road building, to attain maximum density. To ascertain the TML for solid bulk cargoes, Fagerberg created a modified version of the Proctor compression test that is referred to as the Proctor/Fagerberg test and is detailed in the IMSBC code. The lowest moisture content at which liquefaction can occur is known as the Flow Moisture Point (FMP), and it is measurable in a laboratory. The parameter TML is computed by multiplying the FMP by 0.9. Penetration testing was originally developed in Japan to evaluate TML for coal but has also been considered valid for other types of materials. The maximum water content, given as a percentage, at which a cargo sample starts to lose shear strength is known as the flow moisture point. Over-FMP moisture concentration in cargo could cause it to liquefy. Rainfall during open-air storage or the open-top train wagon, barge, or conveyor transit from the mines to the port is the primary cause of the cargo's increased moisture content exceeding TML. International standards should be followed when sampling and testing bulk shipments that have the potential to liquefy [4, 8, 9].

Cargo shift will influence the position of the center of gravity of the ship, resulting in a large angle of heel. The main risks involved in shipping solid bulk loads are those related to structural damage from incorrect cargo distribution, loss or decrease in stability while in transit and cargo chemical reactions. The ship's center of gravity (G) will vary due to cargo shift, creating a significant heel angle. Buoyancy (B) and center of gravity could reverse positions if there is a transverse cargo change. An upward buoyant force equal to W opposes this force through the center of buoyancy B, which is the geometric center of the submerged volume that the ship has displaced. B and G maintain their alignment in the vertical direction while in a stable state. When the ship is exposed to an outside force, such as the wind or waves, it will cause a significant heel. This will result in B to shift while G will not move. The ship will oscillate back and forth due to this variance, resulting in a righting moment. The ship may soon capsize if there is a transverse cargo change because B and G may reverse positions. It shows how liquid cargo will significantly reduce the ship's stability [10]. The quantity of cargo movement and the type of free surface formed as a result of liquefaction both significantly impact the magnitude of the increased heeling moment. Determining the shifting of cargo is crucial for determining the threshold value of the liquefaction phenomenon [9].

The cargoes have a liquefaction risk even though their moisture content is lower than TML due to measurement inaccuracy and atmospheric moisture migration. Consequently, several safety measures can be taken to enhance the ship's stability while at sea. Class NK has suggested measures to prevent the cargo from shifting during the voyage, including the presence of longitudinal bulkheads in the cargo hold and the master's maintenance of the operation handbook. Moisture-containing cargoes should not exceed the TML, and test results should be obtained no later than six months before the date of loading. It is recommended to conduct a moisture content test seven days before the date of loading. The cargo may have been impacted by rain or waves during the transfer from the stockyard to the ship. Utilizing radar to detect early rainfall is advisable. Cargo loading cannot be approved if the moisture content exceeds the TML. Cargo should be appropriately trimmed as much as possible during the loading stage. Moisture should be discharged by a pump during the voyage. Throughout the voyage, moisture deposition and cargo behavior should be monitored. Trimming the load distribution as soon as possible is recommended [1, 4].

3. Conclusion

Liquid or semi-liquid cargoes are not intended for bulk carriers, and when this process occurs, it can lead to stability issues that have frequently resulted in vessels capsizing and sinking. Large liquefaction can occur in a matter of minutes, negatively impacting the shipment's operations and profitability and possibly resulting in serious casualties that are not under the ship's control. Before loading in the hold, the shipper is required to be aware of and declare the characteristics of liquefaction cargo, such as moisture content. When the cargo's degree of saturation rises in the unsaturated condition, the friction coefficient falls. A cargo that has the potential to liquefy must be shipped below a threshold moisture content, known as the "Transportable Moisture Limit" (TML), which is determined using one of three laboratory test methods specified in the International Maritime Bulk Solid Cargoes (IMSBC) Code. When there is a liquefaction process, the ship rolls, and there is an extra heeling moment. The quantity of cargo movement and the type of free surface formed as a result of liquefaction both significantly impact the magnitude of the increased heeling moment. For the safety of the ship, crew, cargo, and environment, a full grasp of the proprieties of the cargo carried and the role it plays in the stability of the ship in both static and dynamic terms is necessary.

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A blockchain based response to fraudulent certification in global shipping activities

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Abstract

This paper presents a blockchain-based solution aimed at mitigating the persistent issue of fraudulent certifications in global shipping activities, with a specific focus on the digitalization of Standards of Training, Certification, and Watchkeeping (STCW) certificates. The study proposes a comprehensive framework for implementing this system through collaborative efforts, emphasizing the advantages of blockchain technology, such as enhanced reliability, transparency, efficiency, and immutability. Utilizing Proof of Authority (PoA) for the validation process ensures an additional layer of network security by restricting protocol operations to authorized individuals. This innovative approach facilitates the recognition of digital certificates, effectively eliminating fraudulent certification problems. Moreover, the implementation of this blockchain-based solution promises expedited inspection processes, contributing to an overall enhancement of safety in global shipping operations.

Keywords: *Fraudulent certificates, maritime digitalization, blockchain network, blockchain applications*

1. Introduction

The maritime industry stands as one of the most safety-critical sectors globally, given its challenging working conditions and reliance on human operators. Consequently, maritime education and training activities play a pivotal role in enhancing the competencies of seafarers. These competencies and their prerequisites are defined by the Standards of Training, Certification, and Watchkeeping (STCW), ensuring that seafarers meet the minimum standards for shipping operations [1]. For this reason, STCW has introduced numerous regulations specifying the minimum standards of maritime training and education. Following successful training completion, crucial information regarding the training scope, newly acquired competencies, expiration dates, and recognizing authorities involved are documented on official certificates [2].

The validation of seafarers' certificates falls under the jurisdiction of responsible administrations such as Port State Control (PSC) during routine or non-routine inspections. However, these inspections, relying on human oversight, can overlook certification-related deficiencies, leading to instances of fraudulent certificates. Recent data from the Black Sea MOU database reported 421 deficiencies related to fraudulent certificates out of 5112 inspections in 2017 [3]. This problem persists across various authorities, with over 6,000 similar cases reported between 2011-2016 by the Paris MOU [4]. Despite diligent efforts, fraudulent certificates continue to emerge, underscoring systemic vulnerabilities to corruption.

Considering these problems, there can be information technologies (IT) based solutions can be applied against fraudulent certification in the maritime sector. However, reliability of such applications depends on the quality, transparency and security of the created system [5,6]. Moreover, these systems can be vulnerable to cyber-attacks even if they would be recognized and verified by various authorities. Considering the benefits of blockchain technology; there are some critical features which can suggest the higher system reliability, immutability, transparency and rapid process [7]. For this reason, this paper proposes a blockchain-based solution model to response fraudulent certificates of seafarers which can be utilized on administrative networks. Therefore, certification process of seafarers can be recorded on a blockchain network in order to gain favour from the latest developments of global digitalization applications. Recognizing the advantages of blockchain technology—including enhanced reliability, immutability, transparency, and efficiency—this paper proposes a blockchain-based solution to combat fraudulent seafarer certifications. Through collaborative efforts and the adoption of Proof of Authority (PoA) consensus, authorized administrations can ensure the integrity of digital certificates, thereby eradicating fraudulent certification practices within the maritime sector.

2. Blockchain technology

Simple definition of a blockchain refers an immutable digital registry network which consists of interconnectedness data blocks working as distributed manner. Therefore, multiple computers can process the same registry, same data storage and blocks, ensuring decentralized verification and validation. The security of blockchain lies in chaining data blocks together and sealing them with cryptographic techniques, rendering the entire registry immune to data forgery [8]. Even in cases of data corruption, the majority of nodes within the network can reconstruct the original data from their blockchain registry. Nodes within a blockchain network, authorized to validate transactions, are pivotal components.

A processor in a blockchain network which has authorized to make validations can be called as 'node'. However, a blockchain system cannot be considered secure if cyber-attacker nodes collectively control more processing power than honest nodes [9]. Even so, this interconnected structure of the blockchain can utilize different protocols to validate blockchain actions, which may also be called as transactions. This interconnected structure of blockchain allows for the utilization of different validation protocols tailored to specific ecosystem purposes [10]. Therefore, careful examination of validation protocols is imperative. Hereby, the type of protocol should be selected in accordance with the purpose of the initiated blockchain ecosystem. For this reason, the validation protocols should be examined more thoroughly.

2.1. Validation protocols

The most renowned validation protocol of a blockchain system is Proof of Work (PoW). This approach suggests a protocol where the nodes can check and validate the blockchain actions via attempting to solve a computational puzzle. This process is a competition between computers, with successful nodes being rewarded. Over time, the solution must be verified by an increasing number of nodes to reach consensus, which then validates the actions. Notably, PoW protocols heavily rely on the processing power of nodes' CPUs [11].

In contrast, Proof of Stake (PoS) eliminates CPU competition, instead rewarding nodes that stake the most currency within the blockchain system. PoS allows only high-value stakeholders to become validators, while others may act as delegators. Delegators can vote for validator selection and are not required to remain online for system operations. Due to its emphasis on currency stakes rather than CPU power, PoS is considered more power-efficient than PoW [12].

Moreover, a modified version of PoS, known as Proof of Authority (PoA), finds application in certain blockchain networks. PoA validates transactions solely by authorized individuals based on their reputation in a business environment, rather than maintaining anonymity. Thus, validation requires company licenses or authenticators, ensuring a centralized yet secure system [13]. Hence, instead of being anonymous; a company license or authenticator can be required to become validator in an administrative based blockchain system.

3. Proposed solution

In the maritime sector, the certificates of seafarers are often checked and verified by PSC surveyors during a ship's inspection. This can be difficult and time-consuming activities which heavily depend on human effort. Given the prevalence of fraudulent certificates in recent years, there is an urgent need for technological interventions to address this issue effectively. Considering the benefits of blockchain technology, fraudulent certificates can be eliminated within a region through a common agreement of multiple MOUs. For this reason, a blockchain system which works with PoA approach can be used by PSC authorities.

Recognizing the transformative potential of blockchain technology, this paper proposes a blockchain-based solution to combat fraudulent certifications within the maritime industry. By leveraging the consensus of multiple Memoranda of Understanding (MOUs), a collaborative framework can be established to ensure the integrity and authenticity of digital certificates. In Figure 1, a certification process through PoA based validation system is illustrated. In this system, the main purpose is to verify and record an authorized training organization's digital certificate transparently. Therefore, authorized personals of different MoUs should verify a certificate and agree in a consensus to complete approval. To achieve this, personnel from different MOUs are designated as validators, tasked with verifying certificates and reaching a consensus for approval. Once approved, the certificate is recorded and stored on the blockchain registry, ensuring immutability and accessibility for monitoring by relevant stakeholders.

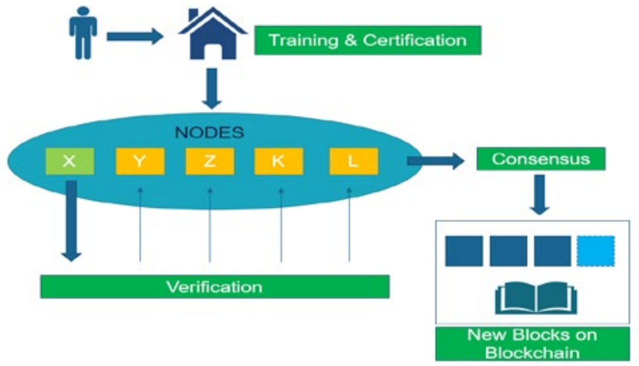

Figure 1. Proposed PoA protocol for certification of seafarers.

Then, approved certificate can be recorded and stored on the blockchain registry which can be easily monitored and readable by human actors as well as various software or algorithms. Hence, any fraudulent attempt may fail as the registries of blockchain network are immutable. In order to execute this system successfully, an agreement between several MoUs is required. Then they assign their authorized personal to establish nodes for PoA as well as monitor the system process. If a recognized training organization create a digital certificate for a seafarer, the PoA protocol select a random node for verification (See X, Y, Z, K and L nodes in Fig. 1). These nodes represent different processors as each belong to a different MoUs authorized server.

To execute this system effectively, collaboration and agreement among multiple MOUs are essential. Each MOU assigns authorized personnel to establish nodes for PoA and oversee system operations. When a recognized training organization issues a digital certificate for a seafarer, the PoA protocol randomly selects a node for verification from a pool representing different MOUs. This decentralized verification process ensures the integrity of the certification process and prevents fraudulent attempts. Then, verified action should be confirmed by all MOUs connected to the same network to reach a consensus. Later, the data of the consensus can create a block to complete a transaction and store the certification process on a block. Since the block data could not be rewritten, these irreversible activities provide immutability of the blockchain network.

Furthermore, the proposed solution incorporates the use of digital currencies or tokens, as well as smart contracts to facilitate smooth system operations. While PoA offers a highly secure and centralized approach to validation, the system remains vulnerable to cyber-attacks. Therefore, proactive cybersecurity measures must be implemented to safeguard against potential threats. In conclusion, the proposed blockchain-based solution presents a promising avenue for addressing fraudulent certifications in the maritime industry. By leveraging the transparency, immutability, and security features of blockchain technology, the proposed system offers a robust framework for ensuring the authenticity of seafarers' certificates. However, ongoing collaboration, technological advancements, and vigilant cybersecurity measures are essential for the successful implementation and maintenance of this solution.

4. Conclusion

In this study, a blockchain-based digital registry system is proposed to combat fraudulent certification issues plaguing the maritime industry. By leveraging blockchain technology, specifically the Proof of Authority (PoA) consensus mechanism, the solution offers a robust framework for ensuring the authenticity and integrity of seafarers' certificates. Since the maritime industry has many strict rules and experienced field in terms of administration, authentication and global integration; the proposed system's integration can be done rapidly. Since PoA depends on only the authorized persons, it can be considered a highly secure blockchain application. Despite the high level of security afforded by PoA, the persistent threat of cyber-attacks should be acknowledged. Therefore, it is imperative to implement proactive cybersecurity measures to safeguard the integrity of the blockchain network and prevent malicious activities.

Consequently, the proposed blockchain-based solution presents a transformative approach to addressing fraudulent certifications in the maritime sector. By facilitating transparent and secure certification processes, safety standards can be enhanced while promoting trust within the global shipping community. Moving forward, further research and collaboration are warranted to explore advanced smart contract functionalities and optimize digital certification implementations for broader adoption in maritime certification activities.

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The Role of Traditional Wooden Boats (Pelra) in Logistics and Transportation Safety Aspects in Indonesia

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Abstract

This paper investigates the integral role of Traditional Wooden Boats, or Pelra, in supporting maritime logistics in Indonesia while ensuring transportation safety. By examining the historical development of Pelra, the study explores their unique contribution to overcoming geographical challenges and connecting islands across Indonesia. The primary focus is on understanding the efficiency of Pelra in logistics and how this role plays a crucial part in meeting local transportation needs.

Transportation safety aspects take center stage in this research. The use of traditional technology in Pelra operations and the diverse maritime conditions in Indonesia pose unique challenges related to marine safety. By investigating these factors, the research aims to provide an in-depth analysis of the safety risks Pelra faces and seeks appropriate solutions to enhance safety standards. The research methodology includes field surveys, interviews with Pelra owners and operators, and analysis of historical and statistical data related to maritime accidents. The results are expected to offer a comprehensive understanding of Pelra's role in maritime logistics and the extent to which safety challenges can be addressed.

Recommendations from this research encompass safety regulation updates, introducing new technologies applicable to Pelra, and active engagement from relevant stakeholders. These efforts are directed toward improving logistics efficiency and ensuring the operational safety of Pelra, which is in line with the preservation of Indonesia's maritime heritage.

This paper is anticipated to significantly contribute to formulating policies and best practices to ensure that the role of Pelra not only endures in the modern logistics era but also meets high transportation safety standards in Indonesia.

Keywords: *Pelra, Logistics, Operational Safety, Policy*

1. Introduction

Traditional Wooden Boats (Pelra) are distinguished in Indonesia's maritime history, embodying centuries-old craftsmanship and serving as lifelines for inter-island transportation and trade[1], [2]. These vessels, characterised by their sturdy wooden construction and distinctive designs, have been essential for connecting remote islands with the mainland, playing a pivotal role in the archipelago's logistics and transportation network. As [3] notes, Pelra has been the primary mode of transportation for goods and passengers in Indonesia's coastal regions, showcasing the enduring legacy of traditional maritime practices.

Figure 1: Pelra wooden boat loading unloading at Gresik port (Source: Eka - Pelra Gresik 2020)

The image captures the unique characteristics of Pelra boats operating as tramper vessels, engaging in manual cargo handling processes at Gresik Port. While they serve a similar function to conventional general cargo vessels, their traditional wooden construction and management practices set them apart within Indonesia's maritime logistics landscape. Pelra occupies a unique niche in logistics and transportation, particularly in catering to the needs of isolated communities and small islands. Their versatility allows efficient shipment of commodities, products, and even livestock to areas inaccessible by modern vessels or infrastructure [4][5]. Moreover, Pelra often serves as the sole means of transport for residents of remote islands, ensuring their connectivity with the mainland and access to essential goods and services [6]. Therefore, understanding the role of Pelra in Indonesian logistics is paramount for devising inclusive and sustainable transportation solutions that cater to the diverse needs of the archipelago's inhabitants. However, safety concerns surrounding Pelra remain a pressing issue amidst their indispensable role in facilitating maritime commerce. With frequent reports of accidents and mishaps involving traditional wooden boats, there is a growing need to address safety aspects to ensure the well-being of passengers and the integrity of cargo shipments [7], [8]. Enhancing safety measures and implementing regulatory frameworks tailored to Pelra operations are essential steps toward mitigating risks and safeguarding the sustainability of Indonesia's maritime transport sector [9]. Thus, this paper aims to explore both the unique contributions of Pelra to Indonesian logistics and the critical importance of safety considerations, advocating for holistic approaches that balance tradition with modern safety standards.

2. Historical Background

Pelra has long been an important part of Indonesia's nautical heritage and transportation system. These vessels have evolved to accommodate the varying demands of coastal communities, serving various services such as transportation, fishing, trading, and tourism. Sails originally propelled Pelra but underwent considerable changes in the 1980s when the government incorporated main engine assistance[10]. As a result, many Pelra vessels began to adopt engines, which reduced the usage of sails. Today, Pelra boats' main masts are frequently converted to house crane foundations for loading and unloading equipment. The sizes of Pelra vary, ranging from small vessels measuring 16m in length and 4m in width, with a capacity of less than 20 tons, to larger ones measuring up to 48m in length, 12m in width, and a capacity of around 300 tons. These boats vary in their crew size, travel distance, and cargo capacity, catering to the specific needs of different regions and industries.

Traditionally, Pelra boats are constructed manually, without blueprints or inspections from the Indonesian Classification Bureau (BKI). Instead, they rely on boat builders' experience and boat owners' requirements. Pelra boats are primarily used for fishing, cargo transport, passenger ferries, and tourism[11]. While regulations exist for construction standards, enforcement varies, with only certain types of vessels adhering to modern management practices and insurance requirements.

Pelra boats transport various goods, such as construction materials, agricultural and livestock supplies, food products, furniture, textiles, and electronics. Although Pelra boats account for less than 10% of the total cargo delivered to major cities in Indonesia, they play a critical role in smaller towns and villages where they are essential for delivering vital goods and sustaining local economies[12]. The importance of Pelra ships in serving the logistical needs of small islands in Indonesia is significant, considering the geographical distribution of ports and islands across the archipelago. Out of the 2,155 ports in Indonesia, a significant number, 207, are located in port cities. However, Indonesia comprises a vast number of islands, totalling 17,508, categorised into five major islands, 35 medium-sized islands, and 17,468 small islands. Among these islands, only 1,556 are inhabited. Considering the inhabited islands and the available ports, it becomes evident that only 13.4% of the ports are served by commercial ships such as general cargo vessels, ferries, and containerships. The remaining 87% of inhabited islands heavily rely on Pelra ships for their maritime connectivity and essential supplies. These Pelra ships play a crucial role in bridging the logistical gap and ensuring the transportation of goods and people to remote and underserved island communities across the Indonesian archipelago.

Despite their historical importance and economic contributions, Pelra boats face several challenges today. These include a decrease in the number of vessels, reduced cargo volumes, lack of insurance coverage, and competition from other vessels. The decline in Pelra boats is due to the scarcity of wood, the need for specialised maintenance, and the diminishing availability of timber resources.

The history and current condition of Pelra boats underscore their importance in Indonesia's maritime culture and economy. However, addressing Pelra boats' challenges requires joint efforts from government agencies, industry stakeholders, and local communities to ensure their sustainability and preservation for future generations.

3. Safety Aspect of Pelra Operation

Pelra operation, which relies on traditional wooden boats, is crucial to Indonesia's maritime heritage and logistics network. However, ensuring the safety of Pelra voyages requires careful attention to various factors. One crucial aspect is the ships' structural integrity, stability, and Pelra vessels' maintenance practices [13].

These boats are crafted using traditional methods and require regular inspections and maintenance routines to uphold seaworthiness standards and prevent structural failures. By prioritising proper hull maintenance, including caulking and timber replacement, Pelra operators can mitigate risks associated with leaks and structural weaknesses, thereby enhancing overall safety. At present, the operation of Pelra boats lacks adequate equipment. Despite the significance of structural integrity, ensuring the presence and quality of navigation and safety gear onboard is crucial for ensuring voyages are conducted safely. Fundamental safety apparatus such as life jackets, distress signals, and fire extinguishers are imperative and should be easily accessible and properly serviced. Additionally, providing Pelra operators with navigational aids such as compasses and communication devices can significantly improve their capacity to navigate securely, particularly in adverse weather conditions or regions with restricted visibility. However, the current state of Pelra vessels falls short in this aspect, posing potential risks to crew members and passengers.

This integration of safety equipment and navigational tools ensures that Pelra voyages are conducted with a high regard for safety standards. Weather-related risks pose significant challenges to Pelra operation, particularly in Indonesia's archipelagic waters prone to strong winds and storms. Pelra operators must closely monitor weather forecasts and exercise caution when navigating to mitigate these risks.

Implementing safety measures such as altering routes, seeking shelter, or delaying voyages during adverse weather conditions is essential for safeguarding passengers, crew, and cargo. By adopting proactive risk management strategies, Pelra operators can minimise the impact of weather-related hazards on the safety of their voyages. Based on observations of several ships operating in three shipping ports in East Java, namely Kalimas, Gresik, Probolinggo, and Pasuruan, it is known that the operating ships have been equipped with Small

Craft Certificates, which are sailing eligibility requirements issued by local authorities with approval from the Indonesian Ministry of Transportation.

However, the ships are not equipped with Class certificates because regulations do not require ships to be classified by the Indonesian Classification Bureau (Biro Klasifikasi Indonesia-BKI). According to government regulations, navigation, and safety equipment, onboard ships must be fulfilled before obtaining Small Craft Certificate approval.

However, several ships were found to lack navigation and safety equipment after experiencing accidents, necessitating attention from all parties involved in ship operations, especially ship owners and crews who are aware of the actual condition of the ships, including their equipment. The government provides weather information through BMKG, disseminating weather news to ships via weather radio and local Port authorities. Port authorities are required to convey this weather information to all ships.

The mechanism for weather notification must be carefully designed to ensure that ships receive the latest weather updates before they sail. Communication and navigation equipment on ships must also be ensured to function properly in obtaining weather information updates and news related to the conditions of the waters traversed by the ships. The regulatory framework for ship safety is available, but implementation and oversight of these regulations need to be considered by all parties. Awareness of the importance of safety needs to be increased for ship crews and owners[14]. Ships' success in sailing is heavily influenced by communication and navigation equipment. Local Port authorities also play a role in pre-sailing inspections. Effective oversight and regulation are fundamental pillars in ensuring the safety of Pelra transportation. Government agencies must establish and enforce safety standards, licensing requirements, and inspection protocols for Pelra vessels.

Collaboration with local communities, maritime authorities, and industry stakeholders is crucial for promoting safety awareness and implementing training programs for Pelra operators. By fostering a culture of safety and accountability within the Pelra industry, regulatory frameworks can significantly enhance safety standards and mitigate risks associated with traditional boat transportation.

Furthermore, embracing technological advancements and best practices in maritime safety can further enhance the safety of Pelra transportation. Integrating modern navigation systems, emergency communication devices, and advanced weather forecasting tools can significantly improve the safety of Pelra voyages.

4. Pelra Accident Analysis Using SHIELD framework.

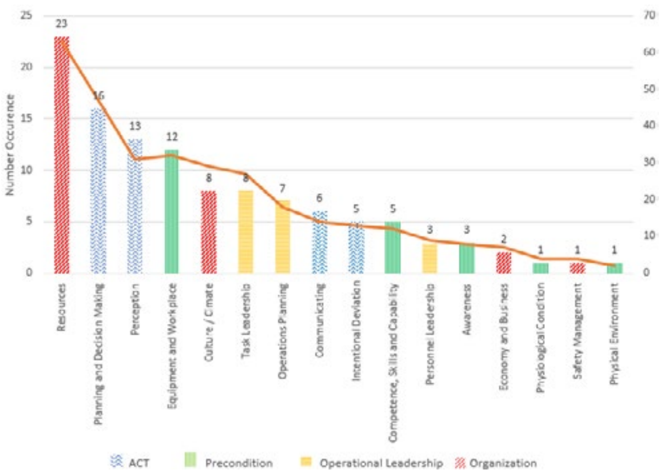
The SHIELD (Safety Human Incident and Error Learning Database) framework is a comprehensive tool used to analyse accidents and incidents in the maritime industry. This framework encompasses various aspects, including human factors, organisational factors, technical factors, environmental factors, and operational factors. Each of these elements is systematically evaluated to understand the underlying causes and contributing factors of accidents or incidents.

In terms of its relevance for analysing ship accidents, the SHIELD framework provides a structured approach to identify and analyse human-related factors, which are often significant contributors to maritime accidents. By incorporating human factors alongside technical and organisational aspects, SHIELD offers a holistic view of accident causation, enabling a more thorough investigation and developing effective preventive measures[15], [16]. One reason for using the SHIELD framework in ship accident analysis is its emphasis on human factors, such as crew competency, decision-making processes, and communication protocols. These factors are crucial in understanding why accidents occur and how they can be prevented in the future. Additionally, SHIELD's systematic approach allows for a more in-depth examination of the interactions between human actions and other elements of the maritime system, providing valuable insights for safety improvement initiatives. Comparing SHIELD with other accident analysis methods, such as the Human Factors Analysis and Classification System (HFACS) or the Swiss Cheese Model, reveals both similarities and differences. Like SHIELD, HFACS focuses on human factors but categorises them into different levels (e.g., unsafe acts, preconditions for unsafe acts) to identify root causes. On the other hand, the Swiss Cheese Model emphasises system vulnerabilities and the role of multiple layers of defence in accident causation. While each method has its strengths, SHIELD's integration of various factors and its structured approach makes it particularly well-suited for analysing complex accidents in the maritime domain. By considering a broad range of influences, SHIELD enhances the understanding of accident causation and supports the development of comprehensive safety strategies to prevent future incidents.

The analysis of Pelra's wooden ship accidents from 2007 to 2022 reveals several critical insights. Out of a total of 30 accidents recorded, only 23 were analysed due to the unavailability of reports for the remaining seven incidents, pending release by the National Transportation Safety Committee. Among the analysed accidents, three predominant types stood out, with 15 cases of capsizing, four instances of collision, and four incidents involving fire or explosion. This pattern underscores the need for comprehensive safety measures addressing these common occurrences.

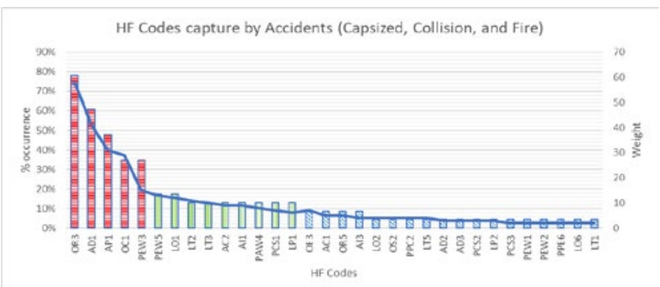
SHIELD is a comprehensive framework structured across four layers, delineating 24 distinct categories and encompassing a total of 114 specific codes. This multi-layered architecture allows for a nuanced analysis of human factors contributing to incidents and accidents, offering invaluable insights into potential areas for improvement and intervention. By providing a detailed taxonomy of human errors and incidents, SHIELD empowers organisations to identify patterns, assess risks, and implement targeted strategies to enhance safety and mitigate future occurrences effectively.

The analysis of Pelra ship accidents using the SHIELD framework highlights significant human factor (HF) categories and their respective weights. Resources emerge as the most prevalent factor, indicating organisational deficiencies in providing necessary equipment and adequate support for safe operations. Planning and Decision Making, Perception, and Equipment and Workplace-related factors also contribute significantly to accidents. Culture/Climatic factors underscore the importance of fostering a safety-conscious culture within Pelra operations. Task Leadership, Operations Planning, Communicating, and Intentional Deviation play moderate roles in accidents. Competence, Skills, and Capability, Personnel Leadership, and Awareness appear to contribute to a lesser extent, but perception, which is significantly affecting the Pelra accidents, is heavily linked to individual skills and qualities. Economy and Business-related factors, Physiological Conditions, Safety Management, and Physical Environment are not captured sufficiently. This analysis emphasises the importance of comprehensive risk management and continuous improvement initiatives in enhancing maritime safety.



Graph 1 HF Categories and Weight for Pelra Accident Analysis

Further examination of the analysed accidents unveiled 32 Human Factor (HF) codes out of the 114 existing codes.



Graph 2: HF Codes by Pelra Accident

Notably, the top three selected HF codes were OR3 (Equipment/parts/materials availability), AD1 (Incorrect decision or plan), and AP1 (No/wrong/late visual detection). This highlights that enhancing crew competency alone may not suffice; ensuring the availability of safety equipment and proper navigation protocols are equally crucial for maritime safety. These findings stress the importance of holistic safety strategies encompassing human and technical elements to mitigate the risks associated with wooden ship accidents effectively. In conclusion, the analysis of Pelra accidents underscores the imperative for a multi-faceted approach to maritime safety. Beyond focusing solely on crew training, it is essential to prioritise the availability of safety equipment and implement sound navigational practices. By addressing these key factors, stakeholders can significantly enhance the safety standards of wooden ship operations, thereby reducing the frequency and severity of accidents in the future.

The analysis of accident reports reveals that Pelra boats are utilised not only for transporting goods but also for carrying passengers. Among 23 Pelra boat accidents, involving 1,507 passengers and 152 crew members, 378 passengers and 26 crew members lost their lives. The number of casualties is notably high due to limited life-saving equipment and inadequate passenger amenities compared to passenger ships. This underscores the importance of improving safety measures and enhancing Pelra boats' readiness to adequately accommodate passengers.

5. Community Perspectives and Socio-economic Impacts

The importance of ports in the development of a nation cannot be overstated[17]. To understand the role of Pelra, an overall understanding of sea transportation in Indonesia is necessary. According to the Indonesian government, in 2022, 2155 ports in the country are classed under 3 types of ports: main ports, feeder ports, and collecting ports, with 2155 ports in the country, as shown in Figure 1.

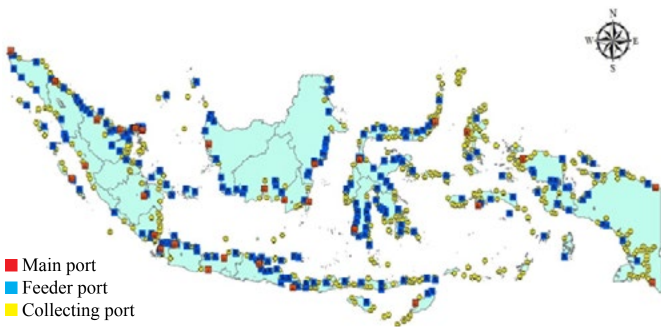


Figure 2: Ports in Indonesia (*Source: Annual Report PT Pelabuhan Indonesia 2022 https://www.pelindo.co.id/investor/laporan-tahunan (accessed on 2024, March 6th)*)

Indonesia has a total of 2155 ports, which are also further divided into three categories. There are 111 commercial ports managed by Pelindo, 914 non-commercial ports managed by local governments, and 1130 special port terminals managed by private companies. Pelindo is a state-owned company responsible for managing the ports divided into four regions. Of the 1241 commercial ports, 33 are main ports, 218 are feeder ports, and 990 are collecting ports. After further investigation, it was found that 2155 ports are only available in 207 islands.

The government has a grand plan for maritime logistics in Indonesia, and it involves the creation of a maritime highway route, as shown in Figure 2.

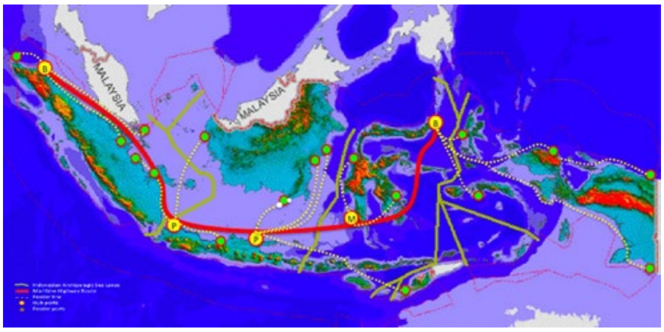


Figure 3: Long-Term Development Program 2045 (Source: Ministry of Transportation 2023 https://hubla.dephub.go.id/storage/portal/documents/ (accessed on 2024, February 6th)

Meanwhile, Figure 3 shows the operating route of Pelra ships, taken from a shipping case study from Kalimas Port, Surabaya.

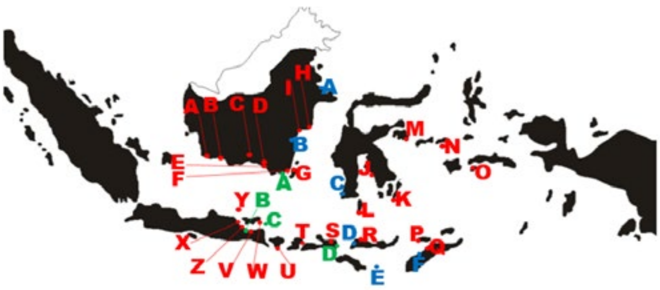


Figure 4: Destination Ports: Kalimas Port for Pelra Operations (Source: Nurleli https://repository.its.ac.id/72474/ (accessed on 2023, October 12th)

Although Pelra's role in the total amount of cargo transported is below 10%, it still plays a crucial role in the number of ports served. Based on information from the Pelra National Board **(**DPP Pelra**)** claims that the Pelra fleet is available in all port cities across Indonesia. Moreover, Pelra ships also provide shipping services to all remote islands not served by other commercial vessels, which is estimated at around 1,349 islands. This is based on combined data from the Geospatial Information Agency, indicating that out of 17,508 islands, 1,556 are inhabited. Meanwhile, according to the Ministry of Transportation, 207 islands have been served by ferries, container ships, general cargo vessels, and Pelra ships. Pelra plays a crucial role in local communities beyond merely ensuring cargo delivery. Particularly, in small island communities, Pelra provides lifeline services, facilitating the transportation of essential goods and enabling passenger travel. These vessels are vital connectors, bridging the gap between remote islands and mainland ports. By transporting passengers, Pelra provides access to healthcare, education, and employment opportunities, fostering social cohesion and economic development within these communities. Additionally, Pelra operations contribute to the resilience of local economies by maintaining essential supplies and facilitating trade between remote areas and urban centres.

Table 1: Destination Ports for Pelra Ships Departing from Kalimas Port

Port name	Code	Distance (Nm)	Cargo (Ton in 2014)	No of Trips
Sukamara	A	326.37	4348.71	29
Kumai	B	334.71	492.70	3
Sampit	C	294.39	1811.32	13
Samuda	D	287.84	7457.96	53
Banjarmasin	E	267.21	24515.82	150
Batulicin	F	325.13	1355.33	10
Kotabaru	G	339.83	2207.45	14
Samarinda	H	495.81	1025.02	6
Balikpapan	I	468.33	28998.73	185
Kolaka	J	620.88	1269.39	10
Bau-bau	K	628.68	321.86	2
Padang	L	507.60	321.86	2
Banggai	M	915.01	4909.77	31
Sanana	N	922.54	445.42	2
Ambon	O	982.84	3968.80	24
Kalabahi	P	729.13	892.12	5
Atapupu	Q	790.77	357.16	2
Reo	R	481.17	3886.45	22
Bima	S	382.84	47570.68	300
Lombok	T	271.25	922.56	7
Benoa	U	230.31	965.58	6
Probolinggo	V	46.31	784.82	5
Kalianget	W	89.08	3139.33	21
Gresik	X	35.10	791.63	5
Bawean	Y	91.42	8712.03	58
Dok Tjg Perak	Z	1.00	#N/A	#N/A
Tg. Batu	A	767.37	156.13	1
Tanah grogot	B	442.14	279.74	2
Ujung Pandang	C	462.09	1399.88	9
Labuhan Bajo	D	441.65	2682.98	17
Sabu	E	637.60	173.16	1
Wini	F	763.82	263.48	2
Pagatan	A	309.84	316.90	2
Pasuruan	B	40.37	2492.50	17
Sapudi	C	97.59	306.83	2
Sape	D	409.66	429.83	3

According to data from the Indonesian Ministry of Transportation, in 2019 there were 1,649 Pelra wooden ships, with a combined Gross Tonnage (GT) of 207,525 tons. Assuming an average crew size of 12 individuals per ship, this implies the direct involvement of approximately 19,788 individuals as operators of these Pelra ships. Such statistics underscore the profound significance of Pelra ships within both social and economic realms. Beyond merely being vessels of transportation, these ships serve as livelihoods for thousands, sustaining communities along Indonesia's vast maritime routes. Moreover, they contribute significantly to the nation's economy, facilitating trade, transportation of goods, and connectivity among various islands, thereby fostering socioeconomic development at both local and national levels. Understanding the community perspective and socioeconomic impact of Pelra ships is vital for formulating policies that support their sustainability while ensuring the well-being of those reliant on them for their livelihoods.

6. Future Directions and Recommendations

When devising plans for Pelra ship operations, it's crucial to consider several key factors. Firstly, the potential of Pelra ship operations is immense, given that they are the only mode of transportation operating in 1349 islands. This highlights their significance in facilitating cargo logistics between small ports and major distribution centers and expanding connectivity across regions in Indonesia, particularly for the sea toll program.

Secondly, safety aspects are paramount in optimising Pelra ship operations. Despite being classified as cargo ships, Pelra ships are often used for passenger transportation. Therefore, prioritising ship safety, including meeting passenger safety standards, is vital. Recommendations include enhancing safety inspections, crew training, and rigorous maintenance to ensure full compliance with all necessary safety requirements, thereby minimising the risk of accidents and unwanted incidents while operating as passenger ships. Additionally, leveraging the potential of Pelra boats to synchronise schedules with larger vessels and exploring alternative materials such as bamboo for construction can further enhance efficiency and sustainability[18]. Transforming freight routes to liner services and investing in shipyard infrastructure will also play crucial roles in advancing the Pelra industry towards a safer, more sustainable future, while preserving its cultural and economic significance in Indonesia.

Based on the findings, it is recommended that the development of Pelra be aligned with government programs and tailored to meet the needs of communities, particularly those in small islands. While Pelra operations are currently considered tramp service, it is essential to continuously enhance service efficiency and quality to fulfill the fundamental requirements of small island communities. One of the primary challenges is the unpredictability of weather conditions, which limits Pelra operations. However, technological advancements and appropriate infrastructure development can help overcome this challenge.

Furthermore, the limited number of operating ships is due to the constraints of shipyards and the availability of wood materials. Therefore, increasing shipyard capacity and exploring alternative, more durable materials is necessary. It is also crucial to synchronise cargo information and schedules of Pelra ships with commercial vessels serving hub and feeder routes to maximise efficiency and coordination between services. By implementing these strategies, Pelra can effectively support government programs and cater to remote island communities' transportation and logistical needs.

7. Conclusion

In devising plans for Pelra ship operations, it is imperative to address several key considerations. Firstly, recognising the immense potential of Pelra operations, particularly their pivotal role in servicing, which accounts for roughly 86.69% of inhabited islands highlights the critical need for seamless coordination among stakeholders. This includes fostering clear communication and collaboration between Pelra operators, government agencies, local communities, and maritime authorities to ensure efficient and effective operation and oversight. Moreover, harnessing new technologies applicable to Pelra vessels can significantly enhance their performance and safety standards. Integrating modern navigation systems, emergency communication devices, and advanced weather forecasting tools can bolster the safety and efficiency of Pelra voyages, thereby reducing the risk of accidents and ensuring smoother logistics operations.

Additionally, prioritising safety remains paramount in optimising Pelra ship operations, especially considering their dual function as cargo and passenger carriers. Enhancing safety inspections, providing comprehensive crew training, and implementing rigorous maintenance practices are essential to uphold passenger safety standards. By adhering to these measures, Pelra operators can minimise the risk of accidents and unwanted incidents, thus safeguarding the well-being of passengers and crew members alike.

Furthermore, leveraging Pelra boats' potential to synchronise schedules with larger vessels and exploring alternative materials like bamboo for construction can further enhance efficiency and sustainability in maritime logistics. Transforming freight routes into liner services and investing in shipyard infrastructure are crucial steps towards advancing the Pelra industry's safety and sustainability goals, while preserving its cultural and economic significance in Indonesia.

In conclusion, embracing new technologies, fostering clear coordination among stakeholders, prioritising safety, and exploring innovative approaches to operations and materials are key recommendations for advancing the Pelra industry towards a safer, more sustainable future. By adopting these recommendations, Pelra operators can contribute to the seamless integration of maritime logistics and connectivity across Indonesia's vast archipelago, while ensuring the preservation of its maritime heritage.

Acknowledgment

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Model-Based Unmanned Surface Vessel Path Planning in Constrained Maritime Environments with Elephant Herd Optimization

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Abstract

In the realm of maritime navigation, the efficient path planning of ships within constrained environments stands as a pivotal challenge. Path planning in constrained environments necessitates meticulous consideration of various factors, from vessel's actuator limitations to environmental constraints. Amidst the myriad of path planning techniques, model-based approach serves as the cornerstone of navigational efficacy, ensuring that planned routes are not only optimal but also executable in the real-world applications by incorporating detailed models of ship dynamics, environmental factors, and navigational limitations. This study delves into the application of Elephant Herd Optimization (EHO) with model-based ship path planning, leveraging inspiration from the collective intelligence of elephant herds to navigate complex map. Traditional optimization methods often struggle to address the intricacies of such scenarios, leading to suboptimal routes. However, the advent of EHO injects a fresh perspective into this domain. EHO rooted in the principles of swarm intelligence, operates on the premise of collaboration and adaptation. Individuals within the herd communicate and coordinate their movements to overcome obstacles and reach a common goal. In the case of ship path planning, EHO facilitates the exploration of optimal routes by iteratively adjusting vessel trajectories based on environmental constraints and dynamic conditions. The integration of EHO into model-based ship path planning unveils a synergy of exploratory characteristic of EHO, coupled with the precision of model-based planning. This approach yields a framework capable of addressing the multifaceted challenges inherent in constrained environments. Through simulation analysis with well-studied 1/80 Duisburg Test Case (DTC) ship model, this research underscores the potential of EHO in revolutionizing ship navigation strategies amidst evolving navigational challenges.

Keywords: *Path Planning, Elephant Herd Optimization, Model-Based Design, Unmanned Surface Vessel*

1. Introduction

The maritime industry is experiencing a surge in interest towards autonomous technologies, with the potential to revolutionize navigation and transportation. Unmanned surface vessels (USVs) offer numerous advantages, including improved safety, reduced operational costs, and enhanced efficiency [1].

While traditional path planning algorithms like A* and Rapidly exploring Random Trees (RRT) provide efficient solutions for navigating from start to goal points, they often have limitations when applied to USVs [2], [3]. A* and RRT do not inherently consider the dynamic constraints and maneuverability of a USV, such as its turning limitations due to inertia [4], [5]. This can lead to unrealistic paths that are impossible for the USV to follow in practice. Therefore, while these model-less path planning algorithms offer a foundation for navigation, they lack the ability to fully consider the physical limitations of USVs. A core challenge lies in developing robust path planning and steering algorithms [6]. Traditional path planning approaches often struggle to account for the underactuated nature of ships, where manoeuvring capabilities are limited by factors like inertia and turning limitations [7]. Additionally, ensuring realistic and smooth rudder movements is crucial for safe and smooth navigation [8].

This paper proposes a novel approach for autonomous ship steering that addresses these challenges. We leverage the Elephant Herding Optimization (EHO) algorithm [9], a bio-inspired optimization technique, to navigate USVs towards target locations while avoiding obstacles. A key feature of our approach is the incorporation of a realistic rudder rate constraint within the EHO framework. This constraint ensures that the generated steering commands are achievable and adhere to the physical limitations of the ship.

The paper is structured as follows: Firstly, Section 2 delves into the constraints of underactuated surface vessel motion, examining the motion characteristics of a scaled 1/80 DTC Ship. Section 3 provides an overview of the EHO algorithm, followed by the presentation of our proposed modifications aimed to further exploit the capabilities of generic EHO frameworks. The implementation of the modified EHO algorithm is detailed in Section 4, with a subsequent discussion on a test case scenario in Section 5. The outcomes of this test case are outlined in Section 6, leading to the conclusion presented in Section 7.

2. Motion Behavior of an Underactuated Ship

Selecting an appropriate ship motion model is paramount in implementing and evaluating path-planning algorithms within maritime environments. The chosen model not only influences the dynamics of vessel movement but also imposes crucial constraints on the simulation's navigational capabilities. In our study, we utilized a scaled 1/80 model of the Duisburg Test Case (DTC) Ship, obtaining ship parameters from [10]. Our simulation adopts the Maneuvering Modeling Group (MMG) model, sourced from the Japan Society of Naval

Architects and Ocean Engineers. This model, renowned for its standardized mathematical frameworks, serves as the foundation for predicting ship maneuvering behaviors [11].

We will first simulate and analyze the response of the 1/80 scale DTC ship over time while considering a rudder angle of -35 ≤ δ ≤ 35 [12], with initial rudder angles $\delta_{initial}$ = [-35, 0, 35] and an initial yaw of ψ = 0° (aligned parallel to the x-axis). The results are depicted in Figure 1, 2 and 3.

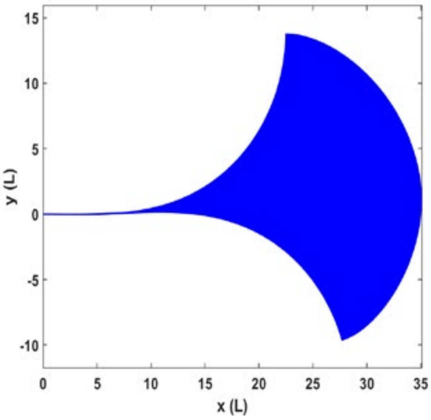

Figure 1. 1/80 DTC Ship Response for $\delta_{initial}$ = 35°

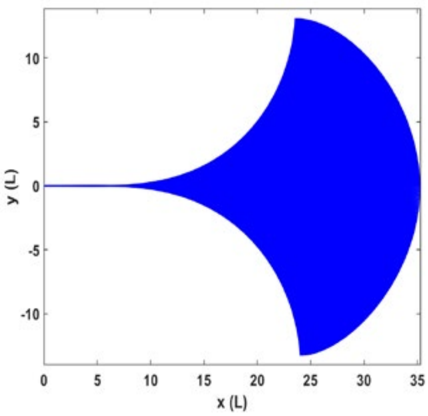

Figure 2. 1/80 DTC Ship Response for $\delta_{initial}$ = 0°

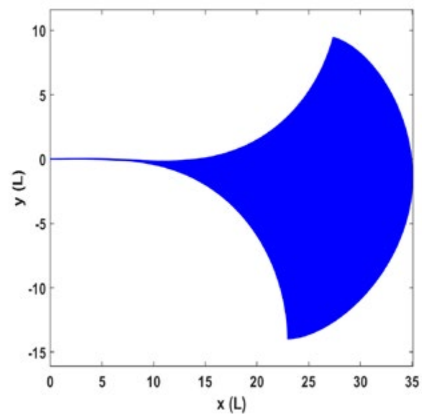

Figure 3. 1/80 DTC Ship Response for $\delta_{initial}$ = -35°

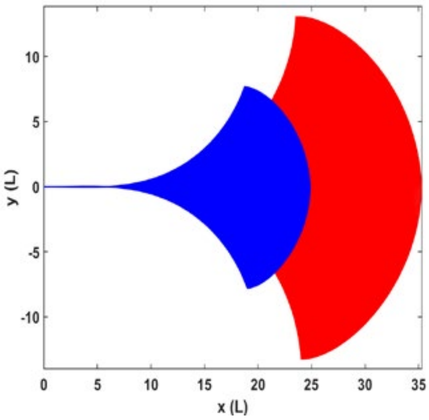

Figure 4. Ship's responses to surge velocity u = [0.5, 0.8]

Figures above illustrate the navigable region of the ship in which different $\delta_{initial}$ results in slight tilt. Additionally, the effectiveness of the rudder is largely dependent on the flow of water, primarily generated by the ship's propeller [13]. In situations where the flow undergoes alterations, either by reduction or augmentation, the effectiveness of the rudder in influencing the ship's course is subject to change. This dynamic presents additional complexities in maintaining precise positional accuracy and heading control, particularly in underactuated vessels. Figure 4 provides a visual representation of the ship's responses to variations in surge velocity u.

Notably, as velocity increases, the ship's coverage area expands at the cost of an enlarged turning radius. It is worth noting that in this study, the propeller speed n_p remains constant. However, fluctuations in ship speed are anticipated due to the nature of the mathematical model's capability to depict speed variations during turning maneuvers.

3. Introduction to Elephant Herd Optimization

Elephant Herd Optimization (EHO) stands out for its emulation of the collective behavior and foraging dynamics of elephant herds. Introduced by Gai-Ge Wang et al. in 2017, this algorithm draws inspiration from the social interactions and coordinated movements of elephants to develop a robust optimization framework [9]. This section provides an overview of the EHO algorithm.

3.1 Clan Updating Operator

Within each clan, all elephants reside under the leadership of a matriarch. Consequently, the subsequent position of each elephant within clan ci is influenced by the matriarch of that particular clan. For any given elephant j within clan ci, its update can be described as follows:

$$x_{new,ci,j} = x_{ci,j} + \alpha \times \left(x_{best,ci} - x_{ci,j}\right) \times r \qquad (1)$$

Where $x_{new,ci,j}$ and $x_{ci,j}$ represents the newly updated and previous positions, respectively, of elephant j in clan ci. α is a scaling factor within the interval [0, 1], determining the influence of matriarch ci on $x_{ci,j}$. $x_{best,ci,j}$ denotes the fittest individual within clan *ci*, serving as the matriarch. The variable *r* follows a uniform distribution over the interval [0, 1]. The most physically fit elephant within each clan cannot undergo updates according to (1), meaning $x_{ci,j} = x_{best,ci,j}$. Instead, for the fittest individual, the update is as follows:

$$x_{new,ci,j} = \beta \times x_{center,ci} \tag{2}$$

In this context, the parameter β within the range of [0, 1] plays a crucial role in determining how much influence $x_{center,ci}$ exerts on $x_{new,ci,j}$. It is notable that the formation of the new individual $x_{new,ci,j}$ as described in (2) is shaped by the collective input gathered from all elephants within clan *ci*. The $x_{center,ci}$ represents the centroid of clan *ci*, and its calculation for the *d*-th dimension is as follows:

$$x_{center,ci,dim} = \frac{1}{n_{ci}} \times \sum_{j=1}^{n_{ci}} x_{ci,j,dim} \tag{3}$$

Where $1 \leq dim \leq D$ signifies the *dim*-th dimension, with *D* denoting the total number of dimensions. n_{ci} represents the count of elephants within clan *ci*. $x_{ci,j,dim}$ corresponds to the *d*-th dimension of the elephant individual $x_{ci,j}$. The clan *ci* center, denoted as $x_{center,ci}$, involves *D* computations, can be calculated using (3).

3.2 Separating Operator

In elephant herds, male elephants typically separate from their family units and live independently upon reaching puberty. This process of separation can be represented by a separating operator when solving optimization problems. To enhance the search capabilities of the EHO method, we propose that elephant individuals with the lowest fitness undergo the separating operator in each generation, as indicated by Equation (4).

$$x_{worst,ci} = x_{min} + (x_{max} - x_{min} + 1) \times rand \tag{4}$$

Here, x_{max} and x_{min} represent the upper and lower bounds, respectively, of the position of an elephant individual. $x_{worst,ci}$ denotes the poorest-performing elephant within clan *ci*. The term $rand \in [0, 1]$ refers to a stochastic distribution, specifically a uniform distribution within the range [0, 1], utilized in our present study.

4. Implementation and Modification of EHO in Ship Path Planning

To enhance our ship path planning using Elephant Herding Optimization (EHO), we introduce a modification to the original algorithm. In the original EHO algorithm, the position of the matriarch is updated iteratively along with the other elephants in the herd. However, this constant alteration of the matriarch's position can lead to unnecessary fluctuations in the herd dynamics, potentially affecting the convergence behaviour and the overall performance of the optimization process. Therefore, we propose the removal of the matriarch update line to ensure the stability of the herd's leadership structure.

By freezing the position of the matriarch, our modified EHO algorithm promotes a more consistent and predictable behaviour within the herd. This approach not only enhances the robustness of the optimization process but also facilitates a clearer understanding of the underlying dynamics governing the herd's movement. Moreover, by reducing unnecessary perturbations to the matriarch's position, our modification can potentially lead to improved convergence rates and better overall optimization performance.

4.1 Simulation Loop

The Pseudocode 1 below explains the flow of the optimization method to find the best rudder input.

Pseudocode 1

```
1.  Initialize ship state x and input (rudder angle) at time k = 0
2.  While cost ≠ 0 (the ship does not reach endpoint) do:
3.      Initialize elephant positions for each clan (uniformly
        distributed)
4.      Perform optimization loop for t = 1 to t-th iteration:
5.          Compute cost for all elephants in each clan:
6.          Predict ship trajectory for each elephant using current
            rudder angle
7.          Calculate absolute error (position) and obstacle avoidance
            penalty with respect to the prediction horizon P.
8.          Compute total cost as sum of errors and penalties
9.          Identify matriarch, centre, and worst (male) elephants in
            each clan
10.         Update elephant positions:
11.         Eq. (1): Update elephants' positions towards matriarch
12.         Eq. (4): Separate male elephants
13.     Compute optimal input for ship based on mean rudder angle
        of each clan's elephants
14.     Apply rudder rate constraint to the optimal input
15.     Update ship state using optimal input
16.     Check convergence condition and break simulation if
        satisfied
```

Within the simulation loop, the algorithm progresses through time instances, iteratively optimizing the ship's trajectory. Elephants within each clan are initialized with their positions distributed uniformly across the acceptable range of rudder angles which are $-35 \leq \delta \leq 35$. Within each clan, an optimization loop is executed to improve the ship's trajectory iteratively. First the ship trajectories are predicted for each elephant based on their assigned rudder angles. Secondly, the cost associated with each trajectory is computed, considering factors such as distance from the target and obstacle avoidance penalties. Next step is to do the matriarch Identification which represents the optimal trajectory (elephant with the lowest value of cost function). Finally, the elephants adjust their positions towards the matriarch, while ensuring separation among male elephants (elephant with the highest cost function value), guided by the modified EHO equations. Based on the collective behaviour of elephants within each clan, an optimal rudder angle for the ship is determined. To ensure smooth and feasible control inputs, a rudder rate constraint is applied to the optimal input. The ship's state is updated using the optimal input, advancing it along its path towards the target destination. The simulation loop continues until a convergence condition is met or until the specified simulation time is reached. Throughout the simulation, the algorithm iteratively refines the ship's trajectory, navigating it safely through dynamic maritime environments.

4.2 Utilization of Prediction Horizon

The prediction horizon, P also plays a critical role in this algorithm since it represents the time span over which future ship trajectories are forecasted and evaluated. In our study, we compare the effects of different prediction horizons. Figure 5 shows a visual representation of the ship's responses for P = 1000 and P = 500.

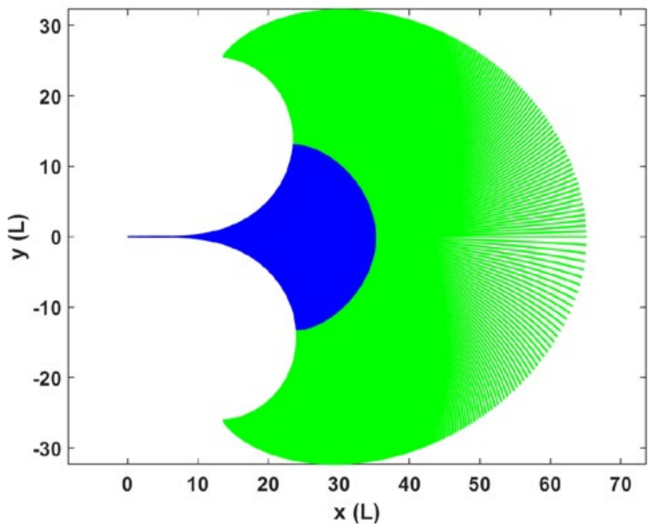

Figure 5. Ship's response for P = 1000 and P = 500

A longer prediction horizon P = 1000 allows for more extensive exploration of future ship trajectories, providing a comprehensive assessment of potential paths and their associated costs. However, this comes at the expense of increased computational burden, as the algorithm must process a larger number of trajectory iterations. On the other hand, a shorter prediction horizon P = 500 reduces the computational load by limiting the scope of future trajectory predictions. While this may result in a narrower search for optimal paths, it offers faster convergence and reduced computational burden. Understanding the trade-offs between these two approaches is essential for determining the most suitable prediction horizon for a given application.

4.4 Cost Function and Obstacles Penalty

In this study, the cost function employed is Sum of Absolute Error (SAE) and noted that other alternative cost may also applicable. The formula for the SAE is as below:

$$c_{SAE} = \sum_{i=1}^{P} \left| x_{ref} - x_k \right| + \left| y_{ref} - y_k \right| \tag{5}$$

It is also essential to include obstacles when testing path planning algorithms. In this study, the obstacle considered is a stationary entity, such as islands. To simplify the modelling process, this entity is represented as a circular object surrounded by peripheral lines, which serve as its safety margin. Figure 6 provides a graphical representation of the obstacle.

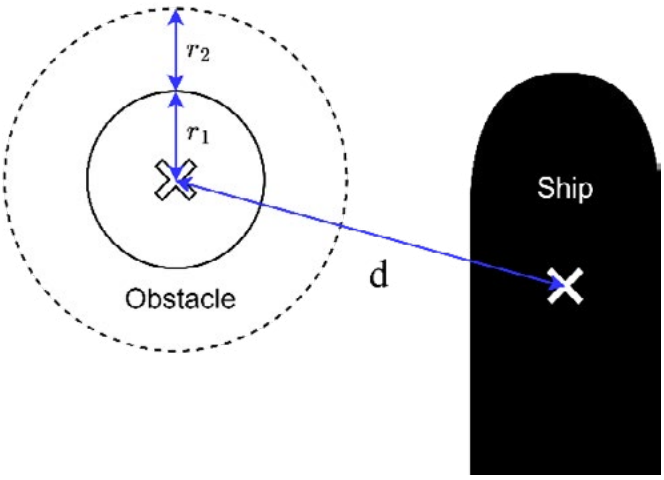

Figure 6. Safety parameter constrained by obstacle

Several techniques exist to incorporate this constraint, with one effective method being the application of a significant penalty to the cost function. This penalty is activated when the ship's distance to an obstacle d falls below a predefined safe distance threshold, denoted as $r_1 + r_2$ for obstacles. The distance to obstacles d can be computed using the Euclidean distance formula in two dimensions:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{6}$$

Where (x_2, y_2) are the coordinates of the ship and (x_1, y_1) are the coordinates of the obstacle. Once the value of d is determined, the costs associated with these distances can be expressed as follows:

$$c_{obs} = \begin{cases} 0 & \text{for} \quad d > (r_1 + r_2) \\ 10e10 & \text{for} \quad r_1 < d \leq (r_1 + r_2) \\ \text{inf} & \text{for} \quad d \leq r_1 \end{cases} \tag{7}$$

as a result, the final cost function is derived as follows:

$$c_{total} = c_e + c_{obs} \tag{8}$$

It's important to emphasize the necessity of increasing c_{obs} when designing paths, particularly in the context of large-scale maps. In such scenarios, the significance of these cost values may diminish relative to the positional error cost c_e.

4.5 Rudder Rate Constraint

In ship path planning, ensuring smooth and controlled manoeuvres is paramount for safe navigation. One crucial aspect of this optimization process is the management of the ship's rudder angle, which directly influences its trajectory.

To address this, our research incorporates a rudder rate constraint within the algorithm, aiming to regulate the rate of change of the rudder angle over time. The rudder rate constraint helps to prevent abrupt and drastic changes in the ship's rudder angle, thereby promoting smoother and more controlled manoeuvres. By limiting the rate of change of the rudder angle, we mitigate the risk of instability and erratic behavior in the ship's motion, to ensure smooth navigation and safety.

The rudder rate constraint is implemented as part of the optimization process within the EHO algorithm. Before updating the ship state using the optimal input, the algorithm evaluates the rate of change of the rudder angle and adjusts it to adhere to the specified constraint. This ensures that the ship's rudder inputs remain within acceptable limits, preventing sudden deviations from the desired trajectory. Equation (9) below describes the flow of rudder rate constraint.

$$\delta_k = \begin{cases} \delta_{k-1} + \dot{\delta}_{max} & \text{for} \quad \delta_k - \delta_{k-1} \geq \dot{\delta}_{max} \\ \delta_{k-1} - \dot{\delta}_{max} & \text{for} \quad \delta_k - \delta_{k-1} \leq -\dot{\delta}_{max} \end{cases} \tag{9}$$

The δ_k and δ_{k-1} represent the current optimal rudder angle and previous rudder angle (actual rudder angle of the ship at previous state) respectively, while $\dot{\delta}_{max}$ denotes the rudder rate constraint of 10 radian per second sample time. The condition checks whether the change in the rudder angle exceeds the predefined rate constraint. If the change exceeds this limit, the rudder angle is adjusted to ensure compliance with the constraint.

5. Test Case Scenario

In this study, maritime maps were designed to serve as the test environment for evaluating the efficacy of our proposed path-planning algorithm. This map was designed to emulate the challenges of navigating through a static obstacle. Each map within our simulation set showcases unique configurations of islands, varying in size and spatial distribution. These maps aim to capture a typical navigational challenge that is commonly encountered. Table 1 and 2 provides the coordinates position and radius of each obstacle.

Table 1. *xy*-coordinates of obstacles' positions and radius for Map 1

	Obstacle 1	Obstacle 2	Obstacle 3
X (L)	30	106	69
Y (L)	-9	10	35
r (L)	10	7	13

Table 2. *xy*-coordinates of obstacles' positions and radius for Map 2

	Obstacle 1	Obstacle 2
X (L)	30	40
Y (L)	24	60
r (L)	5	5

The coordinates and sizes of the islands are specified in nondimensional units and scaled to the 1/80 DTC ship's waterline (L=7 meter). Figure 7 illustrates the designed map from the tables above.

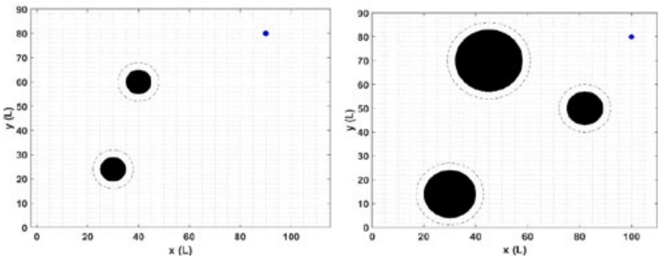

Figure 7: Designated Map 1 with Three Static Obstacles (right) and Map 2 with Two Static Obstacles (left)

The initialized ship position is at *xy*-coordinate (0, 0), with initial yaw angle of ψ =45°, and an initial surge speed $u_{\circ}$= 0.3, initial rudder input $\delta_{initial}$ = 0° and propeller speed n_p = 5 *rps*. Taking into account that precise point convergence is nearly impossible for ship navigation, a circular finishing area was chosen in place of a precise destination. This finishing area has a radius of L which is scaled to the ship waterline, with its center located at the *xy*-coordinate (115, 35) for Map 1 and *xy*-coordinate (90, 80). The prediction was made with the time step fixed at dt = 0.1s. Prediction horizon, P, which represents future time windows used in this simulation were set into P = [500, 1000]. Maximum iteration of simulation was set to 5.

6. Simulation Results

In this study, the simulations were carried out with MATLAB R2023b with a computer equipped with an AMD Ryzen 7 5600HS processor, enhanced with 8GB of RAM and an NVIDIA RTX 3050 graphics card. The simulation results are presented in Figure 8.

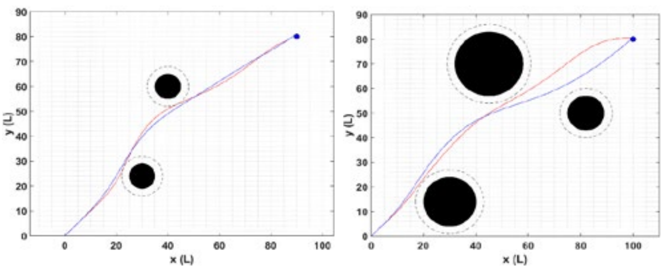

Figure 8. Simulation results for Map 1 (right) and Map 2 (left). Red line shows path with P = 500 and blue line shows path with P = 1000

The obtained result shows that a prediction horizon of P = 500 has a trajectory line that is closer to the safety radius of static obstacles meanwhile when P = 1000, the trajectory line is further than safety radius. The ship maneuvers less when P = 1000 compared to P = 500, which shows the increment of route efficiency as prediction horizon increases. Note that it comes with the cost of simulation time together with the computational capabilities. It is important to note that the generated paths strictly follow the hard constraints for all considered *P*. For example, they do not contact the islands or cross the boundary constraints, which have infinite penalties. Additional details about the simulation results are listed in Table 3 and 4.

Table 3. Simulation Time, T_{sim} vs Processing Time, T_{CPU} for Map 1 (3 Obstacles)

	P = 500	P = 1000
T_{sim} (s)	300.60s	300.30s
T_{CPU} (s)	1,964.00s	3,947.47s

Table 4. Simulation Time, T_{sim} vs Processing Time, T_{CPU} Map 2 (2 Obstacles)

	P = 500	P = 1000
T_{sim} (s)	290.50s	282.40s
T_{CPU} (s)	1,886.55s	3,678.19s

According to the data in Table 3, the simulation times (T_{sim}) recorded for *PP* = 500 and *PP* = 1000 are 299.90s and 300.30s respectively, while the corresponding CPU times (T_{cpu}) are 1,964.00s and 3,947.47s. Similarly, Table 4 indicates that for *PP* = 500 and *PP* = 1000, the simulation times recorded are 290.50s and 282.40s, with CPU times of 1,886.55s and 3678.19s respectively. Analysis reveals a positive correlation between the prediction horizon *PP*, and computation time. The variance between the paths for *PP* = 500 and *PP* = 1000 is significant, suggesting that selecting a shorter *PP* value may offer advantages in processing time, albeit potentially sacrificing the attainment of the most optimal path. However, choosing the prediction horizon value will vary on different occasions depending on the desired outcome. In time constraints, opting for a shorter horizon is feasible, despite potentially compromising optimal path attainment, and vice versa.

7. Conclusions

This study has integrated the modified Elephant Herd Optimization (EHO) algorithm into underactuated path planning algorithm for unmanned surface vessels in constrained maritime environments. EHO algorithm incorporates a realistic rudder rate constraint to ensure achievable and smooth rudder movements within the physical limitations of the ship. The cost function within EHO penalizes maneuvers that violate the rudder rate constraint, guiding the search towards feasible solutions. Additionally, a final check is applied before applying the rudder angle to guarantee adherence to the rate limit. The inclusion of the rudder rate constraint enhances the algorithm's realism and applicability to real-world scenarios. It is important to note that the choice of prediction horizon can influence the control strategy. While a longer prediction horizon can potentially lead to smoother maneuvers with smaller turns, it may also increase computational complexity. This trade-off between maneuver smoothness and computational cost to determine the optimal prediction horizon depends on utilization scenarios under various desired outcome and conditions.

In addition to exploring the optimal prediction horizon, future work should focus on bridging the gap between simulation and reality by implementing the algorithm on physical vessels. This will necessitate addressing the challenges of sensor integration and real-time environmental data processing. Sensors such as radars, LiDARs, and cameras will be crucial for providing accurate and up-to-date information about the surrounding environment, including obstacles and other vessels.

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Maritime and Aviation Accidents between 2013 - 2023: Comparative Analysis

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Abstract

Maritime and air transportation are the backbones of international trade and supply chains. Unfortunately, accidents can cause catastrophic environmental and economic losses. These accidents may occur due to myriad factors and their combination, e.g., severe weather, human error, collusion, and mechanical failure. Analysis of accidents is essential to prevent similar accidents in the future and provide safe and sustainable transport. Therefore, this study provides a comprehensive and comparative review of maritime and aviation accidents between 2013 and 2023 in the academic literature. Historical accident statistics, academic research statistics, top funding organizations, methods used in papers, and research directions are provided to present a general picture of the area. The results of this study prove that the most prominent method is the Bayesian method for both industries. Human-sourced errors were the most seen cause, and they have the potential to trigger severe accidents at that moment and soon.

Keywords: *Aviation accident, Maritime accident, Risk, Transportation safety*

1. Introduction

Transportation safety is a growing challenge due to the increasing world population, growing demand for transportation services, and economic development. Operations of all transportation modes are exposed to accident risk. These events may cause loss of life, injuries, environmental disasters, or undesired consequences. The number and variety of accidents increased due to the growing market size, dissemination of transportation technologies, and expanding Supply Chain operations. Each transportation mode has its characteristics. Hence, accident scenarios should be analyzed by considering specific risk factors. Transportation risk management includes analysis, assessment, and management of accidents. Identifying the root causes of accidents is critical to take pre-actions and avoid undesired results. Risk factors and safety issues need to be incorporated into transportation planning.

According to the European Maritime Safety Agency [90], the total number of reported marine incidents was 2,510 in 2022. According to the Safety Report of the International Air Transport Association (IATA), there were 39 accidents in the aviation industry [89]. Transportation accidents may occur due to technical issues, human factors, weather, or environmental factors such as bad weather conditions [16, 48, 85]. The number of studies in accident literature has expanded in the last ten years. Various studies exist for the prediction and empirical analysis of accidents. Some of the approaches may be listed as follows: data mining [48, 73], multi-criteria decision-making [4, 19], machine learning and deep learning [61, 92], probabilistic approaches [1, 83] and statistical methods [22, 30].

Growing marine and air traffic brings transportation safety and risk management topics to the forefront. Maritime and aviation safety are holistic areas that include many risk factors. However, there are many opportunities to employ advanced quantitative methods to analyze multi-dimensional risk data and develop proactive and data-driven risk management strategies. This study aims to contribute to this vital research area by comprehensively reviewing the literature in both fields. A systematic literature review is performed by using the Web of Science database. The main research questions are as follows: i) What are the statistics in marine and aviation accidents between 2013 and 2023? ii) What are the triggering factors of these incidents? iii) Which methodologies are used to forecast, assess, and manage accidents in these areas? Moreover, a comparative approach is used to reveal the similarities and differences between these two areas. This is a novelty of the paper.

The remainder of the paper is structured as follows. Section 2 presents the methodological approach. Section 3 summarizes the methods used in the reviewed articles, and Section 4 explains the accident types and causes encountered in the literature. Finally, Section 6 provides a discussion and concludes the paper.

2. Methodology

A systematic academic literature review was performed using the Web of Science database with the aim of revealing the current state of air and maritime accident literature. The search was performed on December 22, 2023, based on the flow chart in Figure 1. First, the relevant papers were selected based on the topic by searching the following words in the title, keywords, and abstract: i) “maritime accident,” “marine accident,” “ship accident”; ii) “air accident,” “aircraft accident,” “aerial accident,” “aviation accident.”. This search yielded 10,802 research from air literature and 5,320 from maritime areas. Then, publications were filtered according to the inclusion criteria in Figure 1, which resulted in 1,398 papers related to accidents from the aviation field and 1,151 from the maritime field. It is seen that the dominance of aviation accident studies is higher than that of maritime studies. Figure 2 shows the distribution of the articles per year for both fields.

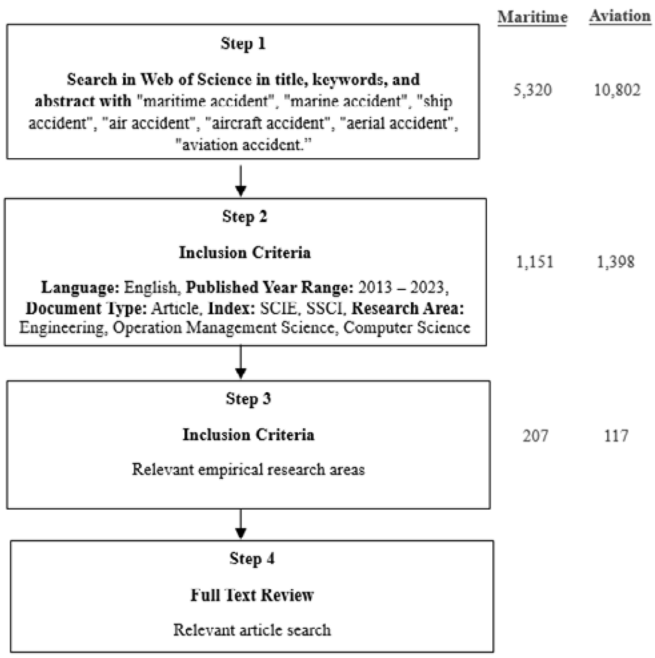

Figure 1. Flowchart of Web of Science criteria selection steps

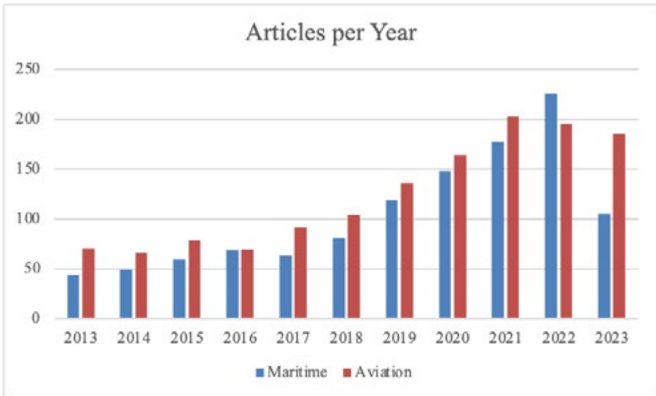

Figure 2. Articles per year.

Then, irrelevant articles were excluded, and only empirical research was considered in the full-text review stage. This was revealed in 207 papers from marine accident literature and 117 papers from the air accident field for full-text review. Table 2 gives the top 10 authors, affiliations of the authors, origin countries, and funding agencies in the reviewed articles for both fields. The results show that Chinese affiliates and funding agencies have outstanding positions for both accident types. Despite having different orders, the top five countries were identical for both accident types. On the other hand, different countries are observed in the continuation of the list. Methodologies approach, accident types, and studied/emphasized accident sources are discussed in detail in Sections 3 and 4.

Table 1. Top 10 Statistics for the Reviewed Articles.

	Top Countries		Top Funding Agencies		Top Affiliations		Top Authors	
Maritime Accident Literature	People R China	702	National Natural Science Foundation of China Nsfc	483	Wuhan University of Technology	131	Kujala, Pentti JS	38
	South Korea	220	European Commission	167	Dalian Maritime University	98	Soares, C. Guedes	34
	USA	178	Fundamental Research Funds for the Central Universities	132	Shanghai Maritime University	83	Goerlandt, Floris	25
	Japan	152	Ministry of Educ. Culture Sports Science and Tech. Japan	78	Aalto University	123	Yang, Zaili	18
	England		Mext	59	Norwegian University of Science Technology	105	Khan, Faisal I	17
	Turkey	139	Japan Society for the Promotion of Science	51	National Engineering Research Center for Water	103	Montewka, Jakub	16
	Norway	138	China Scholarship Council	50	Transport Safety	90	Aono, Tatsuo	16
	Canada	98	Conselho Nacional de Desenvolvimento Cientifico E Tech.	41	Istanbul Technical University	74	Wu, Bing	16
	Finland		Cnpq	40	Universidade de Lisboa	71	Wang, Jin	15
	Spain	86	National Key R-D Program of China	39	Liverpool John Moores University	69	Uğurlu, Özkan	14
		82	National Key Research and Development Program of China		Intituto Superior Tecnico			
		69	Grants in Aid for Scientific Research Kakenhi					
Air Accident Literature	People R China	914	National Natural Science Foundation of China	599	Japan Atomic Energy	136	Saito, Kimiaki	22
	USA	650	Fundamental Research Funds for the Central Universities	119	Helmholtz Association -	97	Inoue, Kazmasa	17
	Japan	361	Ministry of Educ. Culture Sports Science and Tech. Japan	107	United States Department of Energy Doe	90	Boyd, Douglas D.	17
	England S.Korea		Mext -	99	Chinese Academy of Sciences -	85	Fakushi, Masahiro	17
	Germany	235	European Commission	85	Tsinghua University -	80	Sanada, Yukihisa	16
	France	221	Japan Society for the Promotion of Science	80	China University of Mining Technology -	67	Qiu, Sui - Zheng	16
	Italy	192	United States Department of Energy Doe	64	Udice French Research Universities	64	Zhang, Qi	15
	India	161	Grants in Aid for Scientific Research Kakenhi	60	Beihang University	62	Stanton, Neville	13
	Spain	156	National Key R-D Program of China	54	Indian Institue of Technology System	56	Tian, Wenxi	13
		118	UK Research Innovation Ukri	51	University of Tokyo	56	Pang, Lei -	11
		112	China Postdoctoral Science Foundation					

3. Methods used in the reviewed articles

This section summarizes the commonly used quantitative methodological approaches employed in the reviewed marine and aviation accident literature articles. The commonly used quantitative methodological approaches in this study are categorized as Data Mining, Decision Making Techniques, Machine Learning, and Probability and Statistics Methods.

1. Data Mining: Data mining involves discovering patterns, relationships, and insights from large datasets. It uses clustering, classification, and association rule mining techniques to extract valuable information.
2. Decision-Making Techniques: Decision-making methods help in making informed choices by evaluating different options based on predefined criteria. Examples include decision trees, multi-criteria decision analysis, and cost-benefit analysis.
3. Machine Learning: Machine learning algorithms learn from data and improve their performance over time. Supervised learning (using labeled data), unsupervised learning (finding patterns without labels), and reinforcement learning (learning from feedback) are common approaches.
4. Probability and Statistics Methods: These methods quantify uncertainty and analyze data. They include statistical tests (t-tests, ANOVA), regression analysis, probability distributions, and hypothesis testing.

Each of these approaches plays a crucial role in research, problem-solving, and decision-making across various fields.

3.1. Quantitative methods in the maritime accident literature

3.1.1. Data mining

DM algorithms are used at different stages of marine risk management, e.g. risk probability prediction, causality analysis, and accident/sea clustering [13,32]. Researchers especially use association rule mining to identify the frequent item sets, extract cause-analysis, and reveal the patterns in accident data sets [14, 48]. Apriori, Predictive Apriori, and FP-Growth algorithms are used on 477 tugboat accident records from the IHS sea-web database [13]. Also, the Eclat algorithm successfully identifies key factors contributing to accidents using 1554 total loss accident data to investigate patterns based on accident types and severity[40]. A domino effect model is developed based on temporal association rule mining (TAR) [84]. Their results show that unsafe working practices increase risk exposure too much in Ro-Ro, general cargo, and container ships.

Cluster analysis is another approach that may be used to divide the sea into different zones. Dynamic segmentation and the DBSCAN algorithm are utilized to identify black spots, and results demonstrate that most of the identified black spots belong to high-risk waters[80]. In a study, multi-attribute visual DM has been applied to analyze navigational shipping accidents in the Northern Baltic Sea area [32]. At the same time, accident, atmospheric, and sea ice data are also used. Other studies include traffic-based associations [17, 85] and people-based failures due to environmental impacts on small ships [43]. The findings of these studies reveal that accidents may occur due to a number of human, machine, or environment-related factors. Human-sourced accident causes vary as collision due to human error [13], insufficient training/education, opposing actions to COLREG, tiredness, and wrong decisions [16, 48], lack of communication and notifications [14]. According to accident frequency patterns, the likelihood of personal-based faults and mishaps in decision-making and other processes is higher in the spring period and daytime. [43]. Weather conditions also significantly impact accidents [16, 48, 85]. Besides, there may be regional risk triggers for ship accidents, e.g., ice conditions in the Baltic Sea [32]. Additionally, ship properties and conditions, such as age, affect the occurrence of machine and equipment/tool defects [16, 48, 49].

3.1.2. Decision making

Increasing transportation loads necessitated considering risks in decision-making processes [76]. Decision models are used to authentically highlight probable mishaps, such as detecting human role in accidents [3, 44], fatigue measurement [9], fire risk [11], and traffic/navigation-based decision factors [7, 57, 62, 88], event-based incident analyses/comparisons [18, 66, 76, 82]. Human Reliability Analysis is a crucial method to quantify the probability of human error and identify mitigation and prevention policies [86].

Multi-criteria decision-making methods (MCDM) are frequently used in many areas to assess safety and determine the best decision based on predetermined criteria [8,62]. Some researchers used the well-known Analytical Hierarchy Process (AHP) method to assess accident and safety factors [4, 8, 62]. The outputs of these studies present a guide for possible definitions of mishaps and probable plans and prevention actions from the risk management perspective. Barlas et al. [11] utilized the AHP method to prioritize nine possible reasons for fire accidents based on quantitative and qualitative parameters and suggested prevention efforts based on the findings. Lack of learning and practice, deficiencies with ventilation and air pumps, lateness to notice the situation, and hazardous tools on the board are some of the sources of fire accidents [11]. Also, Bal et al.[9] employed AHP analysis to identify the rating of the causal factors of fatigue in seafarers [9] and to find weights of error-producing conditions for vessel operation management with the quantitative approach [4]. In another research, DEMATEL has been used to evaluate causal relationships of maritime accidents during ship navigation [23]. Results show that human and ship-related factors are the essential causes, and sub-factors are inner and outer communication with the people on a ship, education, professionality level, ship draft, and length.

Navigation/congestion-based studies have an outstanding place in the literature, e.g., strait [8, 62] and dam regions [82]. GRA is a rating, classification, and decision-making technique that utilizes the degree of correlation of data sequences to evaluate the existence check of their relation. Zhang et al. [82] analyzed transport safety in dam regions using GRA; to do that, five parameters, shipping flow, water surface slope, backflow, velocity, and depth factors, have been employed to assess navigational risk reliability.

3.1.3. Machine learning

Machine learning (ML) algorithms successfully create models that identify complex patterns and predict possible incidents [45]. ML algorithms were applied in different areas, including safe navigational decisions [31, 74, 78], human fall detection [7], exploring factors leading to tugboat accidents [29], marine anomaly detection based on Support Vector Machine [92], and detecting anomalous behaviors in vessel traffic patterns using Kernel learning [21].

Some studies employ the SVM method, which is a supervised learning technique that is utilized to find classifications, regressions, and outliers, it is frequently preferred by the experts [31, 92]. Long-Term-Short-Term-Memory (LSTM) is one of the outstanding ML methods that uses supervised learning. It provides unique data processing and analyzing functions.

With its three gates (forget, input, output), it tracks networks' timely steps (as current and previous), configures the vanishing-gradient problem proficiently, and remembers long-term memory. Liu et al. [45] applied LSTM forecast ship trajectories provided by AIS data for collision avoidance scenarios. While it deals with ambiguity (motions) for forward moments, ambiguity fusion is solved using a hybrid-driven predictor. The opportunity of LSTM to determine ambiguous ship trajectory forecasts indicates the security of the predictor and the accuracy of prediction provided by ambiguity fusion with ship motion limits.

3.1.4. Probability and statistical methods

Prioritizing safety issues and preventive actions is only possible by employing probabilistic methods that help predict the likelihood of specific types of maritime accidents. The Bayesian method is the most popular and common method for measuring the ambiguity of probability model parameters of accidents, and it is easily combined with different areas, for example, data mining [56] and statistical analysis [30]. As confirmed by sensitivity analysis, naive BN has been employed to evaluate cohesion between risk parameters [28]. Data extracted from MAIB and TSB between 2012 and 2017 has been applied to maritime transport mishaps. Outputs prove that the occurrence of incidents prevalently depended on ship type and its specific features (e.g., hull type, gross tonnage, and operation). The Bayesian application range is too extensive, especially when combining human-based assessments. Some studies focus on evaluating workforce efficacy [55] and operational risk [54], performance reflections based on ship characteristics [26], and affecting risk factors [1, 64]. Besides that, the Bayesian Network (BBN) is a probabilistic directed graph model used for wave height factor assessment [6]. It predicts the wave height node was assessed with hard (accident type, vessel type) and soft evidence (normal distribution) using BBN. The wave height node is a receiver for time and location nodes; on the other hand, the cause (human) node is a receiver for related nodes' time and wave height.

Statistical methods give meaningful numerical results to compare previous and later processes from a preventive point of view, expressing the effectiveness of actualized procedures [30]. Application areas of statistical methods are rock-level analysis [63], risk assessment of human errors for maritime maintenance processes [37], and assessment of mishap types [30, 77, 79].

In the literature, various regression types are preferred to analyze statistical indicators, such as binary logistic regression and zero-truncated binomial regression for assessing accident mishap severity as death and injury [72], and Gaussian process and logistic regression utilized for forecasting possible trajectory of vessels and their terminals [60].

Ordered logistic regression is a classifying algorithm to predict binomial classification problems and analyze contributors assumed as lowest and highest categories response variables are the same. Wang et al. [69] employed to analyze influencing the severity of maritime accident reports between 2010-2019. They investigated many dual relations related to accident severity and related factors (e.g. ship type, event type, human error, ship specifications, and climate relations). For assessing ship operation, a data-driven approach is applied to analyze vessel trajectories, integrating quantile regression to a generative additive model and neural network to predict ship trajectory [41]. Quantile regression has extended properties that utilize ambiguous conditions for trajectory, which cannot be detected with linear regression.

3.2. Quantitative methods in the aviation accident literature

3.2.1. Data mining

Many data mining techniques, such as association rule mining [73] and latent semantic analysis [59], are applied to analyze hidden patterns. These studies cover mishap-cause extraction [59] and air traffic controllers' behavior [59, 73]. Robinson et al. [59] tried to catch meaningful results with a supervised dataset about the importance of human factors from the HFACS perspective. The cognitive condition of regulators and insufficient inspection are the joint sides of forecasting controller-based errors and errors. The specialization atmosphere and the regulator's skill are crucial to estimating regulator-based errors; however, organizational circumstances and procedures play a role in error estimation.

3.2.2. Decision making

MCDM and decision-making methods provide a guide for taking the right actions. MCDM methods such as AHP [65], TOPSIS [15,19], and ANP [15] utilized control of the conditions for a range of alternatives and criteria, which are high, aim accessible and have fast output. Additionally, DM methods like DEA [20] don't consider the weights regarding the decision-maker's preferences. Chou et al. [20] measured the efficiency of airline companies by combining DEA and dynamic networks due to the dynamic structure of airlines. For human factor evaluation, Chiu & Hsieh [19] utilized a comprehensive approach for identifying hidden human errors based on analysis of maintenance contributors (employing RCA and HFACS). The causes are ranked according to influence, time, cost, and benefit criteria.

3.2.3. Machine learning

Machine learning provides an opportunity to learn from past experiences to support process improvement for predicting mishap potentials [. Its usage is too prevalent, and it is so easy to combine with other areas; that is why machine learning algorithms are employed by deep learning and neural networks or vice versa. Application areas are the detection of crucial factors for events associated with tire, roll, and landing distance [42], tiredness prediction with support vector [61], deep learning-based anomaly detection [5, 87], and faulty angle of attack detection [50]. Employed methods are LSTM [5, 10, 24, 25, 34, 87], SVM [61], and Neural Networks (NN) [50, 84].

Some studies, such as Dong et al. [25] and Di et al. [25], employed LSTM for deep learning because LSTM is a feature of a Recurrent Neural Network. It allows the model to expand memory partitions to accommodate more extended periods utilized for various areas, for instance, determining mishap risk contributors via previous reports in ASRS [25].

3.2.4. Probability and statistical methods

Mishap likelihood topics are predicted by considering accident occurrences, reliability, safety, and risk management perspectives. The most utilized method in the literature is the Bayesian, combined with various areas, such as deep learning [39]. Researchers use this method in their studies [36, 46, 51, 52, 71, 83]. Also, the combination of HRA methods [46] has an outstanding place. Considered areas of aerial incidents are technical failures [35, 83], traffic control or management [46], and marine aviation accidents [51]. Zhang & Mahadevan [83] employed BN to analyze mishap documents, while NTSB accident mishaps aligned with BN, using forward and backward inference to analyze potential risks.

Statistical approaches are used in all transportation mode literature due to their appropriateness in calculating the uncertainty of accidents. Statistical distributions such as normal distribution and Poisson distribution may be used to model the behavior of different accidents [12]. Regression analysis is also among the most frequent methods in aviation accident literature [22, 75]. Additionally, ARIMA is one of the forecasting methods employed and integrated with statistical methods [43]. Statistical methods are used in different aviation areas, including turbine-powered engine analysis [12], dynamic crash testing [93], pilot-based analysis [75], and analysis of causal relations between general aviation and air carrier pilot operations [27].

Studies on HFACS state that insufficient inspection-sourced unsafe acts contributed the most to accidents [33]. Erjavac et al. [27] also demonstrated that the latent factors in mishaps were organizational influences, supervision, and preconditions for unsafe acts had a dominant effect on serious-end mishaps for air carriers.

4. Evaluation of the reviewed articles based on accident types, vehicle types and causes

Accidents occur in different ways and places: the grounding of ships, fire during transportation, take-off accidents of planes, and so on. They can also occur due to human error, equipment or technical failure, or natural reasons. Besides that, industry differences and progress affect the outputs and safety level of the industry. Therefore, the literature includes different accident types and conditions. Based on the literature, accident types, causes, and vehicle types involved in the accidents are presented.

4.1. Maritime accident evaluation

According to the European Maritime Safety Agency 2022 report, the total number of accidents in 2022 was 2510. Less severe incidents ranked as the highest occurrence. The importance rate was sequenced as follows: severe marine incident and profound. The severity rate for the ship types was presented from highest to lowest: cargo ship, passenger ship, fishing vessel, service ship, and others. In 2022, fire/explosion, damage/loss of equipment, flooding/foundering, and capsizing/listing (event-type) incidents concluded with death.

In the literature, some of the vessel type-based studies were [54, 55], cargo [3, 76], and tanker [18, 53]. Grounding [2, 30, 63, 77, 79, 81], capsizing [54], collision [14, 43, 57, 62, 77, 92], and fire/explosion [10, 76] studies are researched.

Maritime accidents may occur at different stages of transportation: collision and sinking during sailing, grounding, accidents entering or within ports, bridge collisions, etc. Accident types and causes may vary based on the type of vehicle. For example, Çakır et al. [13] stated that more than half of tugboat accidents occur due to hull/machinery damage and collision, especially during maneuvers. Moreover, Ma et al. [48] focused on several ship types, indicating that the mortality rate in incidents was ranked highly in orderly Ro-Ro, general cargo, and container ships during on-duty, besides grounding and collisions, the most seen accident types [48].

Causes of accidents are sourced from different reasons, such as human, technical, and environmental factors. In the literature, people-based accidents sourced from briefly insufficient training/ education, opposing actions to COLREG, tiredness, and wrong decisions [16, 48], a lack of communication and lack of notification [14], inadequate inspection, and inadequate experience [3, 11]. Technical impacts of mishaps were observed as improper working conditions in the ship's safety management system [3] and deficiencies with ventilation and air pumps [11], hull type, and gross tonnage [28]. Environmental reason-based accidents were sourced from visibility and climate conditions [72] and wind, waves, and temperature [7, 8, 58, 74]. Due to the catastrophic structure of traffic, detecting congestion and avoiding higher-hazard possibility regions or time intervals in bottleneck points [62, 88] and dam regions [82] have seen applications.

4.2. Air accident evaluation

According to the European Aviation Safety Agency 2023 report, there were ten fatal accidents and only 200 fatalities. Between 2012 and 2022, the number of deaths and fatal mishaps was higher in 2014 than in other years. For airplanes, there were 37 fatal accidents and 75 fatalities in 2022. Of the helicopter mishaps in 2022, 18 were incidents categorized as fatal accidents, and 46 of them concluded with fatalities. Serious accidents occurred more frequently than non-fatal accidents for airplanes between 2012 and 2021. In 2022, the frequency of event-based incidents happened in an orderly manner: en route and landing occurred equally, as did approach, take-off, standing, taxi, and tow.

Worldwide air accidents have a decreasing trend, with the proportion of the flight stages from least the most orderly seen as landing, take-off (values of landing and take-off had convergent to each other), approach, and en-route [43]. Forecasted values for 2012-2016: 60% of global civil aviation accidents and 80% of global civil aviation fatalities were higher than actual values [43]. Outputs demonstrate the highest death percentages in twice turbine-powered engines [12] and loss-of-control [22] cases. The literature includes studies related to general aviation aircraft [12, 22, 27, 47, 68, 93], UAVs [5, 36], helicopters [33], and cargo [67]. Also, landing [38, 70, 86], loss of control [68], collision [52], and go-around [22] phases were studied.

Contributors of events are related to one of the HFACS segments, such as fatigue led to control losses [68], intellectual and physical situations, a lack of creating procedures, and commitment to them [19], aircrew error frequency was 0.789 higher than other person-oriented errors [47], maintenance errors are also sourced from a lack of operational management environment [19]. Also, mechanical failures ended with landing, which was sourced from insufficient inspection [83]; landing parameters and equipment quality affect the smoothness of the landing [38]. Wang et al. [70] created an assessment system for the pilot's performance during the landing phase, and the landing phase was affected by three variables: touchdown distance, vertical acceleration touchdown, and pitch angle touchdown. These parameters are used to define landing risk, probability, and severity. Also, environmental factors such as weather, wind, and waves significantly affect aviation mishaps [58].

5. Results and discussion

In this study, Web of Science-based methodological research is actualized, and quantitative methods and their evaluations have been searched for both industries. The findings of this study are categorized under common and different findings.

Common findings for both areas:

1. Standard methods used in each area for both industries are the association rule method for data mining, TOPSIS, DEA, and AHP for decision making, SVM and LSTM for machine learning, Bayesian variations for probability, statistical analysis, logistic regression, and negative binomial regression for statistics. By far, the most prominent method used in both literatures is the Bayesian method, combined with methods from numerous fields.

2. Human errors have an essential place in accidents, and it has been noted that these errors can trigger severe accidents at that moment and soon. HRA tools take accident analysis to the next level by scaling human errors and combining them with other methods.

3. Studies conducted in the navigational dimension in both fields are similar, but the event phases differ. Researchers use sensor-based calculations with deep learning methods to detect abnormalities in collision accidents, incorrect angle of attack, and other issues.

Differentiated ways of maritime and aviation incidents from each other:

1. Different industries have different event types, vessels, and aircraft types. Therefore, comparison scalation is challenging in a literal way, as there are different requirements and regulations.

2. Studies related to general aviation have the highest proportion among the other types of accidents.

3. Grounding and collision accidents are seen frequently in maritime literature.

To sum up, this study highlights the state of air and maritime accidents in the literature, mishap statistics, vehicle types, and event-based accidents in this study. Due to the sophistication of the aviation industry, statistical outputs prove that the number of accidents and their severity were lower than maritime mishaps. Also, the literature outputs demonstrate it. For further studies, unmanned vehicle accidents for both industries can be investigated for comparison.

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Section 2
Marine Risk Assessment

Analysis of Contact Accidents Onboard Ships Assisted by Maritime Pilots

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Abstract

Maritime accidents occur due to various reasons, commonly with interaction of more than only 1 causal factor. In order to reduce risk of accident, maritime pilots offer their assistance at critical waterways such as port basins and narrow passages. However, maritime accidents still occur onboard ships assisted by pilots. Besides its benefits, pilotage operations have its disadvantages as well. These disadvantages are mostly related to insufficient cooperation of ship crew and pilot developing due to reasons like ineffective communication and inadequate teamwork. Contact accidents can be explained as striking fixed objects like piers, shore cranes, buoys etc. As the damage it generates may cause big damages to the ships, long stops at port operations and loss of function at navigational aids, consequences of contact accidents can be tragic. Purpose of our research is obtaining causal factors of contact accidents occurred onboard ships assisted by maritime pilots and analyzing relationships between these causal factors. With this purpose, first, maritime accident reports which investigated contact accidents published by various accident investigation branches are analyzed and causal factors are obtained. Secondly, causal factors are classified using HFACS-MA by an expert group. Then, relationships between causal factors are analyzed by Association rule mining using R Studio version 4.3.1. Finally, results are evaluated, and findings are discussed.

Keywords: *Maritime pilotage, maritime accident, HFACS, Association rule mining.*

1. Introduction

In maritime terms, a "contact accident" refers to a physical contact between a vessel and a fixed or floating object such as a pier, buoy, another vessel or structure aside from those categorized as collisions or groundings[1]. Contact accidents can vary in severity from minor incidents resulting in minimal damage to vessels or structures, to major accidents causing significant damage, injuries, or even fatalities[2]. These accidents can occur due to various factors including navigational errors, adverse weather conditions, equipment malfunction, human error, or a combination of these factors[3]. Maritime accidents including contact accidents are a significant concern in maritime operations due to the potential for damage to vessels, cargo, the environment, and the safety of crew members and passengers [4].

Owing to the unique characteristics of every area, maritime pilotage is frequently used as a substitute to improve the safety of navigation in confined waters and to guarantee adherence to national interests [5]. Pilots with extensive local knowledge gets onboard to advise the captain and the ship's crew in order to navigate and maneuver safely in challenging waterways [6]. Furthermore, the pilots promote communication, often in the local language, between the tug boats and the vessel traffic services. As a result, the effectiveness of the human operators participating in the navigation process is crucial in these circumstances. In the other hand, maritime accidents onboard vessels under pilotage still occurs [7]. Analysis of causal factors of contact accidents onboard vessels under pilotage was never studied by researchers. We aim to shed light on this subject by this research.

2. Literature Review

Bogalecka [8] investigated statistics of collision and contact accidents taking into account ship age, ship type, incident location and consequences to the ship, environment and people. The relevant data was collected from maritime accident investigation reports between years 2004-2021 in Global Integrated Shipping Information System database. The study shows that contact accidents consists 7% of the accidents. Contact accidents most frequently occurred in port, during port approach and in river, respectively. As a conclusion, the research indicates that effective communication, safe navigation practices and adherence to set rules and procedures to prevent mishaps at sea are the key points to reduce such accidents.

Kim et al. [9] analyzed pier contact accidents in Busan Port using System-Theoretic Accident Model and Process method. The analysis was carried out based on one ship accident. Insufficient information exchange between the master and pilot, over relying on pilot's experience and decisions, failing to apply efficient bridge team management procedures and insufficient management of the ship and its crew by the management company were mentioned as the main factors of the accident. The study also underlines that the pilot over relied on his experience and failed to take preventive actions before the accident.

It is discovered that causal factors of contact accidents are studied along with collision accidents in the literature. Uğurlu et al. [10] perused 70 contact and collision accidents of passenger vessels from accident reports and categorized causal factors by using Human Factor Analysis and Classification

System (HFACS). As a result, they concluded that unsafe acts of seafarers have the biggest impact on accident causations with 35.01% frequency.

Ece [11] made a research to analyze ship accidents occurred in Istanbul Strait. As a result, contact accidents were accounted for 11.2% of all accidents. The research revealed that contact accidents most frequently occur by striking to fishing nets. The major accident cause is found to be human error, followed by current and bad weather conditions. In order to reduce human error, the study recommends that ships to be encouraged to assign a marine pilot, particularly during bad weather and strong current.

3. Methodology

Our work basically consists of 3 main steps; collection of data, classification of accident causes according to the HFACS-MA structure and analysis of the relationships between accident causes by ARM.

3.1. Collection of Data

First, investigation reports of collision accidents involving pilots were gathered from the accident investigation authorities listed in Table 1. 22 accident reports have been obtained overall. A team consisting of 3 experts with maritime accident research experience was then assembled to examine all of the investigative reports gathered and determine the reasons of the accidents. A total of 148 contributing factors were discovered after review.

Table 1. Source of maritime accident investigation reports used in the research

Accident Investigation Branch	Country
National Transportation Safety Board	United States of America
Marine Accident Inquiry Agency Japan	Japan
Marine Accident Investigation Department	Panama
Marine Accident Investigation Branch	United Kingdom
Transportation Safety Board of Canada	Canada
Bureau d'enquêtes sur les évènements de mer	France

3.2. HFACS-MA

A thorough analytical technique called HFACS is intended to examine the fundamental reasons for human errors [12]. Shappell and Wiegmann employed HFACS for the first time in the investigation of aviation accidents [13]. A time-tested method for detecting human error, HFACS allows accident events to be analyzed in a hierarchical manner [14]. The method has been used widely in maritime accident researches [15],[16],[17],[18]. Original HFACS structure has been modified by researchers with the purpose of analyzing human errors better. HFACS-MA (HFACS-Maritime Accidents) is proposed by Chen et al. in 2013 with modifications to original HFACS structure in order to adopt the method to maritime accident investigations. HFACS-MA structure is as shown in figure 1.

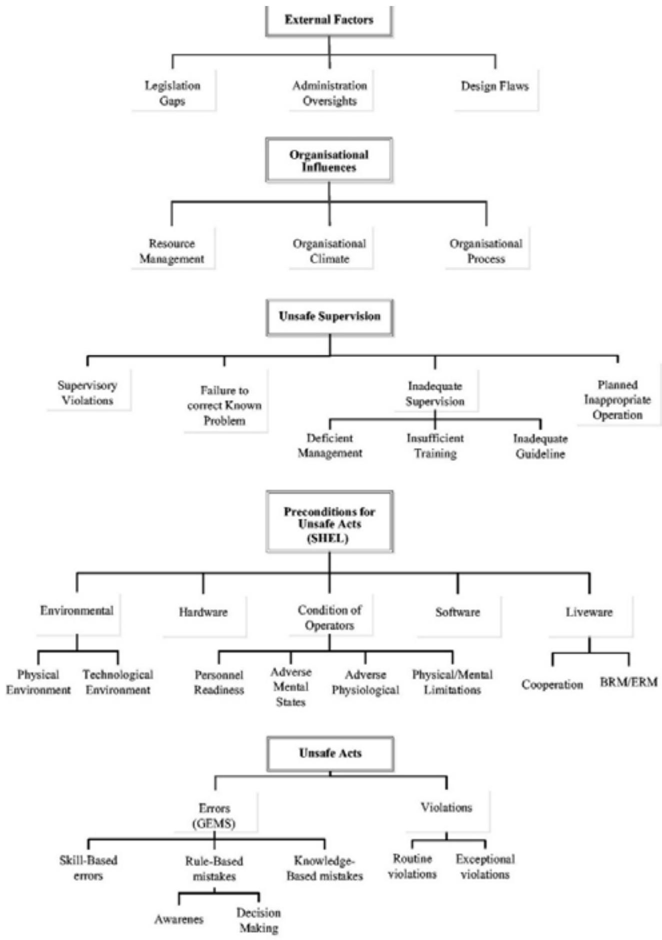

Figure 1. HFACS-MA structure [19]

With the perusal of the maritime accident investigation reports, found nonconformities which contributes to accident causation are classified in HFACS-MA structure with expert team judgements.

3.3. Association Rule Mining (ARM)

A data mining technique called ARM looks for intriguing correlations or links between a group of variables in datasets [20]. An established and popular algorithm for association rule mining is the Apriori algorithm. The Apriori algorithm uses a methodical, level-by-level approach to identify frequently occurring itemsets and derive significant correlations from the data [21]. The Apriori algorithm counts the support (frequency) of each potential itemset by sifting through the dataset. Candidate itemsets that do not reach a minimal support criterion are removed in the pruning process because they are considered infrequent. The Apriori algorithm then generates association rules based on a user-specified confidence threshold after identifying the frequently occurring itemsets. These rules describe the connections between various occurrences or items in the dataset. Another statistical variable which is the lift value is a metric that is used in the Apriori algorithm to evaluate the importance and strength of association rules that are found during the mining phase. Under the presumption that the events are independent, lift is computed by comparing the observed probability of two items occurring together with the expected probability. If the lift value is 1, evaluated factors doesn't affect each other's and they are independent. When lift value is over 1, it indicates positive correlation between the factors. If lift value is below 1, the factors being evaluated are negatively correlated [22].

4. Results and Discussion

After extracting accident contributory factors from the accident reports, each factor was classified into HFACS-MA structure in layers and levels. Layers are consisting of the main criteria of the HFACS-MA structure. From the general to the root cause, the levels are constructed in a manner that mirrors the subheading of the previous level. HFACS-MA structure of the study is represented in table 2.

Table 2. HFACS-MA structure of the study

	Level 1	Level 2	Level 3	Level 4
Layer 1	External Factors (12)	Legislation Gaps (1)	*International Legislations (1)*	Engine Room Requirements (1)
		Design Flaws (5)	*Pier Design (1)*:	Port Facility Design Flaws (1)
			Ship Design (4):	Maneuvering Station Ergonomics (1), Bridge Ergonomics (2), Bridge Blind Sections (1), Engine Chronic Problems (1)
		Administration Oversights (6)	*VTS (2)*:	Inadequate Information Sharing (2),
			Port State (2):	Ineffective Tugboat Maintenance (2)
			Health Authority (2):	Doctor Examination Mistakes (1) Erroneous Health Certificate (1)
Layer 2	Organizational Influences (13)	Resource Management (6)	*Human Resources (5)*:	Lack Of Personnel Training (4), Lack Of Personnel Donation (1)
			Technical Resources (1)	Port State Resource Management (1)
		Organizational Climate (1)	*Company Policies (1)*:	Ship's Working Language (1)
		Organizational Process (6)	*Procedures (6)*:	Engine Procedures (2), Port State Procedures (1), Navigation Procedures (3)
Layer 3	Unsafe Supervision (26)	Inadequate Supervision (12)	*Assessment Of Risks and Hazards (5)*:	Inadequate Risk Assessment (5),
			Surveillance (6):	Surveillance Of Given Commands (4), Surveillance Of Crew Fitness for Duty (2)
			Authority Gaps (1)	Master's Supreme Authority (1)
		Planned Inappropriate Operations (12)	*Operation Planning (12)*:	Maneuvering Planning (10) Tugboat Operation Planning (1) Inadequate Handover (1)
		Failed To Correct Problem (2)	*Ship Equipment Failure (2)*:	Engine Power Known Problems (1) Engine Control Unit Known Problems (1)
		Supervisory Violations (0)		
Layer 4	Preconditions For Unsafe Acts (67)	Software (0)		
		Liveware (53)	*Adverse Mental States (5)*:	Lack Of Situational Awareness (4), Fatigue (1)
			Adverse Physiological States (1):	Health Problems (1)
			Physical/Mental Limitations (4):	Lack Of Experience (4)
			Bridge Resource Management (40):	Ineffective Usage of Bridge Equipment (7), Ineffective Teamwork (6), Ship-Pilot Communication Problems (18), Master-Pilot Authority Conflict (1), Inappropriate Passage Plan (5), Ship Crew Communication Problems (3)
			Fitness For Duty (1):	Being Under Effect of Drugs (1)
			External Communication (2):	Ship To Ship Communication (1), Ship To VTS Communication (1)
		Environment (14)	*Physical Environment (11)*:	Shallow Water (1), Current Effect (6), Weather Conditions (4),
			Technological Environment (3):	Steering System Failure (1), Engine Failure (2),
		Hardware (0)		
Layer 5	Unsafe Acts (30)	Errors (21)	*Rule Based Mistakes (0)*:	
			Skill Based Errors (18):	Inability To Predict the Appropriate Maneuver (9), Inability to Use the Information (3), Incorrect Maneuvering Timing (2), Ineffective Tugboat Operation (4),
			Knowledge Based Mistakes (3):	Maneuvering Knowledge (2) Technical Knowledge (1)
		Violations (9)	*Routine Violations (9)*:	Company Procedures (3), BTM (2), STCW (1), Personal Phone Calls (3)
			Exceptional Violations (0):	

Total 148 contributory factors were extracted from the accident reports. Preconditions for Unsafe Acts layer has a frequency of 67 which corresponds to 45.27% of the nonconformities. This layer has a significant effect on accident causation as per our findings. It is also remarkable to note that Liveware, which is one of the sub-factors of Preconditions for Unsafe Acts, has the most significant frequency in level 2 with 53 nonconformities. In level 3, problems occurred about Bridge Resource Management are dominantly higher than other factors with 40 incidences. In level 4, Ship-Pilot Communication Problems is the most common contributing factor to the contact accidents.

As can be seen from table 2, level 4 involves the root causes of the accidents. After application of HFACS-MA, factors in level 4 were listed in an excel sheet along with ship's length, age, type, navigation area and IMO (International Maritime Organization) number. IMO number was used with the purpose of transaction identification in ARM. As ship's length, age, type, and navigation area cannot be output of relationships, these factors were used as input only in order to understand whether they have any influence on contributing factors.

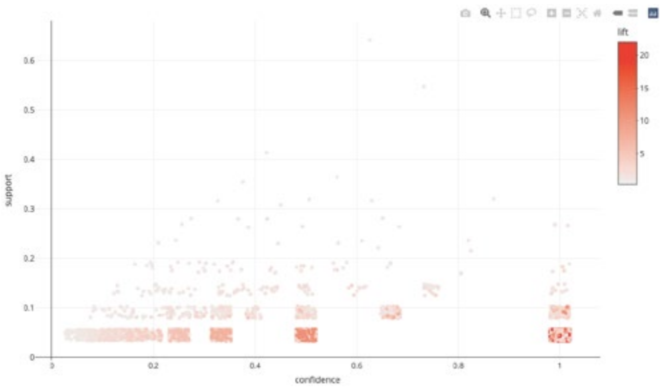

Figure 2. Scatter of association rules

R Studio version 4.3.1 was used for the application of the ARM. A total of 10547 rules were obtained from data mining. Support and confidence threshold values were taken 0.15 and 0.60, respectively. Expert opinions were consulted for determining threshold values in the light of scatter graph shown in figure 2. Association rules where the lift value is greater than 1 are taken into account. After setting these criteria, a total of 17 rules were obtained and 10 rules with greatest lift values were listed for final evaluation. The network of the association rules can be seen in figure 3.

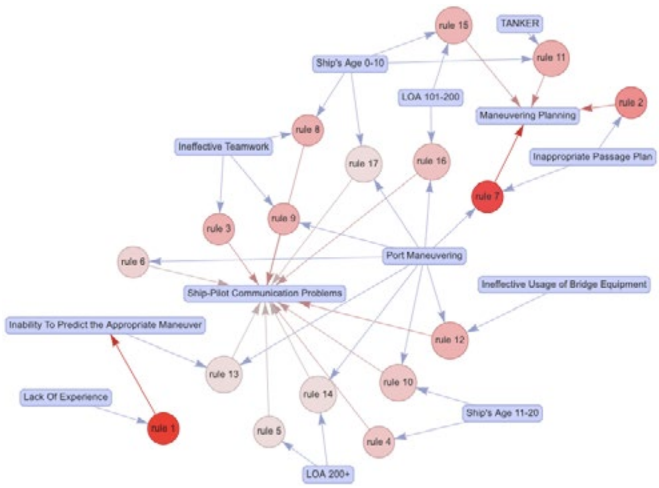

Figure 3. Network graph of the association rules

Support, confidence and lift values of the association rules can be seen in table 2. In the table, input shows the effecting factors where output is the effected.

Table 2. Association rules

Rule	Input	Output	Support	Confidence	Lift
Rule 1	{Lack Of Experience}	{Inability To Predict the Appropriate Maneuver}	0.182	1.000	2.750
Rule 7	{Inappropriate Passage Plan, Port Maneuvering}	{Maneuvering Planning}	0.182	1.000	2.444
Rule 2	{Inappropriate Passage Plan}	{Maneuvering Planning}	0.182	0.800	1.956
Rule 11	{Ship's Age 0-10, TANKER}	{Maneuvering Planning}	0.182	0.667	1.630
Rule 3	{Ineffective Teamwork}	{Ship-Pilot Communication Problems}	0.273	1.000	1.571
Rule 8	{Ineffective Teamwork, Ship's Age 0-10}	{Ship-Pilot Communication Problems}	0.182	1.000	1.571
Rule 9	{Ineffective Teamwork, Port Maneuvering}	{Ship-Pilot Communication Problems}	0.273	1.000	1.571
Rule 12	{Ineffective Usage of Bridge Equipment, Port Maneuvering}	{Ship-Pilot Communication Problems}	0.182	1.000	1.571
Rule 15	{LOA 101-200, Ship's Age 0-10}	{Maneuvering Planning}	0.227	0.625	1.528
Rule 16	{LOA 101-200, Port Maneuvering}	{Ship-Pilot Communication Problems}	0.318	0.875	1.375

Rule number 1 is the most significant rule with 2.750 lift value. According to rule 1, the incidence of "lack of experience" and "inability to predict the appropriate maneuver" factors is 18.2%. As the confidence value of this rule is 1, it means when "lack of experience" is a contributing factor in an accident, we can highly expect to see "inability to predict the appropriate maneuver" factor within the contributing factors. Stated differently, the inexperience of the bridge team members would have an adverse effect on the capacity of team members to plan a suitable and safe maneuver for the ship. After crew training, master experience is the second most important cause factor to maritime accidents under pilotage, according to Demirci et al. They also state that master experience has critical effect on bridge team management [23]. Our results are consistent with these findings, given that the bridge team management involves effective communication between the pilot and the ship's crew.

Rule 7 is the second most significant rule with 2.444 lift value. As per this rule, the accident rate where "improper voyage planning", "port maneuvering" and "maneuver planning flaws" occur together is 18.2% of the accidents. Another information obtained from this rule is when there is passage planning nonconformities on ships engaging with port maneuvering, maneuvering planning flaws should be strongly expected in factors which may contribute to accident causation. According to the study conducted by Uğurlu et al., human error in navigation and maneuvering is the main cause of collision/contact accidents in the Turkish Straits [24]. Our findings can be regarded as consistent with this finding since voyage planning nonconformities are linked to the navigation phase and maneuver planning faults are linked to maneuvering errors.

With 1.956 lift value, rule number 2 is the third most significant rule in the network. As the support value is 0.182, the frequency of "Inappropriate passage planning" and "maneuvering planning flaws" nonconformities play role together in contact accidents is 18.2%. This rule's confidence value is 0.80, meaning that in 80% of the accidents where the "Inappropriate passage planning" factor was observed, the "maneuvering planning flaws" factor was also present. This information can be interpreted as "Inappropriate passage planning" having a strong influence on "maneuvering planning flaws". In the literature, no research was found pointing out any correlation between these factors however, Oraith et al. underlines that inability to establish a good maneuvering plan before pilotage operations is highly increasing the risk of accidents during berthing operations. According to their research, masters and pilots should define the ship's maneuvering characteristics, rapidly evaluate the abilities required to steer the ship effectively, and create an appropriate and practical berthing plan for safe operation [25].

According to other rules, ineffective teamwork has strong influence on ship-pilot communication problems. If the bridge team members are not successful at working as a team, it is likely to cause communication problems between the pilot and the ship's crew. The findings also indicate that new ships and port maneuvering tend to effect ship-pilot communication adversely. Another interesting data gathered from the network is if the bridge equipment cannot be used effectively in port maneuvers, it would have negative effect on ship-pilot communication. In line with this, Chauvin et al. claimed that collisions that happen in confined waters and involve pilot-carrying vessels are directly associated with shortcomings in Bridge Resource Management [26]. According to Hetherington et al., insufficient communication denotes poor teamwork and lack of situation awareness which is also supported by our findings [27].

5. Conclusion

Because of the growing global trade, there are more and larger ships navigating around the world, creating a dense marine traffic. Consequently, it is critical to improve navigational safety in order to prevent economic loss, human loss and environmental disasters. Potential dangers and risks are even higher during pilotage operations as they are carried out in challenging waterways such as confined waters and harbor areas. Our study aims to define contributory factors causing contact accidents under pilotage operations along with their influence on occurrence of the other contributory factors. The knowledge gained from this study can be applied to improve safety of pilotage operations.

HFACS and ARM methods were used in our study to analyze contributory factors and their correlation. When classifying and assessing the causes of marine accidents, HFACS is a crucial technique. In the current investigation, reports of 22 contact accidents were reviewed and the discovered 148 contributory factors were coded in HFACS-MA structure. Preconditions were found to have highest contribution in causation of contact accidents. By outlining the HFACS-MA framework and consulting experts, we determined the root causes of the problem which we named as level 4 in our study. With application of ARM in this level, inter-relations were obtained and the most interesting relations between causal factors were extracted. A broad analysis of the results indicates that preventing human errors through the implementation of preventive measures will significantly lower the number of contact accidents under pilotage.

It should be noted that when human element is involved, gathering all information is almost impossible. There are factors like fatigue and commercial pressure which are very hard to measure during accident investigations. We believe a study conducted by expert opinion could give a better understanding about contribution of such factors to the accident causations.

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A Fuzzy Bayesian Network approach for risk analysis of cargo shifting on RORO ships.

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Abstract

Cargo shifting is a critical risk for RORO-type vessels, threatening ship stability and potentially leading to catastrophic events such as capsizing or sinking. In this paper, a probabilistic risk analysis has been carried out to ensure more safety measures and lessen the possibility of such disasters related to maritime transportation. The methodology used for the research is BN, integrated with fuzzy logic to resolve the complex causality and uncertainty about cargo shifting. BN thus computes conditional probabilities of critical events with a structured understanding of risk, while fuzzy logic deals with uncertainty and imprecision in expert judgments. The study results provide significant messages for RORO ship owners, shippers, maritime safety professionals, and HSEQ managers. This paper explains the risks involved in cargo shifting and ways to control these hazards, thus contributing much to improving safety procedures in the maritime industry. BNs, in conjunction with fuzzy logic, build a robust framework for analysis that will help fully understand the risks and support an informed decision-making process for maritime safety.

Keywords: *Probabilistic risk analysis, Bayesian Network, cargo shifting, process safety.*

1. Introduction

Maritime transportation is a complex and dynamic industry that involves numerous risks and hazards to the safety of ships, crew, and cargo and the protection of the marine environment [1]. As a result, risk analysis is a critical focus in maritime transportation due to the inherent challenges of the industry. Risk assessment evaluates the likelihood and potential impact of risks, allowing maritime professionals to effectively prioritize and analyze resources to mitigate the most critical hazards [2]. Risk analysis, which consists of monitoring and identifying potential hazards, assessing risks, determining control actions and monitoring their effectiveness, can help ensure and maintain safety at sea [3;4]. Risk analysis methods are extensively utilized across different industries, as they play a crucial role in enhancing safety procedures [5]. It is also essential for hazardous operations in the maritime sector, such as cargo handling, cargo transfer, berthing, unberthing, tank cleaning, warehouse cleaning, and bunkering [6]. International governing bodies play an important role in establishing and updating regulations and standards to address the challenges and advances in maritime safety and risk management. The International Maritime Organization (IMO) is committed to controlling maritime transport risks and improving safety through various laws, regulations, and rules. Experiences with large-scale maritime accidents have provided a good basis for current maritime safety [7]. However, statistics show that maritime accidents continue to indicate that the maritime sector still poses high risks despite all the rules and regulations [8]. The rapid advancements in the industry also bring to light numerous security challenges, including difficulties in data sharing and reuse and the evolving scope of risk assessment models. Therefore, maritime safety researchers are more interested in proactive risk mitigation strategies than ever before. Adopting qualitative and quantitative risk assessment methods has increased the study of risks based on both. The Risk-based methodologies such as Fault Tree Analysis (FTA) [9-13], Event Tree Analysis (ETA) [14-16], Bow-Tie [17-20], Failure Mode Effect Analysis (FMEA) [21-23], Hazard and Operability study (HAZOP) [24-26], Evidential Reasoning (ER) [27-30] is highly cited in maritime transportation. The Bayesian Network (BN) approach is another preferred approach for maritime risk assessment. The method enables quantitative calculation of risks by providing conditional dependency concerning edges in a directed graph [31]. BN has been applied individually or combined with conventional risk analysis techniques to mitigate dynamic and integrated risk analysis challenges within the maritime industry [31-35]. Li et al. [37] did a risk analysis by inputting data from 2017 to 2021 of maritime accidents into a BN model that helped them analyze the key RIFs influencing the maritime sector. The paper's findings indicate that the model achieves a prediction accuracy of 91.4% in real-world scenarios, making it highly suitable for accident prevention. In a separate study, the authors identified 28 critical risks using the PESTLE framework and conducted a risk assessment through a hybrid approach that combined failure modes and effects analysis, evidence-based reasoning, and a rule-based Bayesian network.

The study revealed that economic, political, and technical risks affect the container transportation service [38]. Fan et al. [39] proposed a dynamic quantitative risk assessment (DQRA) methodology based on a Bayesian network (BN) to understand the dynamic risks of LNG bunkering SIMOPs (simultaneous operations). This study examined the key time-varying characteristics of the risks associated with LNG bunkering SIMOPs by quantifying risks at different times.

RORO (Roll on-Roll of) shipping is a type of transportation in which all kinds of land vehicles are shipped by sea [40]. RORO transportation is one of the most widely used transportation types in maritime transportation [41]. RORO ships represent one of the main categories of the short-sea shipping (SSS) market [42]. RORO transportation, which allows horizontal handling and mass transportation of different loads with low transfer costs, saves companies time and is economically advantageous. However, RORO ships are one of the ship types that pose a high risk due to their wheeled load transportation and complex operations such as cargo securing and ballasting. Therefore, this paper will analyze the risk of cargo shifting during the voyage of a RORO ship.

In this research, a BN has been used to trace possible causes of failures, and fuzzy logic deals with uncertainty in expert judgments. The article is organized so that Chapter 1 introduces the motivation for the study and provides a basic review of the literature, while Chapter 2 presents the methodology. Chapter 3 presents a probabilistic risk analysis of cargo shifting on a RORO vessel. Finally, Chapter 4 discusses research findings and underlines the possible contributions of the study.

2. Methodology

This section provides detailed information about the study's methodology.

2.1 Bayesian network

Bayesian Network is a directed acyclic probabilistic graph where each node represents variables, and conditional dependency relationships between variables are symbolized by directed edges [43]. The inference principle of Bayesian Networks depends on Bayesian probability theory. It is an effective tool widely used in risk and safety analysis because it combines probability and graph theory [44]. A Bayesian Network essentially consists of two main elements: a graphical structure that models the relationships of variables probabilistically and conditional probability tables for variables associated with the network [45]. BNs are created by adding nodes into a network, referred to as either parent or child nodes. The nodes with incoming edges are referred to as "child," while those that extend outward from the links are known as "parent." Nodes that do not have any parents in this network structure are called the "root" nodes [46-47]. A Bayesian Network works on the concept of Chain Rule that models the joint probability distribution for a set of variables. With this chain rule, both marginal and conditional probabilities can be obtained for every node in the network. Any variable *Xi* can be represented as its joint probability for a set of variables U = $\{X_1, X_2, \ldots, X_n\}$ as follows [48]:

$$P(U) = \prod_{i=1}^{n} P(X_i \mid P_a(X_i)) \qquad (1)$$

Where $P_l(X_i)$ is the parent set of variables and $J \# i$. The probability of *Xi* is calculated as:

$$P(X_i) = \sum_{X_j} P(U) \qquad (2)$$

In a Bayesian Network, Bayes' theorem is applied to update the prior probability of an event occurring based on new observations, referred to as evidence E. This process yields the posterior probability of the outcome, which can be calculated using the following equation [49]

$$P(U \backslash E) = \frac{P(U,E)}{P(E)} = \frac{P(U,E)}{\sum_U P(U,E)} \qquad (3)$$

Where U is the universe of variables $X_1, X_2, \ldots, X_n$

2.2 Fuzzy Bayesian Approach

The Fuzzy Bayesian Approach combines fuzzy logic, which can deal with uncertainty, and Bayesian theory, which allows beliefs to be updated based on new evidence. It provides a framework for making informed decisions in situations where there is partial information or uncertainty.

2.2.1 Expert elicitation

Six maritime experts participated in the research to perform the fuzzy Bayesian Network risk analysis. Experts from different levels of expertise, backgrounds and work experience participated in the research. Therefore, they may express different opinions about the same events and make different subjective evaluations. Linguistic terms are used to obtain expert judgment for each root event. The rating and membership functions of fuzzy sets are shown in **Figure 1**.

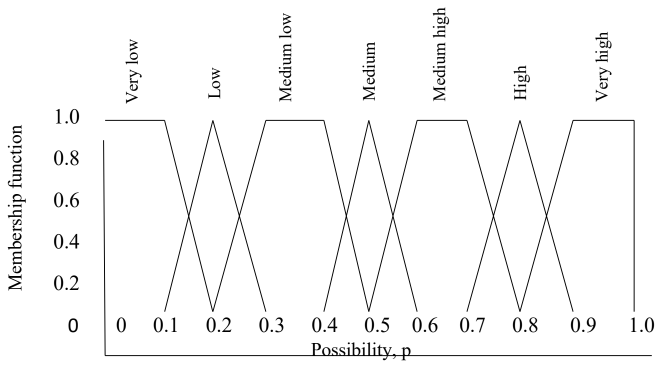

Figure 1. Fuzzy rating and membership functions.

In fuzzy logic, a fuzzy subset A is qualified by a membership function that is correlated with each element x in the universe X to the real number in the interval [0, 1] [50]. The equation $\mu_A(x)$ illustrates the membership of x in the fuzzy set A [51]. The membership function $\mu_A(x)$ for the trapezoidal fuzzy set numbers (a, b, c, d) can be defined as;

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x < a \\ \frac{(x-a)}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \frac{(d-x)}{d-c}, & c \le x \le d \\ 0\ , & x > d \end{cases} \qquad (4)$$

In the defuzzification process, the aggregated trapezoidal fuzzy numbers are converted into FPs under a fuzzy environment. A Centre of Area (COA) technique is adopted for defuzzifying the fuzzy number [13].

$$X^* = \frac{\int u_i(x)xdx}{\int u_i(x)} \qquad (8)$$

Where;

X^* is the defuzzified output i,

$u_i(X)$is the aggregated membership function,

x is the output variable.

3. Probabilistic risk analysis of cargo shifting on RORO ships

Six maritime experts participated in the research to perform the fuzzy Bayesian Network risk analysis. The root events that initiate cargo shifting on RORO ships are partly based on the articles, accident results, and information from face-to-face interviews with experts used to determine possible consequences [52]. After collecting root causes, a Bayesian Network diagram is created. The diagram shows the possible root and intermediate nodes that cause cargo shifting risk. **Figure 2** shows the BN diagram generated by the GeNIe program from the perspective of marine experts.

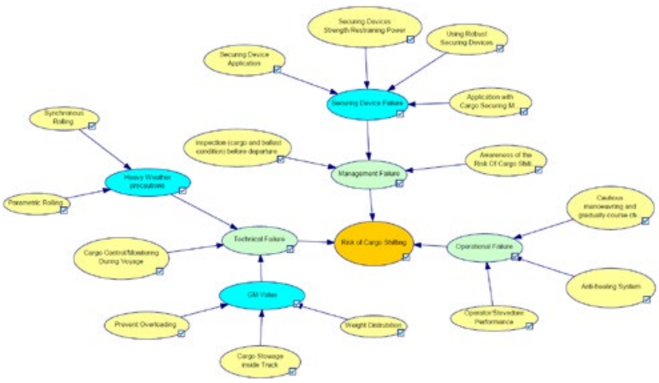

Figure 2. Bayesian Network Diagram Risk of Cargo Shifting.

Equations (5 - 8) are used for aggregation and defuzzification of fuzzy numbers to calculate the fuzzy possibility of root events. **Table 1** demonstrates the fuzzy possibilities of root events obtained by experts' evaluation.

Table 1. Linguistic expert evaluation and fuzzy possibility scores (FPs) of the root events

Root Events	**Expert Judgments**						**Aggregation of Fuzzy Numbers**				**yFPs**
	1	**2**	**3**	**4**	**5**	**6**					
Securing Device Application	ML	L	ML	L	L	L	0,131	0,231	0,261	0,361	0,25
Securing Devices Strength/Restraining Power	VL	ML	L	VL	ML	VL	0,095	0,149	0,235	0,335	0,21
Using Robust Securing Devices	VL	L	L	VL	VL	VL	0,035	0,069	0,135	0,235	0,12
Application with Cargo Securing Manual	VL	L	L	VL	L	L	0,068	0,136	0,168	0,268	0,16
Awareness of the Risk of Cargo Shifting On-board Ship	L	ML	L	M	ML	ML	0,201	0,301	0,355	0,455	0,33
Inspection of Cargo and Ballast Condition Before Departure	L	L	VL	VL	M	VL	0,116	0,172	0,216	0,316	0,21
Cautious Manoeuvring and Gradually Course-Changing	L	M	L	VL	M	ML	0,217	0,301	0,331	0,431	0,32
Anti-Heeling System	VL	VL	VL	ML	L	L	0,065	0,115	0,181	0,281	0,16
Operator/Stevedore Performance	L	M	L	L	L	L	0,160	0,260	0,260	0,360	0,26
Synchronous Rolling	M	ML	L	VL	M	M	0,252	0,336	0,372	0,472	0,36
Parametric Rolling	L	L	L	ML	VL	ML	0,109	0,189	0,239	0,339	0,22
Prevent Overloading	H	H	H	VH	VH	H	0,736	0,836	0,872	0,936	0,84
Weight Distribution	L	M	L	ML	L	ML	0,189	0,289	0,319	0,419	0,30
Cargo Stowage Inside Truck	ML	L	ML	L	L	L	0,131	0,231	0,261	0,361	0,25
Cargo Control/Monitoring During voyage	L	L	ML	L	L	L	0,115	0,215	0,229	0,329	0,22

When determining the conditional probabilities in Bayesian networks, 2n evaluations are necessary to assess child nodes with n parent nodes (53). Due to the extensive number of intermediate and leaf node conditional probability tables, the study provides just one example of a conditional probability calculation. Table 2 illustrates the conditional probability of the GM value according to the Bayesian network developed in the study.

Table 2 Conditional probability of GM value node.

Prevent Overloading	exist				non			
Cargo Stowage inside Truck	correct		incorrect		correct		incorrect	
Weight Distribution	correct	incorrect	correct	incorrect	correct	incorrect	correct	incorrect
Excesive	0.001	0.704	0.324	0.931	0.152	0.834	0.504	1.000
Non	0.999	0.296	0.676	0.069	0.848	0.166	0.496	0.000

3.1 Sensitivity analysis

Sensitivity analysis enables the assessment of how changes in one node of the network affect other nodes. In this study's sensitivity analysis, the probability of the "Risk of cargo shifting" node was initially adjusted to 0% and then to 100%, while the probabilities of the other nodes in the network remained unchanged. Subsequently, the resulting changes in the probability values of each node were analyzed. **(Table 3).**

Table 3 Sensitivity analysis results of the BN.

Factor affecting Accident	**Probability of accident (%)**		
Node	**0(%)**	**100(%)**	**Effect**
Securing Device Application	73	76	3
Securing Devices Strength/Restraining Power	76	81	5
Using Robust Securing Devices	78	91	13
Application with Cargo Securing Manual	80	87	7
Securing Device Failure	60	81	21
Awareness of the Risk of Cargo Shiting On-board Ship	64	72	8
Inspection of Cargo and Ballast Condition Before Departure	77	82	5
Management Failure	63	85	22
Cautious Manoeuvring and Gradually Course-Changing	63	74	11
Anti-Heeling System	78	86	8
Operator/Stevedore Performance	70	74	4
Operational Failure	60	79	19
Synchronous Rolling	63	66	3
Parametric Rolling	76	80	4
Heavy Weather Precautions	63	75	12
Prevent Overloading	74	86	12
Weight Distribution	64	73	9
Cargo Stowage Inside Truck	70	78	8
GM Value	70	85	15
Cargo Control/Monitoring During Voyage	70	81	11
Technical Failure	75	91	16

3.2 Validation

The validation of the Bayesian network is essential and must be thoroughly tested. This paper utilizes the axiom testing procedure for partial validation of the proposed model [54-55].

Axiom 1: An increase or decrease in the prior probabilities of each parent node should consistently lead to a corresponding increase or decrease in the posterior probabilities of the child nodes (**Table 4**).

Axiom 2: The rate of increase applied to the prior probability distributions of each parent node should be proportionate to the impact on the values of the child nodes (**Fig. 3**).

Axiom 3: The combined influence of probability changes in attributes x and y on the values should always exceed the effect of either parent x or parent y individually (**Table 5**).

Table 4 Test of axiom 1 for the node "Securing Device Failure".

Condition	**Parent Nodes**	**Child node**
	Securing Device Application	Securing Device Failure
Incorrect	Prior	0.80
	100%	0.85
	0%	0.70
	Securing Devices Strength/Restraining Power	Securing Device Failure
Insufficient	Prior	0.80
	100%	0.84
	0%	0.66
	Using Robust Securing Devices	Securing Device Failure
Non exist	Prior	0.80
	100%	0,89
	0%	0.48
	Application with Cargo Securing Manual	Securing Device Failure
Non exist	Prior	0.80
	100%	0.86
	0%	0.57

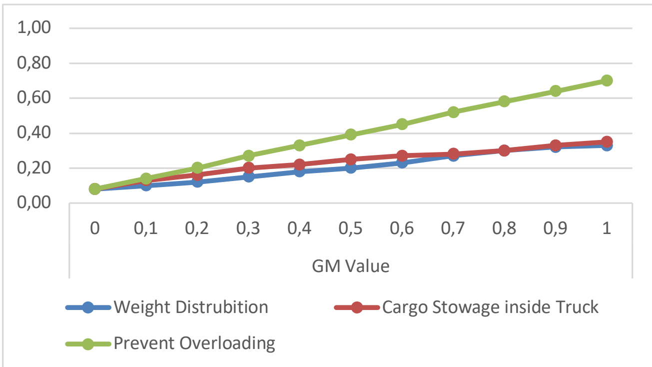

Figure 3. Test of axiom 2 for the node "GM Value"

Table 5. Test of axiom 3 for the node "Risk of Cargo Shifting".

Technical Failure	**Management Failure**	**Operational Failure**	**Risk of Cargo Shifting**	**Percentage Variation**
86	75	74	0,83	
100	75	74	0,90	7%
86	100	74	0,93	10%
86	75	100	0,91	8%
100	100	100	1	17%

4. Discussion and Conclusion

This study conducted a comprehensive risk assessment regarding cargo shifting on RORO ships during the voyage. The Fuzzy-Bayes approach was used to reveal probabilistic relationships between causal factors. The Bayesian network shows the root nodes that cause Cargo Shifting risk and the connections between these nodes. Axiom tests were performed to test the suitability of this Bayesian network. The axiom test revealed that management failures have the highest impact on risk, with a 10% percentage change. Sensitivity analysis was then conducted quantitatively to measure the impact of each causal factor affecting the risk. Thus, the probability weights of the factors causing accidents were calculated. According to the findings of the sensitivity analysis, using robust securing devices is the most critical root node because it changes the probability of the leaf node occurring in the network by 13%. RORO vessels' securing devices are vital in securing vehicles and other cargo during transit on ships. The securing devices used for stowing vehicles on RORO ships are pretty diverse, such as trailer horses, lashing chains, chain turnbuckles, trailer twist locks, trailer and car rubber chocks, or car & trailer webbings. All portable and fixed devices used in stowage must comply with the requirements of the ship cargo security manual (CSM) and the Code of Safe Practice for Stowage and Securing of Cargo (CSS). Also, to avoid defects or deficiencies, planned maintenance of this equipment must be carried out with an effective program. The use of damaged, missing, or faulty equipment may cause ruptures, breakages, and vehicles to topple over during transfer [52, 56]. Another important root node, "Prevent overloading", affects the risk probability by 12%. Especially for commercial and economic reasons, overloading problems may occur in RORO ships operating on liner lines and doing short sea shipping [57]. Loading the ship with cargo beyond its capacity may result in improper lashing, tight stacking of cargo, and cargo shifting on top of each other. When combined with inadequate ballast operation, this situation can create a significant free surface effect, resulting in negative GM and causing the ship to capsize [58]. Cautious Maneuvring and Gradually Course-Changing is the root node with the next impact percentage (11%). Sudden course changes are risky behaviour for all ship types. This manoeuvre can create centrifugal force that could cause the ship to roll over. When manoeuvring, ships must make smooth and gradual turns. This situation becomes even more risky, especially for RORO ships carrying wheeled cargo. A sharp turn causes the ship to tilt outwards, which may cause vehicles loaded side by side to topple over each other. This sliding of the vehicles causes the ship to develop a rapid heel and become capsized [59]. In conclusion, the paper's outcomes provide valuable insights to ship owners, maritime safety professionals, and HSEQ managers (Health, safety, environment, and quality) on how to prevent RORO vessel cargo shifting risk in maritime transportation. Since there is a lack of research in the literature to tackle this topic directly, this paper has novelty. Due to data scarcity, the paper adopted fuzzy sets, which can be considered as a limitation of the study. Further study will be projected to capture a statistical dataset to compare results.

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Examination of Lifeboat Load Tests Employing the AHP Method

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Abstract

In the maritime industry, accidents and emergency scenarios may lead to devastating consequences in terms of human casualties, financial damages, and complete destruction of vessels or equipment. Occurrences of fire, collision, flooding, and grounding may be seen as a result of hazardous working and environmental circumstances. In such circumstances, the life-saving appliances on board the ships can devise an emergency procedure to guarantee the safety of the seafarers. Specifically, life rafts, lifeboats, boats, life jackets, rescue boats, and life buoys are examples of these life-saving appliances. In emergency situations, lifeboats and davits are used for the purpose of abandoning a ship. This paper examines the risk analysis of the procedures associated with the 5-year inspections of lifeboats and davits using the Analytic Hierarchy Process (AHP) methodology. The stages of conducting the lifeboat load test were first divided into phases A, B, C, and D; then each phase was examined. In the study conducted with expert opinions, it has been determined that the riskiest operation steps during the execution of lifeboat load tests are respectively C4, C6, and D5. The conclusion section offers suggestions that target the reduction of risk factors and the establishment of a more safer working environment.

Keywords: *Lifeboat, Risk Assessment, AHP, Risk Analysis, Life-Saving Appliances, LSA*

1. Introduction

Maritime incidents are typically described as unwanted abnormal occurrences that take place aboard a vessel. Incidents resulting in the loss of life or serious injury to any person on board a vessel, and causing various types of property damage, have been a significant concern within the international maritime community since the inception of maritime activities [1]. Maritime operations have been widely regarded as intricate and fraught with risk for quite some time, with incidents at sea frequently leading to substantial casualties, damage to cargo and property, and significant environmental contamination [2]. Safety is very important to prevent these accidents on ships. In fact, as a result of the accidents, the The International Convention for the Safety of Life at Sea (SOLAS) agreement was signed by the International Maritime Organization (IMO) for purposes such as raising safety awareness, standardizing, and determining the minimum required safety equipment [3]. The SOLAS Convention is a global maritime agreement mandating that countries ensure ships flying their flag adhere to specified safety criteria regarding construction, safety equipment, and operational practices [4].

Some of these safety equipment may be called Life-Saving Appliances (LSA). It generally refer to the equipment found on ships and used to preserve human life in emergencies. These may include items such as life jackets, life raft, lifeboats and life buoys. These pieces of equipment are utilized to ensure the safety of crew members and passengers during emergencies that may occur aboard a ship. The importance of Life-Saving Appliances comes from the ability to save lives due to the nature of maritime [5].

Life-saving equipment is available aboard ships to ensure the safety of the crew and establish safe circumstances during emergencies [6]. Lifeboats are used in case the ship has to be evacuated during a potential emergency [7]. It should be readily available for usage in case of an emergency and should function without any issues. IMO has established certain standards that are verified by authorised administrations to assure compliance [8]. Special tests are conducted every five years to guarantee that the davits and lifeboats are capable of carrying all crew [9]. The condition is assessed, and required maintenance is performed. Authorised service providers conduct these five-year examinations under classification society supervision. Thus, in all these procedures, humans take precedence over machines. Therefore, various accidents may occur during lifeboat load tests due to reasons such as human errors, equipment failure, non-compliance with procedures, lack of training. As a result of these accidents, consequences such as death and injury may occur. The lifeboat load test steps are examined with the AHP method in this study, and the risk analysis is determined.

This study consists of five section. Section 1, the reasons for preparing and researching this study are explained. In the second section, lifeboat load test processes and risk analysis in the literature are reviewed. Section 3, the risk analysis Analytic Hierarchy Process (AHP) method used is explained. Section 4 includes a real lifeboat load test study. The fifth and final section includes the findings and outputs obtained as a result of this study.

2. Literature Review

There are many studies about LSA in the literature. For instance, [5] mentioned a system analysis that determines the number of Life-Saving Appliances (LSA) required according to the requirements of The International Convention for SOLAS. In another study, the health importance of LSA equipment during evacuation from the ship in emergency situations was evaluated through performance evaluation [10]. It is mentioned that, [11] the necessity of Totally Enclosed Motor Propelled Survival Crafts (TEMPSC), including lifeboats, in evacuation, rescue and escape operations in Oil and Gas Offshore facilities. In a different study, [12] stated the accidents that occurred during lifeboat tests and drills. A new virtual training (VR) module has been proposed to prevent accidents caused by the use of LSA equipment [8].

Similarly, [6] they emphasized the importance of the competencies of people using their equipment and mentioned the benefit of using simulated VR technology in training to ensure this. In another similar study, the necessity of Mixed Reality (MR) technology in LSA trainings was emphasized and the necessity of utilizing augmented virtual reality (VR) technology was explained.

As a result of the literature review on Life-Saving Appliances (LSA), it was seen that the requirements of LSA equipment within the scope of SOLAS were mostly mentioned. Other studies have emphasized the importance of training those responsible for LSA equipment and focused on the need to benefit from technological developments in these trainings. Except for a few studies, it has been observed that LSA equipment is not considered in terms of risk analysis. A few examples of studies can be given as; risk analysis was carried out by determining the failure modes of LSA equipment and regulatory and preventive actions were determined against the deficiencies of lifesaving systems on cruise ships [13].

In an additional study; [14] tested the risk by studying different designs for risk-based LSA equipment. Although risk analysis has been carried out in some studies, it has been observed that there are gaps in this area. In order to eliminate this gap, the multi-criteria decision-making method, known as the AHP, was used in the study. Therfore; Examining lifeboat loading tests with the AHP method is thought to be necessary for safety, risk reduction and safe working environment.

3. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is regarded as one of the most widely used multiple-criteria decision-making (MDCM) methods. It is Saaty who developed the method and made it a model that can be used in solving decision-making problems [15].

Additionally, quantitative and qualitative criteria can be obtained thanks to the AHP method [16]. Experiences, judgments, intuition and opinions can be included in the decision-making process in the AHP method [17]. It is a method by which complex problems can be solved by being considered within a hierarchical structure. Evaluation of unstructured problems in many fields, such as economics, social sciences and political issues, can also be done with AHP [18].

According to Saaty [19] the application steps of the AHP method are as follows:

1. Define the problem and determine its goal.
2. Outline a hierarchical structure that represents the decision maker's goals. Set a goal at the top. Then determine the goal-related criteria. Then create potential alternatives based on these criteria at the lowest level.
3. Generate a series of comparison matrices (size *n x n*), each corresponding to elements within the immediate lower level in relation to those in the level directly above. Utilize the comparative scale between 1-9 to assess which element prevails over the other in each pairwise comparison.
4. To generate the set of matrices in step 3, you'll need to make judgments. Reciprocal values are automatically assigned in each pairwise comparison.
5. Hierarchical synthesis is now employed to assign weights to the eigenvectors based on the criteria weights, and the sum is calculated over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. Having completed all pairwise comparisons, consistency is assessed by utilizing the eigenvalue, $\boldsymbol{\lambda_{max}}$, to compute the consistency index (CI) as follows: $\boldsymbol{CI = \lambda_{max} - n \,/\, n - 1}$ where *n* represents the matrix size. The consistency ratio (CR) is deemed acceptable if it does not surpass 0.10; exceeding this threshold indicates inconsistency in the judgment matrix. To ensure a consistent matrix, judgments should undergo review and refinement.
7. Steps 3±6 are performed for all levels in the hierarchy.

4. Case Study

In this section, the risk analysis of lifeboat load tests will be conducted using the AHP method. The fundamental steps of the study are derived from the ISO 23678:2022 training sessions at the ITU Maritime Faculty Delmar Academy Training Center. The procedures comprising the lifeboat load test, including pre-entry checks by the service engineer, checks conducted after entering the lifeboat, load test preparation, and test execution, are represented by sections A, B, C, and D, respectively. The operational steps within each section are indicated by the section's name (e.g., A1, B2, C2, D3). A detailed representation of the lifeboat load test steps is provided in **Table 1**.

Table 1. Lifeboat load test steps

Operational Steps	Description
A1	Davit arms are secured using harbor pin.
A2	Fall preventive devices and installation are secured to ensure that the inspection can be performed in a safe manner.
A3	OEM (Original Equipment Manufacturer) certificates for freefall boat and davit are checked and observed. One copy of last 5 yearly inspection report and remarks are controlled.
A4	In order to avoid any trouble during the test, last certificates of fall wires, air bottles and recovery slings are checked and inspected. In addition, expire dates of those equipment's are controlled.
A5	General condition of hanging off pad eye or plate on davit structure and connections are checked before connecting hanging off/simulated launch equipment.
B1	Engine and propulsion system, fuel tank, fuel lines, drain valve, exhaust system, stern tube, stuffing box and engine casing are checked.
B2	Seats and seat belts and internal condition of equipment are inspected.
B3	All pyrotechnics, first aid and emergency equipment's are checked. Expire dates are noted and cross checked with latest certificates.
C1	Boat is taken from ship and connected with the davit. Make sure all connections, slings and release mechanism are properly connected.
C2	Before the lowering of the boat to the sea, its hydrostatic release units are checked in terms of opening time. If they not open at the same time, it is adjusted in order to avoid accident during the test.
C3	Boat is lowered to the sea and putted weight bags to inside of the boat properly.
C4	Water connection is connected, hoses and their conditions are inspected.
C5	Weight bags are filled with water until it reaches to optimum weight according to OEM manual.
C6	Due to release mechanism connected with davit's wire, it must be in the sea and one person goes down, opens release mechanism. If it opens properly, boat passes the test.
D1	After checking the release hook mechanism, boat is lowered to the sea and kept safely.
D2	Governor and gear box are checked properly. Also, they are inspected to detect if any leakages, water in oil, bad condition and unsuitability. If necessary, those items are changed and oil or sealing equipment are renewed.
D3	In order to provide optimum weight distribution for both davits, one hook is connected for both davits and water weight is connected to hook.
D4	In order to carry out operational test, weight bags are filled with water until reaches the davit's safe working load (SWL).
D5	When the weight is equal to safe working load, davit is operated and observed the motion of lowering/heaving.

In the study, a total of eight expert opinions were received. These experts consist of two oceangoing watchkeeping officer, one oceangoing master, three academicians, one technical manager and one assistant operations manager. AHP hierarchy was created with the data received from this expert team. Then, the decision matrix was obtained and AHP formulas were applied. As a result of the analysis, the most risky operations are C4-C6-D5. These operations are followed by D2, D1, C2, D4. A1, C5, A3, C1, D3, A2 , B1 are the risky operations that come after. B2, A5, B3, A4, C3 are the risky operations that come after.

5. Conclusion

Lifeboats are cited as examples of life-saving appliances that may need to be used promptly in various emergency situations such as man overboard and evacuation. The majority of accidents identified in examined reports and literature studies are attributed to lifeboats. In the conducted study, the risk analysis of lifeboat load tests, which are required to be performed every five years, was carried out using the AHP method. Initially, the ISO 23678:2022 training sessions at the Delmar Academy Training Center within the ITU Maritime Faculty were reviewed. As a result of these examinations, the steps of the load test were identified. The lifeboat load test procedures consist of pre-entry inspections by the service engineer (section A), checks after entering the lifeboat (section B), load test preparation (section C), and test execution (section D).

As a result of the analysis and examinations, it has been observed that the most risky/possible operational steps for potential accidents during lifeboat load tests are C4, C6, D5, D2, D5, C2, D4, A1, C5, A3, C1, D3, A2, B1, B2, A5, B3, A4, C3. In order to conduct tests more safely, under control, and without accidents, certain precautions/suggestions have come to the forefront.

Out of a total of 19 operational steps, 12 were found to be due to insufficient technical knowledge (63%), 3 due to lack of Personal Protective Equipment (PPE) (16%), 2 due to carelessness and lack of awareness (10.5%), and 2 due to lack of experience (10.5%). In light of this data, to ensure the safer and less risky execution of lifeboat load tests, it is necessary to eliminate the lack of technical knowledge. To achieve this, technical training sessions can be provided to service engineers, manufacturer instruction manuals can be provided, experiences with different brands and models can be increased at certain intervals, or technical equipment can be improved through remote support. Eliminating the lack of personal protective equipment can be achieved by increasing awareness. Service engineers can be presented with accidents, scenarios, or reports to emphasize the importance of PPE. To prevent carelessness, service engineers can be given briefings before operations and debriefings afterwards. Additionally, ensuring they get more rest or requiring them to undergo attention-memory tests at certain intervals can be beneficial. To address lack of experience, more experienced service engineers can be utilized. For example, both inexperienced and experienced service engineers can participate in lifeboat load tests together. Moreover, technological tools such as simulators, Augmented Reality (AR), Virtual Reality (VR), or Computer Based Assessment (CBA) can be utilized.

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Occupational Health and Safety Risk Assessment of Ship Abandonment Drills Using the TOPSIS Method

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Abstract

The presence of human error plays a crucial role in assessing the hazards involved in the maritime industry. A significant number of incidents, including as collisions, groundings, capsizing, fires, and explosions, may be attributed directly to human errors. It is very important to ensure safety in working environments as many different emergency scenarios occur in the maritime industry. Ship abandonment drills are held periodically on ships to ensure preparedness for emergencies. In this study, occupational health and safety risk assessment examinations of abandon ship drills were conducted using the TOPSIS method. As a result of the analysis, a pre-job checklist was recommended to ensure the safety of abandon ship drills and the safety of the working environment. It is thought that the use of the proposed pre-job checklist in abandon ship drills may be beneficial in terms of occupational health and safety.

Keywords: *safety, risk assessment, TOPSIS, ship abandonment, drill, occupational health and safety*

1. Introduction

Assessing human error in marine transportation is challenging due to the many hazardous tasks conducted on board ships, such as cargo loading, unloading, ballasting, de-ballasting, tank cleaning, gas inerting, and ship-to-ship cargo moving [1]. During maritime disasters such collisions, groundings, floods, or fires on-board ship, the ship's master may order the abandonment of the vessel to save lives [2]. While many study articles have been conducted in the literature, there is a scarcity of studies focusing on emergency ship protocols [3]. The abandon ship drill is a crucial practical training conducted aboard ships. The crew often exhibit significant inadequacies in following abandon ship protocols, which may lead to tragic outcomes [4]. Maritime authorities are examining and analysing abandon ship protocols in light of recent ship catastrophes. An abandon ship practice must be carried out monthly as per the SOLAS (Safety of Life at Sea) treaty. All crew members on the ship must take part in every abandon ship drills to avoid losses during an emergency evacuation [5]. The crew's performance and ability to swiftly and efficiently evacuate the ship are crucial at this juncture. The crew is expected to carry out an abandon ship protocol flawlessly [6]. This research utilised the TOPSIS approach to perform occupational health and safety risk assessment studies of abandon ship drills. A pre-job checklist was suggested after the investigation to guarantee the safety of abandon ship drills and the working environment.

This study is organized in 5 section. The literature review on occupational health and safety, ship abandonment drills and TOPSIS method is stated in the section 2. In the section 3, the TOPSIS method was applied. The findings and results of the study constitute the section 4. Section 5 presents limitations.

2. Literature Review

Despite the abundance of research articles in the literature, there is a dearth of studies specifically risk analysis focusing on occupational health and safety in relation to emergency ship abandonment drills. Flood emergencies occurring on ships were examined [7]. Another study presented the evacuation analysis of cruise ships through experimental scenarios [8]. In their paper, the authors concentrate on validating SIMPEV through computer simulations. There is also another study regarding the evacuation of passenger ships, which aims to provide important decision support to the ship officer responsible for evacuation procedures [9].

Additionally, there are several new research endeavors investigating evacuation procedures during emergency scenarios across various sectors including offshore platforms, the energy industry, petrochemicals, mining, and more [10]. When we look at these studies, it can be seen that they are mostly focused on evacuation procedures on passenger ships and the training of the officers on these ships. There are not many studies on the evacuation procedures or ship abandonment drills on oil tanker ships.

The importance of abandon ship drills becomes evident as a result of mistakes made during ship abandonment. When the literature was scanned, it was stated that abandonment drills on oil tanker ships were not specifically addressed in terms of occupational health and safety. Therefore, there was a need to examine ship abandonment drills steps with the TOPSIS method.

3. Methodology

Recognized widely among decision-making approaches, TOPSIS distinguishes a positive ideal solution, which minimizes costs and maximizes benefits, and a negative ideal solution, which does the opposite. By gauging distances from both ideal solutions, TOPSIS discerns between favorable and unfavorable outcomes [11]. At least two decision options are necessary for its application. With its straightforward analysis process devoid of intricate algorithms or mathematical models, TOPSIS finds utility across diverse fields, owing to its ease of use and straightforward result interpretation [12].

In this study, we tried to achieve the ideal result by applying the following TOPSIS steps.

1. Establish Evaluation Criteria: Define the factors to be considered when assessing the options. These factors should be pertinent to the decision and quantifiable.
2. Standardize the Decision Matrix: Develop a matrix where each alternative corresponds to a row and each criterion to a column. Standardize the matrix to ensure uniformity across all criteria, employing techniques like min-max or z-score normalization.
3. Assign Criterion Weights: Allocate weights to each criterion based on its significance in the decision-making process. These weights reflect the decision maker's preferences and can be determined using methods such as analytical hierarchy process (AHP) or stakeholder input.
4. Define Optimal and Suboptimal Solutions: Determine the best and worst possible outcomes for each criterion. The optimal solution represents the most desirable value, while the suboptimal solution represents the least desirable. These values can be calculated by maximizing or minimizing the criterion values across all alternatives.
5. Compute Similarity Measures: Evaluate the similarity between each alternative and the optimal and suboptimal solutions. Typically, this involves calculating distances using metrics like Euclidean or Manhattan distance.
6. Evaluate Proximity to Ideal Solution: Assess the proximity of each alternative to the optimal solution by comparing its distance to both the optimal and suboptimal solutions. This can be accomplished using a formula such as the TOPSIS score:
7. TOPSIS score = (Distance to Suboptimal Solution) / (Distance to Optimal Solution + Distance to Suboptimal Solution)
8. Rank the Alternatives: Arrange the alternatives in order of their TOPSIS scores. The alternative with the highest score is deemed the most favorable choice.

4. Findings and Results

This section will perform an occupational health and safety risk assessment of ship abandonment drills using the TOPSIS approach. The ship abandonment drill procedure for crude oil tanker (see **Table 1**) is taken from the training sessions at the ITU Maritime Faculty Delmar Academy Training Center.

Deciding to abandon ship is a critical and weighty choice taken by the ship's master. Making the choice is often challenging due to the possibility of the crew facing very perilous circumstances. The ship's master is responsible for issuing an abandon ship order in case of emergencies like collision, fire, explosion, sinkage, grounding, or flooding of the vessel. Three kinds of vessels available aboard a ship for usage during an abandon ship situation include lifeboats (open top, enclosed, or free fall), life rafts, and rescue boats. The lifeboat is the quickest and safest method during an abandon ship procedure, while life raft, and freefall evacuations are more time-consuming in comparison to lifeboats [13].

Table 1. Ship abandonment drill procedure in oil tanker [13].

1. Prepare to abandon ship
1.1 Sound the alarm
1.2 Notify the Master of the ship
1.3 Issue announcement for abandoning ship
1.4 Transmit distress messages (Mayday)
1.5 Provide a report on the situation
2. Gather at muster station
2.1 Ensure that all crew members gather at the muster station
2.2 Verify that all crew members are properly wearing lifejackets
2.3 Brief all crew members on the abandon ship procedures
2.4 Confirm that all crew members fully understand the procedures
2.5 Instruct crew members to board the lifeboat
3. Launch the lifeboat
3.1 Ensure that all crew members boarded the lifeboat
3.2 Set the engine controls for restarting
3.3 Check that the launching area is clear of obstructions and has sufficient water depth
3.4 Verify that the engine is running satisfactorily
3.5 Close the drain plug
3.6 Disconnect the battery charger
3.7 Ensure that all crew members are seated in designated seats and have fastened their seat belts
3.8 Close and secure hatches and doors
3.9 Activate the electrical system using battery power
3.10 Release the lifeboat by operating the hydraulic release mechanism
4. Further actions
4.1 Start the engine
4.2 Open the ventilation system
4.3 Clear away from the vessel
4.4 Initiate radio distress signals

When the steps in table 1 above are weighted with the TOPSIS method, the importance of abandon ship drill is seen in terms of environmental damage, occupational health and safety, death and injury.

The expert team consists of eleven people. These people are working in the maritime industry as three academician, two as chief officer, two as oceangoing watchkeeping officer, two as oceangoing master and two as operations specialists. As a result of the evaluations of this expert team, steps 1.1, 1.5, 2.3, 3.1, 1.4, 3.7, 3.4, 3.8 and 3.2 were found to be risky. It was observed that steps 3.5, 2.4 and 2.2 were followed. As a result of the analysis, the checklist in table 2 was recommended.

Table 2. A pre-job checklist for abandon ship drill

	Action	Personnel Responsible	Completed
1	Sound the abandon ship signal and notify the Master.	Officer on duty	
2	Fix the vessel's position.	Officer on duty	
3	Activate "MAYDAY" signal and provide location.	GMDSS Officer	
4	Direct the crew to put on lifejackets and immersion suits as needed.	Master – Chief Officer	
5	The main engine has been turned off and the propeller has been secured.	Chief Engineer	
6	Discharges overboard have been halted, particularly in places where crafts are launched.	Chief Engineer	
7	Assemble the personnel at the lifeboat stations.	Master – Chief Officer	
8	Gather and ready EPIRB, SART, and SOLAS radios.	Deck officer	
9	Bring extra blankets, food, water, clothing, or useful items.	Medical – Officer - Cook	
10	Check the suitability of muster stations.	Officer on duty	

5. Limitations

In this section, limits and recommendations for future work will be discussed. Firstly, although the TOPSIS method was utilized in the conducted study, assistance can also be sought from various other methods such as AHP, ANP, SLIM, SOHRA, HEART, among others. As the number of methods used increases, the accuracy and reliability of the study will also increase.

Secondly, the lifeboat was used as a reference for abandoning ship in the study. However, various other types of survival craft such as rescue boats, freefall, fast rescue boats, or twin-fall lifeboats are also used in abandoning ship drills. Therefore, in future studies, the inclusion of these types in the analysis could be considered. Thirdly, the inclusion of various factors such as sound, vibration, and temperature on a real ship may alter the results of future studies.

Lastly, testing and reporting the proposed pre-job checklist on operational ships can be cited as an example of another recommendation. Trials can be conducted on various types of vessels such as chemical tankers, passenger ships, or warships to carry out revisions/improvements to the pre-job checklist.

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Approach to Earthquake Risk in Container Ports; A case of Kocaeli Ports Area

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Abstract

Ports, where it is possible to move large amounts of cargo at once with cost advantages, are of indispensable importance for international trade and supply chain. Ports, where transitions between transportation modes are provided, are built at the points where land and sea/water meet. Ports; Although they provide significant benefits in meeting the needs of regions that are likely to be affected by major disasters, their contribution is inversely proportional to the ports' impact from disasters. In the study titled "Capacity Building to Manage Risks and Increase Resilience: A Guidebook for Ports" prepared by UNCTAD (United Nations Conference on Trade and Development), 34 container ports (19 percent of all ports) have very high MMI (Modified Mercalli intensity scale) stated that it is in risk (IX and above) areas. It is known that the probability of an earthquake is high in the Marmara Region, which is located on Anatolian geography and fault lines, where tectonic activity continues. The work that needs to be done to minimize the impact of possible earthquakes on container ports in the Kocaeli region, which has the largest share in our country's maritime transportation with 16%, should be determined.

In the study, the damages caused in ports as a result of major earthquakes in the world were identified and examined. The impact of the 6 February 2023 Pazarcık and Elbistan earthquakes on the Iskenderun Limak Port and the deficiencies in terms of earthquake preparedness were investigated. Fault lines in the Kocaeli region, fault lines intersecting container ports, were examined and the effects of container stacks and dangerous cargo were revealed by meeting with port managers. The measures taken to minimize the impact on the dock, handling vehicles and dangerous loads will be investigated and evaluations will be made regarding what needs to be done in the region.

Keywords: *Naturel Disasters, Kocaeli Port, Earthquake Preparations, Earthquake Risk, Container Port*

1. Introduction

Ports provide different services along with cargo handling and storage activities due to increasing technological and logistics innovations. With the advancement of technology and the expansion of international trade, new markets and new trade corridors are emerging and freight movements are increasing. Therefore, ports are dynamically active. It is the most important instrument, especially in terms of trade fluctuations, crises, imports and exports. Ports make significant contributions to local economies, as well as providing employment, influencing regional economies and providing economic opportunities to the local workforce. Port activities support the local transportation, warehousing, customs clearance and logistics sectors and stimulate the growth of local trade.

Kocaeli ports, in addition to serving the city's industry, also meet the logistics service needs of the region in which they are located. Every year, an increasing number of ships and cargo enter the piers, ports and container terminals in Kocaeli. Although Kocaeli ports have important strategic advantages in terms of their geographical location, they are not yet sufficiently developed in terms of infrastructure. New investments are needed to develop Kocaeli ports to meet the needs and demands of the regional industry and to use them more actively [1].

2. Natural Disasters and Earthquake

Natural disasters are events that harm people. In other words, it refers to naturally occurring events that cause loss of life and property. When natural disasters occurring around the world are examined, there are more than 30 natural disasters. 28 of these natural disasters are described as meteorological disasters [2].

2.1. General Classification and Information about Natural Disasters

Slow-developing natural disasters; severe cold, drought, famine, etc. Sudden Natural Disasters; earthquakes, floods, floods, landslides, rock falls, avalanche storms, tornadoes, volcanoes, fires, etc. can be listed as follows.

The types and importance rankings of natural disasters vary depending on the geographical conditions of the countries. Natural disasters such as drought, floods and forest fires are abundant in the regions of the Mediterranean region. The most common meteorological natural disasters in Türkiye are; hail, flood, overflow, frost, forest fires, drought, heavy rain, strong wind, lightning, avalanche, snow and storms. Tectonic movements in the earth's crust are gaining importance, especially for countries located in the earthquake zone. Türkiye is located in the earthquake zone due to its geographical location and earth structure and earth movements.

2.1. Earthquakes and Their Effects on Country Economies

Earthquake is when sudden vibrations that occur due to fractures in the earth's crust shake the earth in the form of waves. The damage caused by the earthquake disrupts the supply-demand balance, causing consumption to increase. As a natural result of this increase, it causes the inflation rate to constantly increase.

In addition to the loss of wealth and urgent need for shelter caused by earthquakes, another effect of the economic cost is the shrinkage and negative impact on production capacity. The region most affected by the earthquake corresponds to approximately 8 percent of Türkiye's GDP [3].

While earthquakes have negative effects when they result in loss of life and property in the region where they occur, the decrease in production and the negative impact on the regional economy affect the welfare levels of the residents. International Labor Organization (ILO), in its report on the effects of the February 2023 earthquake on the labor market in Turkey; It is stated that they were displaced due to damage to their homes and workplaces, and there was a 16% decrease in economic activity (working hours) due to job and workplace losses. It is also stated that it is 0.1% in Adana, which was less affected by the earthquake, and 58.8% in Malatya, which was more affected by the earthquake, and if the decrease in economic activity continues, there will be a loss of $150 million in labor income every month. (International Labor Organization (ILO)) [4].

Damage cost was calculated that approximately $39 billion was required to repair the demolition and damage on a housing basis, based on a value of $60 thousand per flat, and the shelter and need costs of those who lost their homes were calculated as $5 billion annually. The region covers 7.5% of Turkey's GNP, especially the agriculture, steel, textile and tourism sectors. Since these sectors are labor intensive, they better explain the 16% decrease in working hours in the region. It can be predicted that the regional economy, which is based on labor-intensive sectors due to migration from the region, will continue in the future instead of recovering in the short term [5].

3. Kocaeli Port and Disaster Area

Kocaeli province has a surface area of 3,397 km^2 and is surrounded by Sakarya city in the east and southeast, Bursa city in the south, Yalova province, Izmit Bay, Marmara Sea and Istanbul province in the west, and the Black Sea in the north. Its total population is approximately 2.1 million people.

3.1. Kocaeli Port and Disaster Area

Kocaeli province is at the forefront in the country with the development of the industry and manufacturing sector. According to the data of the Ministry of Industry and Technology, it ranks 5th in Turkey with the total GDP size of these sectors between 2015-2020.

It is seen that Kocaeli province ranks 5th with its industrial GDP of 6.95% and 3rd with its manufacturing GDP of 7.86% in 2020 compared to the rest of Turkey. While imports, exports and foreign trade for the industry and manufacturing sectors throughout the country are largely provided by sea, Kocaeli province, which is a natural port, is also at the forefront with its port facilities.

Table 1. Cargo tonnages handled in Kocaeli ports and across Türkiye by year.

Years	General Rates (ton)	Kocaeli Ports (ton)	General Ratio (%)
2015	416,036,695	64,628,031	15.53
2016	430,201,162	66,406,649	15.43
2017	471,173,896	73,234,029	15.54
2018	460,153,560	73,139,021	15.89
2019	484,168,411	72,196,414	14.91
2020	496,642,651	76,517,625	15.41
2021	526,306,784	81,335,143	15.45
2022	542,610,283	82,799,204	15.26
2023	521,079,804	81,291,544	15.60

Source: Compiled from UAB Maritime Statistics and https://denizcilikistatistikleri.uab.gov.tr/.[3].

According to the Maritime Statistics of the Ministry of Transport and Infrastructure, 521.1 million tons were handled in Turkish ports in 2023 and approximately 26% of these cargoes were due to container handling (133.5 million tons). The amount of cargo handled in Kocaeli ports is 81.3 million tons, approximately 15.6% of the country's total. With this amount, Kocaeli is the second largest port region in Türkiye, right after Aliağa (81.35 million tons) [3].

Table 1. Cargo tonnages handled in Kocaeli ports and across Türkiye by year.

Years	General Rates (TEU)	Kocaeli Ports (TEU)	Kocaeli Ports Yearly Increase (%)	Kocaeli Ports General Ratio (%)
2015	8,146,398	988,906	9.99	12.14
2016	8,761,974	1,143,008	15.58	13.05
2017	10,010,536	1,315,991	15.13	13.15
2018	10,843,998	1,597,620	21.40	14.73
2019	11,591,838	1,715,193	7.36	14.80
2020	11,626,650	1,800,642	4.98	15.49
2021	12,591,470	1,967,946	9.29	15.63
2022	12,366,382	2,059,310	4.64	16.65
2023	12,556,401	2,159,160	4.85	17.20

Source: Compiled from UAB Maritime Statistics and https://denizcilikistatistikleri.uab.gov.tr/.[3].

There are thirty-five international port operations of various sizes in Kocaeli province and within the administrative area of Kocaeli Port Authority, one of which is publicly owned. Although these ports serve various cargoes, there are five container handling ports: Belde Port, DP World Yarımca, Evyap Port, Safi Port Port and Yılport Port.

When we look at the container handling numbers, of the approximately 12.56 million TEU containers handled in all Turkish ports in 2023, 2.16 million TEU, corresponding to approximately 17.2%, were handled in Kocaeli ports. This number makes the Kocaeli region the second region with the most container handling in Türkiye on the basis of port authority [4].

3.2. Gölcük Earthquake and the Damages in Ports

The earthquake, which lasted approximately 45 seconds on the Adapazarı, Kocaeli, Gölcük segment of the North Anatolian Fault Zone on August 17, 1999, and measured 7.4 magnitude by the Kandilli Observatory, caused significant damage to various coastal structures on the shores of the Gulf of Izmit. Among the important coastal structures damaged in the Gulf Region are Derince Port, Tüpraş Coastal Facilities and Petrol Ofisi Pier. Derince and Tüpraş coastal structures were moderately damaged that shown in figure 1 a,b,c. Petrol Ofisi Pier was heavily damaged, and all three remained partially open for operation after the earthquake [7].

According to the report published by the Turkish Earthquake Foundation, the 600-meter concrete block dock in Derince Port has become unusable, although the blocks are not damaged enough to be used, the crane track and railway on the dock have become unusable [8].

The damage that created a bottleneck in the service capacity of the port is the deformation in the 150,000 m2 area used as the back area of all docks. In this section, 2 warehouses were severely damaged.

In addition, there is damage to the cranes used in handling and to some fixed facilities in the port area (such as water network, drainage, power lines).

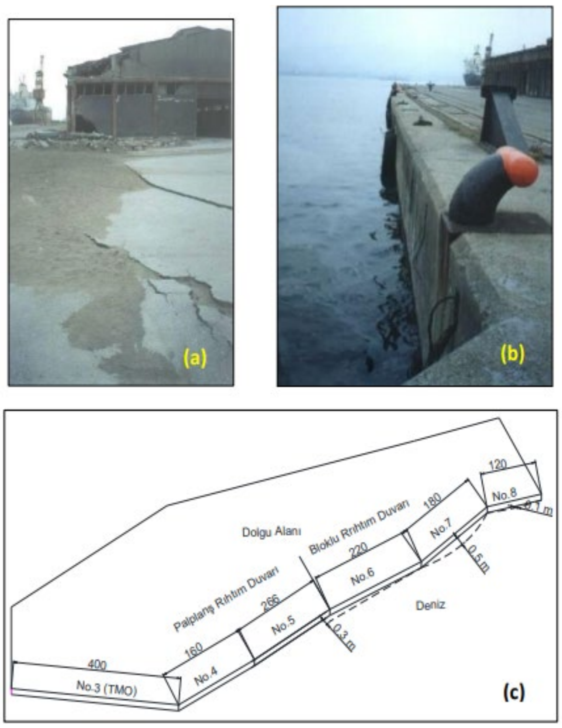

Figure 1. Damages due to the 1999 Marmara Earthquake on the blocky quay wall of Derince Port, (a) Traces of liquefaction in the backfill between the transit warehouse and the quay wall; (b) Seaward movement of the quay wall; (c) Horizontal displacement pattern determined after the earthquake [8].

3.3. Effects of the February 6, 2023 Earthquake

As with all earthquakes, the earthquake that occurred on February 6 affected people, nature, buildings and the economy. The fact that it affected a very wide geography also negatively affected intervention, aid and support efforts. According to FAD data, Kahramanmaraş, Hatay, Adıyaman, Gaziantep, Malatya, Kilis, Diyarbakır, Adana, Osmaniye, Şanlıurfa and Elazığ provinces were affected, 50,783 people lost their lives and 115,353 people were injured [7].As seen in Table A, Hatay was the most affected province in terms of the number of buildings destroyed during the earthquake.

Among the provinces damaged in the earthquake, Hatay is the province connected to the sea. While Hatay province suffered great damage with all its districts, İskenderun district was also more affected by the earthquake due to the damages in İskenderun Limak Port. The most important feature of Iskenderun Limak Port management is that it is the customs gate for the foreign trade of the Western Mediterranean, Eastern and Southeastern Anatolia Regions, with its ports serving a wide variety of products. After the earthquake, structural damage occurred in Iskenderun Limak Port. In addition, İskenderun Limak Port could not provide service for a while due to the fire that broke out after the earthquake. The negativities experienced in Iskenderun Limak Port disrupted the cargo flow in the region for a while. [8].

In the first stage of planning the aid to be delivered to Hatay, these modes of transportation could not be used due to the damage caused to the road and air. This situation once again revealed the importance of the maritime route. Aid ships departing from various ports of the country docked at the port and the aid sent to the region was ensured. The ship, which was converted into a hospital, anchored in the port and provided hospital services to the sick and injured in the region [9].

Along with the buildings and structures in the region, the transportation network was also affected. In the AFAD Report; It has been stated that morpho-tectonic formations such as stream and ridge offsets are encountered, and that these offsets cause damage to highways and railways. It was also observed that there were rock falls and ground liquefaction after the earthquake [7].

4. Findings

Due to its geographical location, Türkiye is located on one of the most active earthquake zones. For this reason, major earthquakes have occurred and continue to occur in our country and surrounding countries, causing very heavy damage. It is not known when the earthquake will occur. On the other hand, the damages caused by the earthquakes that have occurred so far can be approximately estimated.

The Gölcük earthquake that occurred in 1999 caused great damage to the port and piers. In the study, the ports and piers in the Kocaeli region on the coast of the Northern Marmara Sea were included in the research area. For this reason, the data in the study conducted by Yalçın and Güler (2005) were used. In the mentioned study; Petrol Ofisi Pier, Shell Derince Pier, Kural Tarım Pier, UM Maritime Port Facility were heavily damaged, Tüpraş Coastal Facilities, Derince Port, Trans Türk Pier were moderately damaged, Eskihisar Ferry Pier and İzmit Marina were moderately damaged, Eskihisar Fishing Shelter and Rota Maritime Pier were undamaged. It has been detected. In terms of business activities due to post-earthquake damage; It was stated that the entire Shell Derince Pier and the Protection Agriculture Pier collapsed and were out of operation, Tüpraş Coastal Facilities, Derince Port, Petrol Ofisi Pier were partially operated due to damage, and Eskihisar Ferry Pier, Eskihisar Fishing Shelter and Rota Maritime Pier continued to operate. [6].

As can be seen, many coastal and port facilities in the region were damaged, some of them became inoperable or partially operable. This situation caused great losses for the regional economy. At that time, the ports in the region were designed before the 1997 earthquake specification. The ports and piers damaged after the earthquake were repaired and put into service.

By making inferences from these past experiences, it should be designed in accordance with the regulations, taking into account the earthquake loads valid for the region as well as environmental loads such as waves, currents and wind, and it should be planned in accordance with the intended use of the port facilities and the determined capacity.

A survey was prepared to evaluate the approaches of container ports in the Kocaeli region to earthquake risk. The survey preparation phase was evaluated within the framework of the opinions of port officials and faculty members who are experts on the subject, and its arrangements were made and its final form was given. 5 container ports serving in the region (Belde, Yılport, Evyap, DP World, Safiport) were determined as the target audience. In this context, in each port, mid-to-senior level managers with different titles (such as port manager - planning manager - operations manager - port administrative affairs manager) whose responsibilities intersect with the subject were interviewed, and the surveys were sent to 2 officials from each port on 01.03.2024 to answer.

Some managers refrained from answering the survey due to the heavy traffic following the major ship accident in the region. Therefore, the targeted number of survey responses could not be reached. An attempt was made to evaluate the approach to earthquake risk through two ports that answered the survey.

The average age of the company officials who participated in the survey was 42, the average years of experience in port operations was 7, and the average of the total working years in the port they worked in was determined to be 4.

In the port construction and earthquake emergency plans of the ports, respectively; It has been determined that they prioritize previous earthquakes, the possibility of ground liquefaction, fault lines, the height limit and tipping risk of containers, and the positioning of dangerous cargoes, etc.

In this context, information has been obtained that pile systems are used during the construction phase, earthquake drills are carried out at least once a year, and the separation measures recommended by the IMDG code for hazardous loads are applied.

The construction processes of all ports that did not participate in the survey started before the 1999 earthquake and the legislation regarding earthquakes in coastal facilities.

In the legislation prepared by the administration, recommendations or sanctions such as strengthening the ground for earthquakes in existing facilities are not included.

The existence of the regulations had an impact on the ports built after 1999, and the construction and operation processes were carried out by taking into account earthquake risks.

The fact that the ports participating in the study are within this scope and are already carrying out the process shows the self-confidence in their facilities. The approach of other ports that refrained from participating in the study (the construction of which all started before 1999) may be that they do not make retroactive improvements to their existing structures and do not have an obligation in this regard.

The fact that damage occurred only in the Iskenderun Limak Port, which was built in the 1940s in the İskenderun region during the -6 February earthquake, supports the benefits of the regulations and practices after 1999. However, it also brings to mind the vulnerability of ports that were built before the Earthquake Regulation.

5. Results and Discussions

Design of new coastal and port structures under the influence of earthquakes. The latest regulation has come into force to determine the necessary rules and minimum conditions for evaluating the performance of existing structures and strengthening design. Modeling, calculation and design rules to be applied for coastal and port structures to be built in Turkey and evaluation rules to be applied for existing piled docks and piers are included in this regulation. Helping coastal and port structures engineers understand the intent behind certain provisions of seismic design codes will ensure smoother and more uniform application of these technical specifications and the provisions they contain.

Dangerous cargoes in the field were probably involved in the big fire that broke out in Iskenderun Limak Port during the February 6 earthquake. There is no information that a separation beyond what is stipulated by the IMDG code for the separation of dangerous cargoes is applied in this port. In the Limak Port Port Facility Dangerous Cargo handling guide dated 02.06.2022, it is stated that the rules for separating dangerous cargo within the framework of the IMDG code should be applied in the port in question. It can be considered that requiring/evaluating ports located in the earthquake zone to implement segregation measures beyond those stipulated by the IMDG code in our national legislation may reduce the damages that may occur in such events.

When the construction details of the ports are examined, it is seen that the ports that were built in the 1920s and were operated by TDİ or were later privatized were generally built on filled ground. It comes to mind that the construction technique has an important place in the ports that were most damaged in the earthquakes in the region (Derince Port and İskenderun Limak Port).

Before the 1999 earthquake, the effects of earthquakes in ports were not taken into consideration sufficiently in terms of construction, and the fact that the damages occurred in Tüpraş, Petrol Ofisi and Melas piers, which were built by the state, brings to mind some supervisory deficiencies.

Following the Earthquake Technical Regulation on the Construction of Coastal and Port Structures, Railways and Airports issued on 18.08.2007, it is an important development that port constructions are generally carried out on piles and precautions are taken against ground liquefaction. As a matter of fact, there is no data indicating that the Assan Container terminal, which was put into operation in Iskenderun in 2010, was damaged in the February 6 earthquake.

Earthquake preparation should include superstructure and operation as well as infrastructure. The fire that occurred in the Iskenderun Limak port and the delay in the intervention suggest that there is a need for more detail on the separation of dangerous cargoes in the port, the safety in the sequence and the emergency response. In this context, in the studies we carried out in the field, it was seen that no investigation was carried out by the Accident Investigation Board at Iskenderun Limak Port. In the press release made by Limak, it was shared that 1730 containers were burned and damaged, and it was stated by those concerned that no other information was shared with the public due to insurance and legal processes. There are 5 target port facilities in our survey study in our research region, and 3 of them refused to participate in the survey. The fact that the ports that agreed to participate in the survey were put into operation after 2007 suggests that they are self-confident in their earthquake preparedness within the scope of the regulations.

The large fire that occurred in İskenderun Limak Port revealed that even if IMDG code separation rules regarding dangerous cargoes were applied, they were insufficient. For this reason, it is thought that ports located in the earthquake zone can reduce the damage by taking measures such as increasing separation standards, limiting the number of stacks on top of each other, increasing stack strength and diversifying emergency response methods, taking into account earthquake-related risks.

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Appendix 1. Survey Sheet

A. İŞLETMEYE ve OOPERASYONA AİT BİLGİLER
1-Kıyı Limanının Adı;

2-İşleten;

3. İşletmenin Kuruluş Tarihi : ……………………………………..

4-Hizmet verdiği yük türleri; Kuru Yük Sıvı Yük Konteyner

5. İşletmede Çalışan Toplam Personel Sayısı: …………………………………..

6-Son 3 yıla ait <u>yük elleçleme</u> miktarları ve gelecek yıl hedefi; (TEU)

2021…………………...TEU 2022…………………...TEU 2023………………..TEU 2024 hedef; ………….TEU 2030hedef;……………….TEU

7-Limanızda Deprem Acil Durum Planı mevcut mu? Son güncellenme zamanı nedir)

………………………………………………………………………..

B. DEPREM HAZIRLIKLARINA YÖNELİK BİLGİLER

8- Liman İnşası ve Deprem Acil Durum Planınızdaki öncelikleriniz nelerdir?(işaretleyiniz)

Fay hatları ☐	Daha önce yaşanmış depremler ☐
Fay hatlarının yönü ☐	Konteynerlerin yükseklik sınırı, devrilme riski ☐
Zemin sıvılaşma olasılığı ☐	Tehlikeli Yüklerin konumlandırılması ☐
Olası deprem şiddeti ☐	………………………………………………………… ☐

9- Liman sahanızın bulunduğu bölgenin Türkiye Deprem Tehlike Haritalarındaki Deprem Yer Hareketi Düzey nedir, 2020 yönetmeliğine göre revizyon mevcut mu??

……

10-İnşa ve operasyon süreçlerinde "fay hatları"nı göz önünde bulunduruyor musunuz, aldığınız önlemler nelerdir?(örneklendiriniz)

İnşa aşamasında…………………………………………………………………….............................

Operasyon sürecinde……………………………………………………………………………………..

Diğer………………………………………………………………………………………………………

11) İnşa ve operasyon süreçlerinde "fay hatlarının yönü"nü göz önünde bulunduruyor musunuz, aldığınız önlemler nelerdir?(örneklendiriniz)

Konteyner dizileri fay hatlarına paralel planlanmıştır……………………………………………..
Gantry kreynler fay hatlarından en az etkilenecek şekilde konumlandırılmıştır;…………………..,

Diğer…………………………………………………………………………………………………..

12- Limanınız zemin sıvılaşma riskine önlem almış mıdır? evet ………. hayır………

Kazık çakma sistemi uygulanmıştır……………………………………………………

Doldu sistemi uygulanmıştır…………………………………………………………………………

Diğer……………………………………………………………………………………………

13- Son 50 yılda yaşanan ve olası deprem şiddeti gözetilerek önlem alınmakta mıdır?(örneklendiriniz)? evet ………. hayır………

Deprem tatbikatları…………………….sıklığı? ……………………………………………………

Eğitim ve kurtarma faaliyetleri………………………….sıklığı………………………………

Diğer……………………………………………………………………………………………

14- Limanınızdaki elleçleme ekipmanlarının depremde devrilme-yangın riski gözetilmekte midir? Aldığınız önlemler nelerdir?(örneklendiriniz)? evet ………. hayır………

Özel algılama ve otomatik stop sistemleri…………………………………………………

Özel tasarım ve depreme salınımına uyumluluk………………………………………

Diğer……………………………………………………………………………………………

15- Limanınızda konteyner istiflerinin depremde devrilme riski gözetilmekte midir? Aldığınız önlemler nelerdir?(örneklendiriniz)? evet ………. hayır………

İstiflerin fay hatlarına paralel olması…………………………………………………

Maksimum istif sınırlaması…………………………………………………………

Üst sıralarda boş konteyner bulundurma……………………………………………………

Diğer…………………………………………………………………………………………..

16- Limanınızdaki Tehlikeli Yüklerin depremde devrilme-yangın riski gözetilmekte midir? Aldığınız önlemler nelerdir?(örneklendiriniz)? evet ………. hayır………

Tehlikeli yüklerin alt sıralarda istifi……………………………………………………

Tehlikeli yükler için IMDG Kod üzerinde ayrıştırma ………………………………………

T.Y. bulunduğu bölgede otomatik/uzaktan kumandalı yangın söndürme sistemleri…………….

Diğer……………………………………………………………………………………………

76- Depreme hazırlık çerçevesinde limanınızda yürütülen başkaca çalışmalar ya da yapılmasını önemsediğiniz ihtiyaç ya da görüşlerinizi paylaşır mısınız?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………………………………………………………………………………………

Tarih: **Katılımcı İsim ve Unvanı:**

HAZOP analysis of Ship Inert Gas System: A Case Study

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Abstract

HAZOP (Hazard and Operability Analysis) is a method first used in the chemical industry to understand operational problems and potential hazards. In the process, hazard identification skills were developed, and the method was started to be used for system evaluation and development in different fields. In this study, an inert gas system, mostly used in crude oil tankers, where the gas is obtained from the boiler or stack, is analysed using the HAZOP method. Operational problems and potential hazards that the system may have in normal operation are identified. As a result of the examination carried out by the HAZOP team, 27 deviations are found, and root cause analyses are performed for them and preventive actions are determined. It is considered that the findings obtained as a result of the analysis can be an important data for the sector. It is thought that analysing the data obtained from HAZOP method with different risk assessment methods (FTA, LOPA, etc.) can give more ideas about the probability of existing risks.

Keywords: *HAZOP, inert gas system, hazard, operability, safety*

1. Introduction

A systematic design analysis, HAZOP, has been developed to understand the system's operational problems and potential hazards [1], [2]. It is a highly scientific process to monitor process equipment exposed to hazards. The system is designed to identify malfunctions and deviations which may lead to obvious events like explosion, fire and release of toxic materials [3].

HAZOP is the process by which a multidisciplinary team 'brainstorms' the design of the installation during the installation review meetings, according to the experience of the team leaders and the outline of the guide [4]. Stimulating creativity and generating ideas is the main benefit of these brainstorms. This happens as the team interacts with one another and draws on their different past experiences. That is why the process requires everyone to be involved. Team members should try not to criticise each other for making suggestions for reflection. In this case, the design team's task is to identify the nodes in the design. At each node the team uses guidelines to analyse deviations in process parameters in detail. The purpose of the guidelines is to ensure that the design is under control in every possible way, and that the design is under control in every possible way. Once the design is fairly well established, it is best to carry out a HAZOP analysis [5].

There are many factors that can influence whether a HAZOP succeeds or fails. It has been tried to generalise these factors in the form of [6]:

- Correctness and consistency of the data (drawings, etc.) used to support the work carried out.
- Team's intuition and technical ability
- Team capacity to focus on most critical risks

This is a systematic process, and it is helpful to define the terms used [7].

- Process nodes: Points on the pipework, on the equipment drawings and on the procedures where the process parameters are searched for variations.
- Target: Definition of how the plant should operate without deviations at the nodes.
- Deviations: Deviations from the target which have been identified through systematic cueing.
- Reasons: There are several reasons why deviations may occur. When a reliable reason for a deviation is given, it is called a significant deviation. These reasons can be hardware failures, human errors, unexpected process situations (change of composition, etc.), external failures (power failure, etc.).
- Results: Consequences of the deviations that should have occurred are included. Results that are not considered to be significant for the purpose of the study will not be included.
- Guiding Words: Simple words used to describe objectives, identify deviations and stimulate brainstorming. The most common words used in HAZOP are listed in table 1 [8]. At the point of inspection in the plant, each guide word is used for process variables.

Table 1. Guide words, deviations, and explanations

Guide word	Typical deviation	Explanation
No, None	No flow	Line blockage, valve system failure or malfunction
More	Flow, pressure, temperature	Excessive pump activity, extra liquid entering the line, blockage in the line, valve is closed, abnormal high pressure, failed cooling
Less	Flow, pressure	Line blockage, pump or/and fan failure
As well as	Soiled product	Carry over, inward leaks from valves
Part of	Composition	Incorrect composition of the materials used
Reverse	Pressure, flow	Backpressure, backflow
Other than	Unusual conditions, Maintenance, Abnormal operations	Loss of services/supplies, fire, flood, insulation, venting, flushing, emptying, starting, partial loading, etc.

2. Literature Review

HAZOPs were developed by Imperial Chemical Industries (ICI, London) in 1960's when they were reviewing their phenol factory plans. This is a development from using critical inspection studies to identify design defects and deviations. The critical review method is an accepted way of examining activities and generating alternatives by asking questions such as "Has it been achieved?", "What else could be achieved?", "What should be achieved?", "How is it being achieved?" and so on [9]. A guide to hazard and operability studies was published by the Chemical Industries Association in 1977 [6]. This method, which is used for the operational evaluation of the system, has been used in different fields in the literature.

Penelas and Pires made an application of the HAZOP methodology to process and safety operations in the oil production industry. A unit used to produce crude oil was divided into smaller sections which were analysed. Seventy-one relevant risk probabilities were identified by applying HAZOP methodology. The assessment of environmental, health and economic impacts was the basis for establishing safety priorities for these risks. Forty-seven recommendations to mitigate the identified problems were derived from the application of this methodology and the identified safety measures. The contributions of the study are to demonstrate the effectiveness of the HAZOP methodology in identifying potential hazards for new or existing process plants and in assessing the resulting potential for equipment and asset failure, and to be a useful tool to provide company executives, decision makers and plant managers with the necessary information [10].

A Tier 1 PSA of TRR-1/M1 (Thailand Research Reactor-1/ Modification 1) for internal events and human error was the objective of the study by Vechgama et al. In view of the tiered approach, the Hazard and Operability Analysis (HAZOP) and the Human Hazard and Operability Analysis (Human HAZOP), which require a moderate level of detail, were selected to assess the hazardous events and ultimately to identify the initiating events (IEs). Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and Bayesian updating were used to calculate the consequence frequencies (CDFs). The evaluation showed that the HAZOP analysis, which does not require long computation times and detailed failure data, is suitable for a simple research reactor such as TRR-1/M1. Natural operational failures, which had been overlooked in TRR-1/M1, were identified by the human HAZOP analysis. Specifically, the case where valves V-3 and V-4 were kept open to speed up reactor startup. IE1: Loss of Cooling Water Accident (LOCA), IE2: Excess Reactive Additive and IE3: Failure of Fuel Handling Equipment have been identified as the most important IEs. The highest CDF of IE3 (4.36E-02 1/yr) indicates that this is the main risk issue requiring more attention by operators during TRR-1/M1 operation [11].

Lim et al. discuss a recent concept of applying the industrial assessment practice of Hazard and Operability Analysis (HAZOP) to literature review. To guide the literature review process, the traditional HAZOP methodology is modified. As a case study, an overview of a model for the optimisation of the biomass supply chain is presented. To enable a detailed evaluation, the system is broken down for independent analysis. Differences considered are quantity, quality, logistics and market cost/value in the study. The keywords more/higher, less/no and less/low were used to identify potential process hazards. Each hazard identified has been cross-checked against the literature to identify any possible corrective actions. Suggestions are made where protection against the identified hazards is insufficient and potential research gaps are highlighted. HAZOPs provide a systematic platform for detailed evaluation of a complex investigation through guided procedures [12].

Lim et al. aimed to conduct a detailed review of the current status of the palm oil industry's development towards Industry 4.0 by applying the HAZOP concept to investigate the possible adaptation of Industry 4.0 technologies to improve the palm oil industry. In order to determine the feasible adaptation in the industry, existing Industry 4.0 technologies and their characteristics were assessed. This Hazard Analysis resulted in 23 recommendations for palm oil industry improvement using Industry 4.0 technologies for higher level of sustainable manufacturing. Thirteen specific Industry 4.0 characteristics were identified as potential development gaps for palm oil industry stakeholders, including adoption of IoT sensors, cloud computing, blockchains and smart imaging technologies [13].

The primary objectives of this study are a risk analysis of a current inertisation system schematic and the determination of the accident potential of system errors during inertisation. The analysis will be carried out on a shielding gas system diagram where the shielding gas is taken from the boilers. This was followed by descriptive and cross-cutting research to identify the possible risks that could lead to failure of a ship's inert gas system and to assess the risks on a ship. HAZOP provides qualitative and quantitative results to identify, analyse and correct potential faults in protective gas systems and related equipment.

3. Case Study

The inert gas system will be the subject of this study.

3.1. Inert Gas System

The purpose of an IG system is the prevention of tank fires or explosions. They are not permanent firefighting equipment. It can, however, be used to assist in the control of fires and the prevention of explosions [14]. Controlling the atmosphere in a cargo tank to prevent the formation of flammable mixtures is the main use of inert gas. A low oxygen content is the main requirement for inert gas. Otherwise, the composition of the inert gas may differ [14]. O2 contents depend on the nature of the cargo and the presence of volatile and flammable gases. The maximum oxygen content of a hydrocarbon-emitting cargo is 11%. By contrast, the highest oxygen level for a hydrogen gas releasing cargo is 5%, in accordance with the International Convention for the Safety of Life at Sea (SOLAS 1974) [15].

In the flue gas inertisation system, the high temperature contaminated gas passes from the boiler to the scrubber and demister via a shut-off valve in the boiler outlet line. Here the gas is cleaned of its contaminants and cooled. Immediately afterwards, the gas is drawn into the cargo tanks by means of fans, passing through the deck water seal, non-return valve and deck isolation valve respectively. A gas pressure control valve installed after the fans regulates the flow to the cargo tank. To prevent damage to the cargo tank from overpressure or vacuum, a liquid-filled pressure/vacuum switch is also installed in the circuit. A vent is fitted between the pressure/vacuum relief valve and the gas pressure regulating valve to vent any leaks when the system is not in use [16]. Inert gas piping is routed from the deck isolating valve to the front across the entire cargo deck. It is used to supply gas to cargo tanks during cargo unloading, de-ballasting, tank cleaning and to increase tank gas pressure for other voyaging phases. Side pipes exit from the main blanketing pipe at the top of each cargo tank [16]. A standard inert gas system generally consists of the following components:

- Flue gas source: As it contains flue gases, the boiler or main engine exhaust ports are used to extract the inert gas.
- Boiler uptake valve: Serves as a feed valve between the inlet and the rest of the plant, separating the two systems when not in operation.
- Scrubber: The fumes enter the scrubber tower from below and pass through a number of water spray and deflector plates to cool, clean and humidify the gases. The result is a reduction in the SO2 content of the gas to 90% and no soot in the gas.
- Demister: It is usually polypropylene and is used for the extraction of moisture and water from the cleaned flue gas.
- Gas Blower: Typically, there are two different types of blower, a turbine blower for IG and an electric blower for filling.
- I.G pressure regulating valve: Depending on the oil and atmospheric conditions, the pressure in the tanks will vary. To control this variation, a pressure relief vent has been fitted after the fan outlet to return surplus gas is returned to the scrubbing tower.
- Deck seal: It is designed to prevent gases from the bellows returning to the cargo tanks. A wet deck seal is normally used for this. A demister is in place to remove moisture from the gases.
- Mechanical non-return valve: A mechanical non-return valve compatible to deck seal.
- Deck isolating valve: With this valve, the system in the engine room can be completely isolated from the system on deck.
- Pressure Vacuum (PV) breaker: Over- and under-pressure in cargo tanks can be controlled using the PV breaker. To ensure there is no fire in the harbour during loading or unloading operations, the PV breaker vent is fitted with a flame trap.
- Cargo tank isolating valves: A ship has several cargoes holds, each equipped with an isolation valve. The valve controls the flow of inert gas into the hold and can only be operated by a responsible officer on board.
- Mast riser: During loading, the valve remains open to avoid over pressurisation of the cargo tanks.

3.2. Findings

HAZOP provided systematic analysis of the operation of the ship's protective gas system. The analysis begins with the formation of a HAZOP team of ten maritime experts responsible for the use and control of the relevant protective gas systems on crude carriers. A diagram of the system is then drawn up on the basis of a sketch of the crude oil tanker. As shown in figure 1, the HAZOP team divides the system diagram into five separate nodes.

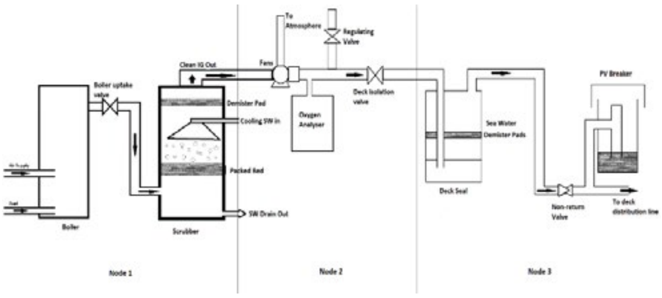

Figure 1. Inert gas system diagram with operating points.

The operational nodes divided by the HAZOP team and analysed with guide words are shown in tables 2, 3 and 4:

Table 2. HAZOP worksheet for node 1 (Boiler to scrubber)

No	Guide Words	Deviation	Possible Cause	Consequence	Action Required
1	None	No flow	(1) Line blockage	Loss of time, high soot concentration in inert gas lines.	(1.1.1) Establish regular patrols & inspections of the boiler receiving line. (1.1.2) Mount the on/off display onto the valve. (1.1.3) Prior to the boiler inlet valve, install a pressure gauge on the line.
2	More of	More heat	(2) Boiler over fuelled (3) Malfunction of the automatic fuel regulator	Physical deterioration of the scrubber and inert line.	(1.2.1) Fit a thermal probe and thermometer to the scrubber assembly and set up periodic control heat. (1.2.2.) Fit the boiler's fuel line with a fuel pressure gauge. (1.2.3) Arrange for the fuel automatic regulator to be inspected and serviced on a regular basis.
3	Part of	High O_2 concentration in IG	(4) Excessive supply of air to the boiler Like in (3)	Loss of time due to unsuitable inert gas.	(1.3.1) Fit a manometer to the boiler air inlet pipe. (1.3.2) Periodically monitor the boiler's O2 level. Encompassed by (1.2.3)
		High SO_2 concentration in IG	(5) Low quality of the fuel Like in (2) Like in (3)	Accelerated corrosion on ship's structure.	(1.3.3) Fuel analysis to be performed regularly. Encompassed by (1.2.2) Encompassed by (1.2.3)
4	Reverse	Seawater coming from the scrubber into the boiler	(6) High level of water in the scrubber unit	Boiler malfunction.	(1.4.1) Scrubber unit should be fitted with high level alarm. (1.4.2) Check the water level in the scrubbing unit on a regular basis.
5	Other	Maintenance	(7) Leakage of gas from the boiler, the IG line and/or the scrubber tower.	Injury to personnel Release of toxic gas into the public environment.	(1.5.1) Regularly carry out a pressure test on the IG line. (1.5.2) Continue to check pressure while running. (1.5.3) Installation of engine room atmosphere monitoring system.

Table 3. HAZOP worksheet for node 2 (Scrubber to deck seal unit)

No	Guide Words	Deviation	Possible Cause	Consequence	Action Required
6	None	No flow	(8) Blockage of the line (9) Faulty inert gas blower (10) Excessively high-water level in scrubber unit (11) Clogging of scrubber tower deflectors	Time wasted, physical destruction of scrubbing unit and inert gas pipework	(2.6.1) On the scrubber outlet line, mount a manometer. (2.6.2) Regular inspection and/or testing of the conditions of the inert gas blowers. (2.6.3) On the scrubber plant, install a high-level alarm. (2.6.4) Periodic inspection and cleaning of the scrubber tower interior.
7	Less of	Less flow	Like in (8) Like in (9) Like in (10)	Loss of time, structural damage to the scrubber tower and inert gas line.	Encompassed by (2.6.2) Encompassed by (2.6.3) Encompassed by (2.6.4)
8	More of	More heat	(12) Inadequate coolant flow in the scrubber plant	Structural damage to gauges and sensors on IG pipework.	(2.8.1) Regular check scrubber seawater line of scrubber. (2.8.2) Place manometer and flow meter on the sea water line of the scrubber.
9	Part of	High SO_2 concentration in IG	(13) Scrubbing deflectors in bad condition. (14) Fuel quality is low	Air pollution.	(2.9.1) Fuel analysis to be performed regularly. (2.9.2) Check the deflector plate condition periodically. (2.9.3) Install a fixed gas detector on the outlet pipe of the scrubber.
10	More than	Soot	Like in (13) Like in (14)	Soot build-up in IG system pipework, air pollution.	Encompassed by (2.9.1) Encompassed by (2.9.2) Encompassed by (2.9.3)
11	Other	Maintenance	(15) Inert gas pipework, connection points and fans in poor condition	Personnel injury. Toxic gas release to public space.	(2.11.1) Carry out regular pressure tests on the IG line. (2.11.2) Continuous pressure monitoring during operation. (2.11.3) In the engine room, fit an atmospheric monitoring system.

Table 4. HAZOP worksheet for node 3 (Deck seal to tanks)

No	Guide Words	Deviation	Possible Cause	Consequence	Action Required
12	None	No flow	(16) O2 content in IG above 5% (17) Automatic diverter valves and/or Oxygen analyser failure (18) Deck seal with higher water level	Waste of time	Encompassed by (1.2.3), (1.3.1), (1.3.2) (3.12.1) Periodically inspect and test automatic diverter valves. (3.12.2) Fit a high-level alarm on the deck sealing.
13	More of	More pressure	(19) IG blowers in overdrive. (20) Inside the PV breaker the oil level is too high.	Deterioration on IG pipework, oil pollution	(3.13.1) Provide IG fans with get started and usage guides. (3.13.2) Check the PV breaker oil level regularly. (3.13.3) Set up the patrol on the deck with the IG system turned on. (3.13.4) Have an oil spill kit ready to hand in the vicinity of the PV breaker.
14	Less of	Less flow	(21) Blocked deck isolating valve (22) The supply valve to the cargo tank is open more than the system can handle. Like in (18)	Waste of time	Encompassed by (3.12.2) (3.14.2) Arrange for the deck isolating valve to be checked and tested at regular intervals. (3.14.3) Check the supply valve of all tanks. Provide a tank inerting procedure.
15	As well as	Water	(23) Deck sealing demister pads in bad condition	Cargo damage	(3.15.1) Periodically inspect, clean and replace the demister pad. (3.15.2) Fit the deck seal water outlet filter.
10	More than	Soot	(24) Deck seal with low water level (25) Deck seal unit is dirty	Cargo damage	(3.15.3) On the deck seal, mount a low-level alarm. (3.15.4) Inspect and keep deck seals clean at regular intervals.
16	Part of	High O_2 concentration in IG	(26) Oxygen analyser fails to operate	Fire, explosion, cargo damage	(3.16.1) Periodically check the O2 analyser with reference gas detector. (3.16.2) The Oxygen analyser must be calibrated with a test gas prior to each inerting operation.

4. Conclusion

The result of this work was the identification of dangerous deviations in the safe inert gas system on tankers by a team of experts. The consequences of the identified dangerous deviations should be carefully considered. At this point, the consequences of the deviation may affect not only the node concerned, but also other nodes or other processes within the system and may lead to serious incidents. Other nodes that contain the findings of the outcome investigation should also be reviewed at this stage. A bias in one node may cause an unforeseen bias in another node.

The results of the HAZOP study should be evaluated in order of importance. The results can be grouped into the following categories.

i. Hazardous (causing accidents or fatalities)
ii. Critical (causing significant loss of production or damage to the facility)
iii. Significant (situations causing delays or failures)
iv. Low (does not cause significant damage to the system or production, but may require planned maintenance)

The HAZOP method is a method for the identification of hazards and does not provide any quantitative results. However, the results of the HAZOP study can be converted into numerical data by various methods such as LOPA or FTA.

Nomenclature

CDF	Core Damage Frequencies
ETA	Event tree analysis
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Analysis
ICI	Imperial Chemical Industries
IE	Initiating event
IG	Inert gas
LOCA	Loss of coolant accident
LOPA	Layers of Protection Analysis
PSA	Probabilistic Safety Assessment
PV	Pressure vacuum
SOLAS	International Convention for the Safety of Life at Sea
SW	Sea water
TRR-1/M1	Thailand Research Reactor-1/Modification 1

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Improving Seakeeping Performance of Fishing Boats by Minimising Radius of Gyration

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Abstract

Since the mortality rate of fishing at sea is the highest compared to other occupations in the world, improving the seakeeping performance is essential to enhance the safety of fishing vessels. One approach is to conduct seakeeping optimisation, which typically involves multiple objective functions. This study simplifies the objective function in seakeeping optimisation by using a single objective function: the Radius of Gyration in the Y direction (Ry), while varying the Longitudinal Centre of Gravity (LCG) and the Vertical Centre of Gravity (KG) positions as design variables. A Central Composite Design was employed to generate sample data, enabling the construction of a mathematical model and the identification of the optimal solution using Response Surface Methodology. The initial and optimal results, based on CFD simulation, were compared. The findings reveal that the optimum design variables in Ry, can enhance seakeeping at certain wavelength ratios, resulting in a lower RAO value compared to the initial condition. Furthermore, the influence of the design variables on total resistance (RT) was investigated. The results demonstrate that the seakeeping optimum has no significant impact on total resistance, as the difference with the optimum design for RT and the initial condition is very low, predicted to be no more than 0.5%. This discovery suggests that minimising Ry can improve seakeeping without significantly affecting total resistance.

Keywords: *Small Fishing Boat, GM Ratio, Seakeeping, Added Resistance, Response Surface Method*

1. Introduction

Consuming fish is essential for humans and is also aligned with Sustainable Development Goals number 2 and 3, which aim to eradicate hunger and ensure a healthy life for all. However, ensuring that people can consume fish, fishermen are exposed to significant risks, as fishing at sea is considered the most dangerous occupation in the world. [1]. The mortality rate in fishing surpasses that of other occupations. Numerous accidents occur during sea fishing, particularly for small fishing vessels [2], [3]. Therefore, research aimed at enhancing safety for fishing vessels is crucial.

One of the contributing factors to accidents is environmental conditions. Poor weather, strong winds, and high waves hinder the operation of fishing boats, leading to a low operability index [4]. Ensuring that fishing boats can operate effectively in their designated areas can minimise the risk of accidents. This can be achieved by enhancing the seakeeping performance of the fishing vessel.

The nature of fishing vessels entails that their loading conditions constantly fluctuate. Upon departure from the shore, the fish tank is empty, gradually increasing in payload based on the number of fish caught during operation. Moreover, the method of fishing and the placement of fish onboard can alter the centre of gravity (CoG), both longitudinally and vertically, thereby affecting stability in waves and potentially triggering the parametric roll phenomenon due to changes in GM and natural period.

Another consequence of the shifting CoG position is its impact on the Moment of Inertia in the Y-axis (Iyy), consequently influencing the Radius of Gyration in the Y-axis (Ry), as illustrated in Eq. 1. With constant displacement, minimising Ry can also minimise Iyy. Since the hull shape remains unchanged, both the damping coefficient (C) and the added moment of inertia in the Y-axis (Iyy(a)) can be considered constant. The change in natural frequency, ω_n, which is relatively small compared to the changes in total Iyy, makes a vessel with a lower Ry exhibits lower critical damping, resulting in a higher pitch damping ratio (ζ), as depicted in Eq. 2. A higher pitch damping ratio helps minimise pitch amplitude.

$$R_y = \sqrt{\frac{I_{yy}}{\Delta}} = \sqrt{\frac{\sum w_i(z_i^2 + x_i^2)}{\Delta}} \tag{1}$$

$$\zeta = \frac{C}{C_r} = \frac{C}{2(I_{yy} + I_{yy(a)})\omega_n} \tag{2}$$

Most literature utilises individual ship responses as objective functions for seakeeping optimisation, including heave, pitch, and roll. [5], [6], with additional objective function such as vertical or (and) lateral acceleration [7], [8], [9] slamming [10], or motion sickness incidence [11]. Thus, to enhance seakeeping, it becomes necessary to minimise all responses, which complicates the optimisation process as multiple objective functions are required.

The research aims to demonstrate the utilisation of Ry as a single objective function to indirectly improve seakeeping performance and to streamline the seakeeping optimisation process by altering the loading position (LCG and KG), inherent to the nature of fishing vessel operation. The

Response Amplitude Operator (RAO) in heave, pitch, and added resistance of both initial and optimum conditions are then compared, as predicted by the URANS CFD method.

Furthermore, the present study also investigates the influence of design variables, LCG and KG, on calm water resistance. A same optimisation procedure to minimise calm water resistance is used and the impact of both design variables on total resistance is investigated.

2. Methodology

2.1. Subject Ship and Simulation Condition

In this paper, a small fishing vessel called FAO-01 is employed based on Pérez-Arribas et al. [12]. CFD simulations were reported by Díaz-Ojeda et al. [13] and compared with the experimental test data. They utilised a dihedral bulbous bow for this fishing vessel to reduce the total resistance in calm water. The results of experimental tests on resistance were presented on a scale factor of 4 at Fr 0.33. The main dimensions are shown in Table 1, while the lines plan is presented in Figure 1. For the CFD simulation in waves, simulations were conducted by varying the wavelength ratio, λ/Lbp, from 1.15 to 3.0. H/λ was set to 0.06 for the wave height across all wavelengths, and Fr = 0.33 was maintained for the forward speed.

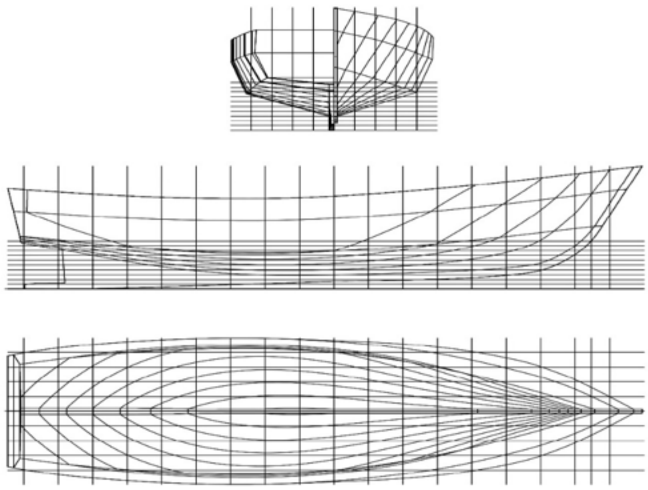


Figure 1. Lines plan of subject ship, FAO-01

Table 1. Main dimensions of FAO-01 fishing vessel

Parameter	Value
Length overall, LOA (m)	9.232
Breadth moulded, B (m)	3.00
Depth moulded, D (m)	1.14
Loaded draft, T (m)	0.983
Volume Displacement, Δ(m^3)	5.846
Block coefficient, C_b (-)	0.267
Mid-boat section coefficient, Cm (-)	0.525
Wetted surface area, Aw (m^2)	23.914

The accuracy of the CFD model was assessed by comparing the CFD results with the experimental data. As the fishing boat only provided resistance data, the well-known benchmark for seakeeping tests of the KCS model, based on Simonsen et al. [14], was utilised. Subsequently, the methodology for setting up the CFD seakeeping simulation was applied to the fishing boat. Meanwhile, the Grid Convergence Index (GCI), based on Roache [15], was employed for the uncertainty study of the CFD model.

2.2. Optimisation Procedure

The optimisation procedure in this study began with determining the objective function and the design variables. As mentioned in the Introduction section, a novel objective function, Ry, was utilised, while LCG and KG served as the design variables.

Following this, the Central Composite Design (CCD), as illustrated in Figure 2, was employed as a Design of Experiment (DoE) to systematically gather sample data [16]. In Figure 2, nine variations resulted from the combination of two variables (x1 and x2). Since the units of each variable are not the same, they were converted to 1 and -1 to represent the maximum and minimum changes in each variable, respectively, determined by ±5% changes from the initial value as shown in Table 2. The code of ±1.414 in Figure 2 corresponds to fractional factorial designs, specifically tailored for two-level factorial experiments involving two design variables, which can be determined by linear extrapolation between 0 and 1.

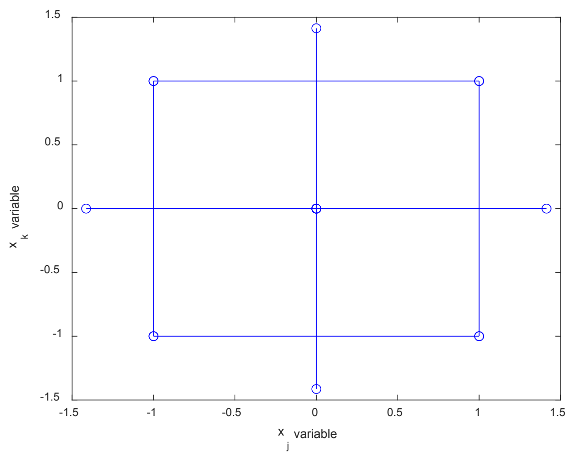


Figure 2. Central Composite Design for Design of Experiment

Table 2. Initial, Maximum, and Minimum Design Variable

Design Variable	FAO-01		
	-1	0	1
LCG (m), x_1	0.898	0.945	0.992
KG (m), x_2	0.360	0.379	0.398

$$y_i(x_j, x_k) = a + bx_j + cx_k + dx_j^2 + ex_k^2 + fx_jx_k \quad (3)$$

$$y_{i\,max/min}(x_j, x_k) = \frac{dy_i(x_j, x_k)}{dx_j} \quad (4)$$

$$y_{i\,max/min}(x_j, x_k) = \frac{dy_i(x_j, x_k)}{dx_k}$$

In Table 2, LCG is measured from AP, and KG is measured from the baseline. The initial LCG is assumed to be the same value as LCB, which ensures the vessels are on an even keel. Meanwhile, the initial KG is assumed to be 75% of KM. Subsequently, based on the responses from each sample data, a mathematical model can be constructed to identify the minimum location of the response, in this case, Ry. This is achieved by employing regression analysis for two variables, as shown in Eq. 3. Then, the optimal solution can be determined from the first derivative with respect to each variable (j, k), as shown in Eq. 4.

2.3. Numerical Simulation

The Unsteady Reynolds Averaged Navier-Stokes (URANS) CFD method was employed to determine the response of heave and pitch, as well as the total resistance in waves for different wavelength ratios. This method has been favoured by numerous researchers, including Guan et al. [17], Zhang et al. [18] and Miao et al. [19], due to its ability to incorporate viscous effects into seakeeping performance, which are neglected in Potential Theory-based methods. By including the viscous term, the accuracy of the predicted ship response becomes significantly improved.

In this case, Star CCM+ software version 17.04 was utilised, which employs the finite volume method to discretise the governing equations. The convection term was solved using a second-order convection scheme, and the unsteady term utilised the implicit method. Velocity and pressure were solved using the Semi-Implicit Method for Pressure Linked Equations (SIMPLE) algorithm. The k-ε turbulence model was selected as the turbulence model.

The free surface was captured using the volume fraction method, assigning a scalar value between 0 to 1 in each cell to represent water and air. The location of the free surface can then be identified simply by a scalar value of 0.5. To model motions, Star CCM+ offers a module called Dynamic Fluid Body Interaction (DFBI). This module enables the calculation of the force and moment on the hull and then calculates the motion equation to determine the new position in a new time step.

The computational domain spans from -3LOA to 2.3LOA in length and from -1.5 LOA to 1 LOA in height. Since the seakeeping simulation uses head waves, only half of the computational domain is required, resulting in a width of computational domain spanning from 0 to 1.5 LOA. The boundary condition where the centre line of the ship is located was set as symmetry. The downstream location was set as a pressure outlet to maintain the hydrostatic pressure. The remaining boundaries were set as velocity inlets, including the upstream location. Here, the VOF Wave Module for Star CCM was utilised at each velocity inlet to model a 'flat wave' for calm water resistance simulation and to model fifth-order waves for seakeeping simulation.

The mesh was generated using the cartesian cut-cell method automatically offered by Star CCM+. In this simulation, an overset mesh was employed, dividing the mesh into two regions: background and overset. At least two refinements were implemented for each region, located at the boundary layer and free surface. At the boundary layer, the first layer height was determined based on the targeted y+, which in this study was targeted between 30 to 100 [20].

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{(g/V^2)} \quad (5)$$

$$\Delta t = 0.005 - 0.01\ \frac{L}{V} \quad (6)$$

In calm water simulation, free surface refinement was initially carried out by determining the cell size in the Kelvin Wake region. This was achieved by calculating the wavelength generated by the ship movement using Eq. 5, where V represents the ship speed in m/s and g is the gravitational acceleration. Subsequently, 24 cells were employed per λ for its length and width, while the height cell (z-direction) was determined by using 1/8 of the cell length. The rest of the free surface was then doubled from the Kelvin wake zone.

In the seakeeping simulation, the free surface refinement was carried out based on the ITTC recommendations, where at least 80 cells were employed per λ and 20 cells for wave height. This recommendation was applied for the lowest wavelength ratio, λ/Lbp = 1.15.

Finally, the determination of the time step utilised the ITTC recommendation, as shown in Eq. 6, where L represents the ship length in metres and V is the ship speed in m/s. For the seakeeping simulation, $T_e/2^8$ was used following the approach by Cho et al. [21], which is lower than the ITTC recommendation ($T_e/100$).

3. Results and Discussion

3.1. Accuracy and Numerical Uncertainty of CFD Model

Table 3 presents the accuracy study of the CFD model by comparing the results based on CFD and EFD. It is evident that the coefficient of total resistance in calm water has a slight difference, which is 1.06%. Meanwhile, in wave conditions, the Transfer Functions (TF) of heave, pitch, and added resistance are compared. The heave TF shows insignificant difference, while for pitch TF and added resistance TF, the difference is around 5%, which is considered acceptable. Table 4 represents the comparison of CFD and EFD results for the calm water resistance of the fishing boat FAO-01. It can be observed that the difference is below one percent, indicating that the CFD result has a good agreement with experimental results.

Table 3. The comparison of CFD and EFD results for calm water resistances and wave condition of the KCS model.

Method	Calm Water	Wave Condition (λ/Lbp = 1.15)		
	CT (*103)	Heave TF	Pitch TF	Added Resistance TF
EFD [14]	4.31	0.950	0.693	9.106
Present CFD	4.36	0.954	0.727	9.564
Difference (%)	1.06%	0.43%	4.89%	5.03%

Table 4. The comparison of CFD and EFD results for calm water resistances of FAO-01 Fishing Vessel

Method	RT (N)
EFD [13]	15.310
Present CFD	15.162
Difference (%)	-0.97%

The uncertainty study for the CFD model was investigated using the Grid Convergence Index (GCI), which required three configurations: fine, medium, and coarse. The CFD set-up for which the results are shown in Table 3 and Table 4 is referred to as the fine configuration. Subsequently, the fine configurations were coarsened into medium and coarse configurations using a refinement ratio.

For the KCS model, a refinement ratio of $\sqrt{2}$ was used to coarsen the fine to medium configuration. Then, with the same ratio, the medium configuration was coarsened again into the coarse configuration. For the fishing boat FAO-01, refinement factors of 1.23 and 1.24 were used to coarsen the fine to medium and medium to coarse configurations, respectively.

Table 5. GCI results of the KCS model

Parameters	CT Calm Water	Wave Condition (λ/Lbp = 1.15)		
	CT (*103)	Heave TF	Pitch TF	Added resistance TF
Fine Configuration	total cell = 3,591,024 time step = 0.01845 s	total cell = 4,330,069 time step = 0.00360 s		
Medium Configuration	total cell = 1,396,929 time step = 0.02609 s	total cell = 1,889,342 time step = 0.00509 s		
Coarse Configuration	total cell = 561,609 time step = 0.03690 s	total cell = 923,707 time step = 0.00720 s		
Fine solution, S_1	0.00436	0.9541	0.7269	9.5638
Medium solution, S_2	0.00444	0.9550	0.7265	9.8579
Coarse solution, S_3	0.00458	0.9650	0.7131	15.2748
GCI (%)	3.05810	0.0117	0.0021	0.2207

Table 6. GCI Results of FAO-01 Fishing Vessel

Parameters	RT Calm Water	Wave Condition (λ/Lbp = 1.5)		
		Heave TF	Pitch TF	Added resistance TF
Fine Configuration	total cells = 1,715,717 time step = 0.0131 s	total cell = 3,536,648 time step = 0.0026 s		
Medium Configuration	total cells = 1,010,918 time step = 0.0161 s	total cell = 1,419,264 time step = 0.0037 s		
Coarse Configuration	total cells = 577,607time step = 0.0200 s	total cell = 512,760 time step = 0.0052 s		
Fine solution, S_1	15.1616 N	1.1177	0.6884	1.9716
Medium solution, S_2	15.5010 N	1.1157	0.6837	1.9473
Coarse solution, S_3	16.2236 N	1.0937	0.6657	1.8631
GCI (%)	2.7495	0.0224	0.3016	0.6250

Table 5 illustrates the GCI results of the KCS model. It is evident that the GCI result for CT is higher than the result for seakeeping simulations, which is less than 1%. However, the GCI for CT is considered acceptable as it is under 5%. A similar trend is observed with the FAO-01, where the GCI for seakeeping simulation is less than one percent, while for the total resistance in calm water, it is around 2.75%.

Based on the accuracy and numerical uncertainty studies conducted, it is evident that the CFD models have yielded good results. Therefore, the CFD results in this study are deemed reliable for further analysis in the following sections.

3.2. Optimisation Results

Table 7 illustrates the Ry response of the FAO-01 fishing boat based on Central Composite Data. The responses are represented by the Calculated Ry (Ry Cal) calculated using Rhinoceros software. All the responses were utilised to construct a mathematical model, as mentioned in section 2.2, and the result of the equation is presented in Eq. 7. This regression equation has an R2 value of 0.9998, indicating that LCG and KG significantly influence the Ry up to 99.98%. Subsequently, the Ry result based on Rhinoceros (Ry Cal) and Ry based on Eq. 7 (Ry Eq. 7) were compared in Table 7. The error between them is also presented in the same table with a maximum absolute value of 0.01%. Therefore, Eq. 7 is sufficiently accurate to be used in this optimisation process.

Table 7. The R_y response of FAO-01 fishing boat based on Central Composite Design

Load Case	X1	X2	LCG (m)	KG (m)	Ry Cal (m)	Ry Eq. 7 (m)	Error (%)
Initial	0	0	0.945	0.379	0.55330	0.55330	0.00%
LC 1	1	1	0.992	0.398	0.55700	0.55701	0.00%
LC 2	1	-1	0.992	0.360	0.55390	0.55386	0.01%
LC 3	-1	1	0.898	0.398	0.55750	0.55754	-0.01%
LC 4	-1	-1	0.898	0.360	0.55430	0.55429	0.00%
LC 5	-1.414	0	0.878	0.379	0.55770	0.55768	0.00%
LC 6	1.414	0	1.012	0.379	0.55700	0.55702	0.00%
LC 7	0	-1.414	0.945	0.352	0.55170	0.55174	-0.01%
LC 8	0	1.414	0.945	0.406	0.55630	0.55626	0.01%

$$Ry\ (m) = 0.5533 - 0.0002x_1 + 0.0016x_2 + 0.0020x_1^2 + 0.0003x_2^2 \quad (7)$$

The visualisation of Eq. 7, known as the response surface, is depicted in Figure 3. From the figure, it is evident how LCG and KG influence Ry. To minimise Ry, it is advisable to maintain LCG as close to the initial condition as possible, while KG should be decreased from the initial setting. The rectangle shown in the figure represents a constraint, ensuring that the optimum design variables are feasible for implementation. The constraint codes are set as ±2.5, indicating ±12.5% changes from the initial value. Therefore, the minimum location should be identified inside this rectangle. Finally, the minimum Ry location is denoted by a point in Figure 3, with the LCG code at 0.05 and the KG code at -2.5.

Table 8 presents the comparison between the initial and optimum Ry, both in code and real value. Subsequently, the Ry value based on the calculation and Eq. 7can be determined and compared to the initial condition. According to the prediction (Eq. 7), the Ry value can reduce by 0.332% when LCG and KG are positioned optimally. Meanwhile, based on the calculation, optimum LCG and KG can reduce Ry from the initial condition by up to 0.352%. The prediction result has a slight difference with the calculations due to the high accuracy of the mathematical model, which is represented by the R2 value. Once the optimum results have been determined, the optimization process is concluded.

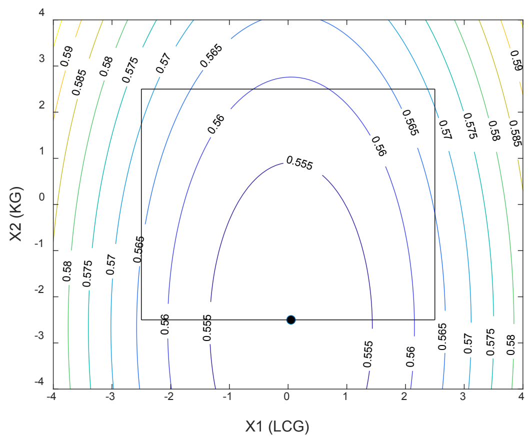


Figure 3. Response Surface Result for R_y Influenced by LCG and KG with the constrains and optimal location

Table 8. The comparison between initial and optimum R_y

Load Case	x_1	x_2	LCG (m)	KG (m)	Ry Cal (m)	Ry Eq. 7 (m)
Initial	0.00	0.00	0.945	0.379	0.55330	0.55330
LC 9 (Optimum Ry)	0.05	-2.50	0.947	0.332	0.55136	0.55147
Difference (%)					-0.351%	-0.332%

3.3. Seakeeping Performance in Regular Waves

The next step is to conduct seakeeping simulations, as described in section 2.2, for both initial and optimum conditions to be compared. Fast Fourier Transformation was employed to determine the heave and pitch amplitude as well as the mean total wave resistance. Finally, each ship response in regular waves is converted to a transfer function (TF), as shown in Eq. 8 to Eq. 10.

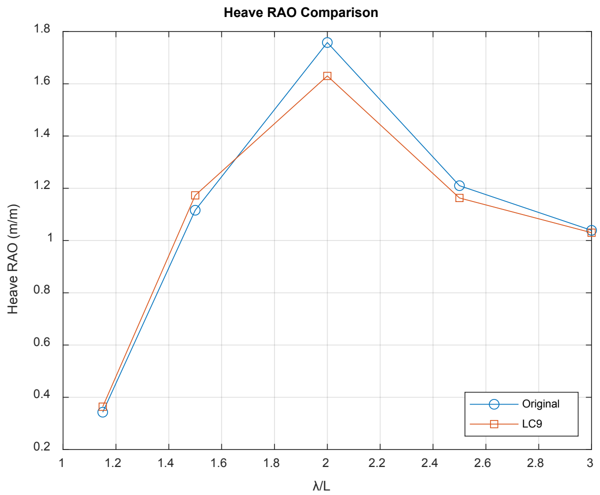
$$Heave\ TF = \frac{z_a\ (m)}{\zeta\ (m)} \quad (8)$$

$$Pitch\ TF = \frac{\theta_a\ (rad)}{k\zeta\ (rad)} \quad (9)$$

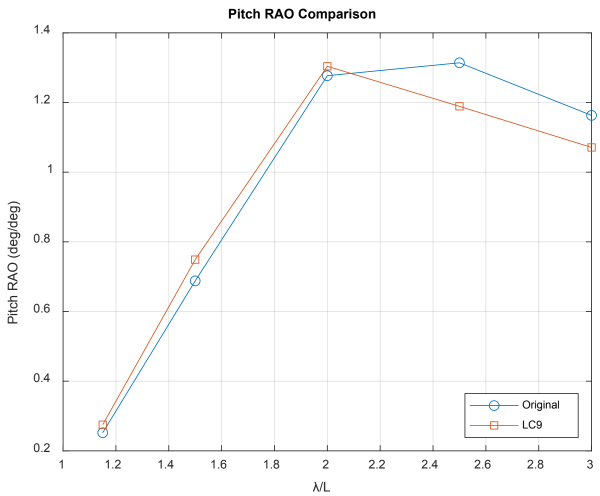
$$Added\ Resistance\ TF = \frac{RT_{wave} - RT_{calm}\ (N)}{\rho g \zeta^2 B^2/L\ (N)} \quad (10)$$

Transfer functions resulting from each wavelength ratio (λ/Lbp) were then plotted to construct the Response Amplitude Operator (RAO), as depicted in Figure 4. From the figure, it is clear that minimising Ry can reduce the amplitude of heave and pitch at certain wavelength ratios. For heave and added resistance, the TF begins to decrease from λ/Lbp of 2, while pitch starts from 2.5.

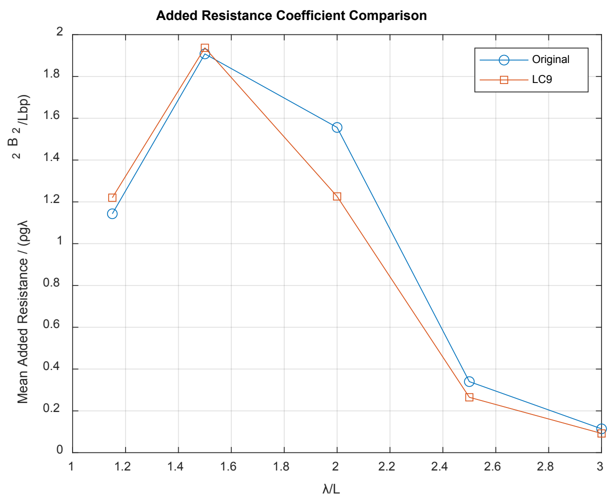
It can be concluded that minimising Ry has an impact on the seakeeping performance. The optimisation process can be considered successful as the optimum design variables can be determined and minimum Ry can be achieved. As the RAO curve is a representation of ship response in regular waves, further investigation is needed to determine ship responses in irregular waves, which represent its performance in its operational area. However, this investigation is not included in this paper. Instead, that is left as a piece of future work.



(a)



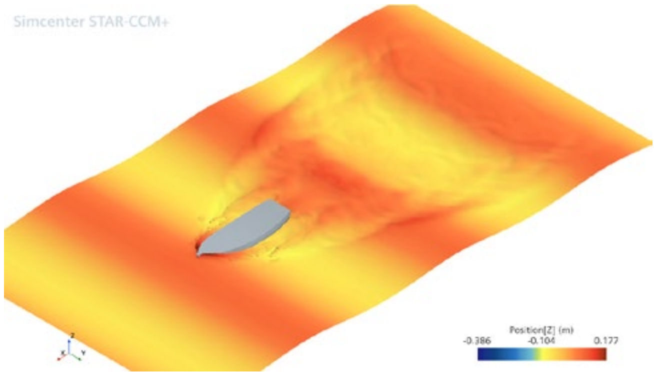
(b)



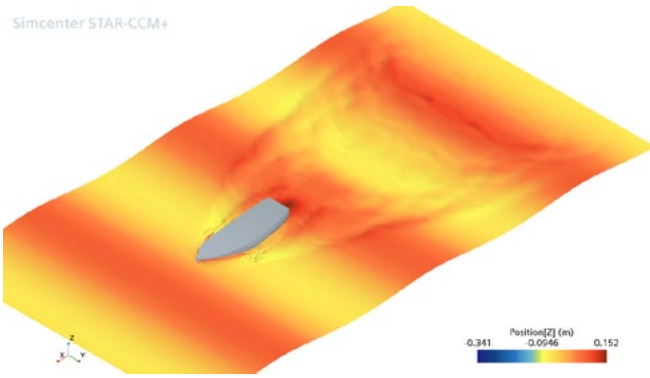
(c)

Figure 4. The heave, pitch, and added resistance RAO comparison between initial and optimum condition

Figure 5 illustrates the comparison of wave elevations for initial and optimum conditions. The differences between both conditions can be observed qualitatively by comparing the wake generated by the vessel movement. The wake generated by LC 9 (optimum condition) is lower than the initial condition, indicating that the vessel has lower amplitude or responses in the same wave condition.



(a) Initial Condition



(b) LC 9

Figure 5. The result of CFD seakeeping simulation at λ/Lbp = 2

3.4. The Influence of LCG and KG to Calm Water Resistance

The previous section concluded that LCG and KG have an impact on the Ry value, which indirectly influences the seakeeping performance. This paper attempts to investigate both parameters' influence on total resistance in calm water by applying the same optimisation process. Based on the resulting mathematical model as well as the response surface figure, the influence of LCG and KG on the total resistance in calm water can be clearly observed.

Table 9 presents the total resistance for each load case variation based on Central Composite Design in Figure 2. The data were then used to construct the mathematical model, as shown in Eq. 8, which has an R2 value of 0.9757. According to the mathematical model, the total resistance of FAO-01 is influenced as much as 97.57% by LCG and KG. The remaining 2.5% represents an unknown factor that also influences the total resistance.

In Table 9, the comparison between predicted RT (RT Eq. 8) and CFD-based RT (RT CFD) shows a slightly higher value compared to the Ry result in Table 7. The maximum error reaches 0.2%, which is still below 1% and considered acceptable. The predicted results will have slightly different values compared to the actual results, as shown in Table 8.

Table 9. The RT response of FAO-01 fishing boat based on Central Composite Design

Load Case	X1	X2	LCG	KG	RT CFD (N)	RT Eq. 8 (N)	Error (%)
Original	0	0	0.945	0.379	15.162	15.162	0.00%
LC 1	1	1	0.992	0.398	15.225	15.217	0.05%
LC 2	1	-1	0.992	0.360	15.253	15.223	0.20%
LC 3	-1	1	0.898	0.398	15.316	15.340	-0.15%
LC 4	-1	-1	0.898	0.360	15.397	15.398	-0.01%
LC 5	-1.414	0	0.878	0.379	15.543	15.524	0.12%
LC 6	1.414	0	1.012	0.379	15.287	15.313	-0.17%
LC 7	0	-1.414	0.945	0.352	15.174	15.193	-0.13%
LC 8	0	1.414	0.945	0.406	15.160	15.148	0.08%

$$RT(N) = 15.162 - 0.0746x_1 - 0.0161x_2 + 0.1282x_1^2 + 0.0042x_2^2 + 0.0132x_1x_2 \quad \text{Eq.1}$$

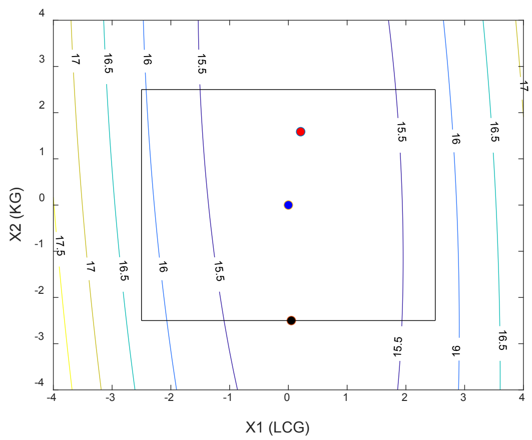


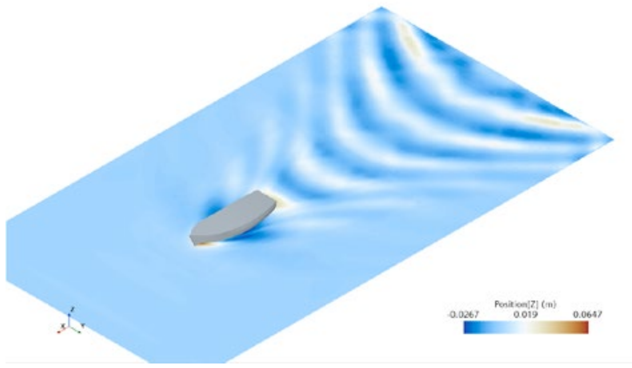
Figure 6. Response Surface Result for RT Influenced by LCG and KG with the constrains and optimal location

Figure 6 illustrates the location of the optimum LCG and KG for total resistance (LC 10), as well as their impact on total resistance represented by red points. Unlike the Ry response, it can be observed that KG has no significant impact compared to LCG towards the RT response. However, the optimum KG is located higher than the initial KG, while the optimal LCG is situated around the initial condition.

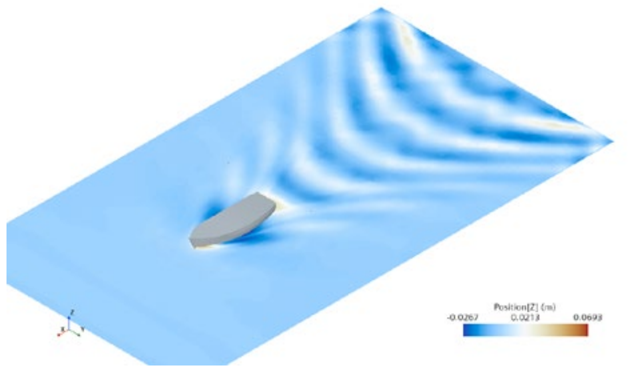
The figure also compares LC 9 (optimum LCG and KG for Ry) represented by black points, for the predicted total resistance. Based on Eq. 8, LC 9 has a total resistance of 15.223, which is predicted to be 0.54% higher than LC 10 and 0.4% higher than the initial condition. This indicates that the improvement in seakeeping achieved by LC 9 has no significant impact on the total resistance in calm water.

Table 10. Comparison between initial and optimum RT

Load Case	x_1	x_2	LCG (m)	KG (m)	RT CFD (N)	RT Eq. 8 (N)
Original	0.00	0.00	0.945	0.379	15.162	15.162
LC 10 (Optimum RT)	0.209	1.588	0.955	0.409	15.173	15.141
Difference (%)					0.073%	-0.136%



(a) Initial Condition



(b) LC 10

Figure 7. Result of CFD resistance simulation at Fr = 0.33

The comparison of total resistance in calm water between the initial condition and the optimum condition (LC 10) is shown in Table 10. It can be observed that, based on Eq. 8, the optimal LCG and KG can reduce the total resistance by up to 0.136%. This reduction is minimal, as it is less than 1%. Additionally, the predicted result may have slightly different results compared to the actual value, which is CFD-based results, due to lower accuracy compared to the Ry optimisation.

When CFD simulation was carried out for the optimum load case (LC 10), the result was slightly higher than the predicted value, with a difference of 0.21%. This discrepancy is considered to have a low error. However, it was found that the optimum results had a slightly higher value of 0.073% compared to the initial condition, which once again indicates a negligible difference, lies in all cases within the predicted discretisation uncertainty obtained in Table 6. These findings suggest that there is no significant improvement in total resistance by changing LCG and KG. Further research is required to investigate the influence of hull form transformation on total resistance in calm water as well as seakeeping performance.

Finally, the CFD-based comparison between the initial and LC 10 results is presented in Figure 7. As the total resistance does not show a significant difference, the wave amplitudes inside the Kelvin wake also appear similar to the initial condition.

4. Conclusions

The radius of gyration in the y direction (Ry) was effectively demonstrated as a single objective function in the seakeeping optimisation process. LCG and KG were employed as design variables in the optimisation process. Seakeeping simulations were conducted using the CFD method, incorporating the viscous effect to enhance the results.

The optimal design variable in minimising Ry, known as LC 9, illustrates that the Response Amplitude Operator (RAO) of heave, pitch, and added resistance in head waves at Fr=0.33 can be reduced at certain wavelength ratios, thereby improving the seakeeping performance. The influence of the same design variables was successfully analysed, resulting in LC 10, which, as predicted by the mathematical model, can reduce the total resistance by up to 0.136%.

However, the CFD-based results for LC 10 showed an increase in total resistance by 0.073%, indicating that both design variables have no significant impact on total resistance. This finding also indicates that LC 9 exhibits no significant difference in total resistance compared to LC 10 (0.54% higher) and compared to the initial condition (0.4% higher). Improving seakeeping performance by minimising Ry can enhance seakeeping indirectly without significantly increasing the total resistance in calm water.

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Section 3

Alternative Fuels & Renewable Energy

Investigation of Reactivity Controlled Compression Ignition Fueled with Diesel and Natural Gas in Marine Engine using Soft Decision-Making Methods

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Abstract

The reactivity-controlled compression ignition (RCCI) combustion shows great promise as it provides high fuel efficiency with reduced soot and NOx emissions. RCCI combustion has the unique characteristics that differentiate it from conventional spark ignition (SI) and compression ignition (CI) engines. RCCI engine uses dual-fuel injection strategies to control combustion phasing and achieve optimal performance. In this study, state-of-the-art soft decision-making methods are utilized to predict the emission and performance characteristics of RCCI engines fueled with natural gas and diesel under different operating conditions through an experimentally validated computational fluid dynamics model. Ranking results of the soft decision-making methods confirm that the model successfully predicts the engine's performance and emission. Moreover, generating an architecture based on soft decision-making using the soft matrices-based mathematical foundation given the study shows that this is a very effective and helpful technique to predict the RCCI engine performance and emission parameters.

Keywords: *Marine engine, Natural gas, Reactivity-controlled, Compression-ignition, Soft decision-making, Parameter optimization.*

1. Introduction

Compression ignition (CI) engines are commonly used as power sources across various industries, encompassing automotive, railway transportation, power generation, and maritime operations. The extensive utilization of these technologies highlights their adaptability and effectiveness in addressing the varied requirements of contemporary transportation and industrial sectors [1]. However, in the face of increasingly stringent emission regulations, the search for cleaner and more efficient combustion has led to the development of various innovative strategies. These approaches aim to not only decrease exhaust emissions but also enhance overall engine efficiency. This ongoing pursuit underscores the importance of continual research and advancement in combustion technologies to address environmental concerns while ensuring optimal performance across various application domains [2], [3]. New combustion strategies have emerged as promising solutions to meet stringent emission regulations and enhance engine efficiency. Homogeneous Charge Compression Ignition (HCCI) represents a revolutionary approach that seeks to achieve combustion similar to that of gasoline engines while utilizing diesel-like compression ignition principles. In HCCI engines, a homogeneous mixture of fuel and air is compressed to the point of auto-ignition, resulting in simultaneous combustion throughout the combustion chamber. This approach offers the potential for ultra-low emissions of nitrogen oxides (NOx) and particulate matter (PM) while maintaining high thermal efficiency. Premixed Charge Compression Ignition (PCCI) blends elements of conventional diesel combustion with gasoline-like premixed combustion. In PCCI engines, fuel and air are thoroughly mixed prior to compression, forming a homogenous charge that ignites through compression. By controlling the timing and rate of injection, PCCI allows for precise control over combustion phasing, leading to reduced emissions of both NOx and PM, as well as improved fuel efficiency. Reactivity-Controlled Compression Ignition (RCCI) combines the benefits of both HCCI and conventional diesel combustion by leveraging the reactivity differences between two fuels or fuel blends [4]. In RCCI engines, an initial injection of a low-reactivity fuel, such as gasoline or natural gas, occurs during the compression stroke to establish a uniform charge. Subsequently, a high-reactivity fuel, such as diesel, is injected at a later stage in the compression stroke. The utilization of a dual-fuel strategy allows for meticulous regulation of combustion timing and rates of heat release, leading to exceptionally low emissions and improved thermal efficiency under various operational circumstances.

The utilization of natural gas and diesel as fuel in the RCCI engine signifies an innovative strategy aimed at attaining remarkable combustion efficiency and minimizing emissions [5]. The synergistic combination of natural gas's low reactivity and diesel fuel's high reactivity governs the combustion process. The compression stroke involves the introduction of a precisely measured quantity of natural gas into the combustion chamber, resulting in the formation of a thoroughly mixed and uniform charge. The initiation of natural gas injection establishes the foundation for regulated ignition and combustion. After the injection of natural gas, a meticulously timed injection of diesel fuel is introduced into the chamber [6]. The combustion process is further enhanced by the high reactivity of diesel, which ignites upon contact with the hot compressed air. The combustion characteristics can be precisely manipulated by changing the ratio and timing of injections of natural gas and diesel [7].

Implementing RCCI as a marine engine holds significant promise for enhancing efficiency and reducing emissions in maritime transportation. This hybrid approach enables the marine engine to operate with improved fuel efficiency and lower emissions compared to conventional combustion methods. In maritime operations, where fuel consumption and emissions are major concerns, RCCI engines offer a compelling solution. The ability to finely tune the combustion process allows for enhanced control over NOx and particulate matter emissions, addressing environmental regulations while maintaining optimal performance [8], [9].

The present study evaluates the performance and emissions of RCCI engines fueled with natural gas/diesel. The various working conditions of the RCCI engine were analyzed using the experimentally validated computational fluid dynamics (CFD) model. The results were analyzed and optimized by harnessing the CFD and four soft decision-making algorithms via fuzzy parameterized fuzzy soft matrices (*fpfs*-matrices) [10], [11], namely MBR01 [12], CCE10 [12], EMK19 [13], and G17(R) [14], showcased in this study, obtaining crucial emission and performance parameters for the RCCI engine becomes readily achievable, eliminating the need for expensive and time-consuming experimental investigations.

2. Materials and Methods

2.1. CFD modeling

Single cylinder direct injection test engine was modeled. The specificions of the engine are listed in Table 1. The start of injection (SOI) timing was changed between 32° to 56° bTDC. The CFD model was performed using CONVERGE software [15]. The computational domain of the engine were generated (Fig. 1). The combustion chamber was optimized for RCCI by [16]. RNG k-ε turbulence model [17], Lagrangian-parcel Eulerian-fluid method [18] for fuel spray, KH-RT breakup model [19], NTC droplet collision model [20], frossling evaporation model [21], O'Rourke turbulent dispersion model [22], and Rebound/Slide spray-wall interaction model [23] were used.

Table 1. Caterpillar SCOTE 3401E test engine specifications.

Cylinders	Single
Total displacement	2.4 liter
Bore × Stroke	137.6 mm
Stroke	165.1 mm
Connecting rod length	261.6 mm
Compression ratio	14.9:1
Engine speed	1300 r/min
Injection	Diesel + Natural gas
Direct injector spray angle	145 deg.

The SAGE combustion model [24] with 76 species and 464 reactions n-heptane mechanism [25] was used. The O'Rourke and Amsden model for heat transfer [26] and Hiroyasu soot model and Extended Zeldovich NO_X mechanism [27] were selected.

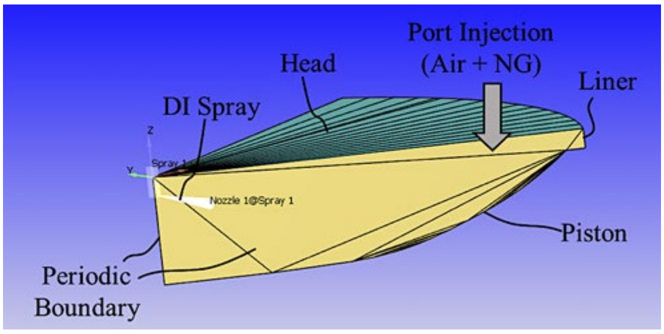

Figure 1. Computational domain of the RCCI engine with bathtub piston bowl at TDC.

2.2. Soft Decision-Making Approaches via Fuzzy Parameterized Fuzzy Soft Matrices

In this subsection, firstly, the concept of fuzzy parameterized fuzzy soft matrices (*fpfs*-matrices) is presented. Afterwards, three soft decision-making algorithms based on *fpfs*-matrices are provided.

Throughout the paper, let E be a parameter set, $F(E)$ be the set of all the fuzzy sets over E, and $\mu \in F(E)$. Here, a fuzzy set is denoted by $\{^{\mu(x)}x \mid x \in E\}$.

Definition 1. [10] Let U be a universal set, $\mu \in F(E)$, and α be a function from μ to $F(U)$. Then, the set $\left\{\left(^{\mu(x)}x, \alpha\left(^{\mu(x)}x\right)\right) \mid x \in E\right\}$, being the graphic of α, is called a fuzzy parameterized fuzzy soft set (*fpfs*-set) parameterized via E over U (or briefly over U).

From now on, the set of all the *fpfs*-sets over U is denoted by $FPFS_E(U)$.

Example 1. Let $E = \{x_1, x_2, x_3\}$ and $U = \{u_1, u_2, u_3, u_4\}$. Then,

$$\alpha = \{(^{0.7}x_1, \{^{1}u_2, {}^{0.7}u_3, {}^{0.4}u_4\}), (^{0.2}x_2, \{^{0.6}u_1, {}^{0.8}u_2, {}^{0.5}u_3, {}^{0.7}u_4\}), (^{0.4}x_3, \{^{0.9}u_1, {}^{0.2}u_3, {}^{0.1}u_4\})\}$$

is an *fpfs*-set over U.

Definition 2. [11] Let $\in FPFS_E(U)$. Then, $[a_{ij}]$ is called *fpfs*-matrix of α and is defined by

$$[a_{ij}] = \begin{bmatrix} a_{01} & a_{02} & a_{03} & \cdots & a_{0n} & \cdots \\ a_{11} & a_{12} & a_{13} & \cdots & a_{1n} & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & a_{mn} & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots \end{bmatrix}$$

such that for $i \in \{0,1,2,\cdots\}$ and $j \in \{1,2,\cdots\}$,

$$a_{ij} := \begin{cases} \mu(x_j), & i = 0 \\ \alpha\left(^{\mu(x_j)}x_j\right)(u_i), & i \neq 0 \end{cases}$$

Here, if $|U| = m - 1$ and $|E| = n$, then $[a_{ij}]$ has order $m \times n$.

Across the paper, the set of all the *fpfs*-matrices parameterized via E over U is denoted by $FPFS_E[U]$.

Example 2. The *fpfs*-matrix of α provided in Example 1 is as follows:

$$[a_{ij}] = \begin{bmatrix} 0.7 & 0.2 & 0.4 \\ 0 & 0.6 & 0.9 \\ 1 & 0.8 & 0 \\ 0.7 & 0.5 & 0.2 \\ 0.4 & 0.7 & 0.1 \end{bmatrix}$$

Algorithm 1. MBR01 [12]

Step 1. Construct an *fpfs*-matrix $[a_{ij}]_{m\times n}$

Step 2. Obtain $[b_{ik}]_{(m-1)\times(m-1)}$ defined by
$b_{ik} := \sum_{j=1}^{n} a_{0j}\chi(a_{ij}, a_{kj})\, i, k \in I_{m-1}$ such that

$$\chi(a_{ij}, a_{kj}) := \begin{cases} 1, & a_{ij} \geq a_{kj} \\ 0, & a_{ij} < a_{kj} \end{cases}$$

Step 3. Obtain $[c_{i1}]_{(m-1)\times 1}$ defined by
$c_{i1} := \sum_{k=1}^{m-1} b_{ik}, \quad i \in I_{m-1}$

Step 4. Obtain $[d_{i1}]_{(m-1)\times 1}$ defined by
$d_{i1} := \sum_{k=1}^{m-1} b_{ki}, \quad i \in I_{m-1}$

Step 5. Obtain the score matrix $[s_{i1}]_{(m-1)\times 1}$ defined by
$s_{i1} := c_{i1} - d_{i1}, \quad i \in I_{m-1}$

Step 6. Obtain the decision set $\{{}^{\hat{s}_{k1}}u_k | u_k \in U\}$

Algorithm 2. CCE10 [12]

Step 1. Construct an *fpfs*-matrix $[a_{ij}]_{m\times n}$

Step 2. Obtain the score matrix $[s_{i1}]_{(m-1)\times 1}$ defined by

$s_{i1} := \frac{1}{n}\sum_{j=1}^{n} a_{0j}a_{ij}, \quad i \in I_{m-1}$

Step 3. Obtain the decision set $\{{}^{\mu(u_k)}u_k | u_k \in U\}$ such that $\mu(u_k) = \frac{s_{k1}}{\max_i s_{i1}}$

Algorithm 3. EMK19 [13]

Step 1. Construct *fpfs*-matrices $[a_{ij}^1], [a_{ij}^2], \ldots, [a_{ij}^t]$

Step 2. Obtain $[b_{ij}]$ defined by

$$b_{ij} := \frac{1}{t}\sum_{k=1}^{t} a_{ij}^k, \qquad i \in I_{m-1}^* \text{ and } j \in I_n$$

Step 3. Obtain $[c_{ij}]$ defined by $c_{ij} := b_{01}b_{ij}$ such that $i \in I_{m-1}$ and $j \in I_n$

Step 4. Obtain the Positive Ideal Solution matrix $[c_{1j}^+]$ and Negative Ideal Solution matrix $[c_{1j}^-]$ defined by

$c_{1j}^+ := \max_i\{c_{ij}\}$ and $c_{1j}^- := \min_i\{c_{ij}\}, \quad i \in I_{m-1}$ and $j \in I_n$

Step 5. Obtain $[s_{i1}^+]$ and $[s_{i1}^-]$ defined by

$$s_{i1}^+ := \sqrt{\sum_{j=1}^{n}(c_{ij} - c_{1j}^+)^2} \text{ and } s_{i1}^- := \sqrt{\sum_{j=1}^{n}(c_{ij} - c_{1j}^-)^2}, i \in I_{m-1} \text{ and } j \in I_n$$

Step 6. Obtain $[s_{i1}]$ defined by

$$s_{i1} := \frac{s_{i1}}{s_{i1}^+ + s_{i1}^-}, \qquad i \in I_{m-1}$$

Step 7. Obtain the decision set $\{{}^{\hat{s}_{k1}}u_k | u_k \in U\}$

Algorithm 4. G17 (*R*) [14]

Step 1. Construct an *fpfs*-matrix $[a_{ij}]_{m\times n}$

Step 2. Determine a set ***R*** of indices such that $R \subseteq I_n$

Step 3. Obtain $[b_{i1}]_{(m-1)\times 1}$ defined by

$$b_{i1} := \sum_{j\in R} a_{0j}a_{ij}, \quad i \in I_{m-1}$$

Step 4. Obtain $[c_{i1}]_{(m-1)\times 1}$ defined by

$$c_{i1} := \sum_{j=1}^{n} a_{0j}a_{ij}, \quad i \in I_{m-1}$$

Step 5. Obtain the set $V = \left\{u_i : b_{i1} = \max_{k\in I_{m-1}} b_{k1}\right\}$

Step 6. Obtain the score matrix $[s_{i1}]_{(m-1)\times 1}$ defined by

$$s_{i1} := \begin{cases} c_{i1}, & u_i \in V \\ b_{i1}, & u_i \in U - V \end{cases}$$

such that $i \in I_{m-1}$

Step 7. Obtain the decision set $\{{}^{\hat{s}_{k1}}u_k | u_k \in U\}$

3. Results and Discussion

Four cases were defined with different IMEPg and intake pressure (Table 2). The model was validated using experimental [28] and numerical data [29]. The prediction of CFD model for combustion timing were accurate within 2° crank angle for all cases (Fig. 2). However, it predicted a faster heat release during premixed combustion, which may be due to simplifications in the reaction mechanism, spray modeling inaccuracies, and possible errors in the experimental measurements [30]. Figure 3 shows the in-cylinder equivalence contours for the validation cases on the spray axis cut plane. Increasing the methane mass in the cases leads to a higher equivalence ratio.

Table 2. Operating parameters of the validated cases.

[bar]	Case 1	Case 2	Case 3	Case 4
$IMEP_g$	7.7	9.4	11.5	13.5
Intake Pressure	1.3	1.6	1.9	2.2

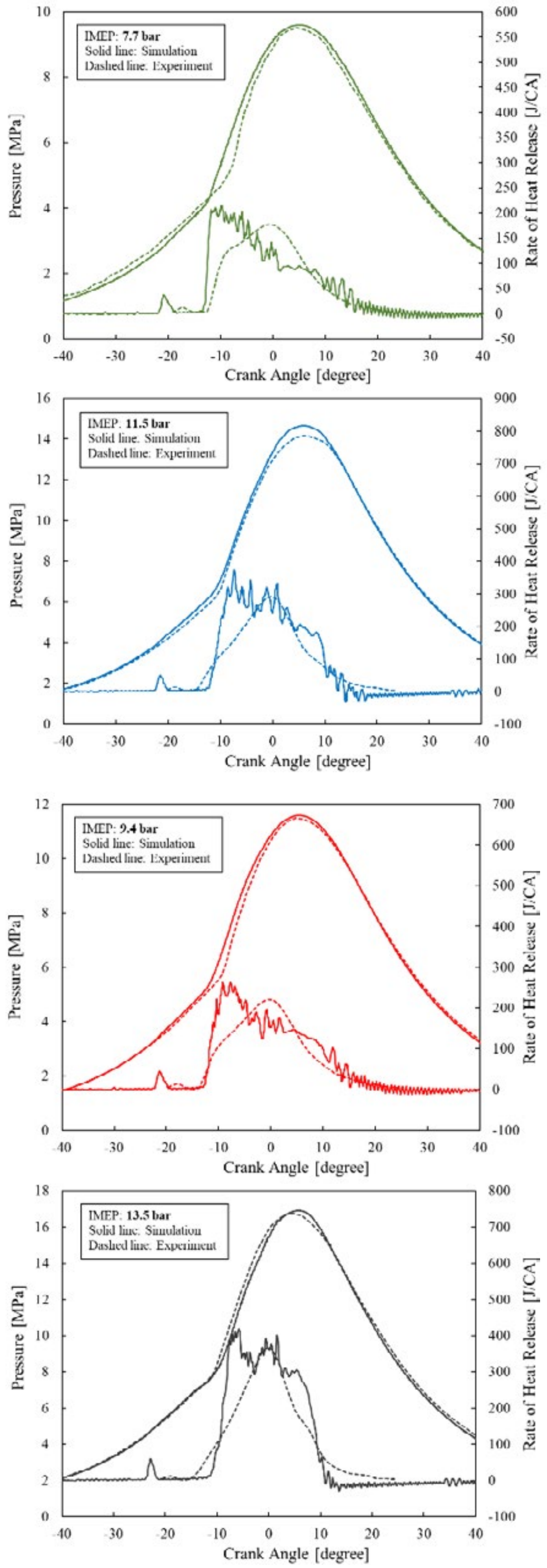

Figure 2. Comparison of experiment and simulation cylinder-averaged pressure traces.

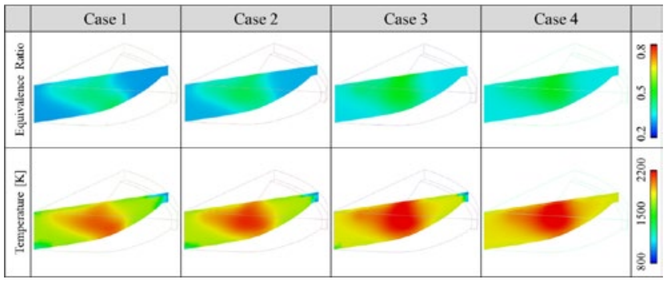

Figure 3. In-cylinder temperature and equivalence ratio distribution for four cases at +10° aTDC.

To obtain the optimal input parameters utilizing the soft decision-making methods provided in this section, the experimental outputs (Power, Soot, and NOx) are processed by considering Indicated Power, Soot, and NOx values should be maximum, minimum, and minimum, respectively. Afterward, feature fuzzification (column normalization) of the values is computed and the *fpfs*-matrix is constructed by equal parameter weights as follows:

$$\begin{bmatrix} 16.534 & 9.729\times10^{-4} & 0.928 \\ 20.914 & 3.236\times10^{-4} & 0.914 \\ \vdots & \vdots & \vdots \\ 25.382 & 7.143\times10^{-4} & 0.002 \\ 29.265 & 9.710\times10^{-4} & 0.001 \end{bmatrix}_{180\times3} \xrightarrow[\text{with equal weights}]{\text{Fuzzification}} [a_{ij}] = \begin{bmatrix} 1 & 1 & 1 \\ 0.4501 & 0.3525 & 0 \\ 0.5694 & 0.7846 & 0.015 \\ \vdots & \vdots & \vdots \\ 0.6910 & 0.5246 & 0.9978 \\ 0.7967 & 0.3538 & 0.9986 \end{bmatrix}_{181\times3}$$

Thereafter, four soft decision-making methods, i.e., MBR01, CCE10, EMK19, and G17 (R), are applied to the *fpfs*-matrix $[a_{ij}]$ and the ranking of the input parameters are provided in Tables 3-6. The ranking results show that the optimal input parameters are those in Cases 144, 148, and 172.

Table 3. Input optimization in experimental results via soft decision-method MBR01.

Case No	Input				Output				Ranking
	IPR (bar)	TFM (mg)	ER (%)	SOI (CA bTDC)	IPW (kW)	PFP (bar)	Soot (g/kWh)	NOx (g/kWh)	
C172	2.79	117.18	10	56	33.448	155.898	6.038×10^{-5}	0.016	1
C144	2.79	128.76	0	53	36.644	168.958	2.468×10^{-6}	0.124	2
C136	2.79	111.39	15	50	31.822	150.981	7.035×10^{-5}	0.022	3
C148	2.79	122.97	5	53	35.227	174.209	4.956×10^{-5}	0.061	4
C124	2.79	128.76	0	50	36.530	171.743	2.072×10^{-6}	0.177	5

IPR: Initial Pressure, TFM: Total Fuel Mass, ER: EGR Ratio (%), IPW: Indicated Power

Table 4. Input optimization in experimental results via soft decision-method CCE10.

Case No	Input				Output				Ranking
	IPR (bar)	TFM (mg)	ER (%)	SOI (CA bTDC)	IPW (kW)	PFP (bar)	Soot (g/kWh)	NOx (g/kWh)	
C144	2.79	128.76	0	53	36.644	168.958	2.468×10^{-6}	0.124	1
C148	2.79	122.97	5	53	35.227	174.209	4.956×10^{-5}	0.061	2
C172	2.79	117.18	10	56	33.448	155.898	6.038×10^{-5}	0.016	3
C124	2.79	128.76	0	50	36.530	171.743	2.072×10^{-6}	0.177	4
C136	2.79	111.39	15	50	31.822	150.981	7.035×10^{-5}	0.022	5

IPR: Initial Pressure, TFM: Total Fuel Mass, ER: EGR Ratio (%), IPW: Indicated Power

Table 5. Input optimization in experimental results via soft decision-method EMK19.

Case No	Input				Output				Ranking
	IPR (bar)	TFM (mg)	ER (%)	SOI (CA bTDC)	IPW (kW)	PFP (bar)	Soot (g/kWh)	NOx (g/kWh)	
C148	2.79	122.97	5	53	35.227	174.209	4.956×10^{-5}	0.061	1
C172	2.79	117.18	10	56	33.448	155.898	6.038×10^{-5}	0.016	2
C144	2.79	128.76	0	53	36.644	168.958	2.468×10^{-6}	0.124	3
C168	2.79	122.97	5	56	35.140	170.966	1.729×10^{-4}	2.79	4
C112	2.79	117.18	10	47	33.369	164.343	1.096×10^{-5}	0.099	5

IPR: Initial Pressure, TFM: Total Fuel Mass, ER: EGR Ratio (%), IPW: Indicated Power

Table 6. Input optimization in experimental results via soft decision-method G17(R).

Case No	Input				Output				Ranking
	IPR (bar)	TFM (mg)	ER (%)	SOI (CA bTDC)	IPW (kW)	PFP (bar)	Soot (g/kWh)	NOx (g/kWh)	
C144	2.79	128.76	0	53	36.644	168.958	2.468×10^{-6}	0.124	1
C148	2.79	122.97	5	53	35.227	174.209	4.956×10^{-5}	0.061	2
C172	2.79	117.18	10	56	33.448	155.898	6.038×10^{-5}	0.016	3
C124	2.79	128.76	0	50	36.530	171.743	2.072×10^{-6}	0.177	4
C136	2.79	111.39	15	50	31.822	150.981	7.035×10^{-5}	0.022	5

IPR: Initial Pressure, TFM: Total Fuel Mass, ER: EGR Ratio (%), IPW: Indicated Power

In Table 7, average rankings of the aforesaid results are presented. The results manifest that optimal input parameters are belonging to Case-144 and these parameters are initial pressure=2.79 Bar, Total Fuel Mass=128.76 mg, EGR Ratio=0%, and SOI=53 CA bTDC.

Table 7. Optimal input parameters via average rankings of the soft decision-method

Case No	Input				Soft Decision-Based Ranking				Average Ranking
	IPR (bar)	TFM (mg)	ER (%)	SOI (CA bTDC)	MBR01	CCE10	EMK19	G17(R)	
C112	2.79	117.18	10	47	6	6	5	6	5.75
C124	2.79	128.76	0	50	5	4	9	4	5.50
C136	2.79	111.39	15	50	3	5	6	5	4.75
C144	**2.79**	**128.76**	**0**	**53**	**2**	**1**	**3**	**1**	**1.75**
C148	2.79	122.97	5	53	4	2	1	2	2.25
C168	2.79	122.97	5	56	11	8	4	8	7.75
C172	2.79	117.18	10	56	1	3	2	3	2.25
Frequency	2.79	122.97,128.76	0,5,10	50,53,56					

IPR: Initial Pressure, TFM: Total Fuel Mass, ER: EGR Ratio (%)

4. Conclusion

The primary goal of modern engines revolves around achieving optimal performance while meeting increasingly stringent emission standards. The dual-fueled RCCI engine stands out for its remarkable ability to emit exceptionally low levels of soot and NOX emissions, all while maintaining high thermal efficiency. As evidenced by this study, the careful manipulation of key engine parameters such as SOI, EGR, fuel mass, and intake pressure plays a pivotal role in controlling exhaust emissions. With the versatility to operate under varied loads and conditions, RCCI engines offer a promising avenue towards achieving both environmental sustainability and engine efficiency in diverse applications.

Building on these findings, applying soft decision-making methods to determine optimal input parameters revealed a systematic approach to enhance engine performance further. Identifying optimal parameters—such as initial pressure, total fuel mass, EGR ratio, and SOI timing—underscores the precision required in tuning engine conditions to maximize efficiency while minimizing emissions. This strategic integration of soft decision-making algorithms with empirical data presented a path for refining engine designs, tailoring them to meet specific operational goals while adhering to environmental regulations. Thus, it is believed that the synergy between computational analyses and experimental investigations paves the way for innovative engine technologies that promise to comply with and exceed current and future emissions and performance standards.

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Design of Hydrogen Fuel Cell-Powered Yacht

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Abstract

Decreasing emissions in maritime transportation is crucial for mitigating climate change and preserving marine ecosystems. In this study, a hydrogen fuel cell-powered yacht was designed. A hydrogen fuel cell and electric motor propulsion system were designed as an alternative to conventional fossil fuel engines. This system has no carbon emissions during operation and is an environmentally friendly option. This will result in a decreased carbon footprint associated with maritime transportation. The hydrogen fuel cell-powered design will reduce the environmental impact of the maritime industry. On the other hand, this design operates quietly and low vibration, thus, it improves the comfort of the cruise. The yacht design has batteries at the bottom. A PEM fuel cell and electric motor are placed on the platform above the battery system. Length, width and draft of the yacht are 15 m, 5 m and 3 m, respectively. The yacht was designed for a speed of 20 knots with 2×250 kW electric motor units. It has been found that PEM fuel cells can be used in private yachts for a better cruise and to reduce carbon footprint.

Keywords: *Marine transport, PEM, fuel cell, hydrogen, yacht design, carbon footprint.*

1. Introduction

The quest for sustainable energy solutions has become imperative in the maritime industry, driven by concerns over environmental impact and the finite nature of fossil fuels. Hydrogen fuel cell technology presents a promising avenue for decarbonizing maritime transport, offering zero-emission propulsion with only water as a byproduct. This study presents the design of a hydrogen fuel cell-powered yacht, aiming to showcase the feasibility and practicality of such a system in the marine environment. A proton exchange membrane (PEM) hydrogen fuel cell and electric motor propulsion system has been designed to be an alternative to fossil fuel-powered engines used in conventional yachts. By leveraging advancements in fuel cell technology, this design represents a significant step towards greener and more efficient yacht propulsion systems.

Maaruf and Khalid highlight in their studies that hydrogen-powered yachts are more reliable and efficient than traditional fuel-powered yachts. They emphasize the use of PEM fuel cells as a common power source for hydrogen-fueled yachts. PEM fuel cells can efficiently and reliably generate electricity [1].

Wang et al. conducted a comparative life cycle assessment focusing on these marine fuels, revealing significant disparities in their environmental footprints based on the production methods employed. Specifically, the study highlighted hydrogen produced through wind energy as the most environmentally favorable alternative, showcasing substantial reductions in both greenhouse gas emissions and acidification potential emissions compared to marine gas oil [2].

Shih et al. examined a PEM fuel cell system as a viable power source for small ships and underwater vehicles. Results show that the PEM fuel cell, utilizing air at the cathode, achieves a maximum power output of 5.5 kW on water. Experiments with pure oxygen increase this output by 47% to 8.1 kW under the same oxidant flow rate. Additionally, tests on a 20 kW hybrid power system demonstrate successful operation at a maximum of 23.37 kW, with the PEM fuel cell contributing 4.83 kW and batteries providing 18.54 kW. These findings suggest the adaptability of the 20 kW system for both small ships and underwater vehicles with minor modifications, highlighting the potential performance benefits of PEM fuel cell systems fueled by pure oxygen in maritime applications [3]. Empirical evidence and research findings suggest that the utilization of PEM fuel cells has the potential to address the issue of reliance on a single fuel source [4].

Fuel cell projects in the maritime sector were identified such as FCShip, METAHPU, FellowSHIP, SF-BREEZE, US SSFC, Felicitas subproject II, MC-WAP, ZEMShips, Nemo H2, Pa-X-ell, SchIBZ and RiverCell. These projects vary from assessments of potential for fuel cell use, rule development and feasibility studies and concept design to testing of fuel cells in various vessels [5].

The SF-BREEZE initiative evaluated the technical, regulatory, and economic feasibility of a high-speed passenger ferry powered solely by hydrogen fuel cells, along with the necessary hydrogen fueling infrastructure in the San Francisco Bay area. This project developed a practical vessel design meeting performance criteria. Regulatory assessments by the US Coast Guard and the American Bureau of Shipping found no significant hurdles to deployment. The project explored liquid hydrogen supply to the vessel, identifying suitable fueling sites at ports and obtaining technically feasible facility designs from industrial gas companies. While the current zero-emission ferry design incurs higher costs compared to conventional diesel ferries, potential cost reduction strategies specific to the vessel and anticipated market developments in fuel cell electric vehicles could lead to future cost parity [6].

Hydrogen storage presents a significant technical challenge, impeding the widespread adoption of hydrogen energy [7]. This challenge is particularly pronounced for vessels and maritime machinery powered by hydrogen fuel cells. Maximizing hydrogen storage capacity while ensuring safety and cost control is crucial [4]. Various methods are currently employed for hydrogen storage, including compression, liquefaction, carbon-based, and solid-state storage. Among these, compression hydrogen storage is the most prevalent [7].

In summary, the studies and projects mentioned underscore the growing interest and research efforts directed toward the design and production of hydrogen-powered yachts. While significant progress has been made in advancing hydrogen fuel cell technology and addressing associated challenges, further research and development are essential to realize the full potential of hydrogen as a sustainable propulsion solution for the maritime industry. In this study, hydrogen fuel cell-powered yacht was designed with the length of 15 m, the width of 5 m and the draft of 3 m. PEM fuel cells and electric motor are placed on the platform above the battery system. The yacht was designed for a speed of 20 knots with 2×250 kW electric motor units.

2. Materials and Methods

This section outlines the procedures and materials employed in conducting the analyses described in this study. The investigation primarily focused on evaluating the performance and feasibility of hydrogen fuel cell technology for maritime applications, particularly in small yachts.

The hull of the yachts is designed with fiberglass material to provide durability and lightness. Fiberglass is highly resistant to corrosion and provides long-lasting durability. Unlike ABS plastic, it does not break, thanks to its flexibility, allowing for easy repairs. This material is health-friendly and applicable in various environments. Additionally, fiberglass remains cool under sunlight, offering insulation against both heat and cold.

Hydrogen storage tanks are specially designed containers for safely and effectively storing hydrogen gas. These tanks can store compressed hydrogen gas under high pressure or liquid hydrogen. Additionally, there are methods for chemically storing hydrogen in various hydrides or physically storing it in carbon-based materials. Hydrogen storage tanks are increasingly used in maritime applications, particularly in fuel cell propulsion systems, as a high-energy-density and environmentally friendly fuel alternative. These tanks contribute to enhancing energy efficiency in yachts, reducing emissions, and supporting sustainable marine transportation. Type III hydrogen tank was selected for this design study (Fig. 1). The specifications of the used hydrogen storage tank were listed in Table 1.

Table 1. The specifications of the used hydrogen storage tank

Tank Type	III
Outside Diameter	435 mm
Length	2616 mm
Vessel Mass	165 kg
Water Volume	270 L
Hydrogen Capacity	6.2 kg
Pressure	350 bar

Figure 1. Type III Hydrogen Tank [8]

As an energy storage system of the yacht, lithium-ion batteries are employed [9]. These batteries offer high energy density and rapid charging/discharging capabilities. The specifications of the lithium-ion battery selected were listed in Table 2. It is a rechargeable battery type, providing versatility in energy storage, and is easily portable due to its small size. With a high-power storage capacity relative to its weight, it proves efficient for various applications. Additionally, it charges more quickly compared to other battery types and does not suffer from memory effect, eliminating the need for full discharge and usage. Its lifespan begins from the date of production.

Table 2. The specifications of the used lithium-ion battery

Voltage	**12.8 V**
Capacity	100 Ah
Energy	1.28 kWh
Battery Cell Type	Prismatic LiFePo4 cell
BMS	Smart 4S
Dimension	255×210×165 mm
Weight	12.5 kg
Total number in the system	36

For the propulsion system of the yacht, an alternating current (AC) electric motor was selected [10]. AC electric motors offer numerous advantages for yacht propulsion. Firstly, they are highly efficient, converting a large portion of electrical energy into mechanical power, thereby reducing energy consumption and operating costs. Their high power-to-weight ratio ensures significant propulsion power while occupying minimal space onboard. Furthermore, AC motors require less maintenance due to fewer moving parts, resulting in reduced downtime and operational costs. They operate quietly, minimizing noise and vibration for improved onboard comfort.

In the propulsion system, PEM fuel cell was chosen. The These fuel cells are a technology that directly converts chemical energy from the electrochemical reaction between hydrogen and oxygen into electrical energy (Fig. 2). The specifications of the used PEM fuel cell were listed in Table 3 [11]. They are characterized by high efficiency, rapid reaction time, and low operating temperature. The key reactions taking place in a PEM fuel cell are as follows:

$$H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

$$0.5O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (2)$$

$$H_2 + 0.5O_2 \rightarrow H_2O \quad (3)$$

These reactions occur at different electrode surfaces separated by the proton exchange membrane.

Table 3. The specifications of the used PEM fuel cell

Power	50 kW
Max Input Voltage	24 V
Hydrogen Supply Pressure	8.5 bar
Type of Cooling	Liquid Cooled
Dimension	939×511×545 mm
Weight	135 kg
Operating Efficiency	%54
Number in the system	4

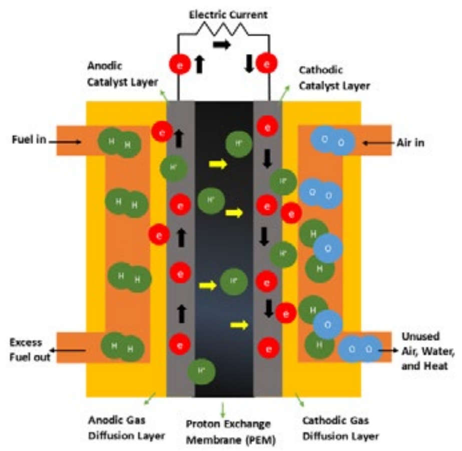

Figure 2. PEM Fuel Cell Working Principle [12]

Hull resistance of the designed ship is calculated using Savitsky (1964) method [13]. Required brake power (P_B) is calculated based on these resistance data while 60% propulsion efficiency is considered. The Schematic diagram of the designed yacht is illustrated in Fig. 3.

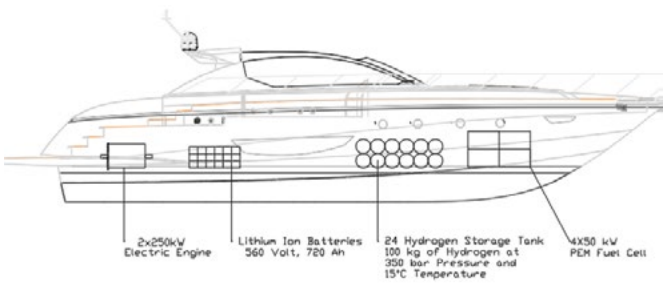

Figure 3. Schematic diagram of yacht propulsion system

Electric Power System:

Electric Motors: The yacht's propulsion relies on two 250kW electric motors, strategically positioned to drive the propellers and propel the vessel forward.

Lithium-Ion Batteries: These serve as the primary energy source for the electric motors. The 560 Volt, 720 Ah lithium-ion batteries efficiently store and supply the necessary electrical energy for yacht operation. Hydrogen Fuel Cell System: Hydrogen Storage Tanks: Integral to the energy production process, the yacht features a hydrogen storage system comprising 24 hydrogen storage tanks. These tanks collectively hold 100 kg of hydrogen at a pressure of 350 bar and a temperature of 15°C. PEM Fuel Cell: The stored hydrogen undergoes a chemical reaction within the PEM fuel cell, resulting in electricity generation. The high-efficiency PEM fuel cell converts hydrogen into electrical power, ensuring sustained operation.

Operational Cycle: As the yacht begins to move, the electric motors engage, setting the propellers in motion. The lithium-ion batteries supply energy to the electric motors, maintaining propulsion. If energy demand exceeds battery capacity or during peak load scenarios, hydrogen is drawn from the storage tanks. The PEM fuel cell activates, catalyzing the reaction between hydrogen and oxygen to produce electricity, simultaneously recharging the batteries.

This integrated system enables the yacht to operate seamlessly using both electric and hydrogen power sources. Significance and Sustainability: This intricate energy integration not only enhances performance but also aligns with environmental sustainability. Electric and hydrogen power systems represent a promising alternative for future maritime transportation. In summary, this holistic approach harmonizes functionality, efficiency, and eco-conscious design, underscoring the yacht's forward-thinking energy paradigm.

3. The Yacht Design and Calculations

The process for designing and evaluating the performance of a hydrogen fuel cell-powered yacht is presented in this section. Figures 4-8 illustrate the detailed views of the yacht design.

Figure 4. Front View of the yacht design

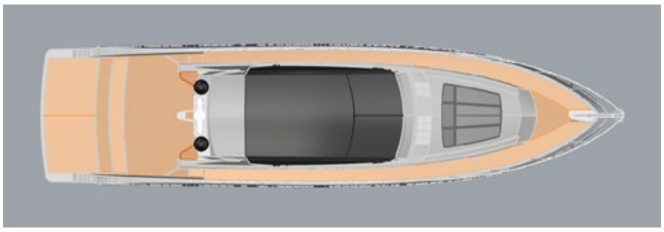

Figure 5. Top View of the yacht design

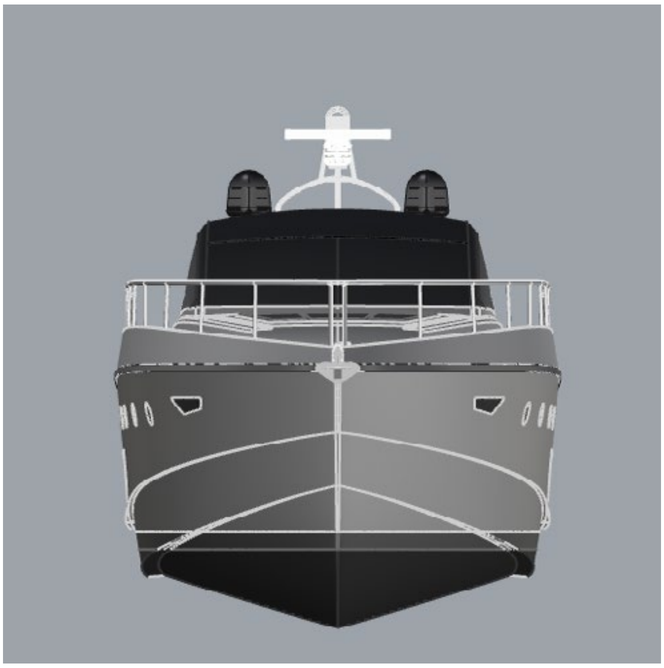

Figure 6. Right View of the yacht design

Figure 7. Left View of the yacht design

Figure 8. Isometric View of the yacht design

Resistance and power calculations for the yacht design were listed Table 4. The design yacht has a power capacity of 500 kW, enabling it to achieve speeds of approximately 22.50 knots. These calculations play a crucial role in optimizing the yacht's performance, ensuring efficient propulsion while meeting the desired speed requirements. By accurately assessing the resistance and power requirements, it can be refined the yacht's specifications to enhance its overall efficiency, maneuverability, and range. Software Used in Yacht Design: Maxsurf and Rhinoceros. This yacht design was realized through the integrated use of professional software tools such as Maxsurf and Rhinoceros. Here are the details of the design process:

Hull Design with Maxsurf: The hull design of the yacht was carried out using Maxsurf software. During this stage, analyses were conducted to optimize the hydrodynamic performance of the hull design. Refinement with Rhinoceros: The hull model designed in Maxsurf was transferred to Rhinoceros software. Rhinoceros was employed for more detailed modeling and shaping. Detailed refinements were made to the hull, considering both aesthetics and functionality. Furniture and instrument panels were integrated into the yacht's cockpit. This enhancement aimed to improve user experience and safety. The design was tailored for individual use, taking into account that implementing a new propulsion system on large-scale vessels might be challenging. This integrated approach harmoniously combines functionality and aesthetics, resulting in a successful yacht design.

Table 4. Resistance and power calculations for the yacht design

Speed (knots)	Resistance (kN)	Effective Power (kW)	Required Brake Power (kW, n = 0,6)
15.00	18.0	138.60	231.01
15.75	18.8	152.60	254.34
16.50	19.7	167.41	279.02
17.25	20.6	183.00	305.00
18.00	21.5	199.33	332.22
18.75	22.4	216.33	360.56
19.50	23.3	233.93	389.89
20.25	24.2	252.04	420.06
21.00	25.0	270.55	450.91
21.75	25.9	289.36	482.26
22.50	26.6	308.37	513.95
23.25	27.4	327.49	545.82
24.00	28.1	346.66	577.77
24.75	28.7	365.83	609.72
25.50	29.3	384.97	641.62
26.25	29.9	404.07	673.45
27.00	30.5	423.14	705.23
27.75	31.0	442.20	737.00
28.50	31.5	461.29	768.81
29.25	31.9	480.44	800.74
30.00	32.4	499.71	832.85
30.75	32.8	519.14	865.24
31.50	33.2	538.79	897.98
32.25	33.7	558.69	931.15
33.00	34.1	578.91	964.84
33.75	34.5	599.48	999.13
34.50	35.0	620.45	1034.09
35.25	35.4	641.87	1069.78
36.00	35.8	663.77	1106.29
36.75	36.3	686.20	1143.66
37.50	36.8	709.19	1181.98
38.25	37.2	732.77	1221.28
39.00	37.7	756.98	1261.63
39.75	38.2	781.84	1303.07
40.50	38.8	807.40	1345.67
41.25	39.3	833.67	1389.45
42.00	39.8	860.68	1434.47
42.75	40.4	888.47	1480.78
43.50	41.0	917.04	1528.40
44.25	41.6	946.43	1577.38
45.00	42.2	976.65	1627.75

Figure 9 illustrates the Resistance-Speed Diagram, providing a visual representation of the relationship between resistance and speed for the yacht design. This diagram is instrumental in understanding the vessel's hydrodynamic performance, depicting how resistance changes with varying speeds. Figure 10 depicts the Power-Speed Diagram, showcasing the relationship between power output and speed. These diagrams offer valuable insights into the yacht's propulsion system requirements, guiding design decisions to optimize performance and efficiency across different operating conditions.

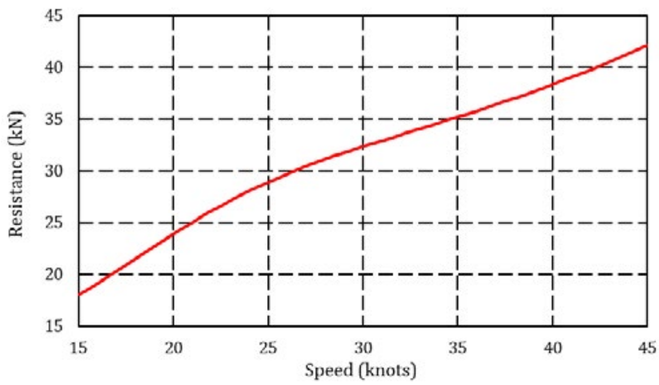

Figure 9. Resistance-Speed Diagram

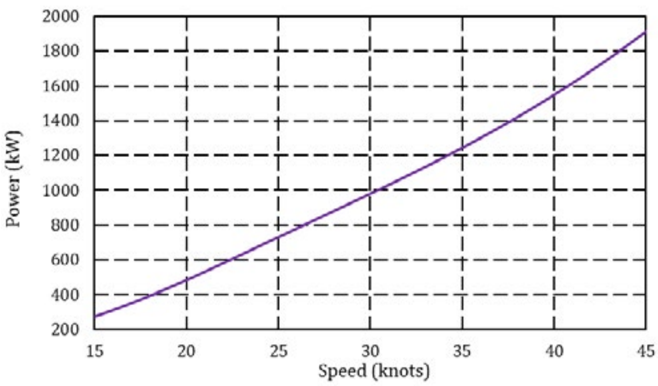

Figure 10. Power-Speed Diagram

5. Conclusion

The development and analysis of the hydrogen fuel cell-powered yacht represents a significant step towards sustainable and environmentally friendly maritime transportation. Through meticulous design, comprehensive calculations, and thorough evaluation, this study has demonstrated the feasibility and potential of hydrogen fuel cell technology in powering marine vessels. The integration of advanced propulsion systems, coupled with innovative design solutions, highlights the possibilities for reducing greenhouse gas emissions and mitigating the environmental impact of maritime activities. Furthermore, the performance assessments conducted, including resistance and power calculations, as well as the examination of resistance-speed and power-speed diagrams, have provided valuable insights into the operational capabilities and efficiency of the yacht design. Overall, this research underscores the viability of hydrogen fuel cell technology as a promising alternative for achieving greener and more sustainable marine transportation solutions.

- The system offers a viable alternative to fossil fuels, promoting sustainability and reducing emissions.
- Recognizing the ecological consequences of current fuels, this study strives to mitigate their negative effects. The transition to cleaner energy sources aligns with global efforts to protect our planet.
- The system will likely become even more practical and efficient. Ongoing research and development will enhance its viability and performance.

In summary, this study represents a crucial step toward a greener maritime industry.

By harnessing cutting-edge technology and prioritizing environmental stewardship, we can propel our seas toward a cleaner, more sustainable future.

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Life Cycle and Cost Assessment of Different Ammonia Fuels on a Case Ship

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Abstract

Amidst the rigorous regulations established by the International Maritime Organization (IMO) and the decarbonization goals outlined for 2050, the maritime sector is actively pursuing alternative approaches to achieve these targets. While alternative fuels hold promises due to their cleaner combustion, concerns persist regarding the harmful emissions generated during their production and transportation phases. Consequently, this study delves into the life cycle emissions and costs associated with conventional, blue, and green ammonia to mitigate GHG emissions. Additionally, the prevalent use of very low sulfur fuel oil (VLSFO) and marine diesel oil (MDO) warrants their consideration, enabling a comprehensive comparison of results. The assessment centers on a specific vessel, calculating the Global Warming Potential over 20 and 100 years according to the IMO guidelines introduced in July 2023. The findings reveal that green ammonia exhibits the highest potential for GWP reduction by 99.8%, followed by blue ammonia at 28.3-43.1%. From a cost perspective, blue ammonia holds an advantage over green ammonia by $3.21M for the reference vessel. Furthermore, the results indicate that conventional ammonia carries a higher environmental impact compared to VLSFO and MDO fuels, coupled with elevated costs, rendering it the least favorable option.

Keywords: *Ammonia, Decarbonization, Life cycle assessment, Life cycle cost assessment*

1. Introduction

Maritime transportation is responsible for the total cargo carried worldwide, with an 85% share, which represents 2.27 billion deadweight tons (dwt) [1]. To meet the energy demand for the transportation process, conventional marine fuels such as heavy fuel oil (HFO), marine diesel oil (MDO), and marine gas oil (MGO) are used. Moreover, after the revision of the sulfur cap on 1 January 2020, very low sulfur fuel oil (VLSFO) became an attractive choice. However, relying on fossil fuels causes harmful air pollutants, and to limit the emission of these emissions, recent regulations and strategies were introduced by the International Maritime Organization (IMO). A recent strategy was announced on 7 July 2023 about limiting GHG emissions by 20% by 2030 and 70% by 2040 regarding the 2008 levels while aiming at total decarbonization by 2050 [2]. Furthermore, at the same Marine Environmental Protection Committee (MEPC 80) meeting, a new set of guidelines was introduced for life cycle assessment (LCA). While currently in the monitoring stage, a new labeling scheme named Fuel Lifecycle Label (FLL) was introduced under the LCA guideline. Fuels will be categorized based on their feedstock, transportation, and combustion characteristics under the FLL scheme [3]. Besides, on 1 January 2024, the EU Emissions Trading System (ETS) entered into force. It is a mandatory regulation for ships above 5000 gross tonnages (GT) traversing in EU and European Free Trade Association (EFTA) ports [4]. Recently, it solely focused on CO_2 emissions, but after 2026, the whole GHG emissions will be included. In addition, FuelEU Maritime regulation will be effective after 1 January 2025, aiming to mitigate GHG emissions, which will also be compulsory for vessels above 5000 GT sailing in EU and EFTA ports [5].

The stricter regulations enforced by the authorities increased interest in alternative fuels, and many studies were conducted on them. However, concerning the decarbonization target of IMO, ammonia and hydrogen fuels became attractive solutions due to carbon freeness. Even though hydrogen provides benefits through decarbonization, alterations on ships are a major setback. Hence, this paper focused on ammonia fuel while considering different production pathways, including conventional, blue, and green ammonia. In this study, LCA and life cycle cost assessment (LCCA) for ammonia, MDO, and VLSFO are conducted on a case ship. Also, MDO and VLSFO fuels are added as the benchmark fuel choices, which enables a comparison opportunity. Despite LCA and LCCA studies being made on these fuels, for instance, Zincir and Arslanoglu, 2024 assessed 14 alternative marine fuels, including ammonia and MDO, in terms of LCA [6], Zou and Yang, 2023 evaluated HFO, ammonia, and other alternative fuels on various sized vessels [7], Zincir et al., 2022 delved into electro fuels for decarbonization target [8] and Bilgili, 2021 investigated alternative marine fuels for maritime transportation [9], it is believed that the paper will contribute to the literature by applying both LCA and LCCA for a case ship fueled by different fuels.

2. Methodology

MDO, VLSFO, conventional, blue, and green ammonia are the fuels included in this paper. MDO is a fossil fuel derived by mixing MGO and HFO. In this study, MDO consists of 52.2% HFO and 47.8% MGO. VLSFO is a residual part of the crude oil obtained after the desulphurization of HFO. Characteristics of VLSFO are the same as the HFO, except the sulfur content of it is less than 0.50%. Conventional ammonia is a carbon-free fuel that is produced from natural gas via steam methane reforming [6]. Blue ammonia is also produced from natural gas, but part of the generated CO2 emissions, while providing sufficient energy for the process, is captured by a carbon capture system. Also, green ammonia is derived from natural gas, yet the electricity requirement is supplied from renewable energy, leading to lower harmful emissions.

In this study, a general cargo vessel with a capacity of 6177 GT is used to assess the impacts of fuel on the environment. To analyze, the fuel data of the reference ship is obtained from the management company. In Table 1 ship, specifications are presented, and in Table 2, the data are demonstrated. The vessel possesses a 2500 kW main engine and three auxiliary engines with 220 kW power output. According to the retrieved data, the case ship combusted 456.10 tons of MDO in 2022 and traveled 11,896.55 nm in a year. Moreover, the ship sailed with an average speed of 7.69 knots.

Table 1. Reference ship specifications.

Ship Specifications	
Ship Type	General Cargo
Ship Built Date	2004
Length Overall (m)	128
Beam (m)	18
Depth Moulded (m)	9.7
Draught (m)	7.6
Gross Tonnage (GT)	6177
Net Tonnage (NT)	3680
Deadweight Tonnage (mtons)	10,300
Main Engine	S.X.D. Daihatsu 8DKM-28 2500kW at 750 rpm
Auxiliary Engine	3x220 kW at 800 rpm
Ship Speed (knot)	12.3
Fuel Type	HFO/MDO
Fuel Tank Capacity (m^3)	363

Table 2. Data retrieved from the management company.

2022 Input Data	
Distance Travelled (nm)	11,896.55
Hours Underway	1546.25
Days at Open Sea	238
Days at Ports and Drydocks	127
Ship Speed (knots)	7.69
ME MDO Consumption (tons)	337.10
AUX MDO Consumption (tons)	119.00

2.1. LCA

LCA is a method to assess the environmental impact of a product or a system with a holistic approach covering its whole life cycle. According to ISO 14040, the LCA should consist of four parts, which are the definition of goal and scope, inventory analysis, environmental impact assessment (EIA), and interpretation of the results [10]. The goal and scope of the study are to analyze the environmental impact of VLSFO, MDO, and ammonia fuels. Consequently, the following assumptions are considered in the inventory analysis step:

- According to the voyage details, the reference ship sailed in the Black Sea and Mediterranean Sea. Hence, the bunkering station is determined in Aliaga (Türkiye).
- In Aliaga, refineries in that region cover 25% of the fuel production in Türkiye [11]. Thus, 25% of the VLSFO and MDO fuels are produced in that region, which requires 10 miles of transportation with pipelines to the port, while the other 75% are exported from Novorossiysk (Russia) by tankers, which is the primary crude oil exporter to Türkiye after Ukraine-Russia War [12]. The distance between the two ports is equal to 708 nm.
- In Türkiye, ammonia is not produced as fuel, therefore it must be imported. The closest facility to Türkiye that produces ammonia is Yara's facilities in the Netherlands and Norway [13]. Although the Netherlands is closer concurrently, conventional ammonia is produced there, while blue and green ammonia fuels are produced in Norway [14]. Consequently, conventional ammonia is imported from Sluiski (Netherlands), and other ammonia fuels are imported from Bergen (Norway). For both cases, ammonia is transported via ocean tankers, while the distance from Sluiski to Aliaga is 3023 nm, and from Bergen to Aliaga is 3534 nm.
- Fuel consumptions for VLSO and ammonia fuels are calculated according to the lower heating value (LHV) of fuels. LHV of MDO is 41.0 MJ/kg, while for VLSFO and ammonia, it is 39.5 MJ/kg and 18.6 MJ/kg, respectively [15].
- The lifespan of the ship is determined as 21 years, and every year, it is assumed that the same outcomes as presented in Table 2 apply.

In this study, LCA is conducted considering GWP_{20} and GWP_{100} results of the fuel choices. Regarding the assumptions, tank-to-wake (TTW) GWP_{20} and GWP_{100} emissions can be determined by using Equations 1 and 2, where $GWP_{CO2(20y)}$, $GWP_{CH4(20y)}$, and $GWP_{N2O(20y)}$ are the CO_2 equivalent of the emissions in 20 years, and for the 100y indices it is CO_2 equivalent in 100 years. For CH_4, the CO_2 equivalent in 20 years is 84, and for N_2O, it is 264, while it is 28 for the former and 265 for the latter [3].

$$GWP_{20}=GWP_{CO_2(20y)}\times gCO_2+GWP_{CH_4(20y)}\times gCH_4+GWP_{N_2O(20y)}\times gN_2O \quad (1)$$

$$GWP_{100}=GWP_{CO_2(100y)}\times gCO_2+GWP_{CH_4(100y)}\times gCH_4+GWP_{N_2O(100y)}\times gN_2O \quad (2)$$

Well-to-tank (WTT) is the other part of the emissions that are emitted, and it is determined by using GREET Model 2023 software. The default database for the production of the fuels is used while conducting the LCA, but transportation modes for the fuels are modeled considering the assumptions.

2.2. LCCA

In this paper, LCCA contains capital expenditure (CapEx) and operating expenditure (OpEx). CapEx considers equipment costs, including their installations, while OpEx consists of maintenance and fuel costs. LCCA is conducted for the reference general cargo vessel, and its 21-year lifespan is considered. Table 3 shows the input data while carrying out the LCCA analysis.

Table 3. LCCA inputs

Fuel	CapEx ($/kW)	Fuel Cost ($/ton)	Maintenance Cost ($/kW)	References
VLSO	272.5[a]	710	0.015[a]	[16-19]
MDO	272.5[a]	660	0.015[a]	[16-19]
Conventional Ammonia	577.7[a]	600	0.015[a]	[6, 18, 20, 21]
Green Ammonia	577.7[a]	800	0.015[a]	[6, 18, 20, 21]
Blue Ammonia	577.7[a]	640	0.015[a]	[6, 18, 20, 21]

[a]€/$ ratio is taken as 1.09

CapEx of the fuel systems is calculated by multiplying the main engine and auxiliary engine power with the CapEx cost in Table 3, while life cycle fuel cost is determined using Equation 3 [18].

$$LCFC_i = LM \times (FC_M \times FP_M + FC_D \times FP_D) \quad (3)$$

In the equation, $LCFC_i$ is the life cycle fuel cost for i type of fuel, LM is lifetime mileage, FC_M is the fuel consumption for the main fuel, FP_M is the price of the main fuel, FC_D is pilot fuel consumption, and FP_D is the price of the pilot fuel. Besides using Equation 4, the life cycle maintenance cost is determined [18].

$$LCMC_i = LM \times EC \times MC_i \quad (4)$$

In Equation 4, $LCMC_i$ represents the life cycle maintenance cost, EC stands for energy consumption, and MC_i is the maintenance cost for an i type of fuel system. EC is calculated by using Equation 5, where P_{MEavg} and P_{AUXavg} are the average power of the main and auxiliary engines.

$$EC = \frac{P_{MEavg} + P_{AUXavg}}{ShipSpeed_{avg}} \quad (5)$$

3. Results and Discussion

In Table 4, findings of the annual GWP calculations are presented for the case of a general cargo ship. Although ammonia is a carbon-free fuel in the combustion stage, during production, conventional ammonia emitted more than ten times higher CO_2 emissions compared to MDO and VLSFO. In addition, CH_4 emission is also higher considering MDO and VLSFO. Hence, conventional ammonia possesses the worst performance among the fuels. On the contrary, blue ammonia has higher GWP emissions in the WTT phase, except for conventional ammonia in TTW, which performed better than MDO and VLSFO. That makes it a competitive choice for maritime transportation. Furthermore, green ammonia has the lowest GWP among the choices, with a quiet margin both in the WTT and TTW phases.

Table 4. GWP results of the reference vessel

Fuel	Emission	WTT	TTW	WTW	GWP_{20}	GWP_{100}
VLSFO	CO_2	170.27	1474.2	1644.5	1644.5	1644.5
	CH_4	1.667	0.024	1.691	142.02	47.34
	N_2O	0.003	0.085	0.088	23.29	23.38
MDO	CO_2	163.80	1462.2	1626.1	1626.1	1626.1
	CH_4	1.647	0.023	1.670	140.26	46.75
	N_2O	0.003	0.082	0.085	22.47	22.55
Conventional Ammonia	CO_2	1781.8	-	1781.8	1781.8	1781.8
	CH_4	5.419	-	5.419	455.15	151.72
	N_2O	0.036	0.243	0.279	73.69	73.97
Green Ammonia	CO_2	-126.98	-	-126.98	-126.98	-126.98
	CH_4	-0.202	-	-0.202	-16.94	-5.65
	N_2O	-0.003	0.243	0.240	63.41	63.65
Blue Ammonia	CO_2	665.72	0	665.72	665.72	665.72
	CH_4	5.686	0	5.686	477.66	159.22
	N_2O	0.008	0.243	0.251	66.17	66.42

WTW: well-to-wake

Figure 1 shows the LCA results of the reference ship through its lifespan. Concerning the figure, green ammonia has the lowest GWP_{20} and GWP_{100} emissions, followed by blue ammonia. MDO and VLSFO fuels have similar outcomes with a slightly better performance with MDO, which is 1.16% for GWP_{20} and 1.15% for GWP_{100}. The least favorite fuel is conventional ammonia, which has 24.9% higher GWP_{20} and 18.5% higher GWP_{100} compared to MDO fuel. On the other hand, blue ammonia has 28.3% and 43.1% GWP_{20} and GWP_{100} reduction potential, respectively, compared to MDO. Additionally, compared to MDO, green ammonia mitigates GWP_{20} by 100.4% and GWP_{100} by 99.8%.

Figure 2 shows LCCA findings for the case ship throughout its 21-year lifespan. According to the results, maintenance cost has the lowest impact on the cost, followed by CapEx, while fuel price has the most. Even though ammonia fuel cost per ton is not that high compared to MDO and VLSFO, its lower LHV makes the fuel cost almost two times higher. Considering the total costs, MDO has the lowest with $7.850M, followed by VLSFO with $8.587M. For the ammonia fuels, conventional ammonia has the lowest with $14.843M, while blue ammonia is $15.646M, and green ammonia is $18.855M.

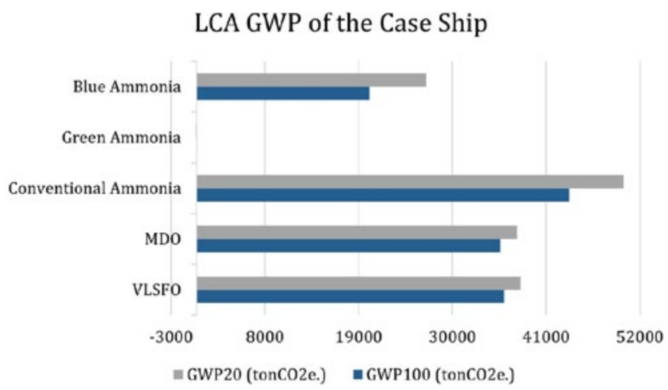
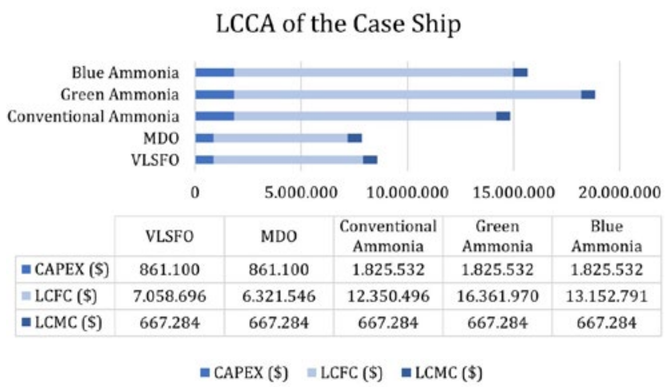


Figure 1. LCA results of the reference vessel through its lifetime



	VLSFO	MDO	Conventional Ammonia	Green Ammonia	Blue Ammonia
CAPEX ($)	861.100	861.100	1.825.532	1.825.532	1.825.532
LCFC ($)	7.058.696	6.321.546	12.350.496	16.361.970	13.152.791
LCMC ($)	667.284	667.284	667.284	667.284	667.284

Figure 2. LCCA results of the reference vessel through its lifespan

Lastly, a decision must be made regarding the LCA and LCCA analysis. The decision is evident among MDO, VLSFO, and conventional ammonia, as MDO demonstrates superior performance in both environmental and cost perspectives. However, for blue and green ammonia, several concerns arise. From an environmental standpoint, green ammonia can fulfill the IMO's 2050 decarbonization targets, while blue ammonia, at present, can only align with the 2030 strategies. On the other hand, recent targets solely focus on the combustion stage, and considering that ammonia is a carbon-free fuel, even conventional ammonia can meet this target. In July 2023, the LCA Guideline was introduced by IMO, indicating that not only the consumption of the fuels but also the production and transportation stages of the fuels will be included in the future years. Besides the environmental impact of blue and green ammonia, the costs of them play an important role. Green ammonia costs $3.21M higher compared to blue ammonia, which is the case for a 6177 GT general cargo vessel. The cost may vary depending on the ship type, size, route, and operations of the engine. Hence, in future studies, investigating those concerns plays an essential role in making a final decision.

4. Conclusion

With the stricter regulations introduced by the authorities in international shipping, alternative fuels emerged as one of the attractive solutions. The paper investigates different ammonia fuel pathways regarding LCA and LCCA. Besides, MDO and VLSFO are included to enable comparison of the fuel choices. The study reveals that green ammonia has the highest positive environmental impact with more than 99.8% GWP reduction, followed by blue ammonia with 28.3-43.1%, while conventional ammonia is the least favorite, performing worse than the current alternatives. Furthermore, in terms of cost, blue ammonia emerges as a promising option compared to green ammonia. However, further revisions to the LCA Guideline will ultimately determine the final decision. In addition, scarcity of green ammonia is still an issue as fossil-fueled electricity is more widely available instead of renewable energy. Consequently, the utilization of both blue and green ammonia may resolve the issues related to the availability of the fuels.

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Nomenclature

CapEx	Capital Expenditure
dwt	deadweight tons
EFTA	European Free Trade Association
EIA	Environmental Impact Assessment
ETS	Emission Trading System
FLL	fuel lifecycle label
GT	gross tonnages
GWP	global warming potential
HFO	heavy fuel oil
IMO	International Maritime Organization
LCA	life cycle assessment
LCCA	life cycle cost assessment
LHV	lower heating value
MDO	marine diesel oil
MEPC	Marine Environmental Protection Committee
MGO	marine gas oil
NT	net tonnage
OpEx	Operation Expenditure
TTW	tank-to-wake
VLSFO	very low sulfur fuel oil
WTT	well-to-tank
WTW	well-to-wake

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The Use of Lithium-Ion Batteries in Reducing the Carbon Footprint of Navigation

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Abstract

Seas are important trade routes that are preferred for transporting various cargoes in large quantities to long distances economically. However, it could also negatively affect the environment. Other pollutants, especially exhaust gas emissions, such as oil spills and noise, can cause irreversible damage to the marine environment. When climate policies are implemented more concretely, the use of more environmentally friendly and sustainable fuel alternatives will inevitably become widespread on ships. The most important alternative that can be offered to reduce the negative impact of fossil fuels on the environment is vehicles that are powered by battery systems. This study aims to meet the energy needs of ship navigation with lithium-ion battery-based energy storage systems, by evaluating the decade of the oceans, blue-growth, and 2030-2100 targets. The study evaluated the operations carried out by cargo ships on a particular route and determined the average amount of carbon footprint and emissions generated during its traditional use. Additionally, cost calculations and the carbon footprint and emissions were analyzed that would be generated if the same ship were to use a lithium-ion battery for electricity while performing the same operations on the same route.

Keywords: *Lithium-ion Battery, Maritime Transport, Carbon Emission, Carbon Footprint*

1. Introduction

The oceans that cover a large part of our world (more than 70% of the earth's surface) also constitute a large living area of our planet. In addition to producing most of the oxygen in the air we breathe, it absorbs most of the carbon we produce [1]. Also, oceans provide climate regulation, transportation, trade opportunities, food, raw materials (as an example for medicine), economic benefits (goods and services), as well as various activities (such as boating, and fishing), and recreation areas [2]. When evaluated from an oceanographic and social perspective, the sustainability of the oceans, which provide many opportunities for us and the environment as mentioned, is in danger due to global warming, which increases with anthropogenic pressure, and the resulting climate change. Global warming is a term that signifies the impact of human activities on the environment, specifically the burning of fossil fuels such as coal, oil, and gas, and the extensive deforestation that results in the release of significant amounts of greenhouse gases (GHG) into the atmosphere (primary and the important one is carbon dioxide (CO_2)) [3]. As mentioned, CO_2 is Earth's most important GHG that absorbs and radiates heat [4]. As stated, oceans, which have a major role in regulating the climate, partially buffer the effects of increasing GHG levels in the atmosphere and increasing global temperatures. Furthermore, the oceans have taken up approximately 40% of anthropogenic CO_2 from the atmosphere since the beginning of the industrial revolution [5]. Marine transportation activities are one of the factors also affecting the climate change. Maritime transport constitutes a large part of international trade [6]. As a result of that, global marine transportation is associated with negative environmental effects, especially on the marine environment [7]. The shipping industry has 3.9% of the CO_2 output of the World (which is equivalent to 1,260 million tons of CO_2) [8]. Therefore, it could be said that carbon emissions sourced by maritime transport contribute huge carbon footprint and ascending demand for maritime transportation will also increase the global carbon footprint in upcoming years [9]. Wiedmann and Minx (2008) defined carbon footprint in their study as follows; "The carbon footprint is a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product". This includes activities of individuals, populations, governments, companies, organizations, processes, industry sectors, etc. [10]. In light of this definition, when we evaluate maritime transport, the carbon footprint of maritime transport includes not only the direct emissions from ships but also the indirect emissions associated with the entire supply chain, including ship production, transportation of goods to ports, infrastructure maintenance and many other related processes. Being a significant part of global trade and the source of CO_2 emissions creates the need to develop methods to reduce these emissions and make efforts to mitigate climate change. Carbon footprint has become an important tool for developing strategies to evaluate emissions caused by anthropogenic pressures and to take the necessary measures [11]. Several actions have been taken to prevent anthropogenic pressure on the ocean and various studies have also been carried out in recent years. There are some formations and concepts to evaluate these resources provided by the seas and oceans. The decade we live in is crucial for the oceans therefore the United Nations announced it as the Ocean Decade (2021-2030) [12]. Additionally, IPCC (The Intergovernmental Panel on Climate Change) and IMO (International Maritime Organization) also carry out studies and set targets to reduce the effects of climate change, global warming, and GHG. Current GHG evaluated by maritime transportation represents around 3% of global anthropogenic GHG emissions and for the meet of Paris Agreement goals, it will have to cut half by 2050 [13]. But until 2050, If no emission control measures are taken and mitigation policies are not established, the IMO's mid-term emission scenarios predict that merchant ship emissions will increase by 150-250% in 2050 due to the growth of world trade [14]. The main source of the emission of ships is the exhaust gas that comes from fuel combustion in the ships' engines [15]. In this regard, using more environmentally benign and low-emission fuels is becoming crucial. However, electrification of transportation, especially with the extensive adoption of electric vehicles (EVs) could be an alternative solution. Storage systems in EVs allow for the utilization and storage of electricity from renewable sources, lowering dependence on fossil fuels for transportation. As global warming has reached critical levels, the importance of clean energy has started to ascend [16]. Energy storage systems play a decisive role in the integration of renewable energy sources such as wind and solar power into the grid [17]. The rapid expansion of the transition to electric systems in vehicles reveals the impact of energy storage systems on reducing the carbon footprint and as an indicator of this situation, we see a rapidly growing battery market [18]. Battery power enables zero carbon operations both onshore (charging infrastructure) and onboard. With the advancement of technology and the widespread use of batteries on an industrial scale, the operation of ships with electric power becoming a focus of interest such as hybrid cruise ships. While serious steps are being taken to reduce the carbon footprint, it is also important to start considering switching to electric systems on cargo ships. The most important factor for electric cargo transport ships to become feasible is the technological and economic developments that will occur in battery systems. Therefore, we tried to emphasize the importance of this issue by various calculations within the scope of this study.

2. Methodology

Symbols, and abbreviations used in methodology and calculations are given in Table 1 with their detailed descriptions and units for better and clear understanding.

Lithium-ion batteries are identified according to their cathode active materials. The most commonly used lithium ion battery types today are; $LiNi_xMn_yCo_zO_2$ (NMC), $LiNi_xCo_yAl_zO_2$, $LiCoO_2$ (LCO), $LiFePO_4$ (LFP) [19]. Within the scope of the study, LFP batteries were selected, and the calculations were made based on their properties. Although LFP types have a 20% to 25% lower energy density (Wh/kg) than NMC and NCA batteries, they provide great advantages in terms of cost, especially in applications where high amounts of energy will be stored [20]. Furthermore, they can provide longer cycle life due to their stable PO_4 structure compared to O_2-based cathodes such as NMC, NCA, and LCO [21]. Therefore, LFP batteries were preferred in the ship designs within the scope of the study, and calculations were made based on the features of commercial LFP battery systems specified in Table 2.

Table 2. Properties of selected battery system

Battery Parameters	Value	Unit
Battery type	Lithium-ion	-
Cathode	$LiFePO_4$ (LFP)	-
Anode	Graphite	-
Battery Management System	Included	-
Capacity	110	kWh
Weight	280	kg
Weight per kWh	2.54	kg
Volume	0.333	m^3
Volume per kWh	0.003	m^3
Price	190	kWh/USD

Table 1. Descriptions and units of symbols and abbreviations

Symbols and Abbreviations	Description	Unit
V	: Vessel Speed	knot
T	: Voyage time	hour
$T_{(annual)}$	: Annual voyage time	day
W	: Main engine power	kWh
$Cost_{(LFP)}$	: Cost of LFP Battery per kWh	USD/kWh
$Weight_{(LFP)}$	: Weight of LFP Battery per kWh	USD/kWh
$Volume_{(LFP)}$	: Volume of LFP Battery per kWh	USD/kWh
C	: Capacity of battery system for related vessel	MWh
$C_{(Annual)}$	: Annual electricity need for related vessel	MWh
R	: Range of fully charged battery for related vessel	NM
$Cost_{(battery)}$	: Cost of the total battery system for related vessel	US
$Weight_{(battery)}$	: Weight of the total battery system for related vessel	tons
$Volume_{(battery)}$	: Volume of the total battery system for related vessel	m^3
F	: Fuel consumption of the main engine	tons/hour
$ACost_{(electricity)}$	: Annual cost of the electricity to charge the battery system for related vessel	USD
$ACost_{(IFO380)}$	: Annual cost of Intermediate fuel oil with maximum viscosity of 380 centistokes (IFO380) would be consumed if the distance traveled by the fully charged battery for the relevant vessel was traveled with a conventional system.	USD
$AWeight_{(IFO380)}$	: The amount of IFO380 would be consumed if the distance traveled by the fully charged battery for the relevant ship was traveled with a conventional system.	tons
$Cost_{(IFO380)}$	: Cost of IFO380 per ton	USD/ton
$Cost_{(electricity)}$	: Cost of electricity per kWh	USD/ton
$E_{(electricity)}$	: CO_2 emission weight for the production of 1kWh electricity	kg
$E_{(IFO380)}$	: CO_2 emission weight for 1 kg heavy fuel oil	kg
$E_{(LFP)}$	: CO_2 emission weight for the production of 1kWh LFP battery	kg
$E_{(LFPsystem)}$	: CO_2 emission weight for the production of LFP battery system for related vessel	kg
$AE_{(IFO380)}$	: Annual CO_2 emission when fuel oil is used	tons
$AE_{(electricity)}$	: Annual CO_2 emission when electricity is used	tons

Nowadays, it is possible to obtain systems that can store high amounts of power by using lithium-ion batteries. In the studies on electric ships, a ferry named Incat Hull 096, which will start its voyages in 2025 and operate between Argentina and Uruguay, has the title of being the world's largest all-electric ship with its 40 MWh battery system [22]. Considering these developments, much larger battery systems may be integrated into ships in the coming years, which will lead to fully electric cargo ships being available. Based on this information, we aimed to analyze the possible cost and CO_2 emission changes that may occur in different types of cargo ships.

Table 3. Features of selected ships

Features	SP1 (Neo-Panamax)	SP2 (Handysize)	SP3 (Coaster)	Unit
Length	368	189	116.2	m
Breadth	51	30	18	m
Draught	15.8	10.7	7	m
Deadweight, max	150000	43000	6494	dwt
Speed	21.5	15	15	kn
Main engine power	40086	7680	2500	kW
Fuel consumption	6.16	1.2	0.462	tons/hour
Non-stop voyage time	168	72	72	hour

In the scenarios where LFP batteries are used, three different-sized ships (neo-Panamax, handysize, and general cargo coaster (which are real ships on the market)) are taken as reference and the technical specifications of these ships are shown in Table 3. While designing suitable batteries for those ships, the non-stop voyage time was determined as 7 days for SP1 and 3 days for SP2 and SP3. This study calculated the different cost and CO2 emission values that would occur if LFP-type lithium-ion batteries with electric motors were used in the main engines of different cargo ships instead of conventional fuel-powered systems. Calculations were made with the current values of 2023 and the estimated values of the parameters that are expected to change in 2050. All equations used in the calculations are shown in Table 4.

Table 4. Equations for calculating CO_2 emission values and battery costs

Equations	Equation Numbers
$C = W \times T$	1
$R = V \times T$	2
$Cost_{(battery)} = C \times Cost_{(LFP)}$	3
$Weight_{(battery)} = C \times Weight_{(LFP)}$	4
$Volume_{(battery)} = C \times Volume_{(LFP)}$	5
$AWeight_{(IFO380)} = T_{(Annual)} \times F \times 24$	6
$ACost_{(IFO380)} = AWeight_{(IFO380)} \times Cost_{(IFO380)}$	7
$C_{(Annual)} = W \times T_{(Annual)} \times 24$	8
$ACost_{(electricity)} = C \times Cost_{(electricity)}$	9
$AE_{(IFO380)} = E_{(IFO380)} \times AWeight_{(IFO380)}$	10
$AE_{(electricity)} = E_{(electricity)} \times C_{(Annual)}$	11
$DAE = AE_{(electricity)} - AE_{(IFO380)}$	12
$E_{(LFPsystem)} = C \times E_{(LFP)}$	13
$Amt_{(LFP)} = E_{(LFPsystem)} / DAE$	14

Also for evaluation of carbon footprint and emissions; fixed parameters that were used in the calculations were specified in Table 5.

Table 5. Fixed values used in CO_2 emission calculations

Year	Parameters	Value	Unit	References
2023	Price of 1-tonne fuel oil (IFO380)	517	USD	[23]
	Price of 1 kWh of electricity	0.23	USD	[24]
	CO_2 emission for 1 kg heavy fuel oil	3.114	kg	[25]
	CO_2 emission for 1 kWh electricity production (global)	0.436	kg	[26]
	CO_2 emission for 1 kWh LFP battery production	76.6	kg	[27]
2050	CO_2 emission for 1 kg heavy fuel oil	3.114	kg	[25]
	CO_2 emission for 1 kWh electricity production (global)	0.15	kg	[27]
	CO_2 emission for 1 kWh LFP battery production	30.7	kg	[26]

It is important to understand and evaluate emissions to make a carbon footprint assessment. Because emissions, especially CO_2 emissions, are directly related to the carbon footprint. When assessing the carbon footprint, it is essential to understand the amount of indirect or direct emissions generated by the components of the selected process, industry, or activity [10]. There are many factors found that affect ship-related emissions; such as fuel type, engine efficiency, vessel size and design, speed, cargo capacity, engine age, distance traveled, weather, and operational mode (at sea, in port, or maneuvering) [14][30]. Considering these factors, two types of approaches are used when calculating ship emissions; The first is the top-down (which is based on the amount of fuel consumption and the type of ship) and the second method is the bottom-up approach (which calculates emissions according to the type of ship, engine class and speed, and navigation mode) [29]. This study analyzed the fuel consumption amount of different types of ships depending on their potential navigation performance rather than ships operating on a specific route. The purpose here is to understand the change depending on the electrical power with a battery system, which is a comparison tool, rather than examining the known carrying capacity-consumption relationship. Considering that information, in this study from general to specific; maritime transportation, various ships, fuel, and energy alternatives were evaluated in this context. While making carbon footprint calculations and evaluations, the carbon footprint of three different selected ships (SP1, SP2 and SP3) was examined when fuel oil, which is traditional fuel for ships, was used and when lithium-ion batteries, which is a new technology for ships, were used. While the energy source of the ships used during evaluations changes; other factors affecting emissions, such as the route they sail, the load they carry, and their speed, are considered similar for all ships. In addition, the carbon footprint that will sourced from the crew, the waste that will be generated, and the resources that will be used for the ship selected during such navigation have been neglected. Although lithium-ion battery systems lead a carbon zero process during navigation, the carbon footprint of electricity generation and battery production processes have been calculated to understand the whole system holistically.

3. Result and Discussion

Results obtained from calculations for 2023 and 2050 were demonstrated in Table 5. The designed battery system is aimed to provide uninterrupted power to the main machine for 7 days for SP1 and 3 days for SP2 and SP3. Battery capacities were calculated using equation 1 based on 110 kWh LFP batteries from Jiangsu Gso New Energy Technology. According to Equation 3, a 6734 MWh battery system was installed in SP 1 for 1279 million USD, while the costs for SP2 and SP3, which have much lower battery capacities, were calculated as 105 and 34 million USD, respectively. The annual cost of fuel oil spent according to the engines of SP1, SP2 and SP3 is 24.45, 4.76 and 1.83 million, respectively (Equation 7). If these ships had operated with an electric engine supported by lithium-ion batteries instead of conventional main engines, the annual electricity cost would have been 70.8, 13.5 and 4.4 million USD. As can be seen from these results, both the initial cost of electric ships and the energy they consume during the voyage are very high compared to conventional systems. However, the most important advantage of these systems is that they have a low carbon footprint. As seen in Table 5; according to Equations 10, 11 and 12, if SP1, SP2 and SP3 ships were operated with electricity instead of a conventional system, there would be a decrease in the amount of CO_2 released into the environment annually by 13.09, 2.98 and 2.67 tons, respectively. However, another issue to consider is the carbon footprint of these battery systems to be integrated into ships. When we look at the carbon footprint of LFP battery production, it is seen that the average is 76 $kgCO_2/kWh$, and approximately 515 thousand tons of CO_2 are released when producing the battery system required for a large ship such as SP1 (Equation 13) [27]. This high amount of CO_2 released from LFP production can only be compensated after approximately 35 years with the lower CO_2 carbon footprint provided by electric ships. The situations given above are calculated according to 2023 data and may not show promising values. However, with the increase of renewable energy usage for electricity generation in the following years, it is predicted that CO_2 emission from electricity production will decrease from 0.436 $kgCO_2/kWh$ to 0.150 $kgCO_2/kWh$ [26]. This will significantly decrease the carbon footprint of charging electric ships and producing the battery systems they need. Depending on the reduction in carbon emissions related to electricity generation and the developments in battery technologies, it is estimated that the carbon footprints per kWh of LFP battery production will decrease from 76.6 CO_2/kWh to 30.7 $kgCO_2/kWh$ in 2050 [25]. When we updated the calculations according to the emission values for 2050 If SP1, SP2 and SP3 ships were operated with electricity instead of a conventional system, the decrease in the amount of CO_2 released into the environment annually would be 101.14, 19.85 and 8.16 tons, respectively, and with this reduction in CO_2 emissions, the carbon footprint resulting from the production of the batteries these ships need can be compensated in less than 3 years.

Table 5. Results obtained from calculations for 2023 and 2050.

Year	Parameters	SP1 (Neo-Panamax)	SP2 (Handysize)	SP3 (Coaster)	Unit
2023	Capacity of Battery system	6,734	552	180	MWh
	Range of fully charged battery	3,611	1,079	1,079	NM
	Cost of battery system (including BMS)	1,279	105	34.2	Million USD
	Weight of the BS	17,142	1,407	458	tons
	Volume of the BS	20,387	1,674	544	m3
	Cost of fully charging of BS	1,548,923	127,180	41,400	USD
	Annual fuel oil consumption	47,308	9,216	3,548	tons
	Annual fuel oil cost	24.45	4.76	1.83	Million USD
	Annual electricity cost for the main engine	70.80	13.56	4.41	
	Annual voyage time	320	320	320	day
	Annual CO_2 emission when fuel oil used	147,319	28,698	11,049	tons
	Annual CO_2 emission when electricity is used	134,227	25,716	8,371	tons
	Annual CO_2 emission difference between IFO380 and electricity usage	13,092	2,982	2,677	tons
	CO_2 emission of BS production	515,858	42,376	13,788	tons
	Amortization of CO_2 emissions from LFP battery production	39.4	14.2	5.15	year
2050	Annual CO_2 emission when electricity is used	46,179	8,847	2,880	tons
	Annual CO_2 emission difference between hfo and electricity usage	101,140	19,851	8,169	tons
	CO_2 emission of BS production	321,233	26,376	8,586	tons
	Amortization of CO_2 emissions from battery production	3.18	1.33	1.05	year

According to the evaluations, when the situation comes to large cargo ships which are navigate the oceans, electric drives are still has a long way because batteries are not efficient enough and too heavy for sailing long distances [22]. In addition, the ports used today do not yet have the necessary technology to port these ships. However, on the other hand, carbon footprint is of great importance, especially in determining the measures that need to be taken. In this regard, various targets are implemented by institutions in order to reduce carbon emissions and carbon footprint, for example; the revised IMO GHG Strategy, which was adopted at the MEPC 80 (Marine Environmental Protection Committee), includes a more ambitious plan to achieve net-zero GHG emissions from international shipping by or around 2050. This plan also includes a commitment to ensure the use of alternative zero and near-zero GHG fuels by 2030 [31]. In addition, the IMO estimates that CO_2 emissions will increase by approximately 50% compared to 2018 levels by 2050 as demand for maritime transport continues to increase, and the sector appears to be under pressure to reduce these emissions [32]. For this reason, it is important to conduct and take into account pioneering and insightful studies such as this study. In order to better understand the evaluations in this study, the determined carbon footprint evaluations are presented in terms of offsets as follows; One hectare of trees can sequester approximately 50 tons of carbon, equivalent to approximately 180 tons of CO_2 in the atmosphere [33]. If we make an evaluation for the SP1 ship used in this study to better understand the situation; Approximately 818 hectares of trees are required to eliminate the carbon footprint due to CO_2 that occurs when fuel oil is used (for one year of navigation). These numbers, which are valid for navigation in SP1 dimensions and under the given conditions, do not seem very encouraging for the environment, considering the size and developing situation of global maritime transportation. On the other hand, in this study, when the same ship is evaluated under the same navigation conditions, approximately 746 hectares of trees are required to offset the carbon footprint due to CO_2 that will be released due to the production of electrical energy when a lithium-ion battery is used. Although the difference may not seem like much, but it is a significant difference under today's conditions. In addition, approximately 257 hectares of trees are required to offset the carbon footprint due to CO_2 that will be released due to the production of electrical energy when a lithium-ion battery is used in 2050. In other words, while the carbon footprint of traditional fuels will not decrease in the future, the carbon footprint of electricity use and production will decrease and offset will become easier, and perhaps even approach zero. It is also important to remember that the ship is carbon-zero while navigating in the ocean [22]. With the possibility of changing energy production methods in the coming years, the carbon footprint of electric ships will inevitably decrease to very low amounts or even be zero.

3. Conclusion

This study numerically shows and evaluates the possible changes of carbon footprint, emissions, and economical situation of selected cargo ships when used Lithium-ion battery systems instead of traditional systems. It is seen that there will be both direct and indirect reductions in emissions and carbon footprint due to lithium-ion battery systems being used on ships in the coming years. Additionally, as stated in the study, oceans and seas provide benefits for humanity in a wide range and also reduce the negative effects caused by GHG. Furthermore, maritime trade routes are preferred for transporting various cargos in large quantities to long distances as economically. For this reasons, it is very crucial to ensure the sustainability of oceans and seas. Therefore, the use of battery systems instead of fuel not only reduces or eliminates the emissions of GHG but also prevents other pollutants such as oil spills and noise, which can cause irreversible damage to the marine environment. Although port processes were neglected during the calculations in this study, if evaluations are made in terms of green port application with different researchers, the carbon footprint will decrease further. The systems operating on a certain route and the potential navigation performances of these systems, which indicate the instantaneous situation rather than the annual capacity-profitability, were also taken into consideration in this work. Obviously, to obtain more extensive results, annual transportation optimizations should be made in future studies and classical/electric navigation should be compared. Another important issue is that considering more ship types and fuels other than HFO will arouse curiosity, especially in terms of comparing green energy with electricity.

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Voyage Based the Carbon Intensity Indicator (CII) assessment of LNG Usage: A Case of Bulk Carrier

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Abstract

The maritime sector is currently experiencing a major transformation as it explores sustainable alternatives to conventional fossil fuels. This study focuses on the Carbon Intensity Indicator (CII) assessment of Liquified Natural Gas (LNG). The data from a one-year noon report for a ship are being analyzed to assess the LNG conversion. This transformation is being examined in terms of its impact on the CII performance of the bulk carrier, a crucial segment of the shipping industry and is being compared to traditional marine fuel Very Low Sulphur Fuel Oil (VLSFO) and Marine Gas Oil (MGO). The methodology involves real data collection from a bulk carrier operating on LNG, measuring key performance indicators such as fuel consumption, greenhouse gas emissions, and operational costs. The findings aim to shed light on the potential reductions in carbon emissions achievable through the adoption of LNG. The outcomes of this research contribute to the ongoing discourse on sustainable maritime practices, offering valuable insights for stakeholders, policy-makers, and industry players. By analyzing the case of a bulk carrier, the study provides a practical application of the CII assessment for LNG, facilitating informed decision-making in the transition toward cleaner and more sustainable shipping solutions.

Keywords: *Decarbonization; Alternative fuels; CII; Bulk carrier*

1. Introduction

The maritime industry, a cornerstone of global trade and transportation, plays a pivotal role in connecting markets, enabling the exchange of goods, and driving economic growth worldwide [1]. Shipping is the primary mode of transport for the vast majority of global trade, with over 80% of the world's goods transported by sea at some point in their voyage [2]. This reliance on maritime transportation highlights the importance of the shipping industry in sustaining global trade flows and supporting economic development. Additionally, shipping is a complex and multifaceted industry that encompasses a wide range of activities [3]. The industry is characterized by its global reach, with ships plying the world's oceans to transport goods between continents and countries. This global connectivity is essential for ensuring the smooth functioning of international trade, enabling businesses to access markets and consumers to access a wide range of products. Despite its importance, the shipping industry is facing increasing scrutiny over its environmental impact, particularly its contribution to climate change [4]. In ships, certain components, including the main engine, diesel generators and boiler generate exhaust gas as a byproduct of their combustion processes [5]. The primary pollutants released into the environment by exhaust gases are sulfur oxides (SO_x), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), volatile organic compounds (VOCs), black carbon (BC), and organic carbon (OC) [6], [7]. Therefore, shipping is responsible for a significant share of global carbon emissions, accounting for around 2% – 3% of worldwide CO_2 emissions, 10% – 15% of NO_x emissions, and 4% – 5% of SO_x emissions [8].

The imperative for change in the maritime sector is driven by a confluence of factors, including tightening regulatory frameworks, growing public awareness of environmental issues, and the imperative to meet global climate goals. The International Maritime Organization (IMO), the United Nations agency responsible for regulating shipping, has set ambitious targets to reduce greenhouse gas emissions from the sector. With the IMO's strategy aiming to cut total emissions by at least 50% by 2050 compared to 2008 levels, the maritime industry faces a pressing need to adopt cleaner, more sustainable fuels and Technologies [9]. Regulatory frameworks, such as those set by the International Maritime Organization (IMO), are also driving change in the industry, mandating reductions in greenhouse gas emissions and stricter standards for fuel quality. As governments, businesses, and consumers increasingly prioritize environmental sustainability, the pressure on the shipping industry to reduce its emissions and improve its environmental performance is expected to grow. To meet these challenges, the shipping industry is exploring a range of emission reduction techniques and alternative fuels. Alternatives being considered include biofuels, LNG, hydrogen, and ammonia, gasoline-diesel, gasoline-biodiesel, ethanol-diesel, natural gas-diesel [10], [11]. These fuels have the potential to significantly reduce emissions compared to traditional marine fuels and could play a key role in helping the shipping industry achieve its environmental goals. In response to these challenges, stakeholders across the shipping industry are exploring alternative fuels and technologies to reduce emissions and mitigate the sector's environmental impact. One of the most promising alternatives is Liquified Natural Gas (LNG), which has emerged as a cleaner and more sustainable fuel option compared to traditional marine fuels [12], [13]. LNG is a natural gas that has been cooled to

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liquid form for ease of storage and transportation. It produces lower emissions of greenhouse gases and pollutants compared to conventional marine fuels, making it an attractive option for reducing the environmental impact of shipping [14]. On the other side, central to the effort to reduce emissions in the maritime sector is the concept of the Carbon Intensity Indicator (CII), a metric that measures the amount of CO_2 emitted per unit of cargo transported. The CII provides a standardized framework for assessing the environmental performance of ships, enabling comparisons across different vessels and fuel types. By evaluating a vessel's CII, stakeholders can gauge its efficiency and environmental impact, informing decisions on fuel selection, operational practices, and investment in emission reduction technologies [15], [16].

The objective of this study is to evaluate the CII performance of LNG in bulk carriers, using real-world data to assess its environmental benefits compared to traditional marine fuels. By analyzing key performance indicators such as fuel consumption, greenhouse gas emissions, and operational costs, the study aims to quantify the potential reductions in carbon emissions achievable through the adoption of LNG. Additionally, the study will compare the CII performance of LNG with conventional marine fuels such as Very Low Sulphur Fuel Oil (VLSFO) and Marine Gas Oil (MGO), providing insights into the relative environmental impact of different fuel choices. The findings of this study are expected to contribute to the broader discourse on sustainable maritime practices, offering valuable insights for industry stakeholders, policy-makers, and researchers. By examining the case of LNG usage in bulk carriers, the study seeks to provide a practical application of the CII assessment framework, supporting informed decision-making and driving progress toward a more sustainable future for the maritime industry. In this line, the first part of this line provides a brief overview to the study. The second part explains LNG, and the third part describes the Carbon Intensity Indicator (CII). A case study is presented in section 4, and section 5 provides the research conclusion.

2. Liquefied natural gas

In the maritime industry, LNG is central to compliance with stringent emission norms set by the IMO. LNG minimizes the environmental footprint of shipping by reducing the emission of harmful atmospheric contaminants such as sulphur oxides (SO_x) and nitrogen oxides (NOx) [17], [18]. The ultra-low temperatures (-163°C) and low-pressure levels (1.7 bar) required to store LNG are meticulously managed using vacuum-insulated tanks, optimizing the onboard [19]. However, a side effect of using LNG as fuel is that, unlike diesel engines, it can lead to methane emissions (CH_4), a phenomenon known as "methane leakage" [20]. LNG stands out as an approach with the potential to reduce the carbon footprint and improve the environmental sustainability of the shipping industry [21]. Enhanced environmental and safety performance profiles are achieved through a comprehensive assessment of factors such as global warming potential, acid rain, toxic effects and potential negative impacts on the ecosystem [22].

3. Carbon Intensity Indicator (CII)

CII is a performance metric used to measure the operational carbon intensity of ships. This indicator calculates a ship's CO_2 emissions per transport and was developed by the IMO to assess the environmental performance of marine vessels [23]. The CII calculation process is designed to ensure that ships meet their sustainability targets and consists of four main components: Reference CII, Required CII, Attained CII and CII Rating [24].

The baseline CII is the initial CII value set from 2019 and calculated depending on the vessel's capacity. This value represents a standard carbon intensity for a given capacity of the ship and is calculated by Equation 1 below [25]:

$$CII_{Ref} = a * Capacity^{-c} \qquad (1)$$

where a and c are coefficients adjusted according to the vessel's capacity.

The required CII is the CII target that the ship must achieve each year. This value is calculated by a reduction factor (Z) applied to the Reference CII and allows CII limits to be progressively tightened over time. The formula used to calculate the required CII is presented in Equation 2.

$$CII_{Req} = CII_{Ref} * (1 - z_x\%) \qquad (2)$$

The resulting CII indicates the carbon intensity actually achieved by the ship in a given year. This value is obtained by calculating the amount of CO_2 produced by the ship per ton-mile of transport. The CO_2 emission factors are 3.151 t CO_2/t for VLSFO, 3.206 t CO_2/t for MDO/MGO and 2.75 t CO_2/t for LNG respectively [26]. The calculation formula for the Attained CII is presented in Equation 3 [23].

$$AttainedCII = \frac{CO_2Emission}{TransportWork} \qquad (3)$$

The CII rating is a mechanism to measure the change in a ship's carbon intensity over time, which is determined by calculating the ratio between the Attained CII and the Required CII. The Attained CII is calculated by dividing the total amount of CO_2 produced by the ship in a year by the amount of transportation work performed by the ship in that year. The Required CII is a target value indicating that the ship's operational efficiency needs to be continuously improved and is based on the annual reduction rates set by the IMO. The CII rating calculation is expressed by equation 4 [27].

$$CII_{Ratings} = \frac{AttainedCII}{CII_{Req}} \qquad (3)$$

This ratio classifies the vessel's environmental performance on a scale from A to E. Here, an A level indicates that the ship's carbon intensity is performing well above targets, while an E level indicates that the performance falls below expected standards. This classification system encourages ship operators to reduce carbon emissions and adopt more sustainable operational practices. The CII process is based on IMO's 2019 datasets and aims to achieve a continuous reduction in the CII values obtained on an annual basis in line with the GHG reduction targets set by IMO. To achieve these targets, the mitigation factors defined in Table 1, which should be taken into account in annual performance assessments, play a critical role.

Table 1. CII reduction factors

Year	Reduction Factors (Z)
2023	5%
2024	7%
2025	9%
2026	11%

4. Case Study

The research provides a comprehensive review of the operational performance of a bulk carrier built in 2018 with a carrying capacity of 81,000 DWT. The vessel is notable for its operations both within Emission Control Areas (ECAs) and on non-ECA trade routes. The dataset used in the study was collected based on daily noon reports from January 2023 to December 2023. According to the data, the fuel consumption of the vessel was calculated as 3665.44 tons for VLSFO and 299.83 tons for MGO. The CO_2 emission amounts resulting from this fuel consumption were determined as 11549.80 tons for VLSFO and 961.25 tons for MGO. During the same period, the total distance traveled by the vessel amounted to 35545.7 nautical miles (Nm).

The consideration of LNG as a potential fuel option is important to consider how it can contribute to the development of sustainable maritime transportation. The impact of this conversion on fuel consumption is presented in Figure 1.

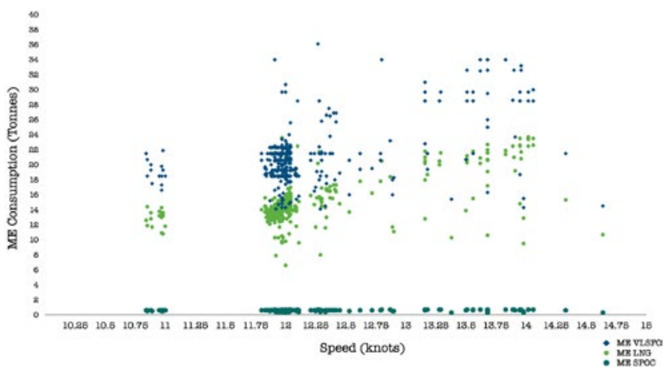

Figure 1. Conversion of the fuels.

Based on the technical analysis of the vessel's fuel consumption and speed data, significant findings on the vessel's operational performance and energy efficiency have been obtained. VLSFO, LNG and SPOC values are taken into account in the analysis. The vessel's speed values generally vary between 11.85 knots and 14.06 knots. In this speed range, HFO and LNG fuel consumption values reveal the energy requirements and performance of the ship.

On average, LNG consumption is 28.3% lower than VLSFO based on the speed and consumption values in the dataset. The highest and lowest consumption values determined for VLSFO are 36.1 tons and 14.1 tons, respectively, while for LNG these values are 23.7 tons and 6.6 tons. This shows that LNG is consumed less while meeting the same energy demand. Furthermore, the average consumption value of SPOC was found to be 0.6 tons across the dataset, indicating that fuel efficiency can be improved by effectively implementing fuel optimization strategies.

In order to determine the optimum range in terms of energy efficiency and performance of the ship, a more detailed analysis of the fuel consumption values was performed. The effects of ship speed and engine power on fuel consumption were analyzed. It is observed that as the engine power increases, the difference between HFO and LNG consumption also increases. This reveals the advantages of LNG as a fuel that can maintain its energy efficiency even at higher engine powers.

It examines in detail the energy consumption and associated CO_2 emissions of an LNG converted bulk carrier. For 2080.9 tons of LNG used in the main engine of the ship, the direct emission amount was determined as 5722.5 tons of CO_2. However, it should be noted that 83.7 tons of MGO was also used as pilot fuel in the main engine in order to use LNG effectively; this additional MGO consumption resulted in a total of 268.4 tons of CO_2 emissions.

In the auxiliary engine and boiler consumptions, 849.3 tons of MGO and 155.1 tons of MGO for additional operations were consumed respectively, resulting in CO_2 emissions of 2722.9 tons and 497.2 tons respectively. T data shows that the use of LNG, especially in the main engine operations, provides significant CO_2 emission reductions. This strongly emphasizes the potential of LNG to reduce the carbon footprint, with the use of LNG resulting in comparatively lower CO_2 emissions.

Following the benchmark in CO_2 emissions, an analysis of the ship's Carbon Intensity Indicator (CII) values, in the context of energy efficiency and environmental impact, provides an even more detailed assessment of sustainability performance. A comparison of fuels is shown in Figure 2.

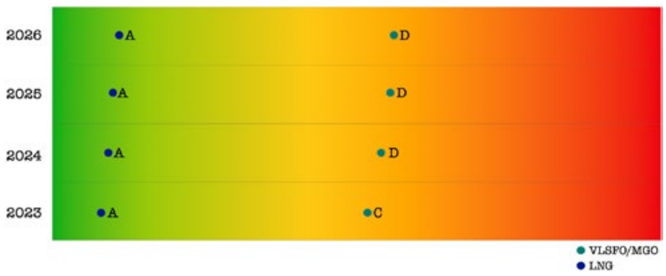

Figure 2. Comparision of CII levels.

As of 2023, the CII value of VLSFO/MGO use is calculated to be 1.05, indicating an intermediate performance with a 'C' rating. However, projections for future years, if fuel consumption remains at a similar level, show that the CII rating of VLSFO increases to 1.08 and 1.12 between 2024 and 2026 respectively, corresponding to a 'D' rating. This trend highlights that the ship's carbon intensity performance is declining over time and improvements are needed to comply with IMO's energy efficiency targets.

In contrast, LNG's CII values are consistently ranked 'A' throughout the analysis period, indicating that the vessel has shown a significant improvement in carbon intensity and maintained its top-ranking performance, despite increasing from 0.74 to 0.79 with values ranging from 2023 to 2026. An 'A' rating represents a CO_2 emissions intensity well below the industry average, indicating that LNG is significantly improving the operational efficiency of the vessel and contributing to the achievement of the shipping industry's environmental sustainability goals.

The comparative analysis highlights the need for ship operators, designers and regulators to consider the impact of fuel choices on long-term environmental performance and sustainability. The CII values and ratings between VLSFO and LNG clearly demonstrate the relative advantages and disadvantages of the fuels in terms of energy efficiency and environmental impact when making important decisions to reduce carbon emissions. Especially in the context of IMO's targets to reduce the carbon intensity of ships by 2023, such analytical assessments play a key role in determining the direction of policies and technological innovations shaping the industry.

5. Conclusion

The Carbon Intensity Indicator (CII) for LNG usage in a bulk carrier is thoroughly evaluated in this study, which provides insightful information about LNG's potential as a sustainable replacement for traditional maritime fuels. The results highlight how crucial it is to switch to greener fuels and boost energy efficiency in order to lessen the maritime industry's carbon footprint. Real-world data analysis demonstrates LNG's substantial benefits over conventional maritime fuels like VLSFO and MGO. It has been demonstrated that using LNG is more efficient, lowering CO_2 emissions and raising CII ratings. These results highlight the necessity for the maritime sector to adopt greener and more sustainable methods, especially in light of the IMO's goals to lower the carbon intensity of ships. The study also emphasizes the need for stakeholders, including ship operators, designers, and regulators, to consider the environmental impact of fuel choices. The declining CII ratings for VLSFO highlight the urgency of transitioning to cleaner fuels, while LNG's consistent 'A' ratings demonstrate its potential to drive significant improvements in carbon intensity and operational efficiency.

In conclusion, this study contributes to the growing body of research on sustainable maritime practices, providing valuable insights for industry stakeholders and policymakers. By demonstrating the environmental and economic benefits of LNG usage in a bulk carrier, the study highlights the importance of transitioning to cleaner fuels to achieve long-term sustainability goals. Overall, the findings of this study have important implications for the future of the maritime industry, emphasizing the need for proactive measures to reduce carbon emissions and mitigate the environmental impact of shipping operations.

As a limitations of the study, the analysis relies on data from a solitary bulk carrier spanning a year. Future investigations might enhance their insights by examining data from multiple vessels and over extended durations, thereby offering a more holistic grasp of LNG's influence on carbon emissions and energy efficiency. It should be noted that the conclusions drawn from this study may not be universally applicable to all vessel types and operational circumstances. Subsequent research could delve into the suitability of LNG across diverse ship categories and under varied operational contexts.

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Statistical analysis of the LNG-fueled marine vessels based on ship types and specifications

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Abstract

International Maritime Organization has recently revised its strategies on Greenhouse gas emissions and has proven commitment to achieving net-zero GHG emissions by 2050. Several alternative fuels such as hydrogen, nuclear, methanol, biofuels, and more have been considered to achieve net-zero greenhouse gas (GHG) emissions but most of them remain underutilized in commercial vessels due to inadequate infrastructure, high and fluctuating fuel prices, operating costs, and more. Among the alternative fuels, Liquefied Natural Gas (LNG) stands out as a well-established alternative fuel prominently utilized in various ship types. LNG-powered vessels have encompassed 5.96% of the total tonnage in maritime transportation. Projections indicate a substantial increase, with this rate expected to reach 40.3% in the coming years. LNG-powered vessels have been analyzed in terms of ship types, regionals, and emissions profiles based on the latest decade reports. The prevailing LNG-powered vessel fleet primarily comprises tankers however, an intriguing shift will be performed when the ordered container ships and car carriers, corresponding to 70% rates of the total number of vessels, are constructed. 61% of LNG-powered vessels have operated in the global region. On the other hand, these rates are followed by Europe, Asia, and America respectively. Findings are highlighted for academicians, industry stakeholders, and experts to address critical gaps in the existing literature. These findings will enable meaningful comparisons for subsequent studies in the future.

Keywords: *GHG emissions, LNG, Ship types, Container ships, Car carriers*

1. Introduction

The shipping industry is a focal point in discussions surrounding sustainability due to its considerable impact on greenhouse gas (GHG) emissions, akin to other economic sectors. International shipping, responsible for transporting more than 80% of global merchandise trade by volume, alone accounts for approximately 3% of the total global greenhouse gas emissions. While shipping's effect on GHG emissions per unit of transport work may seem modest, without proactive measures, emissions from the sector will expand to rise unchecked. Therefore, the IMO is actively engaged in the determination of global rules and regulations for decarbonizing commercial shipping [1]. The 2023 IMO Greenhouse Gas Strategies include reducing the carbon intensity of shipping by further improving energy efficiency for new and existing ships. To comply with the revised strategies and achieve net zero greenhouse gas emissions, maritime authorities have brought up utilizing zero or near-zero fuels on marine vessels for ship owners and operators [2].

To ensure sustainability in maritime transportation, the necessary regulations must be implemented gradually. Conventional-fueled vessels can meet short-term strategies by installing emission reduction systems that cause additional costs such as scrubbers. Nevertheless, the utilization of alternative fuels is inevitable to meet advancing GHG targets. Among the alternative fuels, liquefied natural gas (LNG) is deemed a viable choice considering its operational safety, economic viability, and environmentally friendly [3], [4]. Considering environmental circumstances, the utilization of LNG as a marine fuel has the potential to decrease CO_2 and NO_x up to 90% and 30% respectively, and eliminate SO_x and particulate matter emissions. These reduction rates achieved by LNG fuel align with the progressively stringent IMO regulations on harmful emissions and contribute to the global sustainable development objectives highlighted by the United Nations [5]. Unlike conventional vessels, LNG-powered vessels easily operate in the Emission Control Area (ECA) without using after-treatment systems to mitigate harmful emissions. LNG possesses non-toxic, non-corrosive, and odorless characteristics. Its flammability range is relatively narrow, and in the event of a spill into seawater, it can vaporize rapidly without causing pollution to the marine environment which supports its superiority in terms of safety. The abundance of reserves and relatively competitive price of liquefied natural gas (LNG) make it highly competitive in the global energy market based on economic viability. These advantages are prompting stakeholders to increasingly utilize LNG as a maritime fuel [6], [7]. However, LNG has the potential to cause frost burns upon contact with human skin due to its cryogenic properties. The utilization of LNG can cause metal embrittlement and subsequent formation of cracks in metallic structures, ultimately leading to structural failure. Elevated atmospheric concentrations of methane can result in asphyxiation [8].

The current literature on the utilization of LNG as a fuel in the transportation industry encompasses Life Cycle Assessment (LCA) [9], [10], risk analysis [11], [12]. Development of LNG-fueled ships [3], [5], [7], [13]–[17], comparison of LNG-powered and conventional fuel-powered vessels [4], [18]–[21], environmental benefits of LNG under its lifecycle [22], safety aspects of the use of LNG [8], [23], economic and emission assessment of LNG-fueled ships [24]–[29] have been investigated in maritime transportation specifically. Schinas and Butler [26] have suggested a methodology to stimulate the adoption of LNG as a marine fuel. Favorable energy-price dynamics trigger the use of LNG on ships. Yoo et al. [19] evaluated LNG-fueled ships in terms of economic viability and proved to be a more economical option than MGO-fueled vessels. Fokkema et al. [4] have presented a new investment appraisal method to evaluate the costs of LNG-fueled vessels and conventional vessels. LNG-fueled vessels have lowered fuel consumption costs, but their higher initial investment and LNG fuel cost fluctuation can result in further expenses. Wan et al. [3] have investigated the development level of LNG-fueled ships in a particular region or country under the SRETI (Strategy, Regulation, Economics, Technology, and Infrastructure) model. Norway exceeds both the USA and China in the advancement of LNG-fueled ship development. Jeong et al. [14] have assessed three competitive LNG-fueled engines: ultra-steam turbine, four-stroke medium-speed engine, and two-stroke low-speed engine systems. The two-stroke low-speed engine system is the most efficient option for LNG carriers among the three options. Sharafian et al. [29] have performed a life cycle assessment on LNG and HFO for marine shipping. Only high-pressure dual-fuel (HPDF) engines have provided a 10% GHG emissions reduction in well-to-wake. Xu and Yang [28] have evaluated the economic viability and potential CO_2 emission reduction on LNG-fueled container ships throughout the North Sea Route (NSR). Iannaccone et al. [21] have explored the effects of LNG utilization under sustainability strategies. LNG-based fuel system technologies demonstrate superior sustainability performance in comparison to conventional marine fuel technologies. Cucinotta et al. [9] have conducted a Life Cycle Assessment (LCA) on a cruise ferry considering different fueled engines. LNG-fueled engines have provided environmentally friendly results that mitigate climate change. However, the phenomenon of methane slip is essential to consider because its detrimental effect is further than CO_2 on global warming. Jang et al. [22] have answered the main question of whether LNG contributes to decreasing the environmental impacts of shipping activities. If necessary, precautions are not taken and green production methods are not used, the utilization of LNG triggers global warming more than conventional fuels and causes more the occurrence of local pollutants. Balcombe et al. [27] have executed an extensive environmental life cycle and cost evaluation of LNG as a maritime fuel considering conventional and other alternative fuels. LNG has presented enhancements in air quality impact, decreased fuel expenses, and moderate climate advantages. However, methane slip from certain engines reaches unacceptably high levels. Li et al. [24] have evaluated the economic viability and CO_2 emission reduction potential of LNG-fueled vessels on inland waterway transportation. The advantages of LNG-fueled ships vary depending on the vessel's capacity and type. Extended waiting periods at locks both diminish economic viability and emission reduction rates. Taghavifar and Perera [10] have endeavored to tackle harmful emission reduction, energy, and cost-saving with the utilization of innovative dual-fuel engines. Fuel quality holds greater sway than load fluctuations during ship navigation based on the life cycle cost assessment (LCCA). The existing research on LNG fuel predominantly concentrates on economic viability, safety precautions, and harmful emission reduction rates against conventional fuels. However, a noticeable gap in the literature has pertained to the analysis of LNG-fueled vessels based on ship types and capacities, operated regions, and emission profiles.

2. Methodology

In the study, the distribution of LNG-fueled ships considering the types, capacities, and regions have been determined and illustrated. The insight of the LNG utilization on maritime vessels has been discussed and the tendency of several regions according to their profiles has been evaluated. The statistical distribution of the ships regarding their regions, flag states, and built years has been determined. The mean gross tonnage (GT), deadweight (DWT), length overall (LOA), beam (B), age, and draught considering the ship type have been calculated and presented. The data collection has been ensured by accessing the database presented by Det Norske Veritas (DNV) [30]. The fuel type has been selected as LNG, and the ship types are:

- Tugs (TB)
- Offshore supply ships (OSS)
- Fishing vessels (FV)
- Car-passenger ferries (CP)
- General cargo ships (GCS)
- Oil-Chemical tankers (OCT)
- Gas tankers (GT)
- Ro-Ro cargo ships (RRS)
- Other (OS)
- Car carriers (CC)
- Crude oil tankers (COT)
- Bulk carriers (BC)
- Container ships (CS)
- Cruise ships (CRSS)

If the ship does not belong to the categories listed above, it has been evaluated in the "Other" category by the utilized interface.

3. Results and Discussion

The statistical analysis of marine vessels utilizing LNG fuel around the Globe has demonstrated the mean measurements of the vessel types shown in Table 1.

Table 1. The mean statistics of vessels regarding the ship type.

Ship Type	GT	DWT	LOA (m)	B (m)	Age	Draught (m)
Tugs	569.500	304.600	34.357	12.571	6.357	5.207
Offshore supply ships	4,018.69	4,29.771	81.778	18.328	7.667	5.439
Fishing vessels	5,803.57	5,913.16	86.286	20.714	2.000	7.757
Car-Passenger ferries	8,320.90	1,452.81	118.643	21.286	11.333	4.204
General cargo ships	9,323.36	9,519.78	118.421	22.000	4.053	6.079
Oil-Chemical tankers	16,359.4	24,022.5	150.941	24.059	4.314	7.361
Gas tankers	27,719.9	25,802.4	174.739	27.522	7.043	8.048
Ro-Ro cargo ships	34,259.6	15,180	190.455	28.818	7.818	6.864
Other	36,304.8	6,307.75	189.958	28.792	8.208	6.238
Car carriers	64,897.5	17,910	193.917	36.500	2.083	8.558
Crude oil tankers	87,866.9	155,245	271.085	47.746	2.324	12.455
Bulk carriers	88,287.3	161,948	265.200	43.044	2.400	11.671
Container ships	131,919	135,055	328.803	47.539	3.408	12.739
Cruise ships	155,221	13,661	301.333	40.467	2.867	8.347

The average LOA of the crude oil tankers has been calculated at 271.085 m and 155,245 tonnes of DWT while the bulk carriers have the biggest mean capacity with 161,948 tonnes. The largest vessels in terms of dimensions have been container vessels followed by cruise ships. The maximum LOA has been 400 m with 61 m for the container ships. The fishing vessels have the youngest fleet while the car-passenger ferries have been operated the longest especially in the Baltic area due to the application of emission control areas (ECA). The new amendments about energy efficiency have shown an impact on the oceangoing vessels in recent years therefore, car carriers, crude oil tankers, bulk carriers, and container ships are the following newly built ship types. Figure 1 indicates the number of ships regarding their types.

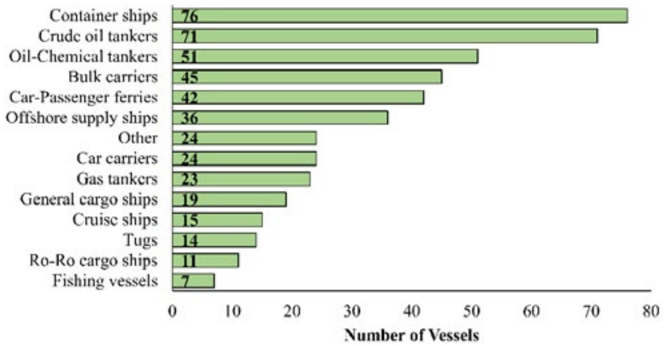

Figure 1. The distribution of marine vessels according to their types.

Container vessels are the most common having a proportion of 16.59% of whole vessels, crude oil tankers are the second most common with 15.5%. The ratio of LNG-powered oil-chemical ship numbers to all vessels has been 11.14% which follows the crude oil tankers in terms of the number of ships. The major ship types have the predominance which shows the effect of new regulations and the path of ship propulsion shortly. Figure 2 indicates the variation of the metrics considering the ship types.

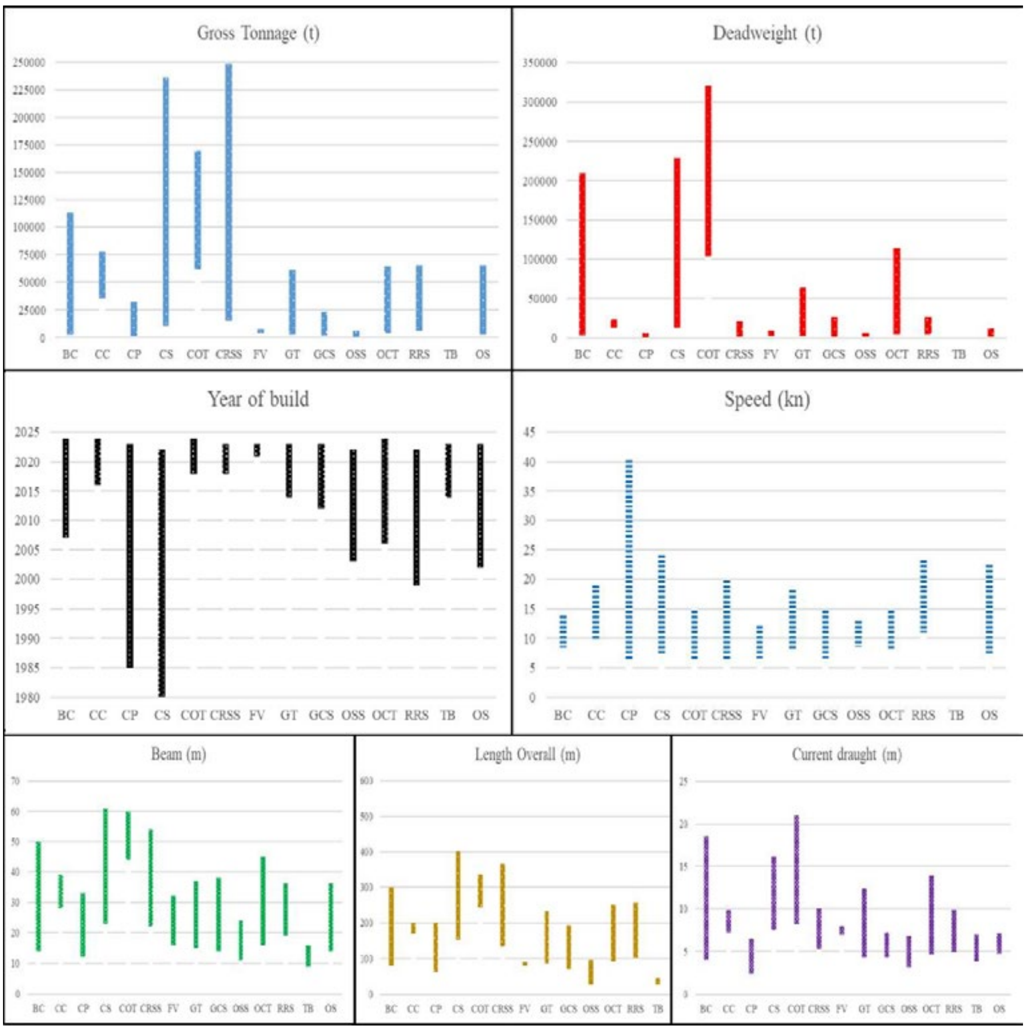

Figure 2. The variation of metrics according to ship types.

In addition to existing different types of LNG-fueled marine vessels, LNG-fueled vessels have differentiated in terms of technical specifications under the same ship types. Cruise vessels and crude oil tankers have shown the most variety when it comes to gross tonnage. The large number of ships and wide operation areas have triggered ranges of gross tonnage distribution. When compared in terms of deadweight, which is one of the other capacity measures, Crude oil tankers have stood out because their deadweight tons have exceeded 300000 tons. The oldest LNG fueled ships date back to 1980 since numerous retrofitting applications have been performed on existing marine vessels. On the other hand, most of the construction of LNG-fuelled ships has intensified in the last 10 years. Among these ship types, the fishing vessels are the newest ones. The fleet of car-passenger ferries has been operating for the longest, particularly in the Baltic region because of the implementation of ECA. Figure 3 illustrates the flag-state distribution of LNG-fueled vessels.

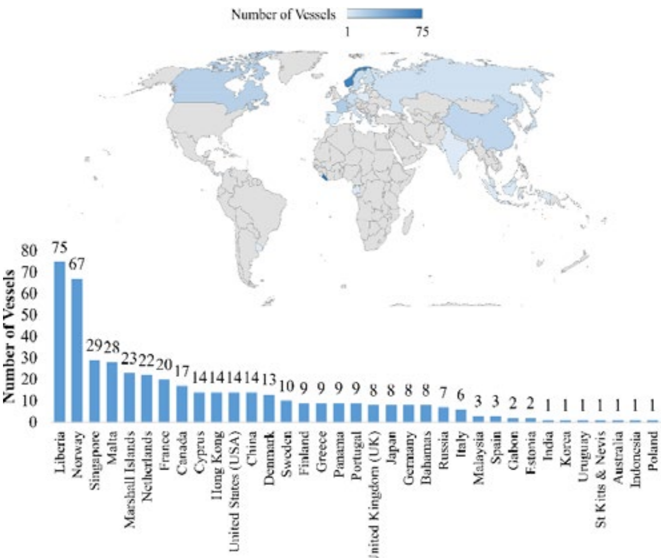

Figure 3. The distribution of marine vessels according to the flag state.

The majority of vessels have carried the Liberian flag which is among the countries offering a flag of convenience so the outcome is natural. However, the second country is Norway which makes innovative and sustainable propulsion research for marine vessels. The reason behind this outcome could be the emission control area in the Baltic Sea, and the increased environmental awareness of the Nordic countries. The ratio of Nordic countries in the Baltic Region in LNG-powered vessels has been 22.27%. Figure 4 demonstrates the number of vessels according to their build year.

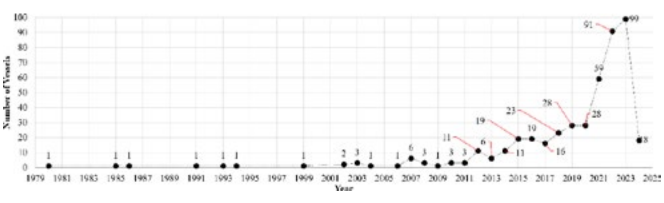

Figure 4. The distribution of marine vessels according to the flag state.

The vessels' build years have been aggregated in the last decade heavily due to the introduction of the Energy Efficiency Design Index (EEDI). There has been a sharp increase in the number of ships built with dual-fuel engines after this year. 93.45% of the LNG-powered ships were built after 2012 which shows the effect of the regulation. However, the impact of the Energy Efficiency Existing Index (EEXI) and Carbon Intensity Indicator (CII) has been observed more clearly since the slope of the line skyrocketed after 2020 and peaked in 2023 which is the entry year. 64.41% of vessels were constructed after the specified date. Figure 5 illustrates the last-known locations of the vessels and gives an idea of the operation points of the ships.

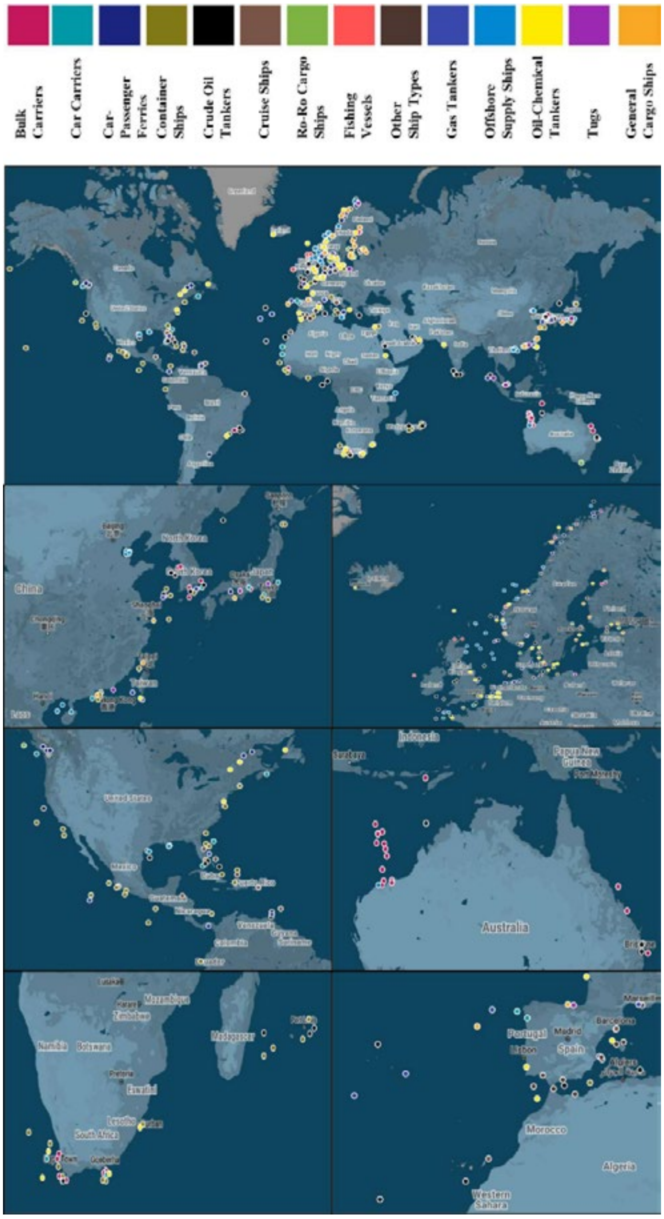

Figure 5. The locations of the vessels.

The LNG-powered vessels have swarmed around the North and Baltic seas which are the ECA. Especially, the oil and chemical tankers are mainly located around Europe. Another

ECA has been the Caribbean region and it is also a popular operating route. LNG-fueled vessels have been operated around the possible future ECA regions like the west coast of the United States, the Yellow Sea, and the Sea of Japan .

4. Conclusion

The study evaluated and depicted the distribution of LNG-fueled ships taking into account their types, technical specifications, and geographical locations. Statistical analysis was conducted and the main conclusions derived from the analysis can be listed as:

- The largest vessel types operated with LNG are container and crude oil ships which are also the most common types.
- Among the flag states, Liberia had the most-registered ships followed by Norway.
- Fishing vessels were the youngest, and car-passenger and ferries were the oldest.
- After the introduction of EEDI the construction of LNG-powered ships grew significantly.
- EEXI and CII regulations increased sharply the building of LNG-fueled ships.

Future studies may involve the investigation of a scenario-based regional emission impact study or the extraction of regression lines of these vessels for machine learning studies using the database.

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Best-Worst multi-criteria decision-making method for alternative marine fuels

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Abstract

Decarbonization is one of the primary objectives of maritime transport. One of the preferred methods in line with these objectives is using alternative fuels. The contribution to decarbonization alone is not the reason for the preference for an alternative fuel. Proper fuel selection is critical for sustainability. To select the proper fuel, it is necessary to make a wide range of economic, technical, and environmental assessments. In accordance with the need for multi-dimensional assessment, we used Best-Worst Method, one of the multi-criteria decision-making methods, in our study. Experts from all stakeholders in the maritime sector shed light on the study. The results of the study differ according to the working areas of the stakeholders in the sector. Although the regulations emphasize Environmental impacts, Technical and Economic criteria are critical for the stakeholders in the sector. Therefore, in expert opinions, academic and governmental experts focus on environmental impacts while engineers focus on the technical impacts of alternative fuels. Experts who are responsible for supplying the fuel also focused on the cost dimensions of alternative fuels. Among the sub-criteria in our study, greenhouse gas emission reduction rate, availability of fuel, and initial investment cost have come to the forefront of the results.

Keywords: *Decarbonization, Alternative Fuel, Best-Worst Method*

1. Introduction

Maritime transport is at the forefront of global efforts to reduce carbon emissions, motivated by the need to minimize environmental impact and promote business sustainability [1], [2]. The quest for decarbonization has driven the exploration and use of alternative fuels as a key strategy in the maritime industry[3]. However, the choice of alternative fuels goes beyond the sole objective of reducing carbon emissions and requires a careful assessment of economic viability, technological feasibility and environmental sustainability[4], [5].

Given the urgency of the situation due to IMO's targets, the shipping industry is currently facing a critical moment where fuel choice will have a significant impact on its future direction[6], [7]. The transition to alternative fuels requires a comprehensive assessment framework that takes into account all aspects of the assessment, including economic viability, technological feasibility and environmental impact mitigation. This framework not only enables stakeholders to make informed decisions, but also promotes a comprehensive awareness of the complex relationship between the different parameters that influence fuel selection techniques.

This study aims to explore the complex nature of fuel selection in the maritime sector using the Best-Worst Method (BWM), a well-known multi-variable decision-making approach[8], [9]. Our study aims to elucidate the complex dynamics of fuel selection methods in the marine sector by involving experts from many stakeholder groups. We also seek to identify the specific preferences and priorities of different groups within the industry.

As we explore the complexities of fuel choice, it becomes clear that while reducing carbon emissions is a top priority, it is not the only important factor to consider. Our research analyses expert opinion from a range of backgrounds including academia, government, engineering and fuel supply. We reveal a complex range of perspectives where environmental, technological and economic factors come together to influence decision-making approaches.

Our research also highlights the subtle differences in preferences and priorities between different stakeholder groups. Academics and government experts prioritize environmental impact, engineers focus on technical feasibility, and fuel suppliers prioritize cost considerations. The existence of multiple viewpoints highlights the need for a detailed and situation-specific fuel selection methodology that recognizes and resolves the conflicting interests of different stakeholders within the wider context of sustainability.

In light of this context, our study seeks to analyze the key factors that influence fuel selection strategies, focusing specifically on the rates of greenhouse gas emission reduction, the availability of fuel, and the initial costs of investment. Our findings provide useful insights into the sustainable fuel selection methods in the maritime sector by clarifying the relative importance of these parameters among different stakeholder groups.

2. Data collection

2.1. Identification of criteria for alternative fuels

Alternative fuels have emerged as prominent contenders in meeting IMO targets, showcasing a diverse array of options. The selection of these alternative fuels' hinges upon a triad of considerations: economic viability, environmental impact, and technical feasibility. Consequently, these pivotal criteria take center stage in the focus of this study.

The sub-criterion of the economic parameter was determined to be the initial investment cost of the alternative fuel. Additionally, within this domain, considerations extend to retrofit expenses, operational costs, and the purchase price of the favored alternative fuel, all of which serve as supplementary sub-criteria[10-13].

The safety aspect of the alternative fuel has been identified as a sub-criterion under the technical evaluation. Alongside this consideration, factors such as maturity, availability, and storage space are recognized as additional sub-criteria within the technical framework[14-16].

Within the environmental criterion, GHG emissions have been delineated as a sub-criterion of paramount importance. Moreover, alongside this assessment, specific attention is directed towards factors including carbon reduction measures and acidification, which serve as supplementary sub-criteria in evaluating environmental impact within the context of maritime transportation[14], [17], [18].

2.2. Expert information of the study

In the process of expert selection, the aim was to establish a diverse pool comprising academic, industry-technical, and industry-commercial experts. Accordingly, experts were chosen from academia, specifically those engaged in research on alternative fuels, as well as technical personnel from sector ships slated to operate with alternative fuels, and commercial authorities who implement alternative fuels in their vessels. In our study, expert opinions were formed face-to-face and by taking their comments on the options. In this way, the critical points in their choices were also indicated by them. The experience, titles, field of expertise and education levels of our experts are given in Table 1.

In our study, experts were primarily utilized in clarifying the main and sub-criteria. Then the BWM methodology was transferred to them and they were asked to transfer their decisions on an excel spreadsheet[32].

Table 1. Expert characteristics of the study.

Experts	Expertise	Affiliation	Exp. (years)	Education
Ex1	Prof Dr.	Academic	26	PhD
Ex2	Assistant Prof.	Academic	8	PhD
Ex3	Port State Control	Governmental	5	Master
Ex4	Working on tanker vessel	Industry-technical	6	BSc
Ex5	Working on container vessel	Industry-technical	4	PhD Candidate
Ex6	Working on tanker company	Technical Inspector	11	Master
Ex7	Owner of 2 bulk carrier	Industry-commercial	2	MSc Candidate
Ex8	Working on tanker company	Industry-commercial	7	BSc
Ex9	Working on container company	Industry-commercial	13	Master

3. Methodology

The selection criteria for alternative fuels and the weighting of these criteria constitute a widely discussed subject in the literature[12], [13], [14], [19], [20]. Taking into account numerous parameters when establishing these criteria is crucial for carriers, shippers, shipowners, technical personnel utilizing such fuels, governments, and the global community impacted by pollution. In light of these considerations, opting for the appropriate fuel among all stakeholders will underpin the sustainability of maritime transportation[21]. Therefore, different MCDMs are available in the literature.[22-26]

In conducting our research on the evaluation of alternative marine fuels using the Best-Worst multi-criteria decision-making (MCDM) method, we followed a systematic and rigorous approach. This study aimed at a comprehensive weighting of various main criteria related to the economic, technical and environmental aspects of alternative fuels. In order to make a comprehensive weighting, the sub-criteria of the main criteria are also weighted among themselves in order to get to the essence of the subject.

The main and sub-criteria are as shown in Fig 1 below.

Main Criteria	Economical	Technical	Environmental
Sub-Criteria	Capital (E1)	Safety (T1)	GHG Emission (En1)
	Retrofit (E2)	Maturity (T2)	Specific Carbon Reduction (En2)
	Operational (E3)	Availability (T3)	Acidification (En3)
	Fuel (E4)	Storage Space (T4)	

Figure 1. Main and Sub-criteria of the study

3.1. BWM Methodology

The study used the Best-Worst Method (BWM) to classify and rank drivers and externalities due to its effectiveness in directing intricate decision-making procedures[27-29]. BWM has been widely implemented across several fields and academic disciplines, establishing itself as a leading method for decision prioritization and criterion comparison[30], [31].

The necessary stages for the original BWM are as follows.

Step-1

Establish the decision criteria for the Multiple Criteria Decision Making (MCDM) problem as determined by the Decision Maker (DM).

Step-2

By using the DM, determine which of the criteria is the best (for example, the most important or the most desirable) c_B and which is the worst c_W (for example, the least important or the least desirable) criterion.

Step-3

Obtain the preference values a_{Bj} (j=1,...,n) for the best criterion c_B compared to the other criteria c_j (j=1,2,...,n) using a number from the set {1,2,…,9} as determined by the decision maker (DM). Next, acquire the vector that is superior to others, known as the best-to-others (A_B) vector, using the following method:

$$A_B = (a_{B1}, a_{B2}, \dots \dots a_{Bn},) \tag{1}$$

Step-4

Obtain the preference values a_{jW} (j=1,2...,n) from the decision maker (DM) for all criteria c_j (j=1,2,...,n) in comparison to the worst criterion c_W. The comparison findings are expressed as the vector representing the relative positions of the other options compared to the worst option (A_W).

$$A_W = (a_{W1}, a_{W2}, \dots \dots a_{Wn},)^T. \tag{2}$$

Step-5

Determine the optimal weights $w^*=(w_1^*,\ w_2^* ....., w_n^*)$ by applying the min–max optimization model provided. The ideal weight for the criteria is the one where, for each pair of w_B/w_j and w_j/w_W, we get $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$ To meet these criteria for all j, we need to develop a solution that minimizes the maximum absolute differences for all j. One can reduce the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j = 1 , 2 , . . . , n . Additionally, the weight vector must satisfy the properties of non-negativity and summing to one. Consequently, the optimization problem below can determine the ideal weight vector w*.

$$\min_w \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\}$$
$$s.t.\ \ \sum_{j=1}^{n} w_j = 1,\ \ w_j \geq 0\ \ \forall j = 1,2, \dots, \tag{3}$$

The weight vector can be determined using the following problem in a similar manner.

$$\text{s.t.} \left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi \ \ \forall j = 1,2, \dots, n$$
$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi \ \ \forall j = 1,2, \dots, n$$
$$\sum_{j=1}^{n} w_j = 1,\ \ w_j \geq 0\ \ \forall j = 1,2, \dots, n \tag{4}$$

To assess the trustworthiness of the ideal weights, the veracity between the input pairwise comparisons and their related weight ratios are checked using the following consistency ratio (CR).

$$CR = \frac{\xi^*}{CI} \tag{5}$$

The optimal objective value of model (4) is denoted as ξ*, and CI (consistency index) is a predetermined value for each BW, which may be found in Table 1. CR is a numerical measure ranging from 0 to 1. A CR of 0 indicates complete consistency, whereas a higher CR signifies decreasing consistency in the pairwise comparison system.

4. Result and Discussion

Table 2 was formed as a result of the best opinions of the experts on the main and sub-criteria. Table 2 shows the best option of each expert for both main criteria and sub-criteria. Although the experts showed different distributions in the main criteria, they gave closer answers to each other in the sub-criteria. The importance of GHG emissions (En1) is the criterion on which all experts agree. Among the technical criteria, availability(T3) and storage space(T4) were prioritized by the experts. Also, among the economic criteria, capital cost (E1) and fuel cost (E4) were emphasized by the experts.

Table 2. Best options of experts

					Main criteria			Sub-criteria											
Experts	Best Main	Best Sub			ECO	TEC	ENV	E1	E2	E3	E4	T1	T2	T3	T4	En1	En2	En3
Ex1	ENV	E4	T3	En1	7	5	1	3	5	3	1	3	6	1	2	1	3	5
Ex2	ENV	E4	T3	En1	7	3	1	2	7	4	1	2	7	1	3	1	2	7
Ex3	ENV	E1	T4	En1	5	3	1	1	5	4	2	3	5	2	1	1	3	5
Ex4	TEC	E1	T4	En1	4	1	2	1	6	6	3	4	6	3	1	1	3	9
Ex5	TEC	E4	T3	En1	5	1	4	2	5	5	1	4	9	1	2	1	2	7
Ex6	TEC	E1	T4	En1	5	1	3	1	5	5	2	3	7	2	1	1	3	7
Ex7	ECO	E1	T4	En1	1	5	7	1	7	5	3	2	5	3	1	1	3	7
Ex8	ECO	E4	T3	En1	1	3	3	2	9	7	1	2	5	1	3	1	2	9
Ex9	ECO	E1	T3	En1	1	4	3	1	6	4	2	5	7	1	2	1	2	7

Table 3 was formed as a result of the worst opinions of the experts on the main and sub-criteria. Acidification (En3) is the criterion that all experts consider the least important for environmental criteria. Among the economic criteria, retrofit cost was the least important by the experts. Besides, among the technical criteria, maturity was the least important. Although the experts are divided on the best option in the sub-criteria, they agree on the worst criterion.

Table 3. Worst options of experts

					Main criteria			Sub-criteria										
Experts	**Worst Main**	**Worst Sub**			**ECO**	**TEC**	**ENV**	**E1**	**E2**	**E3**	**E4**	**T1**	**T2**	**T3**	**T4**	**En1**	**En2**	**En3**
Ex1	ECO	E2	T2	En3	1	2	7	7	1	4	5	2	1	5	4	5	3	1
Ex2	ECO	E2	T2	En3	1	4	7	7	1	3	7	4	1	7	4	7	4	1
Ex3	TEC	E2	T2	En3	5	1	3	6	1	3	5	4	1	5	7	5	3	1
Ex4	ECO	E2	T2	En3	1	7	6	6	1	5	5	3	1	5	9	5	2	1
Ex5	ECO	E2	T2	En3	1	6	4	5	1	5	7	3	1	7	5	3	2	1
Ex6	ENV	E2	T2	En3	5	3	1	7	1	7	4	3	1	4	7	5	3	1
Ex7	TEC	E2	T2	En3	5	1	3	7	1	3	5	2	1	3	6	3	5	1
Ex8	TEC	E2	T2	En3	6	1	5	5	1	4	5	4	1	7	6	5	3	1
Ex9	ENV	E2	T2	En3	5	3	1	9	1	5	5	5	1	9	7	5	2	1

Experts who emphasized environmental criteria stated that alternative fuels have emerged by considering environmental impacts rather than economic and technical ones. Experts who prioritize technical criteria think that with the technical barriers to be overcome with scientific developments, the right fuels will be able to reduce emission and these fuels will be economically accessible. The experts who highlighted the economic criterion emphasized that environmental and technical impacts alone cannot be sufficient and that fuels that are economical will be selected for the continuity of maritime transport.

Table 4. Optimal weights of criteria

Experts	**E1**	**E2**	**E3**	**E4**	**T1**	**T2**	**T3**	**T4**	**En1**	**En2**	**En3**
Ex1	0,019	0,011	0,019	0,051	0,028	0,013	0,074	0,042	**0,552**	0,117	0,074
Ex2	0,025	0,005	0,012	0,041	0,076	0,016	0,124	0,051	**0,375**	0,225	0,050
Ex3	0,032	0,008	0,016	0,056	0,169	0,050	**0,318**	0,129	0,148	0,049	0,025
Ex4	0,009	0,005	0,026	0,044	0,042	0,009	0,068	0,028	**0,466**	0,241	0,064
Ex5	0,032	0,008	0,016	0,056	0,169	0,050	**0,318**	0,129	0,148	0,049	0,025
Ex6	0,065	0,015	0,017	0,042	0,124	0,053	0,186	**0,265**	0,146	0,054	0,032
Ex7	**0,382**	0,076	0,107	0,178	0,031	0,019	0,031	0,075	0,074	0,016	0,010
Ex8	0,174	0,069	0,069	**0,313**	0,065	0,026	0,116	0,043	0,078	0,031	0,016
Ex9	**0,253**	0,056	0,084	0,169	0,015	0,009	0,064	0,037	0,176	0,098	0,039
Average	0,110	0,028	0,041	0,105	0,080	0,027	0,144	0,089	**0,240**	0,098	0,037

5. Conclusion

The process of selecting alternative fuels entails a thorough evaluation of environmental, economic, and technical factors, making it a complex task. A multi-criteria method is suitable for conducting an integrated evaluation. Hence, this study employs the MCDM method BWM for this paper.

A thorough list of identified criteria and sub-criteria, together with verification, has been created to tackle the lack of information regarding fuel selection criteria. This enables shipping businesses to choose suitable alternative fuels in compliance with regulatory requirements. This research project is one of the first to combine sustainability concerns with the use of alternative fuels, focusing on the viewpoints of shipowners and ship management. To fully understand the perspectives of shipowners and managers, who play a critical role in making decisions and using the finished product, it is essential to grasp their viewpoints, which are the focus of this research.

Following study endeavors will focus on exploring alternative fuel and energy possibilities in different developing nations by utilizing the suggested MCDM framework. Conducting comparative research in different circumstances can provide insights into the actual potential of alternative energy sources for achieving sustainable shipping. It is important to also consider using actual data for each option based on the criteria, if it becomes available in the future. Within the realm of a country, future research should focus on analyzing the necessary policy modifications needed to effectively incorporate sustainable alternative energy sources within the industrial sector.

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Integrating of Potential Renewable Energy Resources on Offshore Oil and Gas Platforms in the Black Sea: Opportunities for Carbon Emission Reduction

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Abstract

The world's energy demands are predominantly met through the extraction of subterranean natural resources. However, the relentless increase in energy consumption has resulted in the depletion of these resources and a consequent surge in carbon dioxide emissions, significantly impacting the climate and posing a grave threat to ecosystems. Addressing this challenge requires a shift towards renewable energy sources to replace finite underground resources in energy production. While this transition is widely acknowledged by the public, civil society organizations (CSOs), and many governments, it is fraught with economic, political, and social challenges during the implementation phase of renewable energy projects. Consequently, the full replacement of fossil fuels with renewable alternatives in energy production may require a considerable period.

Oil and natural gas, essential non-renewable resources utilized across various industrial sectors and for energy generation, are extracted both onshore and offshore and cannot be abruptly phased out. To mitigate carbon emissions, alternative strategies must be devised concurrently with the ongoing operations of these extraction fields.

The integration of renewable energy sources into offshore platforms has become increasingly viable due to cost reductions and technological advancements. This study delves into the efficacy of deploying renewable energy solutions for an oil and gas field slated for development along the Black Sea coast of Türkiye. It elucidates how strategically incorporating renewable energy resources can enhance the operational efficiency and environmental sustainability of offshore platforms.

Keywords: *Renewable Energy, Marine, Offshore, Oil&Gas Industry*

1. Introduction

The global demand for energy is experiencing an exponential growth trajectory annually. Despite ongoing efforts to transition from conventional energy sources to renewable alternatives, this shift has not yet reached the desired levels. Consequently, the rising energy demand is driving an increased reliance on oil and natural gas resources [1]. While renewable energy technologies are gradually gaining market share over traditional fossil fuels, projections indicate that the demand for oil and natural gas consumption will peak around 2030. This projection suggests that, at least in the foreseeable future, oil and gas will remain the primary energy sources to meet escalating energy demands, despite the expanding contribution of renewables [2].

The future of energy production is heavily focused on reducing hydrocarbon consumption, expanding the utilization of renewable energy sources, promoting electrification, and advancing low-carbon hydrogen technologies. Among renewable sources, wind and solar energy systems exhibit the most rapid growth rates [3]. Notably, in 2023, these systems experienced a staggering 50% increase, marking the fastest growth rate in two centuries. Countries and companies are increasingly committing to renewable energy sources as they strive to achieve Net Zero targets [4]. In fact, by the end of 2023, renewables accounted for a remarkable 43% of total installed capacity, with wind energy alone contributing 116GW out of the 473GW of renewable energy capacity added that year. Despite this rapid expansion, the sector is still striving to meet its 2030 targets [5].

The integration of renewable energy sources into offshore oil and gas fields will play a pivotal role in achieving ambitious carbon emission reduction goals. As Türkiye progresses towards full-capacity production in the oil and natural gas sector in the coming years, maximizing efficiency to ensure investment returns while curbing escalating emission rates becomes imperative. Offshore wind turbines present a promising avenue to significantly reduce emissions in the Black Sea's oil and gas field [6].

This paper is structured as follows: Section 2 delves into offshore oil and gas activities in Türkiye, while Section 3 offers a comprehensive overview of the global and Turkish offshore wind energy sectors. Section 4 evaluates potential locations for installing wind turbines to link the Black Sea region's oil and gas platform with renewable energy sources. Finally, the concluding section summarizes the key findings of the study.

2. Offshore Oil&Gas Field at Black Sea

Türkiye made its initial gas discovery in the Sakarya Gas Field in 2020, followed by two additional discoveries in the same year, and a third in 2021. The cumulative estimated reserve size now stands at 540 billion cubic meters (bcm). Currently, the field is undergoing development, with full-capacity production anticipated in the forthcoming years [7]. To facilitate production and transport the gas to shore, a floating production storage and offloading (FPSO) platform will be utilized [8]. FPSOs are long-term projects with operational lifespans ranging from 20 to 30 years [9].

FPSO vessels play a crucial role in offshore oil and gas operations, accounting for 28% of such activities. Their significance in the extraction, processing, and storage of oil and gas cannot be overstated [10]. These vessels, in conjunction with subsea systems, exhibit substantial electrical power demands, typically ranging from 10 to 100 megawatts (MW) [11]. To sustain their daily operations, they rely on fuel consumption to meet their energy needs, consequently leading to notable carbon emissions. Notably, the operational phases of these vessels contribute the highest share of their total emissions, constituting 88.2% over their operational lifespan [9].

3. Offshore Wind Energy

Investment in renewable energy is growing rapidly around the world to meet net-zero targets. Total global renewable energy capacity has more than doubled from 1,854,105 MW in 2015 to 3,869,705 MW in 2023, with annual investments driving up capacity rates. In Türkiye, renewable energy capacity has grown from 31,516 MW in 2015 to an impressive 58,462 MW in 2023. From 2015 to 2023, the wind energy sector experienced a remarkable capacity growth rate of 144% globally and an impressive 160% in Türkiye. While Türkiye has yet to establish any offshore wind capacity, global capacity growth during the same period was an astounding 519%, largely due to China's aggressive capacity expansion[5].

Table 1: Renewable Energy Capacities of Countries

	CAP(MW)	**2015**	**2020**	**2021**	**2022**	**2023**
Total Renewable Energy	**World**	1 854 105	2 822 931	3 088 809	3 396 323	3 869 705
	Europe	465 127	609 130	651 439	715 542	786 788
	China	479 103	896 412	1 017 852	1 156 126	1 453 701
	Türkiye	31 516	49 195	53 175	55 946	58 462
	Denmark	7 109	9 656	10 867	12 167	13 024
	France	43 024	55 847	59 700	64 692	69 301
	Germany	97 851	131 686	139 077	149 143	166 939
	UK	30 800	47 518	49 263	53 064	55 561
	USA	196 010	293 392	326 629	356 413	387 549
Total Wind Energy	CAP(MW)	**2015**	**2020**	**2021**	**2022**	**2023**
	World	416 335	733 719	824 602	901 231	1 017 199
	Europe	143 015	221 517	221 517	240 278	257 111
	China	131 048	328 973	328 973	365 964	441 895
	Türkiye	4 503	10 607	10 607	11 396	11 697
	Denmark	5 077	7 004	7 004	7 084	7 482
	France	10 298	18 551	18 551	20 811	22 196
	Germany	44 580	63 711	63 711	66 163	69 459
	UK	14 305	25 748	25 748	28 762	30 215
	USA	72 767	133 019	133 019	141 674	148 020
Offshore Wind Energy	CAP(MW)	**2015**	**2020**	**2021**	**2022**	**2023**
	World	11 735	34 369	54 265	61 967	72 663
	Europe	11 006	24 928	26 415	29 539	32 369
	China	559	8 990	26 390	30 460	37 290
	Türkiye	0	0	0	0	0
	Denmark	1 271	1 701	2 306	2 306	2 650
	France	11	2	2	2	2
	Germany	3 283	7 787	7 807	8 149	8 407
	UK	5 093	10 383	11 256	13 928	14 746
	USA	0	29	41	41	41

Source: (*Renewable Capacity Statistics*, IRENA, 2024)

Türkiye has the potential to generate up to 69GW of offshore wind power, of which 12GW is fixed wind power and 57GW is floating wind power, thanks to its favorable geography. Achieving this capacity requires significant investment and presents challenges, but Türkiye has the potential to realize this and support the country's strategic energy planning. Türkiye can achieve its global energy goals by integrating these renewable energy opportunities with its oil and gas fields[12].

Table 2: Türkiye's Offshore Wind Turbine Capacity

TURKEY			
Type	Water Depth (m)	Wind Speed (m/s)	GW
Fixed	≤50	7-8	6.6
	≤50	8	5.6
		Total	**12**
Floating	≤250	7-8	21.3
	≤250	8	20.6
	≤500	7-8	5.4
	≤500	8	5.6
	≤1,000	7-8	7.4
	≤1,000	8	2.7
		Total	**57**

4. Potential Offshore Wind Farm Installation Areas at Black Sea

In order to meet technical requirements and achieve operational success, offshore wind turbine installations must consider several site selection criteria. These include wind speed, sea depth, distance from the coast, military and civil aviation zones, maritime and pipeline routes, and international waters. By carefully considering all of these factors, we can determine the optimal installation locations for wind turbines with confidence and authority[13].

Floating platforms for offshore wind turbines are divided into four main groups: Spars, barges, semi-submersibles, and tethers platforms. These have various advantages and disadvantages in terms of seabed, depth, project suitability, and cost. These platforms keep wind turbines on the sea surface by using gravity stabilization, mooring stabilization, and waterplane stabilization[14].

At present, for the installation of offshore wind power plants in Türkiye, 4 candidate areas have been declared as renewable energy resource areas. The offshore areas of Bandırma (1111 km^2), Bozcaada (299 km^2), Gelibolu (75.6 km^2), and Karabiga (410 km^2) have been declared by the Ministry of Energy as candidate areas for wind power plants. These areas are technically sufficient. None of these locations are in the Black Sea, and it is not feasible to supply energy to the oil and gas fields from these locations[15].

Two different options should be investigated at this stage to supply offshore oil and gas fields in the Black Sea with renewable wind energy: either to install floating wind turbines along the coastal route and connect the offshore field to the renewable energy with subsea cables or to connect the platform to the renewable energy with floating wind turbines installed close to the production platform. Both options have some operational and technical issues.

Karasu, Amasra, and Inebolu have been identified as potential regions in the Black Sea for the installation of wind turbines that can operate with high efficiency. Despite the presence of a military area in the Amasra region, which is the most efficient wind area on the Southern Black Sea coastline, we remain confident in our ability to find a solution that will allow for the installation of wind turbines in that region. In terms of efficiency and other criteria, Inebolu is the most suitable location, excluding Amasra from the evaluation[13], [16].

The Amasra-Inebolu coastline has been identified as a potentially suitable region for a floating wind power plant, according to The World Bank's wind efficiency atlas for the Black Sea. The shaded area in the Fig.1 below meets the technical criteria for floating wind turbines[12].

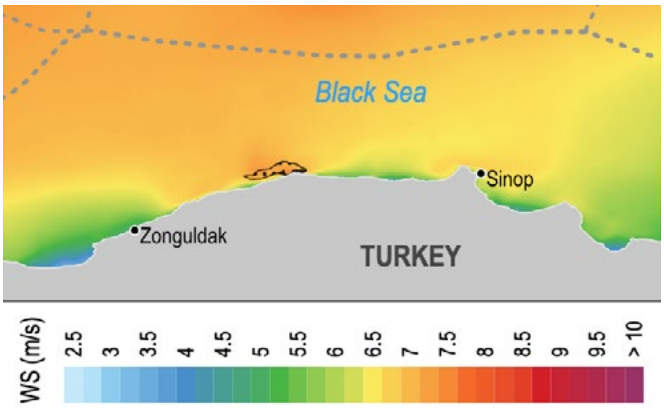

Fig 1. Optimal Offshore Wind Energy Sites

The Inebolu coastline's strategic advantage lies in its proximity to the Filyos port and the oil and gas field. The production platform for oil and gas in the Sakarya Gas field, located approximately 170 km away from Filyos Port, can be connected to renewable wind energy from the wind farm to be established off the coast of Inebolu via subsea cables (Fig 2). When laying cables under the sea, it is crucial to take into account the length of the cable and the energy loss that may occur due to distance[17]. The Filyos port is specifically designed for offshore operations, making the installation and maintenance of wind power plants much more efficient. Furthermore, the extensive experience gained in offshore oil and gas will undoubtedly be valuable in the development of offshore power plants.

Fig 2. Offshore Wind Energy Planning

Placing a floating wind power plant near the oil and gas field is another option. Mooring the floating power plant to the seabed in this region is costly due to the 2000 m depth of the sea[7], [18]. Despite the operational difficulties and high costs associated with installing the plant due to the sea depth in the region, approximately 170 km away from Filyos, it is the most effective way to meet the energy needs of the platform. It is important to consider the distance of the region from the harbor when calculating the operating costs of maintenance vessels that will need to sail to the field at regular intervals[19].

1. Conclusion

Türkiye has made substantial investments in the offshore oil and gas sector over the years. The recently discovered reserves are projected to satisfy 30% of Türkiye's energy demands. However, as development and production activities progress, carbon emissions from offshore oil and gas operations are anticipated to rise annually. Therefore, integrating renewable energy sources with conventional ones will play a pivotal role in Türkiye's journey towards achieving net-zero targets.

One effective strategy is the integration of wind energy with oil and gas fields, leading to a substantial reduction in carbon emissions in the Black Sea region. Floating wind energy platforms emerge as key components in this endeavour. Although high initial installation costs pose a significant challenge, Türkiye's advancements in offshore technologies suggest that this barrier is not insurmountable. Offshore wind power facilities, contingent upon thorough feasibility and project assessments, represent a critical stride towards mitigating carbon emissions associated with oil and gas production.

Following meticulous evaluation, we have identified optimal locations for floating wind power installations, notably offshore Inebolu on the southwest coast of the Black Sea or a site closer to the oil and gas field. Despite inherent drawbacks in terms of costs and operational aspects at both locations, key factors such as water depth, proximity to the coast, and wind potential in the designated regions have been considered in determining the most suitable location for these installations. Subsequent studies will delve into the feasibility of these projects and ascertain their comparative efficiency.

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Numerical Investigation of Exhaust Emissions of Ammonia on Medium-speed Marine Diesel Engine Under Different Ammonia Fuel Injection Timing

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Abstract

Ammonia, as a fuel that carries hydrogen without emitting carbon, possesses the capacity to effectively address the issue of greenhouse gas emissions, thereby presenting substantial potential for its utilization in marine engines. In this study, the effects of four different ammonia fuel injection timing (-5, 0, 5, 10 CA) on exhaust emissions were numerically investigated in a medium-speed marine engine. The MAN B&W engine simulator was used to obtain the experimental data of the cylinder pressure variations. Using these values, the CFD model was verified via mean absolute percentage error criteria. The skeletal ammonia/n-heptane mechanism, consisting of 69 species and 389 reactions, was used in the CFD approach. When the timing of ammonia fuel injection was delayed, there was an increase in NO_X *and* CO_2 *emissions, while the emissions of HC and CO decreased as the timing of ammonia fuel injection advanced.*

Keywords: *Marine engine, Numerical investigation, Ammonia, Exhaust emissions*

1. Introduction

The increasing concern over environmental sustainability and the impact of greenhouse gases has led to a surge in research on alternative fuels. One such alternative is ammonia, a carbon-free fuel that has the potential to significantly reduce exhaust emissions. This paper presents a numerical investigation of exhaust emissions of ammonia on medium-speed marine diesel engines under different ammonia fuel injection timings.

The International Maritime Organization (IMO) has set ambitious targets to reduce the maritime industry's greenhouse gas emissions by at least 50% by 2050 compared to 2008 levels [1]. Achieving these targets requires a shift away from traditional fossil fuels towards more sustainable alternatives. Ammonia, as a potential carbon-free fuel, has been gaining attention in the marine industry due to its high energy density and ease of storage. However, the combustion characteristics of ammonia differ significantly from conventional diesel fuel, which can affect engine performance and emissions [2-4]. Understanding these effects is crucial for the successful implementation of ammonia as a marine fuel. Medium-speed marine diesel engines are widely used in various types of ships due to their reliability, durability, and fuel efficiency. However, these engines are also significant contributors to global exhaust emissions. The use of ammonia as a fuel in these engines could potentially mitigate their environmental impact [5, 6].

Previous studies have explored the use of ammonia in internal combustion engines, focusing on aspects such as combustion characteristics, engine performance, and emission formation [7-9]. However, there is a lack of comprehensive studies investigating the impact of fuel injection timing on ammonia combustion and emissions in medium-speed marine diesel engines. Furthermore, the impact of fuel injection timing on ammonia combustion and emissions in marine engines remains largely unexplored.

This research aims to fill this gap in the literature by numerically investigating the exhaust emissions of ammonia in medium-speed marine diesel engines under different fuel injection timings. The specific objectives are to develop a numerical model that accurately simulates the combustion process of ammonia in medium-speed marine diesel engines, to investigate the impact of different ammonia fuel injection timings on exhaust emissions, and to identify the optimal fuel injection timing that minimizes exhaust emissions without compromising engine performance. The findings of this study could provide valuable insights for engine manufacturers and ship operators, contributing to the development of more sustainable marine propulsion systems.

2. Numerical Model

In numerous Research and Design (R&D) fields, Computational Fluid Dynamics (CFD) software suites are extensively employed for simulation studies. In this investigation, a numerical model of a medium-speed marine diesel engine (specifically, the MAN Diesel L32-40) was developed using CONVERGE Studio v3.2 [10]. The use of sector geometry, which can represent the results obtained in a full engine geometry, has been preferred both to shorten the numerical analysis time and to reduce the volume of operations. The sector geometry of the engine under examination is depicted in Figure 1. The specifications of the marine diesel engine operating under full load conditions are enumerated in Table 1.

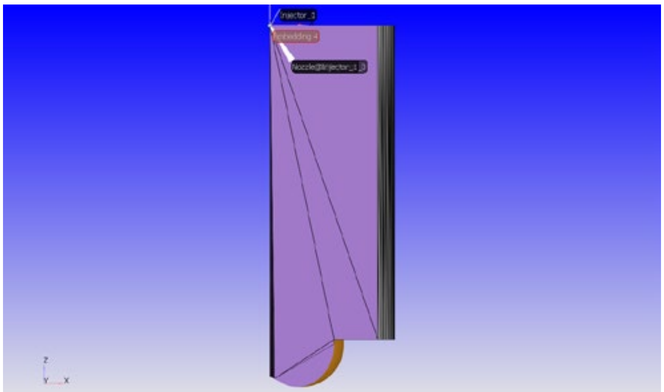

Figure 1. MAN 32/40 medium speed marine diesel engine sector geometry.

Table 1. MAN 32/40 engine specifications for the medium speed marine diesel engine.

Parameters	Value
Compression ratio	22.0
Engine speed (rpm)	750
Bore (mm)	320
Stroke (mm)	400
Connecting rod length (mm)	533
Diesel nozzle hole diameter (mm)	0.259
Diesel injection temperature (K)	341
Number of diesel injector	1
Ammonia nozzle hole diameter (mm)	0.259
Ammonia injection temperature (K)	300
Number of ammonia injector	1
Number parcels of per nozzle	5000

The main computational models used in the simulation are as follows: The RNG k-ε turbulence model [11] is commonly used in engineering. The modified KH-RT model [12] was chosen for the spray breakup model, model parameters are set as $B_0 = 0.61$ [13], $B_1 = 7$, $C_{RT} = 0.1$ [14], $C_{bl} = 0$ [15]. The Frossling Correlation model [16] was used to simulate the evaporation process. As the combustion model, the SAGE model [17] is selected, and the chemical reaction kinetic mechanism is coupled with the chemical kinetic solver to solve the combustion reaction process of the computational fuel. The mechanism used in this study merges the ammonia and n-heptane mechanisms, replacing diesel with n-heptane, which has similar combustion characteristics to diesel. The chemical reaction kinetic mechanism, which is come from Xu et al. [18], contains 69 species and 389 reactions. Its prediction result on the skeletal mechanism is acceptable.

Wall boundaries were respectively described as piston and cylinder head. Periodic boundaries were determined as front and back faces. Initial and boundary conditions are listed in Table 2.

Table 2. Initial and boundary conditions

Initial conditions	**Value**	**Unit**
Velocity	(0, 0, 0)	m/s
Temperature	319	K
Pressure	196000	Pa
Turbulence kinetic energy	10	m^2/s^2
Turbulence dissipation	5000	m^2/s^3
Species (Air) Mass Fraction	N_2: 0.76, O_2: 0.233	-
Boundary conditions		
Piston (Boundary Type: WALL)		
Wall motion type	Translating	
Surface movement	MOVING-Law of wall	
Temperature Boundary Condition		Law of wall - 320 K
Heat Model		Han and Reitz
Turbulence kinetic energy (tke) Boundary Condition		Zero normal gradient (NE)
Turbulence dissipation (eps) Boundary Condition		Wall model
Cylinder wall and Cylinder head (Boundary Type: WALL)		
Wall motion type	Stationary	
Surface movement	FIXED-Law of wall	
Temperature Boundary Condition		Law of wall - 330 K
Heat Model		Han and Reitz
Turbulence kinetic energy (tke) Boundary Condition		Zero normal gradient (NE)
Turbulence dissipation (eps) Boundary Condition		Wall model
Front face and Back face (Boundary Type: PERIODIC)		
Periodic type	Stationary	
Periodic shape	Rotational	
Angle	60 degree	

3. Results and Discussions

3.1. Model Validation

All computational procedures were executed using the CONVERGE Studio v3.2. The analyses incorporated cell counts of 50000, 75000, and 100000, which were derived from base grid dimensions of 4.82413 mm, 4.214267 mm, and 3.82892 mm respectively. The Mean Absolute Percentage Errors (MAPE) were computed for all scenarios, taking into account the experimental data, and the results are presented in Table 3. Based on the MAPE outcomes, Case-2 was identified as the most optimal solution.

Table 3. MAPE for in-cylinder pressure results

Case Number	Cell Count	Base Grid [mm]	MAPE (%)
1	50,000	4.82413	18.62
2	75,000	4.214267	17.25
3	100,000	3.82892	17.48

3.2. Exhaust Emissions

For four different ammonia start of injection timings (-5, 0, 5, 10 CA), the variation of nitrogen oxides (NO_X) emissions, unburned hydrocarbon (HC) emissions, carbon monoxide (CO) emissions, carbon dioxide (CO_2) emissions and soot emissions on crank angle was examined.

The variation of NO_X emission with respect to the crank angle is shown in Figure 2. It has been observed that as the start of ammonia injection is delayed, the NO_X emission increases. The increase in NO_X emissions with delayed ammonia injection is due to higher combustion temperature, increased ammonia content, incomplete combustion, and changes in the equivalence ratio. The maximum NO_X emission value is obtained as 0.000199138 kg at 10 CA ammonia start of injection case. The final NO_X emission values are respectively as 0.000170316 kg, 0.000185849 kg, 0.000190973 kg, 0.000195633 kg from -5 to 10 CA ammonia start of injection cases.

The variation of HC emission with respect to the crank angle is shown in Figure 3. It has been observed that as the start of ammonia injection is delayed, the HC emission values decrease. This can be attributed to the enhanced combustion efficiency and reduced fuel-rich regions that are achieved with delayed ammonia injection. The maximum HC emission value is obtained as 0.0001684 kg at -5 CA ammonia start of injection case. The final HC emission values are respectively as 4.5030056E-5 kg, 2.6536705E-6 kg, 2.6426235E-8 kg, 4.9645681E-10 kg from -5 to 10 CA ammonia start of injection cases.

Figure 4 illustrates the fluctuation of CO emissions in relation to the crank angle. It has been discerned that delaying the initiation of ammonia injection leads to a reduction in CO emission levels. This phenomenon can be ascribed to the enhanced oxidation of CO, facilitated by the increased availability of oxygen and higher combustion temperatures. Consequently, combustion becomes more thorough, resulting in diminished CO emissions. The peak CO emission value is recorded as 0.000950106 kg at the -5 CA ammonia start of injection case. The concluding CO emission values for the -5 to 10 CA ammonia start of injection cases are sequentially 0.000745819 kg, 0.000481625 kg, 0.000352988 kg, and 0.000195672 kg.

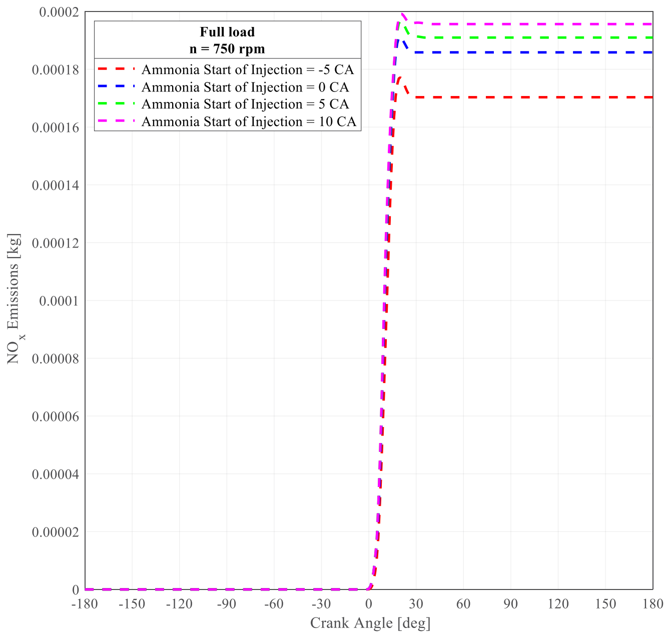

Figure 2. NO_X emissions for different ammonia injection timing.

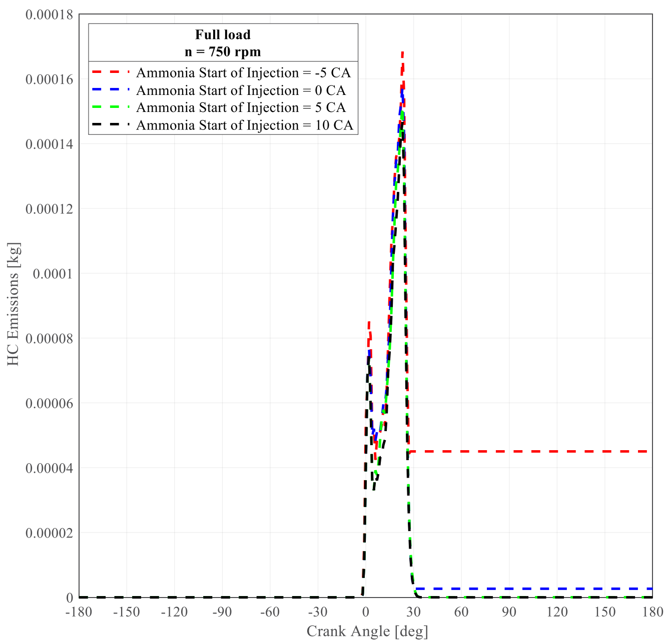

Figure 3. HC emissions for different ammonia injection timing.

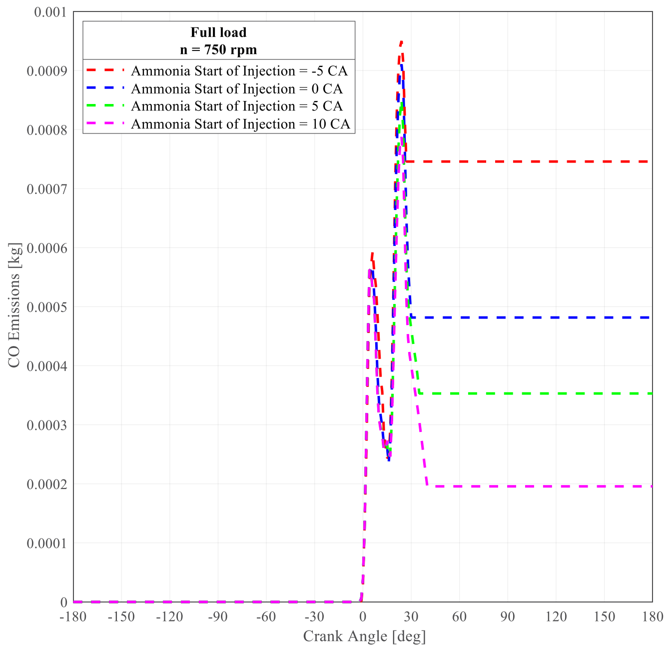

Figure 4. CO emissions for different ammonia injection timing.

Figure 5 presents the changes in CO_2 emissions in relation to the crank angle. It is observed that a delay in the start of ammonia injection leads to an increase in CO_2 emission levels. This can be ascribed to the improved combustion efficiency, which facilitates more thorough combustion of the fuel and consequently results in a higher concentration of CO_2 in the exhaust gases. The peak CO_2 emission value is recorded as 0.010022345 kg at 10 CA ammonia start of injection case. The final CO_2 emission values are respectively as 0.009017247 kg, 0.009565089 kg, 0.009775143 kg, 0.010022345 kg from -5 to 10 CA ammonia start of injection cases.

The variation of soot emissions with respect to the crank angle is shown in Figure 6. It is noted that a delay in the initiation of ammonia injection results in a reduction in soot emission levels. This phenomenon can be linked to improved combustion efficiency and elevated combustion temperatures, which promote more thorough fuel oxidation and consequently decrease the production of soot particles. The peak soot emission value is recorded as 7.5962818E-06 kg when the ammonia injection begins at -5 CA. The final soot emission values for the -5 to 10 CA ammonia start of injection cases are sequentially 7.1632227E-6 kg, 4.345086E-6 kg, 2.5417913E-06 kg, and 1.4232022E-06 kg.

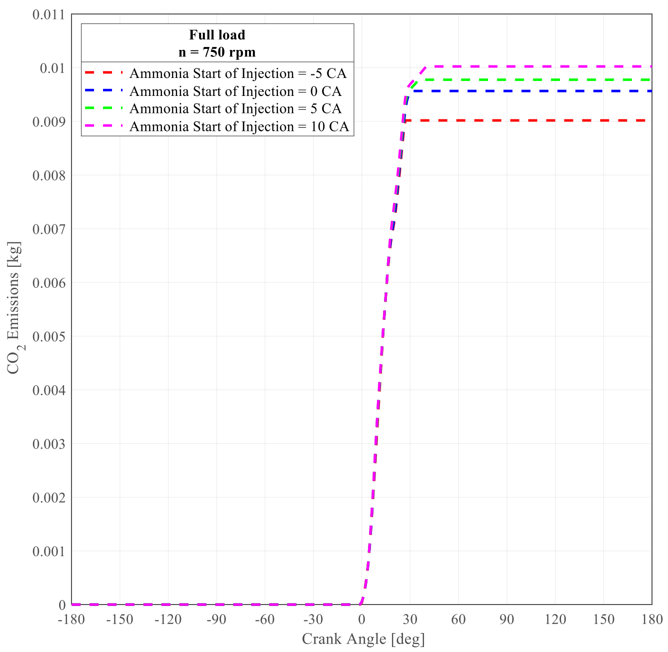

Figure 5. CO_2 emissions for different ammonia injection timing.

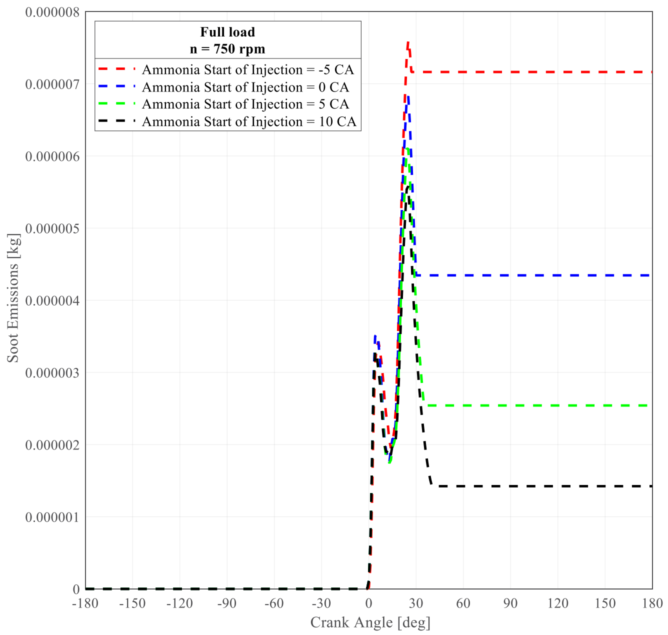

Figure 6. Soot emissions for different ammonia injection timing.

4. Conclusions

A numerical analysis was conducted using CFD software to simulate and scrutinize the performance of a medium-speed marine diesel engine operating on an ammonia/diesel dual-fuel system. The study examined the impact of the timing of ammonia injection on exhaust emissions. The CFD model presented was corroborated by experimental data. The optimal scenario, referred to as Case-2, was identified with a cell count of 75,000 and a MAPE of 17.25%.

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Navigating a Greener Marine Future with Vessel Electrification and DC Power Management Systems

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Abstract

The International Maritime Organization has introduced ambitious emission reduction targets to accelerate decarbonization and net zero operations in international shipping by 2050. To enhance vessel efficiency, the industry is examining unique alternatives with electrification of ships emerging as a vanguard solution facilitating the integration of multiple onboard energy sources. However, electrification poses various complications for the control and management of onboard power systems. One method to address the challenges of electrification is through the adoption of a comprehensive marine solution that combines AC and DC Power Management Systems into one powerful control platform. Vessel electrification is relatively new to the industry and often necessitates complex PLC development. This paper examines an innovative DC Power Management control system, developed by ComAp, which can manage any onboard energy source, including battery packs, fuel cells, traditional or shaft generators, shore connections, and grid converters. The paper reviews the technology of the solution and the efforts to standardize PLC functions, simplify commissioning and crew operations, and optimize costs. A practical implementation of this system on a fully electric tugboat is examined, demonstrating real-world benefits. The system effectively controls battery packs, backup diesel generators, and DC shore fast chargers, underlining its potential for decarbonizing the shipping industry.

Keywords: *decarbonization, electrification, DC Power Management, shipping, marine, technology*

1. Introduction

The maritime sector is at a critical juncture, with requirements for decarbonization dominating the agenda. The United Nations has warned that without immediate and significant action, shipping emissions could increase to 130% of their 2008 levels by 2050 [1]. Over the past decade, emissions from maritime vessels have risen by 20%, and the International Maritime Organization (IMO) has reported that international shipping is responsible for nearly 3% of global carbon emissions. This figure may appear small, but critically, around 90% of global commercial goods are transported by sea, and the demand for marine transport continues to grow. As the sector expands, new ships will be built, and the volume and cargo being transported will increase.

Consequently, major global regulatory bodies are asking the sector to take immediate action. 2023 was a turning point, with significant decisions and regulations introduced to promote emission reduction for maritime vessels. Midway through the year, the IMO revised its initial decarbonization strategy and set ambitious new targets for international shipping, with the ultimate goal of achieving net zero greenhouse gas (GHG) emissions by 2050. This represents a significant shift from the previous target of a 50% reduction in GHG emissions by 2050. Additionally, the new strategy includes interim GHG reduction checkpoints of at least 20% by 2030 and 70% by 2040. Furthermore, all targets will be assessed on a well-to-wake basis to prevent the shifting of reduction responsibilities to other sectors. The industry will also need to focus on improving the energy efficiency design of new ships to reduce their carbon intensity. By 2030, there should be an uptake of zero or near-zero GHG emissions technologies, fuels, or energy sources. These are expected to represent at least 5% of the energy mix used by international shipping [1].

Later, in September 2023, the European Parliament and Council co-legislators signed regulations to adopt the FuelEU Maritime initiative, which aims to reduce the carbon footprint of the European maritime sector by up to 80% by 2050 and promote the use of renewable and low-carbon fuels [2], [3]. This initiative forms part of the broader EU Fit for 55 package, which seeks to decarbonize the EU economy and reduce net greenhouse gas (GHG) emissions by at least 55% by 2030. Additionally, localized maritime emissions governance from organizations such as the California Air Resources Board and others provides a complex regulatory environment for maritime stakeholders [4]. Nevertheless, the end goal is clear, and compliance with these various pieces of legislation will require new decarbonization technologies and solutions. A range of such technologies and alternatives have been proposed and are being tested, piloted, and in some cases, adopted. These technologies include, among others, onboard carbon capture and storage (CCS), and the use of alternative fuels such as Liquified Natural Gas (LNG), hydrogen, methanol, and ammonia [5], [6]. Each of these technologies offers impressive emissions reduction potential, but as is the case with many emerging technologies, there are challenges and limitations presented with each of them, and their implementation is not suitable for all vessel types worldwide.

Some of the common challenges to each of these technologies are the need for additional onboard storage space and improved infrastructure for logistics, production, or supply. In the case of CCS, storage and liquification of sequestered CO_2 present difficulties as onboard space and power are limited [7]. Production, supply, and onboard hydrogen storage are challenging due to the fuel's relatively low volumetric energy density [8]. Similarly, ammonia's energy density is roughly three times less than that of conventional fuels, and it is also highly toxic to both humans and marine life [9]. Methanol, too, has a lower energy density, requiring storage tank sizes to be about 2.4 times larger than those installed for traditional fuels [10]. Additionally, it is toxic to humans and corrosive to certain materials which may require the redesign of combustion engine parts, storage tanks, and piping [11].

In contrast to these technologies, electrification in the maritime industry presents a promising and viable solution. Electric and hybrid propulsion systems, powered by batteries or a combination of batteries and other onboard traditional sources, are increasingly being adopted due to their high efficiency, near-zero emissions at the point of use, and compatibility with renewable energy sources [1]. Onboard direct current (DC) grids offer both power stability and quality benefits as well as economic and environmental benefits [12]. Battery electric vessels are particularly suitable for short-sea shipping and ferry operations, where the vessels operate close to shore and can be recharged frequently [13]. However, adopting these technologies also presents challenges, such as the need for significant infrastructure investment for charging stations. Nevertheless, electrification is economically viable for a large portion of the fleet and provides significant reductions in GHG emissions and air pollution, making it a key strategy in the decarbonization of the maritime industry [14], [15].

While electrification offers a promising path toward decarbonization, it is not a panacea for all vessel types and operational profiles. In this paper, we will examine the control and automation solutions developed by ComAp which enable efficient and optimized electric vessel operation. The paper provides an overview of the technology, the standardization of application functionality and inter-system communication protocols, the simulation, debugging, and testing of the software, and the benefits that all of these provide to the end user. It explains some of the challenges that vessel electrification presents and offers an answer to these challenges using the pivotal developments of ComAp's control systems, furthering the ongoing dialogue of sustainable practices in the maritime industry.

2. Electrification and the Necessary Controls Systems

2.1. Benefits of Electrification

In the pursuit of sustainable practices in the maritime industry, the electrification and hybridization of ships emerge as a potentially feasible solution. This process involves the utilization of electricity as the primary power source for both propulsion and auxiliary systems, entirely replacing conventional prime movers, or in some cases, augmenting them. The integration of diverse onboard energy sources, such as diesel generators, batteries, fuel cells, and solar panels, is facilitated by ship electrification. Coupled with an increased implementation of shore power, this integration enhances the flexibility, reliability, and sustainability of the onboard power system.

The benefits of ship electrification are vast. Firstly, it can significantly reduce fuel consumption and emissions by optimizing the operation and efficiency of onboard energy sources [16] and enabling the use of renewable and low-carbon energy sources. Secondly, it can improve the performance and safety of ships by providing more precise and responsive control of propulsion and auxiliary systems, and by enhancing the redundancy and fault tolerance of the onboard power system. A study by DNV, one of the leading accreditation and certification organizations globally for the maritime industry, demonstrated that ship electrification could enhance the maneuverability, stability, and availability of ships, and reduce the risk of blackouts [16]. Lastly, ship electrification can lower the operating and maintenance costs by reducing fuel consumption and emissions, and by simplifying the design and configuration of the onboard power system. A study by Siemens Energy estimated that over 70% of the ferry fleet could economically benefit from electrification, thereby reducing the total cost of ownership [14].

These benefits are well recognized across the globe, and the resulting uptake in battery ship proliferation has been documented in DNV's Alternative Fuels Insight database. The number of vessels with these technologies is dynamic, and the data indicated in Tables 1 through 3 below was retrieved in March 2024 [17]. This data shows the varying degrees of adoption of battery technologies in the maritime sector across different regions, highlighting the areas where significant progress has been made and where further electrification potential exists.

Table 1. Battery Ships by Region

Region	Vessel Count
Norway	380
Europe	349
Asia	148
Other	112
America	69
Oceania	13
Africa	1

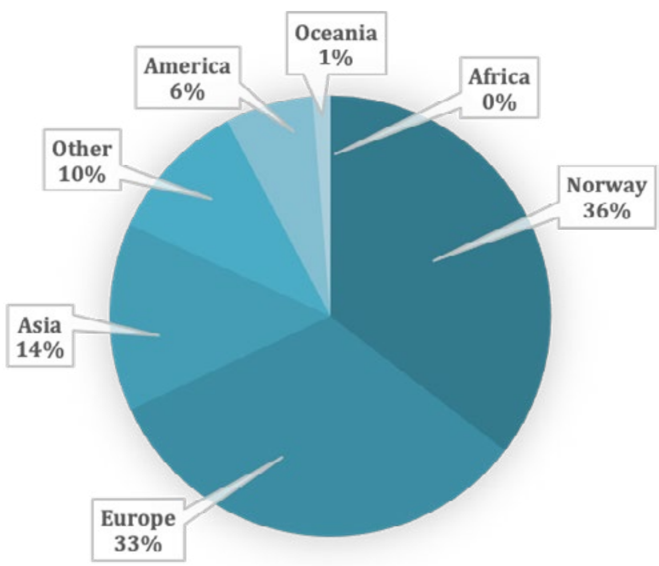

Figure 1. Battery Ships by Region

The data presented in Table 1 and Figure 1 provide a comprehensive view of the adoption of battery technologies by vessels across various countries and regions.

Norway leads the fleet with 380 vessels, accounting for 36% of the total, demonstrating a strong commitment to sustainable maritime practices. The rest of Europe follows closely with 349 vessels, making up 33% of the total. Asia, with 148 vessels, and the Global category, with 112 vessels, represent 14% and 10% of the total respectively, indicating a growing interest in ship electrification. America, with 69 vessels, contributes to 6% of the total, while Oceania, with 13 vessels, represents a small fraction at 1%. Africa, with only 1 vessel, has almost negligible representation, indicating a need for increased focus on sustainable maritime practices in the region.

The data presented in Table 2 and Figure 2 provide insight into the distribution of battery ships by their mode of operation.

Table 2. Battery Ships by Application

Mode	Vessel Count
Hybrid	767
Pure electric	247
Plug-in hybrid	175

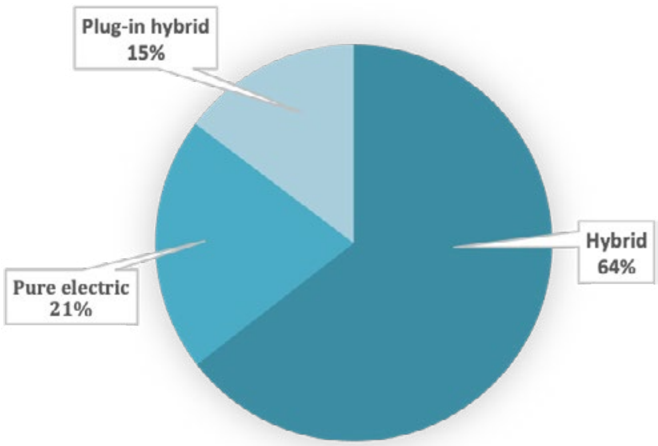

Figure 2. Battery Ships by Application

Looking at the numbers, hybrid vessels dominate the sector with a total of 767 units, accounting for a significant 64% of the total. This dominance can be attributed to the flexibility and efficiency that hybrid systems offer, allowing for the use of electric power in optimal conditions and switching to conventional methods when necessary. Purely electric vessels, with a total of 247 units, make up 21% of the total. The adoption of pure electric vessels is likely driven by their zero-emission operations and lower operating costs, although their range and speed may be limited compared to hybrid vessels. Plug-in hybrid vessels, with 175 units, represent the smallest group at 15% of the total. These vessels offer the benefits of both hybrid and pure electric vessels, with the ability to operate on electric power when near shore or in port, and switch to conventional methods for longer voyages.

This distribution underscores the growing trend towards electrification in the maritime sector, with hybrid systems leading the way due to their versatility and efficiency. Nonetheless, the substantial presence of purely electric and plug-in hybrid vessels suggests a varied strategy toward achieving sustainable maritime operations through electrification. Further advancements in battery technology and charging infrastructure are likely to influence these trends in the future.

Table 3. Battery Ships by Ship Type

Ship Type	In Operation	On order
Car/Passenger ferries	330	95
Other activities	174	62
Offshore supply ships	99	19
Fishing vessels	75	27
Other offshore vessels	45	52
Cruise ships	34	1
Tugs	29	14
Ro-Ro cargo ships	22	40
General cargo ships	17	19
Oil/Chemical tankers	13	3
Bulk carriers	11	3
Yachts	9	9
RoPax	8	1
Container Ships	6	4
Crude oil tankers	6	0
Fish factory	1	0

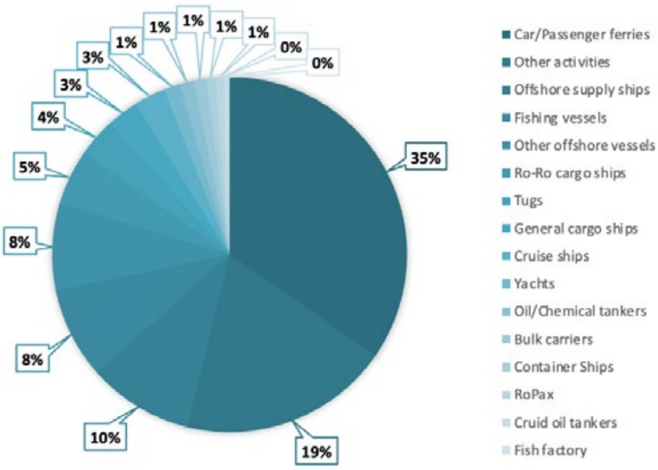

Figure 3. Battery Ships by Ship Type

The data presented in Table 3 and Figure 3 provides an overview of the adoption of battery technologies across various types of vessels.

Car and Passenger ferries lead the adoption with 330 vessels in operation and 95 on order, representing 35% of the battery fleet. This dominance can be attributed to the frequent short-distance travels that these ferries undertake, making them ideal candidates for battery operations due to regular docking schedules and battery charging opportunities. Offshore supply ships also have a significant number of vessels with battery technologies, likely due to their operational patterns and energy requirements being well-suited for batteries. In contrast, crude oil tankers, container ships, and fish factories have the least adoption. Several factors may contribute to this including long-distance travel, heavy energy requirements, or imposed legislation making investment in these sectors less feasible.

However, it is important to note that the slower adoption of electrification in certain vessel categories does not necessarily reflect their incompatibility with this technology. Many of these categories are capable of electrification, albeit with certain considerations. A study published in Nature Energy illuminates a potential pathway for the battery electrification of container ships, suggesting that over 40% of global container ship traffic could be electrified within this decade [15]. This indicates that even for vessel categories with traditionally high energy requirements and long-distance travel, such as crude oil tankers and container ships, electrification is not only feasible but also potentially beneficial. The key to further adoption across the world fleet lies in the continuous advancement of battery technologies and the development of efficient operational strategies tailored to the unique requirements of each vessel category.

2.2. Comprehensive Controls Systems

When considering the practicalities of electrification in the maritime sector, it becomes increasingly clear that the potential energy source configurations, power plant topologies, vessel functionalities, and operating profiles vary significantly across the world fleet. Therefore, the adoption of standardized control systems with embedded functionality becomes a key enabler. These control systems, based on advanced microprocessor technology, provide a unified platform for managing various aspects of a ship's operations, including electric propulsion and power management. By standardizing these systems, shipbuilders and operators can leverage economies of scale, reduce development time, and ensure compatibility across different types of vessels and equipment.

The embedded functionality in these control systems allows for seamless integration of electric and hybrid power systems. This is particularly important in the context of hybridization, where the control system must manage the interaction between conventional engines and electric motors to optimize performance, efficiency, and emissions. With embedded functionality, the control system can dynamically adjust the power mix based on real-time conditions, such as speed, load, and battery state of charge, all through the simple selection of setpoints via drop-down menus, or adjustment of parameters via value entry in free-text fields. This not only simplifies the engineering and commissioning needs of electric and hybrid vessels but also enables quick and efficient system adjustment during the life of the vessel.

As we transition to a more detailed discussion of a specific control technology, it is worth noting that the effectiveness of such a system on a wider scale is largely dependent on its adaptability and scalability. A well-designed control system should be able to accommodate a wide range of vessel types, power configurations, and operational scenarios. It should also be scalable to handle future upgrades and expansions, such as the addition of new electric propulsion units or energy storage systems. This flexibility is crucial in the rapidly evolving maritime sector, where new technologies and regulations can quickly render systems obsolete that lack the ability to adapt.

3. Technology and Standardization

3.1. InteliGen1000 Marine Electrification Controls Solution

To support maritime electrification efforts, and to enable shipowners' compliance with emission reduction regulations, ComAp, a pioneer for control solutions for power generation and energy management, developed a new generation of marine controllers for paralleling applications, the InteliGen1000 Marine. This product is capable of managing and controlling any onboard energy system, encompassing both Alternating Current (AC) and Direct Current (DC) sources or buses, which is a precedent for the industry. The details in this section describe ComAp's InteliGen1000 control system and are extracted from ComAp's website [18].

When starting development of the solution, the goal was to introduce a unique concept of a pre-programmed controller to facilitate rapid and straightforward power plant commissioning and operation, while still providing the capability to customize and adjust system configuration as needed for non-standard applications. The InteliGen1000 Marine utilizes dedicated application firmware for each type of onboard power plant element, such as AC generators, DC generators, AC-bus connected Battery Energy Storage Systems (BESS), DC-bus connected BESS, grid-forming inverters, AC bus-tie breakers, DC bus-tie breakers, AC or DC shore connections, and more. Users can select the appropriate application firmware for each power plant element, and the InteliGen1000 Marine will automatically configure the parameters and functions according to the selected application. It also includes a large built-in Programmable Logic Controller (PLC) interpreter to cater to individual project requirements. Additionally, the standardization approach carries over to user interfaces where all dedicated displays offer a plug-and-play solution in which pre-programmed screens present a unified and structured set of relevant data and graphical icons for each application.

The large built-in PLC interpreter allows users to customize the parameters and functions according to the specific needs and preferences of each project, using a dedicated PC tool for configuration and monitoring. This drastically reduces the engineering and commissioning time requirements for both simple and complex marine power management projects. The PLC interpreter utilizes function blocks to create customized access and control of any parameter, input, output, or function of the InteliGen1000 Marine. It can also communicate with other devices and systems using various protocols, such as Modbus or Controller Area Network (CAN).

The InteliGen1000 Marine utilizes high measurement accuracy for both AC and DC sources or buses. It can measure AC voltage with an accuracy below 0.25% up to 690 VAC, AC current with an accuracy below 0.75%, and frequency with an accuracy below 0.001 Hz on a range of 20 Hz to 520 Hz. This frequency range enables the monitoring, control, and protection of various applications such as slow-speed shaft generators or variable-speed generators. Additionally, it can measure DC parameters via a new extension module named Inteli-DC4/4. This enables DC voltage measurement with an accuracy below 0.2% up to 1500 VDC, and DC current measurement with an accuracy below 0.5% up to 3000 ADC. The Inteli-DC4/4 measurement module, like the InteliGen1000 Marine, is type-approved, offering a proven and safe package for measurement and insulation monitoring of a wide range of DC systems. The high measurement accuracy of the InteliGen1000 Marine ensures precise control and protection of onboard energy sources and other power plant components and the accurate monitoring and reporting of the power quality and consumption.

Additionally, the controller complies with the latest industry standards and legislation including the International Association of Classification Societies (IACS) Unified Requirements, the International Maritime Organization (IMO) regulations, and the International Electrotechnical Commission (IEC) standards. Specifically, the InteliGen1000 Marine satisfies the IACS Unified Requirements E10 and E22, which delineate the test procedures and performance criteria for the type of approval of marine controllers. Furthermore, the InteliGen1000 Marine aligns with the IACS Unified Requirement E27 and pertinent IEC standards, such as IEC 62443. These provide guidelines and requirements for the cybersecurity of industrial automation and control systems.

A wide range of communication capabilities are built into the controller's functionality, facilitating remote communication and control of the onboard power system. The controller can concurrently handle up to 16 ComAp clients (remote displays and/or, PC tools), 6 Modbus TCP clients, 1 Modbus RTU client, and 1 SNMP agent. This multi-user and multi-device support caters to the increasing complexity of marine power management systems. The InteliGen1000 Marine also incorporates an integrated Modbus master function, enabling it to act as a Modbus client and poll data from any Modbus-based device. It can connect up to 64 controllers on one CAN bus segment, with all data being user-configurable. This communication capability enhances the connectivity and interoperability of the onboard power system, enabling data collection and analysis for system optimization and maintenance.

The controller ensures the reliability and scalability of the onboard power system by providing built-in CAN redundancy for the essential communication bus between controllers and "Hot-Swap" capability. The CAN redundancy feature allows the controllers to communicate and operate even if one of the CAN lines fails. The Hot-Swap feature allows the replacement of a faulty controller without interrupting the operation of the other controllers, providing added reliability for critical applications such as dynamic positioning platforms.

The InteliGen1000 Marine controller also allows the expansion and customization of the I/O capacity by using extension modules and distributed I/Os. It has 4 direct analog inputs, 1 direct analog output, 12 direct digital inputs, and 12 direct digital outputs on board, and can extend these capabilities up to 80 analog inputs, 30 analog outputs, 120 digital inputs, and 120 digital outputs, by using extension modules. It can also share up to 32 distributed binary outputs and 4 distributed analog outputs over the CAN bus, which can be used by any controller on the same site. Additionally, the InteliGen1000 Marine, in combination with other ComAp marine controllers, can integrate engine monitoring, control, and protection over CAN bus. The extendibility features of the InteliGen1000 Marine controller enable the integration of a wide array of marine power plant topologies and enhances the performance and safety of the onboard power system.

Protecting the vessel's operations from cyber-attacks is another critical function of the controller. It is developed with integrated cybersecurity features and implements resilient security concepts to provide a secure solution for the complete vessel power plant. It covers all aspects of security, including user login, secure ciphering connections with the controller, brute force protection, signed (protected) ComAp firmware, and firewall protection, among others. The InteliGen1000 Marine complies with the relevant chapters of the IEC 62443 standard, which outlines the guidelines and requirements for the cybersecurity of industrial automation and control systems. It also enables compliance with the IMO MSC.428(98) resolution, which encourages maritime administrations to ensure that cyber risks are appropriately addressed in the safety management systems of ships. Additionally, the InteliGen1000 Marine complies with the applicable section of IACS Unified Requirement E26 and E27, which defines the requirements for the cyber resilience of Ships and on-board Operational Technology systems and comes into effect on July 1, 2024, for most vessels contracted for new construction over 500 Gross tons [19], [20].

3.2. Simulation, Debugging, and Automated Testing

In the development of an embedded control system such as the InteliGen1000 Marine, capable of managing a diverse range of energy sources and power plant components, the importance of extensive simulation, debugging, and automated testing cannot be overstated. These processes form the backbone of a robust development strategy, ensuring the reliability, efficiency, and safety of the control system. Simulation allows for the modeling of various scenarios and conditions, providing valuable insights into the system's behavior and performance under different circumstances. Debugging aids in identifying and rectifying potential issues, enhancing the overall stability of the system. Automated testing, on the other hand, ensures consistent performance and functionality across all components, validating the system's readiness for real-world deployment. This section delves into the necessity of these processes and their integral role in the successful development of a versatile and reliable embedded control system.

The Research and Development (R&D) department at ComAp has engaged in the development of numerical models for all elements involved in the technologies controlled by ComAp controllers. This initiative was undertaken with the objective of developing and testing control algorithms. The REXYGEN System framework, a product of Rex Controls and the University of West Bohemia, serves as the foundation for this endeavor. A close collaboration between ComAp and these entities has resulted in the creation of a library of PowerGrid modeling blocks, encompassing models of synchronous generators, AC/DC converters, batteries, photovoltaic sources, transformers, and more.

The REXYGEN System is a suite of software products designed for real-time control of technical processes. Control algorithms are configured using a graphical editor (REXYGEN Studio) from a prepared list of functional blocks. The system boasts a comprehensive functional block library, RexLib, which facilitates the easy configuration of control logic, PID control, and more complex control algorithms. The models created are compatible with Simulink. Within ComAp, REXYGEN is utilized as a modeling environment (referred to as InteliSiteSim) for simulating power system topologies of both AC and DC types, making it a good fit for marine control systems.

Special communication blocks within the modeling library, coupled with corresponding options in the firmware configuration of ComAp controllers, enable the connection of the simulation model with a real ComAp controller. This results in virtually identical control unit wiring in the controlled technology as in the actual application, in line with the concept of modified hardware-in-the-loop. This approach leverages the ComAp principle of extensive customization of firmware behavior via a configuration tool.

For firmware development and testing of the InteliGen1000 Marine controller, hardware testbeds equipped with approximately 10 controllers were constructed. Comprehensive simulation tests were developed to support relevant tests, particularly those involving parallel cooperation modes of power sources and real-time changes in power topology (such as connection/disconnection of sources and mode changes of sources, i.e., discharge/charge of battery packs). The R&D department at ComAp employs a Continuous Integration/Continuous Deployment (CI/CD) approach with automatic nightly builds and testing, which facilitates rapid error detection. Regression tests were efficiently conducted during the development of different project stages at the aforementioned sites, leading to the detection of some very rare anomalies and bugs. However, the approach of working with simulation models does not guarantee satisfaction with the quality of development work achieved. Tests with real devices and verification of control algorithm behavior in industrial use form an integral part of the development process. These tests are conducted in close collaboration with partner companies and are crucial in proving the development results from the simulation environment on real-world physical devices.

4. Practical Implementation

4.1. Commissioning and Operations Simplification and Cost Optimization

Embedded control systems, such as ComAp's InteliGen1000 Marine controller, offer significant advantages over traditional PLC solutions. Both embedded control systems and PLCs are capable of managing and optimizing onboard AC and DC power management systems by controlling, monitoring, and protecting individual power sources in real time and managing their cooperation based on vessel-specific requirements.

One of the key benefits of an embedded control system is the significant reduction in engineering and commissioning time frames for a given project. Based on ComAp's experience, a typical vessel electrification project can require approximately 120 man-days for control system design, functional development, documentation preparation, Hardware-in-the-Loop testing, and commissioning. However, the embedded control system comes with application guides that satisfy the documentation component, and additional aspects such as functional development, regression testing, and debugging are already completed. This pre-emptive approach eliminates the need for extensive time investment in these areas, thereby reducing the overall project timeline and costs.

Moreover, the embedded control system allows for commissioning within 5 to 10 man-days, a significant reduction compared to PLC solutions. The system's inherent efficiency via the elimination of extensive debugging, regression tests, and reprogramming contributes to this shortened timeframe. When compared to a comparable PLC control system project, which could require 60 – 80 man-days for debugging, regression tests, and reprogramming, the benefits of the embedded control system become even more apparent. By reducing the time frames for engineering and commissioning, the embedded control system allows for quicker project completion, leading to cost savings and increased productivity.

Lastly, embedded control solutions offer the added benefit of reproducibility without relying on the same software programmer or team of programmers for each project. This allows system integrators to install and commission new hybrid or electric projects even if their workforce has changed since the last project, or their programmers from previous projects have left, taking with the requisite knowledge and expertise.

4.2. Case Study: Fully Electric Tugboat

One of the first real-world implementations of ComAp's DC power management system was for a revolutionary electric tugboat for Damen, one of the biggest privately owned shipyards globally. In 2022 Damen unveiled the RSD-E Tug 2513, known as Sparky, marking the introduction of the first fully electric tugboat in their portfolio. In the preceding years, ComAp was entrusted to develop the new AC/DC PMS for this groundbreaking harbor tug. The PMS, a system that controls the eight-battery pack primary power sources with a total output of 2,784 kWh, enables the tug to safely maneuver vessels to berth at the Ports of Auckland in New Zealand with up to 70 tons of bollard pull [21]. In addition to the battery packs, Sparky's DC PMS controls the backup generators with directly coupled fire-fighting pumps and DC Shore Power. This meticulously engineered tugboat has garnered global acclaim, having been distinguished as one of TIME's most innovative inventions of 2022 [22], bestowed with the prestigious ITS Tug of the Year Award in 2022 [23], and being a contender for the esteemed 2023 Ship of the Year Award [24].

This project is distinguished by its innovative integration of both AC and DC systems onboard the vessel, powering all electric consumers, including the electric propulsion thrusters. However, the technical aspects are not the sole remarkable features of this project. The global collaboration, spanning from ComAp's headquarters in Prague, Czech Republic, to Damen's headquarters in Gorinchem, The Netherlands, and their Damen Song Cam shipyard in Vietnam, where Sparky was constructed, adds another layer of uniqueness. The operations of Sparky are primarily based in New Zealand's Ports of Auckland, making this project truly international in scope.

Since her initial trials, Sparky has demonstrated exceptional reliability and performance. She is capable of executing two or three berthing operations within a single charging cycle, after which she can be recharged in less than two hours using the DC shore power fast-charging mode and be ready for another set of berthing operations. Operating solely on electricity, Sparky reduces CO_2 emissions by 465 tons annually, while operating at a third of the costs of comparable diesel tugboats in the Ports of Auckland fleet.

4.3. Real-world Benefits

The transition to electric propulsion in the maritime sector has the potential to significantly decrease emissions, thereby promoting more sustainable vessel operations. Electrically powered vessels do not emit greenhouse gases during operation, which can contribute to pollution reduction and minimize the impact on marine ecosystems. This is made possible by the superior energy efficiency of the electric grid compared to marine engines, which typically operate on marine diesel or heavy fuel oil. Consequently, the emissions per kilowatt of electric energy production are substantially lower than those produced by a marine engine. Moreover, the typically lower cost of electricity compared to marine diesel offers an operational expenditure savings incentive for vessel owners.

Statistical data from 2021 indicates that the average price of industrial electricity is 11.38 euro cents per kilowatt-hour, with even lower prices in regions such as North America and parts of Europe [25]. In contrast, global average bunker prices, which vary by fuel type, equate to around 17.15 euro cents per kilowatt-hour when converted to equivalent units [26]. Although this is dependent on factors such as engine type, size, and load conditions, among others, on average, the equivalent energy output is approximately one-third cheaper when sourced from the grid compared to marine diesel.

In addition, the global average carbon intensity from the electric grid in 2021 was approximately 400g CO_2/kWh. This figure varies by region, with the Americas and Europe producing a lower carbon footprint of approximately 280gCO_2/kWh, and Asia, Africa, and Australia producing an average of 520g CO_2/kWh [27]. The average CO_2 emissions from marine diesel engines vary depending on factors such as engine size, load conditions, operating modes, and the specific emission control technologies implemented by manufacturers. However, the carbon intensity typically falls within the range of 600 - 900 gCO_2/kWh.

5. Conclusion

This paper underscores the pivotal role of stringent emissions reduction regulations in driving technological advancements in the maritime industry. These regulations have catalyzed the shift towards more sustainable and efficient solutions, with vessel electrification and hybridization emerging as viable alternatives. The transition to these technologies is not merely a response to regulatory pressures, but also a strategic move that yields operational expenditure savings and significant reductions in emissions. Electrification offers tangible benefits, including operational cost savings and a marked decrease in emissions. The cost-effectiveness of electricity, when compared to traditional marine fuels, presents a compelling case for vessel owners to transition to electric or hybrid systems. Moreover, the reduction in emissions aligns with global efforts to mitigate the impacts of climate change, making electrification a sustainable choice for the maritime industry. The successful integration of these technologies hinges on the implementation of standardized and embedded control systems. These systems ensure a smooth and seamless transition, enabling vessel operators to reap the benefits of electrification and hybridization without significant disruptions to their operations. In this context, the InteliGen1000 Marine control system emerges as an enabler of the maritime sector's electrification efforts. This advanced control system, capable of managing a wide array of energy sources and power plant components, makes it highly adaptable to the diverse needs of electric and hybrid vessels. Its sophisticated algorithms and user-friendly interface simplify the complex task of power management, ensuring optimal performance and efficiency of the vessel's power plant. The confluence of regulatory changes, technological advancements, and the inherent benefits of electrification and hybridization heralds a new era in the maritime industry, characterized by sustainability and efficiency.

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Transition Fuels in Sustainable Power Generation: A Natural Gas Power Plant Analysis

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Abstract

The global power generation market is currently undergoing a significant transition, aiming to eliminate carbon emissions throughout the production cycle, from fuel production to end consumption, to achieve net-zero emissions within a short timeframe. To meet this ambitious goal, finding an optimal transition fuel is crucial while searching for a carbon-free alternative. For this purpose, this study focuses on examining the potential of natural gas and methanol as transition fuels. The study specifically analyses the annual data from a Natural Gas-fired combined-cycle floating power plant, comparing it with data on methanol use to determine the optimal transition fuel. The methodology involves utilizing the actual annual data of the power plant, which includes key factors such as engine loads, electric power production, fuel consumption, and carbon dioxide emissions. Based on the analysis results, methanol emits more carbon dioxide compared to natural gas, while being superior at aspects such as storage. These findings provide valuable insights for maritime stakeholders, guiding their future endeavors, developments, and investments toward achieving net-zero emissions for a more sustainable future.

Keywords: *Alternative fuels; LNG; Methanol, Greenhouse Gas Emissions; Floating Power Plant*

1. Introduction

Electricity plays a pivotal role in modern society, serving as an essential component of our daily lives and the foundation of our civilization[1], [2]. With electricity at the center of our lives and industry, the global generation capacity is increasing yearly with the increasing population. In 2022, the power sector experienced a growth in investment by 12%, [3], [4]. While the investments are at the given level, global electricity demand has grown almost by 2%. It is anticipated that the increase in worldwide electricity demand [5]. Globally, electricity is generated by different sources, [6]. Even though electricity production is crucial, it is generating a large amount of Greenhouse Gas Emissions (GHG) in the world. Studies highlight the profound [3], [4], [7], [8], [9], [10]. As seen from the data provided above, with the rise in power demand and generation, greenhouse gas emissions are also climbing, highlighting the need for measures to mitigate climate change impacts resulting from these emissions. T[11]. Overall, the Net-Zero targets set by different nations, companies, and stakeholders increase every year. Currently, Net-Zero commitments from national governments [12]. [13], [14]. To meet the Net-Zero commitments by 2050, these emission sources have to be replaced with cleaner options. [15]. It is without question that the global mix of power generation will be comprised of low-carbon resources. One of the main low-carbon resources that is currently available today and a part of the global generation matrix is natural gas. Due to its [3], [16], [17], [18], [19]. While natural gas as fuel in power generation offers lower emissions, it has its challenges. Another fuel that can be used as a replacement to conventional fossil fuel generation is Methanol, replacing the natural gas as the transitionary fuel. [20], [21]. As explained in the following section "1.1 Literature Review" current studies comparing methanol's and natural gas's properties and effects as fuel is mainly focused on the maritime perspective. Within our study, we aim to compare natural gas and methanol fuel from the perspective of power generation. This comparison includes calculation of CO_2 emissions inventory for both fuel types and fuel consumed for both different type of fuel, for the same amount of energy (MWh) generated. Along with the methanol, the pilot fuel (diesel) consumption and CO_2 emissions generated by the use of such fuel is also calculated. The study is divided into five sections. The first section serves as an introduction, providing an overview of the study. The second section presents a comprehensive literature review on the studied topic. The third section discusses the properties of the fuels used for the engines. In the fourth section, the application of the study is elaborated. Finally, the fifth section presents the conclusions drawn from the study.

2. Literature Review

Several studies investigate methanol as a fuel for internal combustion engines. While some of these studies focus on the combustion characteristics of methanol, others give a more comprehensive approach and compare methanol with several alternative fuels, in terms of economic and environmental aspects. Most of the comparative studies come from the maritime industry where methanol is considered a strong alternative to natural gas as a marine fuel.

[22] investigates LNG, methanol, and ammonia as shipping fuels, applying SWOT and TOPSIS analyses to identify key criteria like safety and emissions. Study shows that LNG and methanol have similar results in the analyses. [23] investigates methanol's potential as an alternative maritime fuel, emphasizing its benefits in lowering emissions and enhancing engine performance via the partially premixed

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combustion (PPC) approach. Methanol is compared with LNG, underscoring its advantages in emission mitigation and environmental friendliness, despite its energy density and storage requirements.[24] studies the general characteristics of methanol as a fuel for internal combustion engines. The study delves into the characteristics of methanol, and its potential use as a future alternative fuel in different configurations, such as dual-fuel or pure methanol. The study concludes that the technology is mainly tested in the laboratory and field test is required. [25] examines a diesel engine with an electrically controlled common rail system, to operate with methanol fuel and pilot diesel fuel for combustion. Results show the dual-fuel system using methanol reduces smoke and NO_x emissions. [26] investigates methanol as the fuel for a cellular container ship. Results from the study show reduced GHG emissions when compared to diesel. The reduction rates for NO_X, SO_X, CO, CO_2 and PM emissions are 76.78%, 89%, 55%, 18.13%, and 82.56% respectively. [27] investigates methanol, ethanol, liquified natural gas, and hydrogen as alternative marine fuels, on environmental and economic aspects. The study uses an analytic hierarchy process to weigh each alternative fuel for comparison. As a result, methanol and ethanol are not preferable when compared to liquified natural gas and hydrogen. [28] investigates the life-cycle emissions as well as energy analysis of methanol as a marine fuel. The report compares methanol with other marine fuels, which are liquefied natural gas, low-sulfur marine fuel, and heavy fuel oil blends. The study shows that methanol becomes more favorable to conventional marine fuels and more favorable to liquefied natural gas when produced from a renewable source. [29] studies the exhaust gas emissions of a ferry using a dual-fuel marine engine using methanol as its main fuel and marine gas oil as the pilot fuel. Emission factor is found between 12.3 g/kWh and 6.5 g/kWh for NO_x. This value and the PM matter measurements were found lower than the conventional marine fuels and similar to LNG fuel, however, an after-treatment is required for lower NO_x emissions.

3. Properties of the Fuels

The objective of this study is to analyze and contrast the CO_2 emissions and fuel consumption resulting from power generation by using natural gas and methanol. Thus, it is essential to understand the properties of the fuels used in these engines. One of the engines that we used for the comparison of under this study uses only natural gas as fuel. On the other side, the other engine uses methanol as its primary fuel, while using a small amount of pilot fuel, which in our case is diesel. Thus, the selected specifications of natural gas, methanol and diesel, in their capacity as fuels, are provided in Table 1. This table includes the carbon content and emission conversion factor for CO_2, as stated in "Resolution MEPC.364(79) - 2022 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships" [30]. The reasoning behind using the MEPC calculation is that methanol is considered a future alternative to LNG for the use of onboard power production and propulsion, as such, the emission factors are being updated by the Marine Environment Protection Committee [30], [31]. IPCC does not provide an emission factor for the use of methanol as fuel [32].

Table 1: Selected Physical Properties of Fuels [20], [33], [34], [35]

Properties / Fuel	Natural Gas (LNG)	Methanol	Diesel (MGO)
Color	Clear	Clear	-
Toxicity	No	Yes	No
Chemical Structure	CH_4	CH_3OH	-
Physical State at Room Temperature	Gas	Liquid	Liquid
Storage Type	Cryogenic Liquid	Liquid	Liquid
Boiling Point	-162 °C	64.7 °C	-
Auto Ignition Temperature	599 °C	470 °C	
Energy Content (LHV)	48.0 MJ/kg (LNG)	19.9 MJ/kg	42.7 MJ/kg
Energy Density	21.2 MJ/L (LNG)	14.9 MJ/L	35.7 MJ/L
Carbon Content	0.7500	0.3750	0.8744
Emission Conversion Factor (t-CO_2/t-Fuel)	2.750	1.375	3.206

4. Case Study

In this section, a comparison is made between the actual calculated CO_2 emissions of a natural gas-fired engine from a power plant, and theoretical CO_2 emissions that would be emitted for the same amount of installed capacity, running on methanol. For the scope of this paper, CO_2 emissions and fuel consumption are made for one engine of the power plant, operating at base-load condition for 30 days. The same conditions is applied to the methanol engines.

4.1. General Specifications of the Power Plant

For the sake of confidentiality and due to the commercial exposure that our data supplier would face, the data supplied hereunder is limited to the information needed for CO_2 emission calculation, and fuel consumption calculation. The power plant has a total installed capacity of 440 MW, comprised of 24 pieces of medium-speed reciprocating engines. The engines are fueled by natural gas. Table 2 outline the general information about the power plant and the engine information, while graph 1 outlines the load profile of the engine.

Table 2: General Information on Power Plant

Property	Value
Installed Capacity	440 MW
Prime Mover Type	Medium Speed Reciprocating Engine
No. of Engines	24
Rated Power per Engine	18.32 MW
Fuel	Natural Gas (LNG)
Number of Cylinders	18 Cylinder
Piston Configuration	V - Type

4.2. Methanol Engine Specification

Currently, 4-stroke methanol engines are under development by the major engine manufacturers [21], [36]. However, "Online Engine Configurator" of an original engine manufacturer (OEM) provides test data of the engines under development. This data includes the methanol fuel consumption of the engine. The data that can be obtained through the engine configurator is rather limited to smaller engine capacities. For the calculations of this paper, we used the largest methanol engine that can be obtained from the configurator, with the installed capacity of 5,220 MW. The engine we used to make the comparison is a dual-fuel engine, where a small amount of pilot fuel (diesel) is injected to start the ignition. Specifications of the engine are given in Table 3.

Table 3: General Specifications of Methanol Engine

Property	Value
Rated Power	5.22 MW
Primary Fuel	Methanol
Pilot Fuel	Diesel
Number of Cylinders	9 Cylinder
Piston Configuration	In-Line

4.3. Fuel Consumption and CO_2 Emissions

As explained at the beginning of this chapter, the calculations for the CO_2 emissions are made for one engine of the actual power plant, operating at base-load conditions. For the calculation of the CO_2 emissions, the following method is used:

$$CO2_{LNG,methanol,pilot} = FC_{Tonnes} \times ECF_{LNG,methanol,pilot} \quad (1)$$

Where $CO2_{LNG,\ methanol,\ pilot}$ is the CO_2 emissions in tonnes, FC_{Tonnes} is the fuel consumed for 1 month of operation in tonnes, and $ECF_{LNG,\ methanol,\ pilot}$ is the emission conversion factor for the respective fuel.

For the natural gas engines, the emission factor is only the $CO2_{LNG}$ value. However, due to the technology difference of methanol dual-fuel engine, $CO2_{methanol}$ and $CO2_{pilot}$ will be added together, as a small amount of diesel is injected and burned within the combustion process:

$$CO2_{methanolengine} = CO2_{methanol} + CO2_{pilot} \quad (2)$$

4.3.1. Fuel Consumption of the Natural Gas Engine

The fuel consumed for natural gas is converted from pounds (lb), as the fuel consumption data is provided in such form. The conversion factor used from pounds (lb) to tonnes(t) is as follows:

$$FC_{LNG,Tonnes} = FC_{LNG,lb} \times 0.0004536 \quad (3)$$

Where $FC_{LNG,\ Tonnes}$ is the fuel consumption in tonnes, $FC_{LNG,\ lb}$ is the fuel consumption in pounds and 0.0004546 is the conversion constant [37].

4.3.2. Fuel Consumption of Methanol Engines

To compare both engine CO_2 emissions and fuel consumption, the same amount of capacity shall be working for the same period for methanol engines as well. Because the capacity of the methanol dual-fuel engine is lower in comparison to natural gas engine, 3 pieces of methanol engine is considered to be operating at 100% load, and 1 piece of methanol engine is considered to be operating at 50% load.

Fuel consumption data obtained through the "Online Engine Configurator" for the methanol engines. The raw data from the online source is supplied as energy consumption at the given load. From this data and the LHV value data given in table 1, we calculated the gram per kWh equivalents for both methanol and diesel fuel. The results of our calculations are provided under the table 4.

Table 4: Fuel - Energy Consumption at Different Engine Loads (Methanol Engine)

Engine Load (%)	Fuel - Energy Consumption (Methanol)	Fuel - Energy Consumption (as Pilot Fuel – Diesel)
100%	365 gr/kWh - 7,261 kj/kWh	16.60 gr/kWh - 709 kj/kWh
85%	366 gr/kWh - 7,280 kj/kWh	18.85 gr/kWh - 805 kj/kWh
75%	358 gr/kWh - 7,130 kj/kWh	21.08 gr/kWh - 900 kj/kWh
50%	360 gr/kWh - 7,165 kj/kWh	31.03 gr/kWh - 1,325 kj/kWh

4.4. Results & Discussion

Table 5 provides the actual fuel consumption, CO_2 emission and MWh generated of the natural gas engine, running at base-load condition.

Table 5: Monthly Result for natural gas engine (base-load condition)

Findings	Value
Amount of natural gas consumed (ton)	2,178.53
CO2 emissions generated (ton)	5,990.96
Monthly generated electricity (MWh)	13,090.45
Monthly average capacity (MW)	18.16

Figure 1 provides the load distribution of the for the entire month. The average operating capacity for the month was 18.16 MW, which is equal to 99.11% engine load.

Figure 1: Load Variations of the Engine in the Month

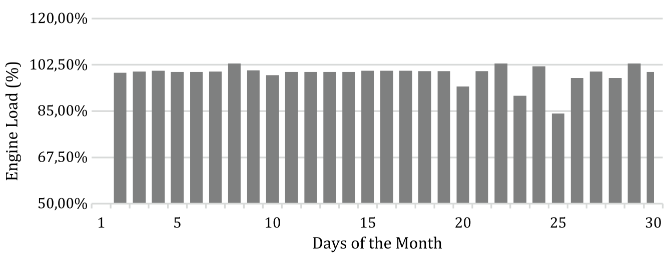

Table 6 provides the results of the calculations for monthly fuel consumption for both methanol and diesel, CO_2 emissions generated, MWh of electricity generated, as well as the monthly average capacity of the engines.

Table 6: Monthly Calculation results for Methanol Engines

Findings	Value
Amount of methanol consumed (ton)	4,790.64
Amount of diesel consumed (ton)	245.53
CO2 emissions generated (ton)	7,374.29
Monthly generated electricity (MWh)	13,154.40
Monthly average capacity (MW)	18.27

From the calculations we made, total CO_2 emissions generated by the methanol dual-fuel engines in comparison to natural gas only engine generated a total of 23.09% more CO_2 emissions. The main reason behind this is the calorific value and resulting fuel consumption of methanol. Since the LHV (lower heating value) of the methanol (19.9 MJ/kg) is lower than the natural gas's LHV (48.0 MJ/kg), the total amount of fuel needed to generate 1 kWh of energy is higher. This can be seen from the total amount of fuel consumption by the end of the month, where methanol engine consumed 131% more fuel, in terms of weight. By the calculations we made, it is understood that the methanol dual-fuel engines are emitting more CO_2 when operating at constant high loads, due to the fact that the LHV value of methanol is lower than of the natural gas. This difference resulted in higher fuel consumption, leading to higher CO_2 emissions overall. Figure 2 and Figure 3 demonstrate the comparison of the fuel consumption and calculated CO_2 emissions.

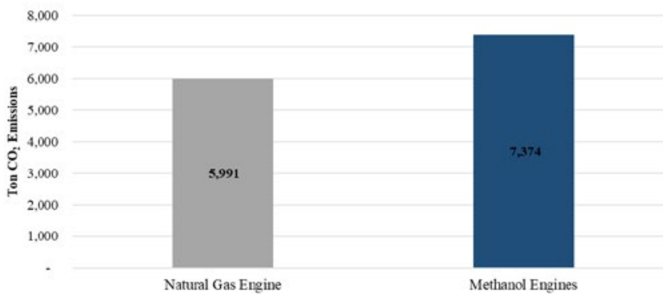

Figure 2: CO_2 Emission Comparison of natural gas and methanol (Ton CO_2)

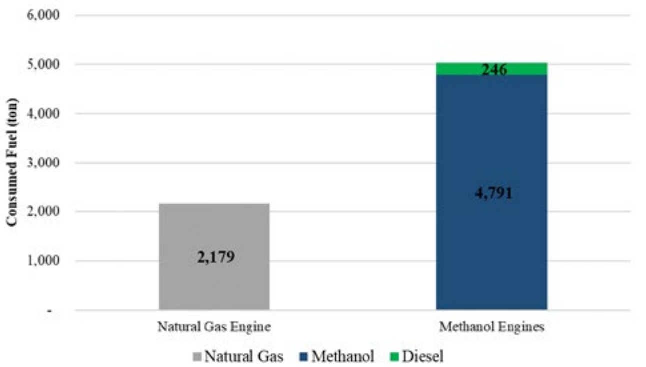

Figure 3: Fuel consumption for natural gas, methanol and diesel (ton)

5. Conclusion

To alleviate the impacts of climate change, many countries, stakeholders, and corporations are implementing measures to reduce carbon emissions in energy-intensive industries. The generation of electricity using fossil fuels is a significant contributor to greenhouse gas (GHG) emissions. To eradicate the utilization of carbon-based fossil fuels, there have been established objectives of achieving net-zero emissions, with the ultimate goal of eradicating these fuels by the year 2050. The achievement of low emissions necessitates the utilization of a transitional fuel to gradually replace the current generation of coal and fuel oil. Natural gas (LNG) is commonly regarded as the preferred fuel for this purpose.

This study investigates the potential of methanol as a viable alternative to natural gas as a transitional fuel. To accomplish this, a comparative analysis was conducted between a theoretical methanol engine and an electric power plant engine that operates on natural gas fuel. This study examines the correlation between fuel use and the resulting carbon dioxide (CO_2) emissions.

The study findings indicate that methanol exhibits favorable storage conditions in comparison to natural gas. However, the combustion of methanol fuel leads to approximately 21% higher total carbon dioxide (CO_2) emissions in the methanol engine. This can be attributed to the fewer Lower Heating Value (LHV) of methanol fuel, which consequently results in increased overall fuel consumption. In future studies, we will thoroughly examine the subject, analyzing the full operational year of the natural gas-fired power plant, and comparing the power generation using natural gas engines with potential use of methanol engines.

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Assessment of Energy Potential from Waves and Wind for Offshore Oil & Gas Platforms

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Abstract

Over the years, carbon emissions are changing the composition of the atmosphere and exacerbating global warming and the climate crisis. On the other hand, the world's growing demand for energy causes the use of fossil fuels to increase day by day. Many states in the United Nations have agreed to reduce carbon emissions, but the transition to alternative energy sources that can replace fuels such as oil and natural gas requires a long time and strong strategic plans. Until the transition is complete, underground oil reserves will continue to be extracted and utilized, albeit in diminishing quantities over time. Oil and natural gas extraction take place not only on land but also at sea. In recent years, Türkiye has been actively drilling in the seas and has discovered natural gas reserves. In order to extract the gas found in the reserve areas, petrol platforms will be installed in the region. Offshore oil and gas platforms are usually equipped with independent electrical systems using gas turbines for energy needs. Considering the fact that fossil fuels will not be out of our lives in a short time, it would be a good start to turn to emission-reducing alternatives in offshore platforms. In this study, the feasibility of supplying the energy needs of oil and gas platforms to be installed in the identified reserve areas in the Black Sea from renewable resources has been evaluated. It is aimed to determine the potential of wind energy and wave power from renewable energy sources. For this purpose, it is planned to evaluate with three different scenarios as only wave power, only wind power and a combination of both.

Keywords: *Renewable Energy, Wind Energy, Wave Power, Offshore Platform*

1. Introduction

Global warming and climate change are increasingly affecting human life in a negative way. At the same time, global energy demand is increasing, which in turn increases the demand for different energy resources [1]. This situation leads scientists to alternative energy sources. Many states have begun to take steps to reduce carbon emissions, but the transition to alternative energy sources to replace fossil fuels with the effect of increasing energy demand requires a long time and strong strategic work [2]. During this transition, fossil fuels will continue to be used, albeit in decreasing amounts. Although natural gas is a fossil fuel, it is a cleaner source of energy than other fossil fuels, which is why many countries are rapidly continuing natural gas drilling activities. Drilling can be carried out on land and at sea. Türkiye stands out with its offshore drilling activities in recent years.

Offshore oil and gas platforms can have different sizes depending on production capacity. Offshore oil & gas platforms are energy-intensive systems and can use from a few megawatts to hundreds of megawatts of energy, depending on system requirements [3]. Most offshore platforms use gas turbines to meet their energy needs. The efficiency of these gas turbines is around 30% and they produce high amounts of emissions [4]. These emissions are NOx, SO2, CO2, CO, CH4 particulate matter and volatile organic compounds (VOC)[5]. Norway has made efforts to reduce these emissions since the 2000s and has resorted to supplying energy to offshore platforms from land and has expanded the use of alternative renewable energy sources such as wind and wave energies for offshore platforms [4]. In a simulation study conducted by Korpas et al. [6] in 2009 in the North Sea, oil platforms were supported by 4 wind turbines with a power of 5 megawatts. Thanks to the energy generated from wind energy, a reduction of 53,790 tons of CO2 emissions and 367 tons of NOx emissions was calculated on a yearly basis. It was also concluded that 24 million cubic meters of gas can be saved annually[6]. Since the wind is not always at the same efficiency, the intermittency of the energy produced is often a problem. While utilizing the wind with turbines, it is also possible to obtain energy by utilizing water movements on the sea surface. Hybrid systems that use wave energy converters together with wind turbines are also possible today. The biggest advantage of wave energy converters is that they can produce energy continuously, albeit in small amounts, because the sea surface movements are more continuous[7]. The Department of Energy and Climate Change in the Digest of United Kingdom Energy Statistics (DUKES) estimates that 40-50 TWh/year could be produced in the UK from wave energy alone. This estimate is the estimate that reveals the potential of wave energy[8]. Although oil & gas platforms and offshore renewable energy sources exist separately, integration between them results in very positive emissions benefits[9]. In addition, renewable energy sources that will be installed to provide energy to oil & gas platforms can be installed as wind farm or wave energy converter farm on a large scale, considering the long term. Thus, cost advantages can be achieved by distributing the investment costs between renewable energy companies and oil companies[10]. There will also be an opportunity to generate extra income by selling the extra energy produced to the land grid. This will also reduce the operating costs of the platform [11].

Based on this information, this study focuses on achieving the potential emission benefits of wind and wave energy by integrating renewable energy into oil & gas platforms to be installed in Türkiye's recently discovered natural gas reserve areas. In this context, first of all, wind turbines and wave energy converters that can be used are determined. Then, the wind power potential in the Black Sea is analyzed. Finally, with the information obtained, the possible results of supporting the platforms to be established in the natural gas reserve areas discovered in the Black Sea with wind turbines and wave energy convectors are revealed.

2. Renewable Energy Systems

Wind turbines are one of the leading renewable energy sources that have been used for many years. Wind turbines differ according to their size, output power and design structure (onshore or offshore)[12]. In this study, a choice was made between offshore wind turbines since renewable energy will be integrated into the oil & gas platform. Vestas V90, one of the most widely used offshore wind turbines in the world, was selected and it was assumed that wind energy would be obtained from this turbine. Its fuselage height is 80 meters and its wing diameter is 90 meters. The cut-in wind speed is 4 m/s and the nominal wind speed is 16 m/s. The basic structure of Vestas V90 is designed to be floating, so it can be used in open seas [13]. Siemens, General Electric and Vestas can redesign existing wind turbine models on a floating basis. Output power information of Vestas V90 depending on wind speed and air density is in Table 1.

Table 1. Electric power output of Vestas V90 3 MW in kW [13].

Wind Speed (m/s)	Air Density (kg/m3)											
	0.97	1	1.03	1.06	1.09	1.12	1.15	1.18	1.21	1.225	1.24	1.27
0	0	0	0	0	0	0	0	0	0	0	0	0
4	53	56	59	61	64	67	70	72	75	77	78	81
5	142	148	153	159	165	170	176	181	187	190	193	198
6	271	281	290	300	310	319	329	339	348	353	358	368
7	451	466	482	497	512	528	543	558	574	581	589	604
8	691	714	737	760	783	806	829	852	875	886	898	921
9	995	1028	1061	1093	1126	1159	1191	1224	1257	1273	1289	1322
10	1341	1385	1428	1471	1515	1558	1602	1645	1688	1710	1732	1775
11	1686	1740	1794	1849	1903	1956	2010	2064	2118	2145	2172	2226
12	2010	2074	2137	2201	2265	2329	2392	2454	2514	2544	2573	2628
13	2310	2382	2455	2525	2593	2658	2717	2771	2817	2837	2856	2889
14	2588	2662	2730	2790	2841	2883	2915	2940	2958	2965	2971	2981
15	2815	2868	2909	2393	2960	2975	2984	2990	2994	2995	2996	2998
16	2943	2965	2979	2988	2993	2996	2998	2999	2999	3000	3000	3000
,17	2988	2994	2997	2998	2999	3000	3000	3000	3000	3000	3000	3000
18	2998	2999	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
19	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
20	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
21	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
22	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
23	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
24	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
25	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000

Wave energy converters are much newer technologies than wind turbines. It is estimated that wave energy has the capacity to provide 10% of the world's total energy demand in the coming years and is predicted to be one of the largest renewable energy sources that has not yet been widely used[14]. Wave energy converters are available in different sizes, types and output powers. The world's first wave farm, Pelamis, was established in Portugal in 2009. It was installed with the Pelamis P1 750 kW model. The developed version, Pelamis P2 750 kW, was tested in Orkney between 2010 and 2014[15]. Since Pelamis was the first commercial producer and its experimental and theoretical studies were used in previous research, it was assumed in this study that energy was obtained from the Pelamis P2 750 kW wave energy converter. In Table 2, you can see the output power information according to wave height (Hs) and period (Tp).

Table 2. Electric power output of Pelamis P2 in kW [13].

Hs: (m)	Tp: (second)																
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	11	27	50	62	64	57	49	41	34	28	23	0	0	0	0
1.5	0	0	26	62	112	141	143	139	110	91	76	63	52	43	36	30	23
2	0	0	66	109	199	219	225	205	195	162	135	112	93	77	64	54	41
2.5	0	7	93	171	279	342	351	320	274	230	210	174	145	120	100	84	65
3	0	91	180	246	402	424	417	369	343	331	275	229	208	173	144	120	93
3.5	0	86	211	326	484	577	568	502	421	394	330	312	260	216	196	164	140
4	105	216	326	394	632	616	583	585	494	454	374	361	339	283	236	197	153
4.5	94	233	371	467	735	744	738	634	626	520	473	390	382	319	299	250	208
5	259	364	469	539	750	750	750	750	644	641	531	482	399	394	330	308	274
5.5	428	497	566	612	750	750	750	750	750	635	642	532	482	400	399	341	322
6	597	630	663	684	750	750	750	750	750	750	616	633	525	476	396	386	329
6.5	750	750	750	750	750	750	750	750	750	750	723	592	617	513	458	430	384
7	750	750	750	750	750	750	750	750	750	750	750	692	566	560	500	474	425
7.5	750	750	750	750	750	750	750	750	750	750	750	748	610	607	542	518	467
8	750	750	750	750	750	750	750	750	750	750	750	750	630	653	584	562	509
8.5	750	750	750	750	750	750	750	750	750	750	750	750	650	699	626	606	551
9	750	750	750	750	750	750	750	750	750	750	750	750	670	746	668	650	592
9.5	750	750	750	750	750	750	750	750	750	750	750	750	691	750	710	694	662
10	750	750	750	750	750	750	750	750	750	750	750	750	711	750	750	738	734

3. Wind and wave potential in the Black Sea

The Energy Sector Management Assistance Program (ESMAP) has published an atlas showing wind speed measurements in territorial waters on a global scale. Wind measurement data were created on sea areas up to 200 km from the coast and at an altitude of 100 meters above sea level[16]. When this map is examined, it is seen that the highest potential in Türkiye is on the Aegean coast. Looking at the Black Sea, the average wind speed off the western Black Sea coast is around 7 m/s.

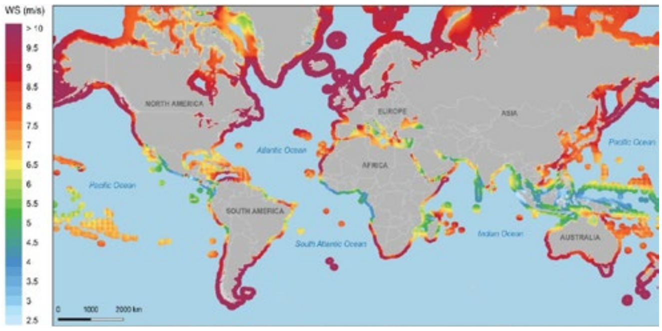

Figure 1. Global wind atlas[16].

In addition, a project titled "Identifying and Mapping Offshore Wind and Wave Energy Potential of Türkiye" was carried out with the European Bank for Reconstruction and Development (EBRD) to determine Türkiye's offshore wind and wave energy potential and the project was completed in May 2020. Within the scope of the project, a new wind atlas was created for Türkiye. The map was created separately for Türkiye as a whole, seven geographical regions and each province, and the general map is shown in Figure 2. When this atlas is analyzed, it is seen that it is in parallel with ESMAP's atlas. In the areas off the western Black Sea where Türkiye has discovered natural gas reserves, the average annual wind power is 6.5-7 m/s.

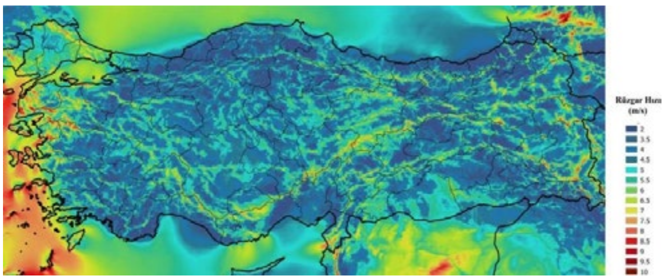

Figure 2. Türkiye's wind atlas [16].

In the global wind atlas and Türkiye wind atlas, the annual average wind speed in the western Black Sea can be inferred to be around 7 m/s. When the output power values of the Vestas V90 wind turbine given in Table 1 are examined, it is observed that it can produce power between 451 kW and 604 kW depending on the air density with an average annual wind speed of 7 m/s. If we take the air density according to the International Standard Atmosphere (at sea level, +15 °C temperature and 1013.25 mb atmospheric pressure), it will be 1.225kg/m3. In this case, the Vestas V90 wind turbine will operate with an annual average output power of roughly 581kW off the western Black Sea coast. In this case, the capacity factor will be 19.36%.

Wave energy is a type that is becoming more common among renewable energy sources. For this reason, many countries have carried out studies to determine the wave energy potential on their sea coasts. The wave energy potential of the Black Sea coast of Turkey was calculated by Aydogan B. et al.[17] using the Mike 21 Spectral Wave Model. European Center for Medium-Range Weather Forecasts (ECMWF) wind data were used in the study. Wave power values were calculated at specific locations along the Black Sea coast and an energy atlas showing the spatial distribution of the average wave power was produced. This energy atlas can be seen in Figure 3. The results show that the southwestern coasts of the Black Sea have the highest wave energy potential and that this potential decreases as one moves eastward.

In addition to the average wave power distribution, percentage distributions of wave height and period on the Black Sea coast were also determined. The percentage results of wave height and period at the location closest to the reserve areas in the Western Black Sea are given in Figure 4. In percentage terms, the wave height was clustered between 1 and 5 meters and the period between 4 and 8 second.

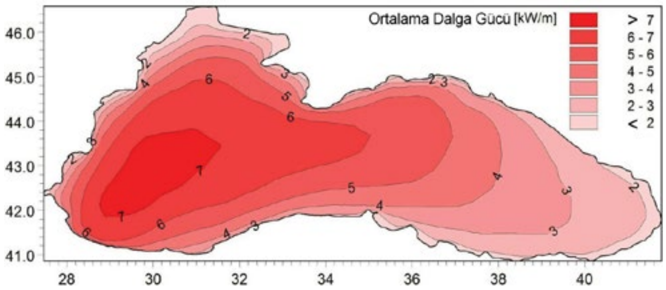

Figure 3. Black sea's average wave power distribution[17].

Te (s) \ Hs (m)	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.5	0.2	2.8	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5	0.1	2.9	5.5	3.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.5	0.0	0.9	3.4	6.1	6.6	2.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5	0.0	0.0	0.9	2.1	3.9	7.4	5.8	2.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.5	0.0	0.0	0.0	0.4	1.0	1.2	2.7	5.1	4.5	2.3	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.5	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.7	1.1	2.5	3.2	2.4	1.9	0.6	0.1	0.0	0.0	0.0	0.0
9.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.3	0.9	2.6	2.5	0.6	0.3	0.1	0.0
10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.4	0.1

Figure 4. Wave power distribution according to wave height and period[17].

When the wave power distribution according to wave height and period in the Black Sea are examined, it is seen that the main cluster wave height is between 1 and 5 meters and the period is between 4 and 8. When the output power values of the Pelamis P2 wave energy converter were examined with these values (indicated with yellow filling in Table 2), it was observed that it could produce roughly an average of 280.2 kW of power in the specified ranges. In this case, the capacity factor of Pelamis P2 is 37.36%.

The capacity factors of the wave energy converter Pelamis P2 and the wind turbine Vestas V90 show that it can meet some of the energy needs of the oil & gas platforms to be installed in the Black Sea.

4. Conclusions

In this study, the feasibility of offshore oil and gas platforms to be installed in the natural gas reserve areas discovered in the

Black Sea to support renewable energy sources such as wind and wave energy is examined. For this purpose, a sample wind turbine and a wave energy convector were selected and their energy output power values were obtained. Wind and wave energy studies around the reserve areas discovered in the Black Sea were examined and the capacity factors of the wind turbine and wave energy convector were determined with these data. The main findings of the study are;

- It has been observed that the coasts with the highest wind energy potential in Türkiye are the Aegean coasts. In the Black Sea, especially in the western parts, the existence of wind energy potential has been observed, although not as much as the Aegean coasts.
- Using the annual average wind speed data obtained from wind atlases around the reserve area, the capacity factor of the selected wind turbine was determined as 19.36%. This value can be increased by selecting smaller wind turbines that can operate more efficiently at lower wind speeds.
- It has been observed that the southwestern coasts of the Black Sea have the highest wave energy potential and the highest wave energy is obtained from waves with a period of 5-6 seconds and a height of 4-5 meters.
- Using the wave height and period data around the reserve area, the capacity factor of the selected wave energy converter was determined as 37.36%. This value shows the availability of wave energy potential in the southwestern parts of the Black Sea.
- The capacity factor of a wave energy converter is about twice that of a wind turbine. Based on this result, choosing 4 Pelamis P2s with the same total output power instead of Vestas V90 will increase efficiency.
- This study shows that the southwestern Black Sea coast has a significant wave power potential and providing renewable energy to oil and gas platforms to be installed in the reserve areas with wave energy convectors can have positive consequences in terms of carbon emissions. However, feasibility studies should be carried out by examining many technical, ecological, economic and environmental factors at the point of integration and installation of these systems on the platforms.

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Environmental Assessment of Fuel EU Maritime Regulation: Compliance of Marine Fuels

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Abstract

One of the Market-Based Measures (MBMs), FuelEU Maritime regulation, will govern the Well-to-Wake (WtW) Greenhouse Gas (GHG) emissions energy intensity requirements within the European Union (EU) after 2025. Mandatory usage of Onshore Power Supply (OPS) for container and passenger ships in certain EU ports and incentivization of Renewable Fuels of Non-Biological Origin (RFNBOs) are the other main objectives of the policy. Furthermore, the carbon intensity limit will be reduced every five years, reaching up to 80% accumulative reduction of CO_2, CH_4, and N_2O by 2050. However, the high ambitions of the EU may not match the environmental performance of either the world fleet or marine fuels. This paper focuses on FuelEU Maritime regulation's environmental feasibility on the industry via analyzing the marine fuels on GREET with their respective Well-to-Tank CO_2 equivalent limits. Projections have been drawn to display the differences in circumstances in the industry. As a result, different marine fuels' compliance with the updated maritime policy framework will be highlighted.

Keywords: *FuelEU Maritime, Market-Based Measure, Well-to-Wake emissions, Carbon Intensity Limit*

1. Introduction

In the year 2023, the International Maritime Organization (IMO) revised the Initial Greenhouse Gas (GHG) strategy with new ambitions that seek to reduce and phase out the emission intensity of maritime shipping. This strategy aims to finalize the proposed basket mid-term measures in 2024, approval and adoption in 2025, and finally enter into force in 2027 [1]. In the sense of having a technical measure, IMO has plenty of measures. Energy Efficiency Design Index (EEDI), Energy Efficiency Operational Indicator (EEOI), Ship Energy Efficiency Management Plan (SEEMP) in 2011, and Energy Efficiency Existing Ship Index (EEXI), and Carbon Intensity Indicator (CII) in 2021 were developed by IMO [2]. After the 80th session of the Marine Environment Protection Committee (MEPC), intentions of being more stringent are revealed [3]. Although this new strategy includes a basket of candidate measures and one possible Market-Based Measure (MBM), the European Union (EU) policy environment has already been introduced to an MBM with the European Union Emissions Trading System (EU ETS) via the inclusion of shipping in 2021[4]. In the same year, the "Fit for 55" legislative package was proposed by the European Commission (EC) [5]. In 2023, the European Parliament (EP), the EC, and the Council of the European Union (Council) agreed on the package, which includes a technical measure called FuelEU Maritime Initiative [6]. This initiative contains high ambitions for reducing GHG intensity, mandatory usage of onshore power supply (OPS) wherever applicable, and incentivization of Renewable Fuels of Non-Biological Origin (RFNBOs) [7]. MBMs not backed up with such technical measures and monitoring tools are bound to be subject to evasion [8]. The FuelEU Maritime Initiative cannot be a standalone measure in uptaking alternative fuels [9]. The EU has been establishing methods to make the EU ETS system viable, starting with the Monitoring, Reporting, and Verification (MRV) database to evaluate fuel types, consumption, and subsequent emissions [10]. These data highlight that actual emissions are probably more influenced by a ship's operational practices than its design, unlike the performance indices such as EEDI, which were designed to give [11]. Compared with other technical measures combating climate change, the EU is showing its "exemplary leader" role in the decarbonization process of maritime transportation with this initiative [12].

The legal environment of maritime business swiftly altered the course of academic literature alongside traditional operational processes. Hence, studies do not provide enough coverage for the newly developed policies. One of these policies is the newly developed FuelEU Maritime Initiative. Although there are limited papers on the subject, some cover policy-related issues [e.g., 13,14], and some cover the alternative fuel side of the subject [e.g., 15]. The intended research in this paper covers evaluating different types of marine fuels' performance with the upcoming regulations. To be more precise, the study utilizes previous databases, existing literature, and estimations to evaluate how much emissions could change with updated perspectives and whether the initiative covers these with recent updates. Even though LCA studies are one of the focal points of environmental studies, the constant minor changes across studies and the future of this policy have never been focused on. The outcome of the calculations displays the need for minor updates and scrutiny of the EU's environmental perspective.

2. The Importance of Alternative Marine Fuels

A study by Eyring et al. [16] predicted a 43.5% increase in ship-related fuel consumption by 2050 in the most optimistic way. In a recent study by IMO [17], expectations by 2050 are stated as a 50% increase compared to 2018. It has been thought that combinations of measures can be sufficient to reach considerable sector-wide reductions [18]. IMO's fourth GHG study shows that 64.08% of total CO_2 reduction is projected to be the outcome of alternative fuels, followed by speed reduction by 7.54% [17]. Therefore, the main criterion for establishing an efficient working environmental scheme in maritime transportation relies on fuel types [18]. The very essence of this issue is overcoming technological-readiness levels of fuels [19]. For instance, since the end of 2020, methyl and ethyl alcohol as fuel have been enabled to be used onboard [20]. Recently, the number of methanol-fueled ships has been growing in the order books of retrofit and newbuild [21]. This can be explained by this fuel type's lower capital expenditure requirement [22].

In decarbonization, some fuels are categorized as transitional fossil fuels, such as Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG). Since methanol can be obtained from fossil-free sources, it is still part of the process [23]. LNG as a marine fuel has problematic issues with regard to the high output of GHGs and overall bad performance on GWP due to methane slip [24]. Most ships using LNG fuel use low-pressure dual-fuel technology with fossil fuels, the type of technology where methane slip occurs frequently [25]. At the same time, dual-fuel systems affect global warming, acidification, and eutrophication less than their counterparts [26]. Marine Diesel Oil (MDO)/ Marine Gas Oil (MGO), Heavy Fuel Oil (HFO), Dimethyl Ether (DME), methanol, and Fischer-Tropsch (F-T) diesel fuels were compared in a study of Life Cycle Assessment (LCA). While LNG reduces Particulate Matter (PM), the fuel's overall Global Warming Potential (GWP) does not deviate much from the medium. Although methanol, DME, and F-T diesel diminish the GWP values by 56%, 80%, and 78%, respectively, if one accounts for the production stage, DME and F-T diesel are deemed more environmentally friendly among them [27]. Electrofuels are a type of synthetic fuel that is produced via electrolysis. E-fuels such as e-LNG, e-methanol, and e-diesel are prioritized in this approach because of the low modification requirement. On the other hand, e-hydrogen and e-ammonia need to be transformed into a system different from the existing one. The evolution of e-MGO, e-LNG, e-methanol, and e-ammonia are deemed as priori decarbonization solutions. The main issues are technological readiness level and bunkering infrastructure [28]. According to Lindstad et al. [29], e-fuels with these performances are viable but costly. Solakivi et al. [30] projections indicate that the cost competitiveness of e-fuels is even beyond 2050. The FuelEU Maritime Initiative catalyzes the creation of a level playing field between fossil fuels and e-fuels [31]. Initiative's counterpart in aviation deals with quantitative targets, whereas in maritime, the aim is to force market operators to change into alternatives [32]. The focal point of the initiative is the overall impact assessment of GHGs with CH_4 and N_2O rather than focusing solely on CO_2 [33]. Hughes [34] mentioned that one of the most critical potential hindrances to the initiative is the lack of predictability and high risks of investments. Concerning the point of the initiative, higher marine fuel prices can lead to lower exports [35]. Sectoral differences also might create injustice since each other segment of maritime transportation has a different operation [36].

3. Methodology and Analysis

The LCA of the emissions of an alternative marine fuel can expose emissions at different stages, such as the occupation of agricultural land to produce the fuel [37] or on a different variable other than CO_2, such as CH_4 or N_2O [38]. FuelEU Maritime calculates emissions based on Well-to-Wake (WtW) emissions along with specified factors in Annex II of the regulation. WtW emission takes into account both Well-to-Tank (WtT) and Tank-to-Wake (TtW) emissions; therefore, a holistic approach to LCA has been applied. The initiative applies to ships above 5000 GT that make transportation for commercial purposes regardless of their flag. Calculated energy reflects all the energy used between two EU ports of call, all the energy used at the berth of the EU port, and half of the energy used on a voyage between a member state and a third-party country in grams of CO_{2eq} (equivalent) per MJ. The bar is getting set higher every five years from the last five years with reductions of 2%, 6%, 13%, 26%, 59%, and 75%, respectively, until 2050. Almost every fuel has its coefficient factor; in the case of fossil fuels, default values are given to calculate. Non-fossil fuels bunker delivery notes can be used when a ship performs better than default values [7, 15, 39].

The MRV baseline for average energy used onboard in 2020 was calculated as 91,16 gCO2eq/MJ, which is the point zero for the initiative. Article 20 (1) and Annex V of [39] emphasize the remedial measure, given in the formula below, applicable after 2025. The OPS requirements and overall energy acquired from land are not included in this study, but it is in the calculation of the overall remedial penalty. RFNBOs will be incentivized from 2025 to 2034 by halving their emissions. Depending on the compliance deficit of the higher-intensity fuels, operators pay a proportional remedial penalty. The deficit refers to the difference between the reference GHG intensity and the actual one multiplied by the energy consumption. Consumption includes a mass of the fuel along with its lower calorific value and electricity consumption delivered at the ship. Compliance balance is converted to energy and divided by the actual GHG intensity of the ship. Finally, it is multiplied by the penalty of EUR 2400 per tonne of Very Low Sulfur Fuel Oil (VLSFO) equivalent energy. RFNBO sub-target should pay a remedial penalty calculated as the difference between the 2 percent of the total energy used onboard minus the total energy of RFNBOs multiplied by the price difference between RFNBO and fossil fuels. In case of consecutive non-compliance for both measures, penalties increase. In this study, RFNBO sub-target calculations are not included; however, they can play an essential role in the fuel mix. Also, the wind-assisted propulsion factor is not considered. Carbon intensity limits will be 89,34, 85,69, 77,94, 62,9, 34,64, and 18,23 for 2025, 2030, 2035, 2040, 2045, and 2050 [7, 39].

$$Compliance\ Balance = \left|GHG(target - GHG(actual)\right| \times Mass\ of\ fuel \times Lower\ Calorific\ Value + Electricity\ Consumption$$

$$\text{Remedial Penalty} = \left(\frac{\text{Compliance Balance} \times 2400}{\text{GHG Intensity Actual} \times conversion\ factor\ from\ MJ\ to\ tonnes\ of\ VLSFO\ (41{,}0\,\frac{MJ}{kg})}\right)$$

According to Argonne's National Laboratory life cycle product GREET [40], which was updated in 2021 to include marine fuels in a very detailed version [41], "ammonia from H_2 from Polymer electrolyte membrane (PEM) electrolysis" or in short, e-ammonia with the best version under layers of "marine fuels" and "ammonia for fuel" releases minus 7,5 g GHG for 1 MJ which in GJ makes minus 7,5 kg in the target year of 2022 [42]. These values differ from the EU's values due to the fact that GREET calculates GHG-100 values of fuels as total GHGs (air pollutants included) in the GWP-100 correspondent value given in the Intergovernmental Panel on Climate Change - Assessment Report 6 or IPCC AR6. Accordingly, values of CH_4 and N_2O in AR6 are 29,8 and 273, respectively. The calculations utilize these values instead of the EU's reference values for these GHGs in AR5, 28 and 265 [43]. The EU is known for up-to-date policy amendments; therefore, the policy could get stricter in the future. "Residual Oil (Petroleum) from Crude Oil for Use as a Marine Fuel (Heavy Fuel Oil [HFO] 0.1%%S" under "marine fuels" produces 13,9 kg of GHGs in every 1 GJ. "Residual Oil (Petroleum) from Crude Oil for use as a Marine Fuel (Marine Gas Oil [MGO] 0.1%S "under "marine fuels" emits 13 kg per GJ. "Ammonia Fuel from Natural Gas," on the other hand, releases 122,16 kg per GJ. Table 1 lists these emissions according to the authors' curation on the database, as mentioned earlier. It also lists the "GHG-100" values of marine fuels as the sum of GWP-100 values of all emissions, including air pollutants such as Nitrogen Oxides and Sulfur Oxides. In estimating the WtT values, authors included only criteria emissions.

Table 1. WtT gCO_{2eq} Values of the fuels per MJ

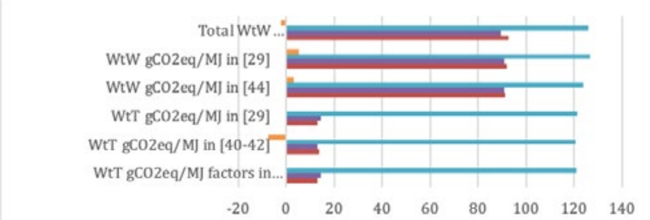
Marine Fuels	CO_2	CH_4	N_2O	GHG-100	Total WtT gCO_2q/MJ
HFO with 0.1% S	10,9	0,099923	0,00018745	13,9	13,929
MGO with 0.1% S	10,1	0,097351	0,00016881	13	13,047
Ammonia Fuel from Natural Gas	110,4	0,33036	0,0022513	122,2	120,859
Ammonia from H_2 from PEM electrolysis	-7	-0,015459	-0,00014475	-7,5	-7,500

For TtW emissions, Lindstad et al.'s work [29] gave a sound database for emissions of alternative fuels and VLSFO and MGO. The authors' work assumed e-ammonia as "Ammonia from H2 from PEM electrolysis (dual fuel)" (Table 2). The difference between GHG-100 and Total WtT gCO_{2eq}/MJ values indicates mostly other emissions. For instance, "Ammonia Fuel from Natural Gas" has 0,659 gCO_{2eq}/MJ, but Ammonia from H_2 from PEM electrolysis only has a 0,0002 difference.

Table 2. TtW gCO_{2eq} Values of the Selected Fuels per MJ [29]

Marine Fuels	CO_2	CH_4	N_2O	Total TtW gCO_{2eq}/MJ	Total WtW gCO_{2eq}/MJ
HFO with 0.1% S	77,6	0,2	1,1	78,9	92,829
MGO with 0.1% S	75,1	0,2	1,1	76,4	89,447
Ammonia Fuel from Natural Gas	0	0	5,3	5,3	126,159
Ammonia from H_2 from PEM electrolysis	0	0	5,3	5,3	-2,200

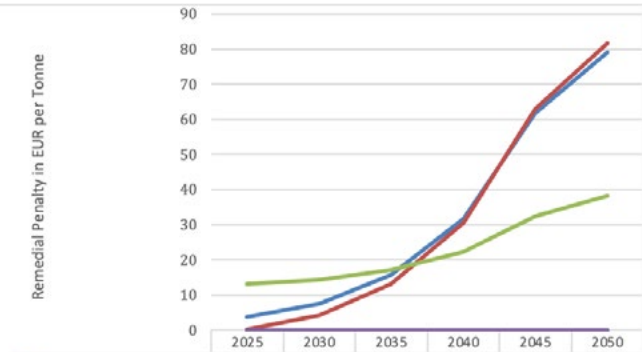
After these calculations, factor values and comparison of studies are given below (Fig 1). Although "Ammonia Fuel from Natural Gas" has already passed the GHG Energy Intensity Limit (35,28%), the TtW values are identical to the e-fuel variant. If the EU decides to update its values instantly, none of the fossil fuels can achieve compliant status. Also, the actual emissions of "Ammonia from H_2 from PEM electrolysis" are negative.



	WtT gCO2eq/MJ factors in EU's [39]	WtT gCO2eq/MJ in [40-42]	WtT gCO2eq/MJ in [29]	WtW gCO2eq/MJ in [44]	WtW gCO2eq/MJ in [29]	Total WtW gCO2eq/MJ(WtT values [40-42], TtW values [29]
Ammonia from H2 from PEM electrolysis	0	-7,51	0	3	5,3	-2,2
Ammonia Fuel from Natural Gas	121	120,87	121,4	124	126,7	126,159
MGO with 0.1% S	14,4	13,05	14,4	90,8	90,8	89,447
HFO with 0.1% S (VLSFO)	13,2	13,94	13,2	91,4	92,1	92,829

Fig 1. WtT gCO_{2eq} Values of the fuels per MJ across studies

None of the e-ammonia values are paying remedial penalties in the strictest case of the year 2025 (Fig 2). The most significant deviation can be seen among WtT values in "MGO with 0.1% S". Unlike other figures, GREET gives less relative importance to the impact of MGO but adds up to HFO. WtW values do not differ vastly as well. According to these values, HFO, even in the VLSFO form, will be punished alongside all fossil fuels.



	2025	2030	2035	2040	2045	2050
HFO with 0.1% S (VLSFO)	3,698	7,567	15,783	31,725	61,681	79,076
MGO with 0.1% S	0,123	4,304	13,184	30,415	62,793	81,594
Ammonia Fuel from Natural Gas	13,028	14,320	17,062	22,384	32,383	38,190
Ammonia from H2 from PEM electrolysis	0	0	0	0	0	0

Fig 2. Remedial penalties on WtW gCO_{2eq} values with consumption calculated as mass of fuel per tonne multiplied with LCV of the fuels for each period's energy intensity limit

Europe's high ambition stance makes the Maritime FuelEU Initiative act imminently; therefore, the push for alternative fuels has already started. According to the calculations, even with half of the emissions calculated, fossil fuels have no future for European commerce.

Considering half of the operational expenses are structured after fuel expenses, this size of penalties may be matched with slow steaming if shipping operators choose to do so. These calculations and the Initiative point only in one direction: the shipyard, if imposed penalty is unwanted. On the other hand, penalties in the last 5-year period would get out of hand if updates with inflation occur. In both ways, this initiative is designed to be the catalyst for emission reduction, and chances of achieving this would occur with a combination of MBMs. Although 1000 to 7000 nm is not rare in MRV data, penalties might be increased.

Nonetheless, fossil fuels will not be viable options after 2030, apart from LNG Otto slow speed and diesel slow speed and LPG variants [44]. Values of [29] and our calculations also leave out LNG fuels outside the conversation. WtT values of Liquid Hydrogen and Ammonia devastate their WtW outcomes even though their TtW emissions are minimal.

4. Conclusion

Traditional fuels' primary emissions aside from CO_2 are Nitrogen oxide (NOx) and Sulfur oxide (Sox). They usually contain comparably high Black Carbon (BC) too. These emissions are already restricted to some extent via policies. The main GHGs from marine fuels are targeted by the FuelEU Maritime Initiative, which manages above decent environmental criteria.

The study aimed to evaluate different marine fuels and business-as-usual scenarios environmentally. The results indicate that the emission factors do not differ vastly among LCA studies. Also, total emissions, including air pollutants, do not increase WtT values substantially. This study did not consider the pollutant's total lifetime; however, some pollutants have relatively shorter atmospheric lifetimes to be considered in GWP-100. This policy heavily favors e-fuels' WtW emissions, which is understandable according to the values.

The EU's display of leadership in the decarbonization of the maritime industry will eventually spread worldwide. Even though slow steaming and half of the emissions will not be enough to perform evasive approaches after 2050.

The interesting case of the EU ETS and FuelEU combination surely shall mitigate emissions from EU maritime transportation. The EU being a catalyst to global MBM would not be a far-sighted argument.

This study concentrates on the EU's newly developed Initiative which is not in effect yet. Studies on the operational, technical, and economic aspects of this policy will be more explanatory in the future regarding the decarbonization of the maritime transport process.

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Section 4
Energy Efficiency & Energy Management

Combined Evaluation of Thermoelectric Generator and Organic Rankine Cycle in Waste Heat Recovery of Marine Diesel Engines

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Abstract

This study examines the process of converting waste heat from marine diesel engines into energy using thermoelectric generators (TEG) and Organic Rankine Cycle (ORC) systems. The aim of the study is to integrate these two innovative technologies to transform exhaust gases into more efficient and environmentally friendly usable energy. According to results, the use of 1296 TEG modules will save approximately 5.54 liters of fuel per hour and the system will pay for itself within 5.1 years. On the other hand, when integrated with the ORC system, which uses R245fa fluid, on the same exhaust line as TEG, additional energy production is achieved. This system effectively works even at low temperatures, enabling more waste heat to be utilized. As a result, the combined heat recovery system can generate 719.45 kW of power. This integrated approach not only increases the efficiency of marine diesel engines but also reduces their environmental impact. The economic analysis is based on the initial investment cost. The analysis reveals that the payback period is approximately 3.66 years, after this period, the system can save $402,632.48 in fuel costs annually. These results offer a significant incentive to reevaluate the use of waste heat in the maritime industry.

Keywords: *Thermoelectric generator, Organic Rankine Cycle, Waste heat recovery, Fuel savings, Sustainable energy solutions*

1. Introduction

The Industrial Revolution, which commenced in 1763 with James Watt's revolutionary invention of the external combustion steam engine, marked the beginning of an era where the demand for energy could be fully met through the use of fossil fuels [1]. Over the subsequent 250 years, the Earth's atmosphere has been subjected to uninterrupted exhaust emissions. According to reports published by the International Energy Agency (IEA), the post-pandemic period, characterized by a significant increase in consumption rates, witnessed the highest level of global CO_2 emissions ever recorded, reaching 36.3 billion tons of CO_2 in 2021 [2]. This figure saw an increase of 0.9% in 2022, reaching 36.8 billion tons of CO_2 [3]. IEA projections for 2023 estimate the amount of CO_2 emissions to reach 40.9 billion tons [4]. Analyzing the data from the last three years, a linear increase in CO_2 emissions can be observed, correlating with rising population and consumption rates.

When examining emission levels on a global scale, the transportation sector's carbon footprint has notably increased, from 2.84 billion $GtCO_2$ in 1970 to 7.64 billion $GtCO_2$ in 2021, marking approximately a 2.5-fold increase [5]. The maritime sector over the last 22 years shows a similar trend; CO_2 emissions were 502 Mt in 2000, 618 Mt in 2012, and saw a 14% increase from the previous year, reaching 706 Mt in 2022 [6]. Reports which published in 2020 by International Maritime Organization (IMO) shows that the maritime sector accounts for about 2.89% of global greenhouse gas (GHG) emissions [7]. Even though it is not a very large proportion, the IMO is doing its part and has taken action to realize the zero emission target in the maritime sector by striving to reduce CO_2 emissions by 40% until 2030 and 70% by 2050, respectively, in line with the targets set in 2023. Also within the goal set by IMO; it is planned to reduce GHG emissions by 20% and 70% by 2030 and 2040, respectively, in order to reduce ship-origin greenhouse gases (GHG) [8], [9].

The Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), introduced by the IMO under The International Convention for the Prevention of Pollution from Ships (MARPOL) starting January 1, 2013, are pioneering measures in the reduction of GHGs. EEDI mandates the use of more energy-efficient equipment and engines in newly built ships, including improved hull designs and waste heat recovery systems. SEEMP focuses on cost-effective operations to enhance the energy efficiency of existing vessels, optimizing characteristics such as speed, draft, and trim [10].

The IMO's "Future Fuels and Technology" project supports the GHG strategy by exploring alternative fuels, including Ammonia, Hydrogen, Ethane, and Dimethyl Ether [11]. Another significant step by the IMO was the "IMO 2020" regulation under MARPOL, which reduced the global fuel sulfur limit from 3.5% to 0.5%. This led shipowners to prefer installing "Scrubbers," systems that wash exhaust gases with fresh or seawater to reduce sulfur dioxide (SO_2) emissions, over using more expensive low-sulfur fuels. The number of ships equipped with scrubber systems increased from 243 in 2015 to over 4300 in 2020 [12], [13].

Reducing emissions in the maritime sector, in alignment with the IMO's goals, will undoubtedly involve the gradual decrease in the use of fossil fuels. In this context, marine diesel engines, with specific fuel consumption values ranging between 155-225 g/kWh [14], are being targeted for waste heat recovery methods to reduce fuel consumption without compromising performance. Modern internal combustion engines can convert approximately one-third of the fuel energy into functional energy. The remaining two-thirds are discharged into the environment as waste heat through exhaust gases [15]. The primary source of waste heat on ships, with temperatures ranging between 350-410°C, comes from exhaust gases [16]. While there are various waste heat recovery applications onboard, this study will examine the Thermoelectric Generator (TEG) and the Organic Rankine Cycle (ORC)

1.1. Thermoelectric Generators (TEGs)

Thermoelectric generators can be broadly defined as devices that generate electrical potential by exploiting temperature differences within a closed system, which does not permit mass entry or exit. This conversion is facilitated by components such as conductive and insulating materials, along with p-type and n-type semiconductor legs. The performance of these devices depends on the ZT coefficient of the semiconductor materials contained within them [17], [18]. The absence of moving parts, which eliminates the need for periodic maintenance and their lightweight nature are among the most significant advantages of using these devices [17], [19], [20].

A study published in 2022 aimed at recovering waste heat from a five-cylinder, 4900 kW marine diesel engine. According to this study, a rectangular prism measuring 900 mm x 900 mm x 900 mm, designed to encase the 900 mm diameter exhaust outlet manifold of the marine diesel engine, was equipped with a total of 11,520 TEG systems on all surfaces, estimated to generate 792.8 kWh of electricity [21].

In the literature, Uyanık et al. [22] evaluated a TEG system proposed to be installed on the exhaust outlet line and jacket water cooling heat exchanger of a tanker ship's main engine, which has a power output of 8502 kW. Calculations suggested that 13,286 TEGs positioned on the main engine could generate 79.72 kW of power, potentially saving 77.9 tons of fuel annually. Additionally, a power output of 7.94 kW from 1,800 TEGs applied to the jacket water cooling heat exchanger could avoid the use of 13.3 tons of fuel per year. The total power generated would be 87.66 kW.

Kishita et al. [23] predicted that a TEG system, with a temperature difference of 250°C between hot and cold surfaces, comprising 20 units each measuring 50 mm x 50 mm x 4.2 mm, would generate 480 W of power. The system's weight was reported to be 0.94 kg.

1.2. Organic Rankine Cycle System (ORC)

The Organic Rankine Cycle (ORC) system differs from the traditional Rankine cycle primarily in the working fluid used; instead of water, it utilizes organic, hydrocarbon-based fluids with lower boiling points. This adjustment saves energy required for vaporization and achieves higher pressures. The working fluid, pressurized by a pump, enters the heat exchanger to transition into the superheated vapor phase. The superheated vapor then expands in a turbine, converting its kinetic energy into mechanical energy. In the final stage, the working fluid is condensed, allowing it to be reused in the system [24], [25], [26].

The implementation of an ORC system aboard a vessel was first tested on the MV Figaro, with IMO number 9505041, generating 500 kW of electricity [27]. This practical application of the ORC system to a marine diesel engine, traditionally a theoretical concept, marks an important contribution to the literature.

Choi et al. [28] conducted a theoretical study in 2013 based on a marine diesel engine coded 12K98MC-CMK6. The study proposed a dual cycle configuration, pairing the traditional Rankine cycle with an Organic Rankine cycle using R1234yf as the system fluid in the second stage. The calculations indicated that this setup could produce a net power of 2069.8 kW, reducing specific fuel consumption and associated CO2 emissions by 6.06%.

Akman and Ergin [29] performed a study on waste heat recovery from a marine diesel engine using R245fa as the system fluid, which has a critical temperature approximately 2.43 times lower than water, at 154.01°C [30]. Utilizing a combination of jacket cooling water, scavenging air and exhaust gas as the waste heat source, 524 kW of waste heat was recovered at 82% MCR. The authors noted that the recovered power was sufficient for the selected tanker ship's navigation system. At 100% engine load, the net power output was estimated to be 688.35 kW, potentially saving 703.78 tons of fuel annually.

A study on a 10,000 TEU container ship using an Organic Rankine system for waste heat recovery from a 10S90ME-C9.2-TII engine explored different working fluids, including R123, R141b, R245ca, and R245fa. R141b was identified as the most economically viable and efficient option, with a net power recovery of 1472 kW. The payback period, depending on fuel prices, was estimated to be no more than two years [31], [32].

2. Methodology

The objective of this study is to integrate Thermoelectric Generators (TEGs) with Organic Rankine Cycle (ORC) systems into the exhaust line of a marine diesel engine to enable synchronized operation. The primary goal is to achieve fuel savings and make progress both economically and in terms of emissions reduction, as determined by the chosen method.

The general logic of the methodology is illustrated in Figure 1. The developed method relies on the utilizing the high-temperature exhaust gases from the engine by a TEG system installed in the exhaust line, before being used as a heat source in the ORC system. The integration of the TEG system into the exhaust line is depicted in Figure 2.

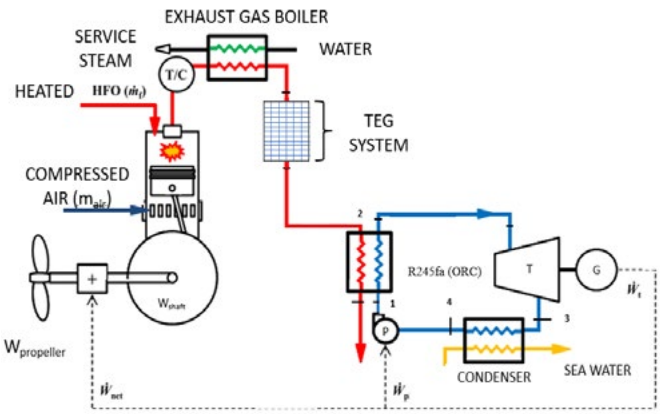

Figure 1. Example diagram when ORC and TEG are used together [28].

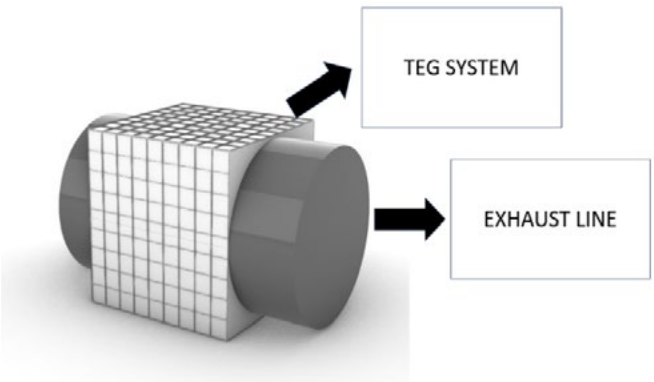

Figure 2. Integration of the TEG system into the exhaust line.

3. Results and Discussion

This section evaluates the implications of integrating Thermoelectric Generators (TEGs) and Organic Rankine Cycle (ORC) systems into a marine diesel engine exhaust line, focusing on costs and the amortization period. The amortization period is primarily influenced by two factors: the installation costs and the profits derived from fuel savings achieved by the combined system. Due to a lack of data, maintenance costs of the Organic Rankine system have not been included in the amortization calculation. For realism in calculated data, this assessment is based on the engine type which MAN B&W 6G50ME featured in the study by Akman and Ergin [29].

Given that the exhaust pipes of marine diesel engines are generally of similar dimensions, this study adopts the geometry used by Yoluş et al. [21] planning for a TEG installation surface measuring 900 mm × 900 mm × 900 mm. According to data provided by Kishita et al. [23] a total of 1296 TEGs can be placed on a rectangular prism of these dimensions, with the cost of 1296 TEGs being $129,600 and the total system weight calculated as 60.91 kg. Focusing solely on the installation of 1296 TEGs on an engine specified by Akman and Ergin [29] with an SFOC of 176.4 g/kWh, the net power generation is calculated to be 31.1 kW, saving approximately 5.486 kg/h of fuel. The amortization period, based on the IFO 380 price at the time of the study ($536.0/mt) [33], is approximately 5.10 years. After this period, the TEG system is projected to yield an annual profit of $25,401.6.

In the literature, Akman and Ergin [29] discussed the installation of an ORC system on a marine diesel engine alone, which could potentially generate 688.35 kW of power and save 703.78 tons of fuel annually. The total installation cost of this system is approximately $1,347,196.42. Based on the IFO380 price ($536.0/mt) [33], the annual fuel savings are valued at $377,226.08, with an estimated amortization period of about 3.57 years.

Separate evaluations of TEG and ORC systems integrated with a MAN B&W 6G50ME engine have been discussed. When considering the combination of both systems, the total power output is estimated at 719.45 kW, with annual fuel savings of $402,632.48, and an amortization period of 3.66 years.

Combining both systems results in a decrease in the SFOC value of the MAN B&W 6G50ME engine from 176.4 g/kWh to 168.09 g/kWh, indicating an efficiency improvement.

Due to the absence of specific CO2 emission values for IFO 380 fuel combustion in the literature, emission reductions from saved fuel were calculated using emission values for HFO, which emits 3.15 tons of CO2 per ton [34]. The calculated emission reductions are as follows:

- When only thermoelectric generators are used, the amount of fuel saved is approximately 47.40 tons per year. In other words, 149.3 tons of CO2 emissions per year are avoided.
- Implementing only the ORC system leads to annual fuel savings of 703.78 tons, corresponding to 2216.91 tons of CO2 avoided.
- Combined use of both systems results in fuel savings of 751.18 tons, equivalent to 2366.22 tons of CO2 emissions avoided.

When evaluating the emission values and fuel savings calculated for all three scenarios, the implementation of the system is deemed appropriate due to its short payback period.

4. Recommendations

- A study could be conducted to assess the emission outputs during the production of components used in TEG and ORC systems, to fully understand if the developed method aligns with its environmental objectives.
- Enhancing the design of the geometry on which TEG systems are mounted could increase system efficiency.
- When selecting components for TEG systems, consideration should be given to the maximum temperature at which TEG components can operate,

taking into account the exhaust gas temperature as the primary heat source.

- To maximize the efficiency of TEG systems, the temperature difference between the hot and cold surfaces should be as large as possible. Considering high specific heat capacity fluids for the cold surface could help achieve this goal.
- In scenarios where the ORC system is used with R245fa as the working fluid, utilizing a working fluid with superior performance characteristics could increase the net power output.
- Should fuel prices increase while the initial investment costs of the systems remain constant, a reduction in the amortization period for all three scenarios could be observed.

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Speed Optimization Strategy for Marine Vessels Based on Artificial Neural Networks

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Abstract

Optimizing vessel speed is a multifaceted challenge that involves a delicate balance between swift transportation and fuel efficiency. On the other hand, ANNs, a subset of artificial intelligence, have the ability to process vast datasets and make real-time decisions. This paper aims to propose an influential speed optimization strategy for marine vessels by benefiting from the strength sides of the ANN method. Within the scope of the analysis, a noon report related to a merchant ship is received. Then, it is examined in detail to determine navigational status such as berthing, cruising, and anchoring, and operational parameters such as fuel consumption, cruise miles, and vessel speed. Based on the data obtained from the noon report, an ANN structure is developed to achieve define optimal ship speed. In this sense, anchoring periods are tried to eliminate as much as possible during the optimization process. As a result of the analysis, the contribution of the developed methodology is presented in the perspectives of savings from fuel consumption, emission, and operational expenses. The proposed strategy can be improved by considering more operational information in the ANN structure and applied for any kind of marine vessel.

Keywords: *Maritime; Energy efficiency; Speed optimization; Artificial neural network*

1. Introduction

Since the marine sector accounts for more than 80% of freight carriage globally, it plays a crucial role in business. In 2020, 98,140 commercial ships or 100 billion gross tons (GT) were declared as a total capacity [1]. Additionally, it plies to expand because of its benefits, which include resource discovery, cost-effective transportation, and economic contributions connected to personnel. Nonetheless, environmental concerns have made transportation difficult recently, with estimates of 1,056 million tons of carbon dioxide (CO_2) released even though it accounts for just 2.89% of all anthropogenic greenhouse gas (GHG) emissions [2]. In this sense, if no effort is made to limit it, it is projected that shipborne emissions are growing day by day.

Accordingly, the International Maritime Organization (IMO) has implemented restrictions to reduce pollutants such as SOx [3], NOx [4], and CO2 [5] to handle difficulties. In this regard, emission control areas around the world have been established to manage and minimize the quantity of SOx, NOx, and particulate matter (PM) in ship exhaust gases [6]. In addition, a Greenhouse Gas (GHG) policy for the marine industry was introduced. According to the most current amended version of the strategy [7] total annual GHG emissions from ships are expected to be reduced by at least 20% in 2030 and at least 70% in 2040, compared to 2008.

There are several strategies considered to comply with energy efficiency regulations. In this regard, various types of techniques [8], [9], problems for seafarers [10], and directions toward emission reduction approaches [11] were studied in the literature. Among them, some of the most effective operational efficiency-enhancing methods include fuel consumption modeling using smart methods such as artificial neural networks (ANN) and speed optimization.

The fuel consumption of a ship may be modelled by statistic and machine learning based-approaches [12]. At this point, while statistic-based approaches employ single and multiple linear regressions, ridge regression, and lasso regression, machine learning applications utilize artificial neural networks (ANN), random forest (RF), support vector machines (SVM), and decision tree (DT) models [13]. Smart methods have also been employed for a variety of applications, including fuel consumption estimation [14], hull fouling assessment [15], and condition-based maintenance implementation [16]. Among the algorithms, the ANN is an effective method that may provide a more robust prediction process with reduced failure rates compared to other approaches [17].

Regarding the fuel consumption modelling, several comparative analyses were conducted using data-driven machine learning methods to identify the best algorithm [18]–[20]. Le et al. [21] presented an analysis based on the multilayer perceptron ANN where the estimation of fuel consumption for five different container ships grouped by size was achieved. Jeon et al. [22] conducted a comparative analysis including data collection, clustering, compression, and expansion within different structures of the ANN. Farag and Ölçer [23] proposed a fuel prediction model combining multi regression and ANN methods to increase energy efficiency and decrease fuel consumption via achieving just in time strategy.

On the other hand, smart algorithms have been considered for speed optimization which is an influential strategy for improving the energy efficiency of a marine vessel. Tarelko and Rudzki [24] developed an ANN model where the fuel consumption and travel time to port destined can be estimated by input operational parameters. The model is also supported by a decision support system since setting proper commended outputs is hard because of variable environmental conditions. Bassam et al. [25] proposed an ANN model to predict ship speed. As a result, they achieved estimation with less than 1 knot error. Similarly, Moreira et al. presented a comparative analysis within different ANN configurations to model ship speed as well as fuel consumption.

This paper deals with a speed optimization strategy for ships to increase the energy efficiency level of a marine vessel. In this regard, an ANN structure has been created considering ship speed and navigation period as input parameters while fuel consumption is an output variable. Then, a speed optimization strategy is employed for the sea trials of the ship. Accordingly, new fuel consumption values within the routes have been identified by the elimination of anchor times. As a result of the analysis, it is found that the strategy provides 284 tons of fuel savings in total.

The remainder of the paper is as follows: Section 2 introduces the ship specifications. Section 3 performs the case study within the bulk carrier. The results are presented and discussed in Section 4. Section 5 concludes the analysis.

2. Ship Specification

Within the scope of the study, operational information regarding a bulk carrier type of vessel has been evaluated. The ship's gross tonnage is 45,310 tons. Its length and beam are 229 m and 32 m, respectively. The ship can reach a maximum of 14.5 knots speed thanks to the main engine which is a 2-stroke MAN B&W 6S60MC-C type of engine. The features of the ship and its engine are presented in Table 1.

The noon report belonging ship that is analyzed within the study covers the time period from April, 2019 to October, 2019. The ship has performed 4 different sea trials. The operational information of the ship along the specified duration is illustrated in Figure 1.

Table 1. Ship & engine features

Ship Features	
Vessel type	Bulk carrier
Deadweight	82,744 tons
Gross tonnage	45,310 tons
Length overall	229 m
Beam	32 m
Draft	14.45 m
Speed	14,5 knots
Engine Features	
Engine	MAN B&W 6S60MC-C
RPM	89
Total power	9,659
Propeller type	Fixed pitch

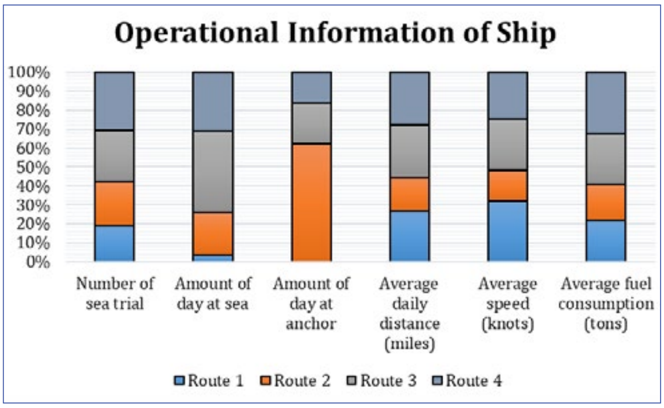

Figure 1. Operational information of the ship

3. Case Study

In this study, a noon report of a bulk carrier ship was obtained, which included ship speed, engine rpm, daily distance traveled, daily fuel consumption, fuel type utilized in operations, and transportation mode. The raw data is altered based on the analysis. In this regard, faulty records and irrelevant data are eliminated. The routes are classified into days with harbor, sea, and anchoring. Then, the ANN structure is developed in which speed and daily distance are input parameters and FO consumption is the output parameter. The methodology of the analysis is shown in Figure 2.

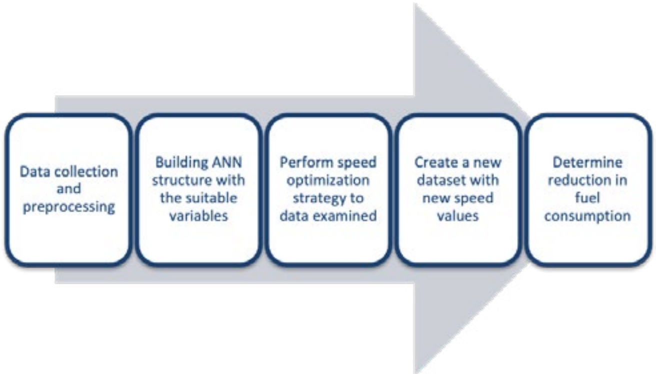

Figure 2. The methodology of the analysis

In addition, the model is evaluated by coefficient of determination (R^2) and root mean square error (RMSE) to specify accuracy and prediction success. The formulations of error metrics are as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - f_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y_i})^2} \tag{5}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - f_i)^2} \tag{6}$$

where y_i is the actual value, f_i is the predicted value, $\bar{y_i}$ is the mean of the data and N is the total number of values in the data.

4. Results and Discussion

Within the scope of the methodology, an ANN model has been structured with 10 neurons in the first hidden layer and 20 neurons in the second hidden layer. In the ANN models, daily distance and ship speed are taken as input parameters to predict daily fuel consumption. The ANN structure developed is illustrated in Figure 3.

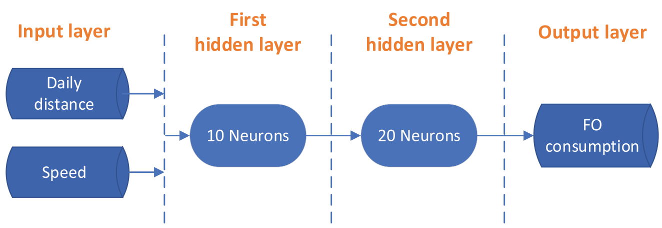

Figure 3: ANN structure developed

The prediction within the ANN model is realized in MATLAB. The feed-forward backpropagation type of ANN is used for the prediction. To perform analysis, the dataset is classified into three subsets; 70% for training, 15% for test, and 15% for validation. The Levenberg-Marquardt optimization approach for the training step and the hyperbolic-tangent method as an activation function are considered. The prediction processes are carried out with 100 epochs.

The validation performance of the analysis is given in Figure 4. In addition, the performance regarding each step of the estimation process is shown in Figure 5.

The model is also evaluated by error metrics. As a result of the calculations, the R2 and RMSE scores of the ANN model are found as 0.8038 and 2.9780, respectively.

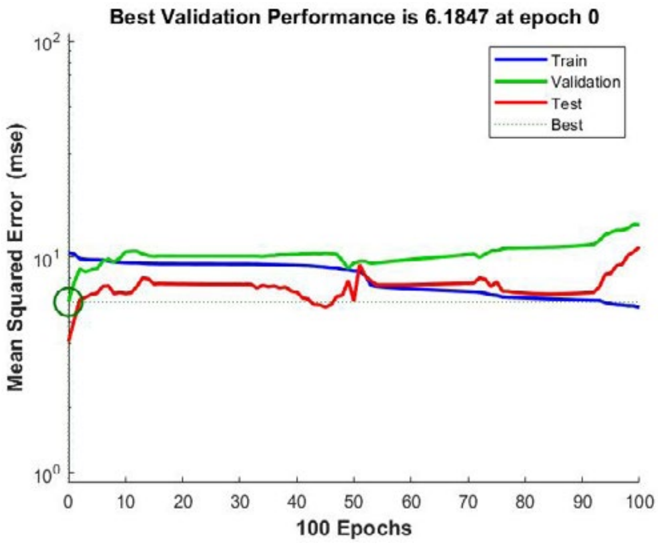

Figure 4. Best validation performance

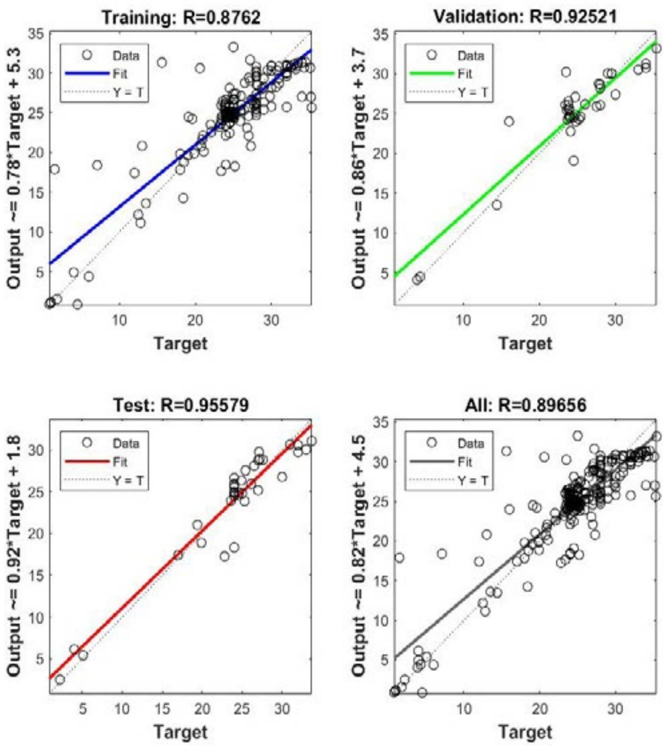

Figure 5. The performance of the prediction process

After successfully creating the ANN structure, the optimal ship speed for each route has been determined. The difference in the speed is demonstrated in Figure 6.

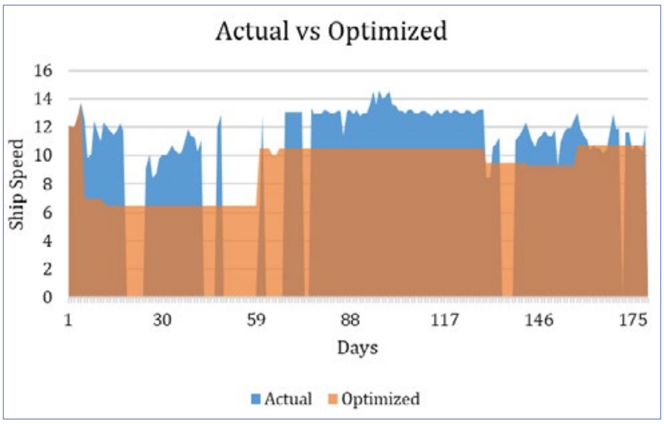

Figure 6. The difference in the ship's speed

In the speed optimization strategy, the anchor durations were eliminated and the optimum speed of the ship was determined considering the total distance of the corresponding sea trial. Accordingly, the amount of fuel consumption and savings throughout each route has been found as presented in Table 2.

Table 2: The results of the speed optimization strategy

	Amount of fuel consumption (tons)		
	Real Case	**Speed optimized**	**Savings**
Sea trial 1	90.90	90.90	-
Sea trial 2	856.70	801.77	54.93
Sea trial 3	1,575.60	1,438.44	137.16
Sea trial 4	1,391.90	1,299.36	92.54
Total	3,915.10	3,630.48	284.62

5. Conclusion

This paper is aimed at demonstrating the impact of the speed optimization strategy performed through a bulk carrier ship regarding its amount of fuel consumption. In this regard, a noon report has been evaluated and an ANN model that may estimate fuel consumption based on ship speed and daily distance traveled has been developed. The speeds within the different sea trials are optimized by eliminating anchor periods in corresponding routes. Impacts of the speed optimization approach regarding fuel consumption predicted by the ANN model considering optimized speed values have been determined. Accordingly, approximately 284 tons of fuel have been saved thanks to the optimization approach without making any investment. In addition, it is obvious that this saving affects the emissions released and positively runs fuel costs. At this point, the paper is limited in that changes in environmental conditions within routes were not considered in the analysis.

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Location Optimization In The Maritime Industry: A Bibliometric Review

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Abstract

Location optimization is a problem that determines the best location for any object to be placed, considering constraints such as usage area, demand, cost and distance. This approach enables the determination of the optimal locations of equipment and systems in different areas of the maritime industry in accordance with their intended use. For this reason, different methods and understandings have been used in the literature to solve the problem. Bibliometric analysis allows a detailed analysis of academic studies on a subject. In this method, bibliographic data includes descriptive statistical data regarding publications on the relevant topic. The bibliometric data used in this study were taken from Web of Science (WoS) and Scopus databases. This study examines academic articles on maritime location optimization, layout and facilitation problems between 1986 and 2023. A deep database review identified 200 relevant publications. In this study, publications, journals, authors and institutions with high impact related to maritime location optimization were identified through citation analysis measurements. In addition, a network of research collaborations based on institutions, authors and countries was extracted to explain trends related to maritime location optimization calculations. This comprehensive bibliometric analysis provides a detailed perspective on the subject by revealing emerging trends, areas of use of the method, and clusters of research methodologies.

Keywords: *Maritime, location optimization, layout, bibliometrics, literature review*

1. Introduction

Due to its benefits, including the ability to move huge amounts of cargo across continents and its greater economic convenience compared to other modes of transportation, maritime is the most popular form of transportation in international trade [1]. With the changing world and developing technologies, the needs of the maritime industry are also changing. In this sense, optimization studies are also shaped according to the sector's needs. Bibliometric analysis provides an overview of extensive collections of scholarly literature. It allows for mapping characteristics and developing scientific outputs in a specific subject area through quantitative analysis of publication history data. [2-3]. This paper conducts a systematic literature review (SLR) on maritime location optimization and equipment placement guided by the PRISMA framework. Additionally, this paper provides a macro view of the existing literature, attempting to outline a solid framework for future research efforts. The bibliometric data were also collected from Web of Science (WoS) and Scopus databases, and the collected data were analyzed using the Bibliometrix tool in R software. When early research on equipment layout problems is examined, it can be seen that the focus is on the method of mathematical analysis of the logistics sequence and material flow between equipment. In 1961, Richard Muther first proposed the Systematic Layout Planning (SLP) method. Since then, scholars have been delving into the equipment layout problem, leading to its application in diverse fields and a continuous stream of research and solution methods innovations. The ever-evolving nature of this problem, with its numerous restrictive conditions and targets, has made fuzzy theory and optimization algorithms indispensable for its resolution [4-6]. Many concepts and solutions related to object placement and equipment layout are available in the literature. For example, Cant and Langensiepen [7] described three ways to organize the object placement process: by means of rule-based approaches, genetic algorithms, or artificial neural networks. In another paper, the authors suggested a new approach to automatic object positioning in three-dimensional spaces using constraints, allowing accurate control over object placement [8]. Farahani et al. [9] surveyed the problems of locating objects and their applications in transport network planning, store location problems, warehouses, and medical centres. The authors also discussed the use of tools based on various variants of p-median and p-centre algorithms to solve the issues of transport network planning and locate stores and distribution centres [10]. Positioning and layout optimizations have been done in different areas in various maritime studies. In the study of Dkhil et al. [11], a new integrated model was presented in which the authors focused on optimizing sea container terminals using straddle carriers. The authors also considered a maximized distance tailored for a range of targets to explore the non-convex Pareto Front region effectively. Zhang et al. [12] conducted a study on the safest placement of gas detectors belonging to an offshore platform. This paper introduces three p-median optimization models, each with distinct objectives: the minimal cumulative detection time (MCDT) model, the minimal cumulative leakage concentration (MCLC) model, and the minimal cumulative individual risk (MCIR) model. The first is the Fuzzy Comprehensive Evaluation Method (FCEM), which has been applied to find out and calculate a comprehensive impact index of factors on the potential storage sites in the South China Sea, putting forward the uncertainty rate under the influence of the geographic environment in the target area. Consequently, an overall optimization process was developed, resulting in an emergency resource storage plan by improving the expected reproduction rate at a certain probability level regarding establishing storage points in the immunity algorithm [13]. Several studies have proposed solutions for optimizing equipment placement or installations in ship technical rooms. For instance, one article outlined the criteria for assessing equipment placement in the ship's engine room and introduced analytical methods to identify the optimal choice regarding safety, energy efficiency, and cost-effectiveness [14]. Additionally, this study discussed methods and technologies designed to enhance access to equipment in the engine machinery room, focusing on maintenance cost planning and implementing effective maintenance strategies [15]. In a different article, the authors show the integration of computer-aided and knowledge-based systems in design regarding ship machinery equipment and installations. They define how their interaction enables optimization to improve the efficiency of the design process, raise reliability, and make the operation of the devices more straightforward [16]. Chaudhuri and Thakur [17] address the problems of ship pipeline system design. Indeed, they contributed to the design criteria of layout design given difficult working conditions like vibration and corrosion. Studies on the cabin layout on ships also attract researchers' attention. Meng et al. [18] systematically examined existing human reliability analysis (HRA) methods to reveal the human reliability method that is more suitable for the layout optimization of cabin equipment. At the same time, taking HRA, equipment correlation and cabin balance as objective functions, they transformed the optimization problem of cabin equipment placement into a mathematical model. Based on bibliometric analysis, this descriptive paper aims to provide a macroscopic overview of the main characteristics of location optimization in maritime industry publications.

The information presented in this paper offers a comprehensive overview of the advancements made in location optimization research. It is a valuable resource for researchers and practitioners, helping them identify critical contributions from various authors, journals, countries, institutions, references, and research topics.

2. Data and Methods

One of the techniques that allows an in-depth view of published academic works is bibliometric analysis. Bibliographic data yields statistical insights into publications on the subject under study [19]. This data can be used to identify the links between authors, journals, universities, and keywords and further measure the impact of the publications. The results can be used to identify research clusters, provide an understanding of the scope of research currently being conducted, and reveal trends on topics emerging in a field. Figure 1 illustrates the four-step process that has been taken in the paper at hand. The first step is data collection through a systematic literature review. The second step involves a detailed field assessment through bibliometric citation analysis and network analysis in search of publication trends, impactful journals, studies, institutions, and authors. This explores collaborations and relationships. The third step concerns bibliographic coupling, which identifies clusters of research. The fourth and last step is cluster analysis, mapping the sub-cluster system that synthesizes results and points out possible future directions in research.

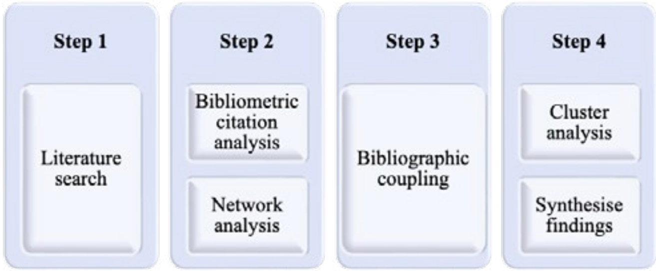

Figure 1. Bibliometric review flowchart.

2.1 Literature search for keywords

This review is based on the gathering of bibliographic data from two influential academic databases: ISI WoS and Scopus. The search for relevant bibliographical data by mean of keywords, using Boolean operators, was conducted in these databases during February 2024, covering all publications from 1986 to 2023. **Table 1** describes the step-by-step process of the keyword search by Boolean operators. The keywords used in searching for relevant literature concerning location optimization in a maritime context were "place," "layout," "location," and "ergonomics." In explaining the application area, the keywords that were used included "maritime," "object," and "equipment." Literature searching on both databases was done via the Boolean function in the "Topic" section. Only documents in English were included. Targeted document types were "Articles," "Proceedings Papers," "Review Articles," "Early Access," and "Editorial Materials."

Table 1. Keyword search in WoS and Scopus databases.

Steps	Keyword search	Number of Papers according to database	
		WoS	Scopus
1	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*")	273209	85185
2	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*")	3413	839
3	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel")	8144	1396
4	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel" OR "port")	10347	1759
5	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel" OR "port" OR "offshore")	12656	2024
6	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel" OR "port" OR "offshore" OR "mari*")	14709	2681
7	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel" OR "port" OR "offshore" OR "mari*") AND ("optim*")	2089	420
8	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel" OR "port" OR "offshore" OR "mari*") AND ("optim*" OR "simulat*")	3470	700
9	("object" OR "equipment") AND ("place*" OR "layout" OR "location" OR "ergonom*") AND ("ship*" OR "vessel" OR "port" OR "offshore" OR "mari*") AND ("optim*" OR "simulat*") AND ("safe*" OR "fire" OR "life*")	856	160
10	Refined by Languages: English	814	155
11	Refined by Document Types: Article, Conference Paper, Book Chapter, Review, Book and Editorial	769	155

2.1.1 Preliminary results

Table 1 outlines the keyword string used for searching WoS and Scopus databases. Initially, the results presented here bring only one group of numbers recovered, and it was realized that their results did not include all the entries using our main keywords. So, the search string had to be further fine-tuned, generating 769 documents in WoS and 155 for Scopus. Because the preliminary results were heterogeneous, the need to proceed with the PRISMA [20] methodology was realized, which would homogenize the search. Systematically, it includes relevant documents but excludes irrelevant ones for this study. A PRISMA flowchart (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used to adapt the obtained WoS and Scopus data for further quantitative analysis. A four-step flow chart was followed, as in Figure 2. The steps are Identification, Screening, Eligibility, and Inclusion. In the identification section, WoS and Scopus databases were searched, the data were combined, and duplicate records were removed. Titles were screened for eligibility, followed by abstracts. All records were evaluated in the suitability section. In the last section, the flow chart on the screen shows that 200 studies were included in the analysis.

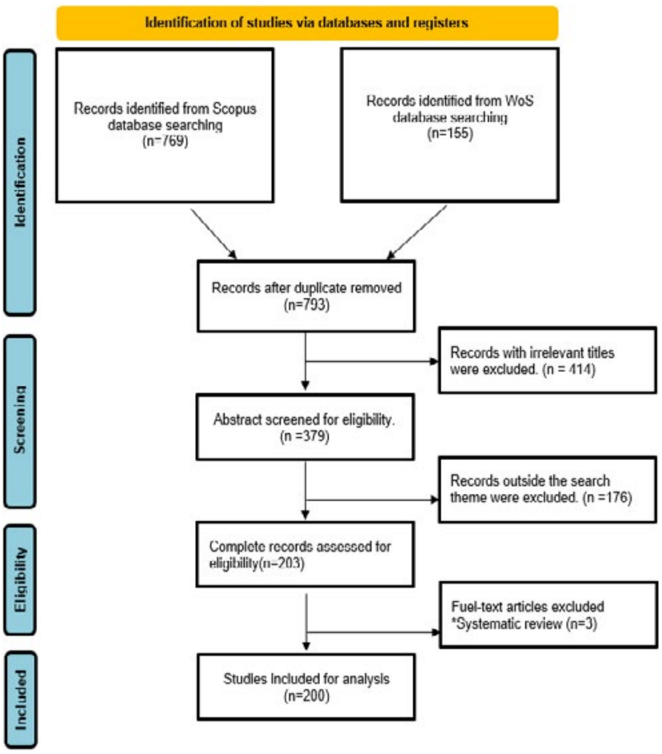

Figure 2. Flowchart of the literature search process.

2.2. Bibliometric analysis method

It is a research method that uses quantitative analysis to identify the characteristics of publications within a specific field and to draw conclusions about the academic status of those publications [21]. The term "bibliometric analysis" was first coined by Alan Pritchard in 1969, who referred to it as a tool for quantifying the process of written communication. Much interest in bibliometric studies has developed over time because of its capacity to give a detailed examination of the development process of scientific research. Such studies are very important for the literature and researchers, as they provide insight into the existing status of research in differing scientific fields and indicate how it has changed over time [22]. Bibliometric approaches are applied to many research topics for measuring a specific field's impact, the influence of a team of researchers, the importance of an article, and for finding highly influential works related to a certain research theme. It enables recognising the most productive researchers in any area and examining their interaction in bibliometric research. It also provides a measure that enables comparisons between countries, institutions, or academic schools on topics of interest. A lot of powerful tools in software have been developed to conduct such bibliometric analysis; the most frequently used tools are Bibliometrix [22] and VOSviewer[23], which can be applied for the mapping of co-citation analysis, bibliographic coupling, and keyword overlap among others. For this study, the open-source Bibliometrix package was utilized using R programming, and its visualization plug-in, Biblioshiny, was launched to provide graph enunciation. After careful consideration of the searched outcome, 200 articles were evaluated in such a way to enable the use of publication count and citation count in checking Lotka's Law, outlining publication trends, and finally finding journals of relevance, the most influential articles, key institutions, impactful keywords, and leading authors [24].

3. Result and Discussions

This amount will be specific only in the academic publication of papers related to the facilitation of maritime equipment location from the period 1986 to 2023. After careful assessment with a database search, 200 publications were retrievable. Out of this amount, 73 are articles, 1 is a book, 3 are book chapters, 2 are review papers, 2 refer to the proceedings, and 119 are papers from conference proceedings. It found that the average number of citations per document was 4.925. The study involved 725 authors who co-authored papers and 19 single authors. As seen from Table 2, scientific productivity indicates 673 authors who have published just one paper in the maritime equipment layout area. In contrast, three authors have published up to a maximum of four printed research works. **Figure 3** further illustrates the productivity of the authors with Lotka's Law.

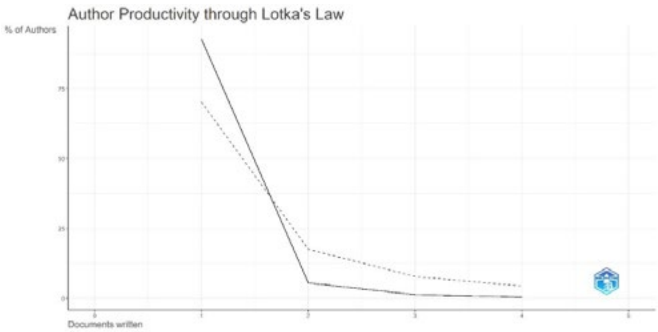

Figure 3. The frequency distribution of scientific productivity.

Figure 4 illustrates the annual publication trend, showing a marked increase in the number of published papers starting from 2015. The year 2018 stands out as the most productive, with 18 publications.

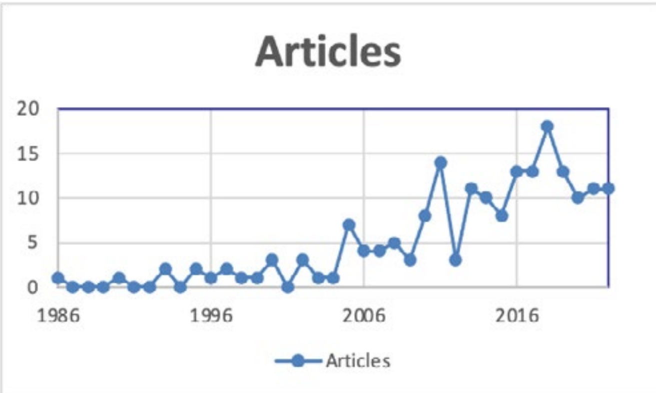

Figure 4. Annual scientific publication.

Table 2 presents the most relevant journals for several metrics: number of papers, total citations, h-index, g-index, and m-index. "Journal of Marine Science and Engineering" holds the top position for publications, and the second is "Journal of International Ocean Engineering" as the most relevant journal for this area of knowledge. It is a global measure which tries to evaluate the productivity and citation impact of all work by a scientist. The index is defined as the highest value of 'h' such that the author or journal has published 'h' articles, each of which has been cited at least 'h' times. Contrarily, the g-index is a function of a distribution of citations across a researcher's publications; it considers the largest unique number g such that the top g articles together have at least g² citations. The last method to be considered is the m-index, computed with the formula h/n, where h is the h-index, and n is the number of years since the researcher's first publication.

Table 2. Most Relevant Resources.

Rank	Publication Outlet	NP	TC	h_ index	g_ index	m_ index	PY_ start
1	Journal of Marine Science and Engineering	7	11	2	3	0,4	2020
2	Ocean Engineering	6	69	4	6	0,44	2016
3	American Society of Mechanical Engineers, Pressure Vessels and Piping Division	4	3	1	1	0,03	1995
4	Fusion Engineering and Design	3	27	3	3	0,21	2011
5	Journal of Offshore Mechanics and Arctic Engineering	3	28	2	3	0,25	2017
6	Computers and Chemical Engineering	2	66	2	2	0,07	1997
7	Proceedings of the Human Factors and Ergonomics Society	2	14	1	2	0,08	2013
8	IEEE Access	2	7	1	2	0,167	2019
9	International Journal of Naval Architecture and Ocean Engineering	2	6	1	2	0,33	2022
10	Applied Sciences	2	2	1	1	0,33	2022

* Ranking by NP. We present journals with a minimum of three relevant publications. In the case of equal NP, presented journals with higher TC. (NP. Number of Publication, TC. Total Citation, PY_start. Year of the first published paper.

This section ranks the 200 chosen papers by their mean citation numbers. The top 8 papers are exhibited in Table 3. Of these, the article of Alvarez 2010 stands out as the most highly cited in total and average annual citations since publication.

Table 3. Most Global Cited Documents.

Rank	Paper	DOI	Total Citations	TC per Year
1	Alvarez Jf, 2010, Marıt Econ Logıst [25]	10.1057/mel.2010.11	65	4,33
2	Azofra M, 2007, Saf Scı [26]	10.1016/j.ssci.2006.09.002	45	2,50
3	Wıllems N, 2010, Int J Geogr Inf Scı [27]	10.1080/13658816.2010.515029	37	2,47
4	Georgıadıs Mc, 1997, Ind Eng Chem Res [28]	10.1021/ie9702845	36	1,29
5	Georgıadıs Mc, 1997, Comput Chem Eng [29]	10.1016/s0098-1354(97)87524-2	33	1,18
6	Kang Hj, 2017, Ocean Eng [30]	10.1016/j.oceaneng.2016.11.018	32	4,00
7	Verma M, 2013, Omega [31]	10.1016/j.omega.2012.10.007	32	2,67
8	Xing SH,2016 Ocean Eng [32]	10.1016/j.oceaneng.2015.12.047	20	2,22

** Ranking by TC per Year. (TC per Year. Total Citation per Year, TC. Total Citation, PY. Publication Year)*

In total, all the identified papers were from 179 unique institutions. Out of those, 143 institutions contributed only one paper. The top two institutions that contributed the most papers on this topic were Seoul National University and China University of Petroleum. **Table 4** lists institutions relevant to the topic with their respective counts of papers.

Table 4. Most Relevant Affiliations.

Rank	Affiliation	Articles
1	Seoul National University	9
2	China University Of Petroleum	8
3	Dalian Maritime University	5
4	Naval University Of Engineering	5
5	Schlumberger	4
6	Wuhan University Of Technology	4
7	Gdansk University Of Technology	6
8	Harbin Engineering University	3
9	Klaipeda Univ	3
10	Shanghai Maritime University	3

** Ranking by number of articles. Presented the institution with a minimum of five relevant publications.*

Figure 5 illustrates the university collaboration network, where a bibliometric analysis is made regarding nodes and edges. The institutional collaboration network analysis showed six clusters with different institutions. Of these, the red one had three universities and became the most prominent and influential.

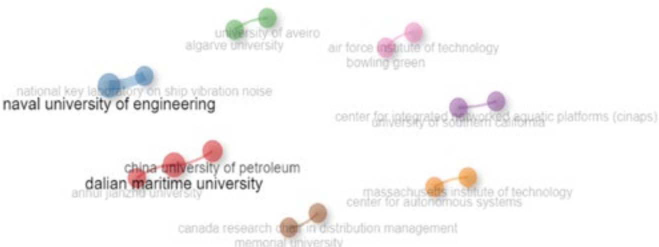

Figure 5. University collaboration network (*50 nodes, 1 minimum edge, walktrap clustering algorithm, association normalization*).

Figure 6 depicts a country-based view of scientific production. The number of analyses shows that most of the papers produced derive from the USA, precisely 41 publications. Most are from China, with 40 publications, while the UK takes the third position with 14 publications. The list is further populated in decreasing order by South Korea, Poland, India, and Norway.

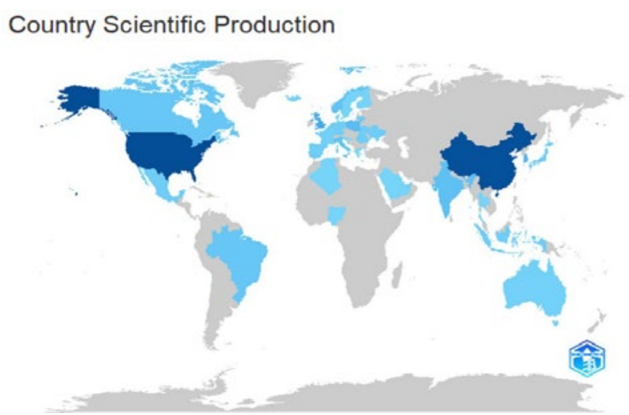

Figure 6. Country scientific production with world map.

A list of the most impactful authors who have published object layout optimization in maritime in Table 4. The authors' h-index, g-index, and m-index data are shown in **Table 5**.

Table 5. Most impactful authors.

Rank	Authors	NP	TC	h_index	g_index	m_index	PY_start
1	Lee S	4	4	1	1	0,1	2015
2	Liu Y	4	5	1	1	0,111	2016
3	Roh M	4	13	1	3	0,125	2017
4	Barua R	3	1	1	1	0,091	2014
5	Bath Z	3	1	1	1	0,091	2014
6	Bratteteig A	3	1	1	1	0,091	2014
7	Kamal F	3	4	1	2	0,111	2016
8	Kim K	3	13	1	3	0,125	2017
9	Sharpe E	3	1	1	1	0,091	2014
10	Singh H	3	4	1	2	0,111	2016

** Ranking by NP. Presented authors with a minimum of four relevant publications. In the case of equal NP. Presented authors with higher TC. (NP. Number of Publication, TC. Total Citation, PY_start. Publication Starting Year)*

Figure 7 plots the most influential authors according to their relationship network. Seven clusters were recognized, and the connections between the clusters were rotated in depth. Usually, the most productive authors, publishing many papers, cooperate with one another. Liu Yuxiang is the most influential author in the red cluster. For all other clusters, the influential author makes no difference.

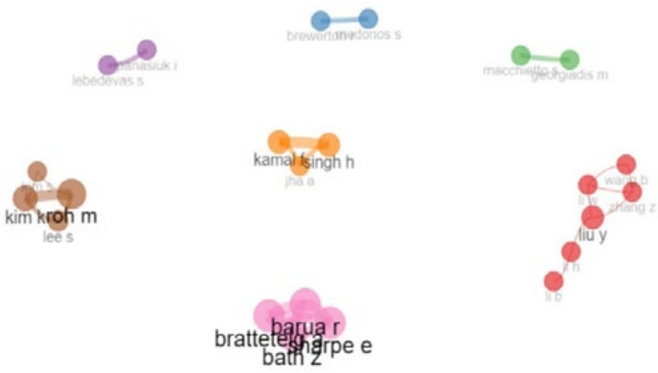

Figure 7. Authors collaboration network (*30 nodes, 1 minimum edge, walktrap clustering algorithm, association normalization*).

The keywords selected by the authors offer insights into the main topics and methodologies addressed in the papers. Analyzing the relationships between these keywords helps to identify the areas in which the papers are concentrated and widely accepted. Figure 8 illustrates the most frequently used keywords and their interconnections, with "analysis," "design," "algorithm," "modeling," and "optimization" emerging as the most prevalent terms.

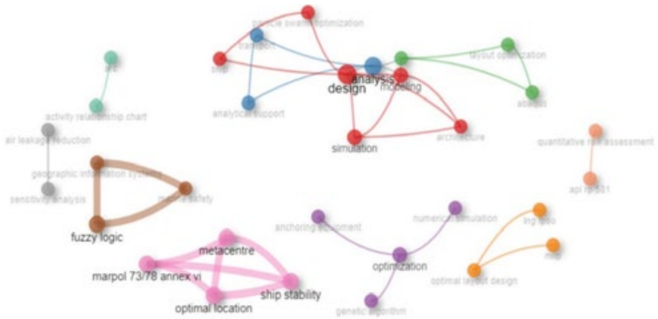

Figure 8. Author's Keywords Co-occurrence Network

Figure 9 presents the increased level of the keywords used by the authors over the years. When the graph is examined, it is observed that there is a significant increase in the number of papers produced with the keywords "algorithm", "analysis", "optimization", and genetic algorithm" every year.

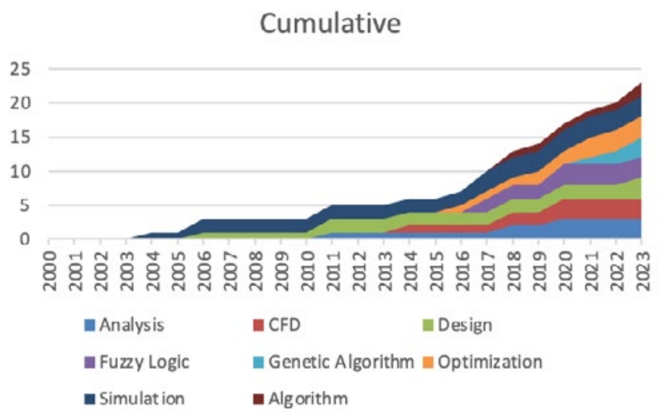

Figure 9. Word dynamics of author keywords.

The interrelationships among journals, research topics, and countries provide valuable insights. To illustrate this, an innovative three-field plot is presented in **Figure 10,** depicting the interactions among the most relevant publication outlets (left), author keywords (middle), and countries (right) within maritime research focused on third-party inspection. It was found that studies on location optimization in maritime are predominantly published in the "International Fusion Engineering and Design" journal, with fuzzy logic being a common method used in these publications, and Polish academics author the majority of these studies.

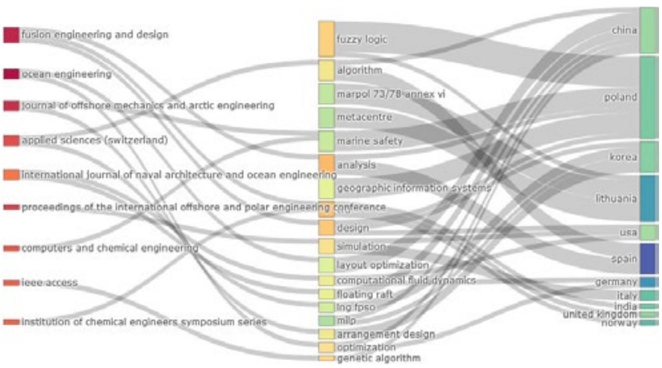

Figure 10. Three-Fields Plot (Left Field: Sources – Middle Field: Keywords – Right Field: Countries)

4. Conclusion

This conference paper presents a bibliometric analysis of studies in the field of Location optimization in the maritime industry. Specifically, an analysis of journal articles in which studies on the topic were published from 1986 to 2023 is presented. When the number of papers is analyzed, the USA ranks first order with 41 publications, China ranks second order with 40 publications, and the UK ranks third order with 14 publications. Popular universities are Seoul National University China University Of Petroleum.

Location optimization is a classical optimization problem that determines the best location for any placed object according to its intended use and necessary constraints and variables. It is frequently used in maritime with the keywords ship stability, optimal location, and ship stability. The uniqueness of our analysis is that we display the exact findings in the form of mind maps.

In the future, studies will be conducted to determine which methods are most preferred and which sub-branches of maritime the approach is more preferred.

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An Implementation of Hardware-in-the-Loop System for Accurate Vessel Heading Control

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Abstract

The maritime industry is constantly looking for advanced technologies to improve ship operations and improve safety. The Hardware-in-the-Loop (HIL) simulations are proven to be a powerful tool for testing and validating control systems. This study presents a new HIL application that downloads focused on heading control of the ships, equipped with a National Instruments (NI) cRIO-9045 installed controller. Our analysis focuses on a linear vessel model, which provides a simple but accurate representation of the dynamics of the ships. The cRIO-9045, known for its real-time processing capabilities, is used as an embedded controller, which facilitates easy integration of the HIL system. This application aims to demonstrate the effectiveness of HIL simulations in ship management validating algorithms in a controlled iteration environment. The test system interfaces with the embedded controller, cRIO-9045, allowing real-time execution of the vessel heading control system. The linear vessel model is designed in simulation environment by using the LabVIEW software to capture the vessel dynamics requirements, enabling a more accurate analysis of the proposed ship management methods. An LQR controller is designed and tested in the HIL environment to demonstrate the system validation in the test setup.

Keywords: *Hardware-in-the-Loop, Unmanned Surface Vessel, Ship Heading Control, Autonomous Ship*

1. Introduction

Adaptation of the maritime industry to autonomous technologies is increasing rapidly. These advancements offer significant advantages, such as efficiency improvement, safety enhancement, and reduced crew fatigue. An autonomous control system for the marine industry can include many aspects such as optimizing navigation routes, eliminating the risk of human error, trajectory tracking and the digital twin concept[1]. However, in order to have an effective control performance, reliable and robust controllers are required. Most of the advanced controllers require an accurate mathematical model of the ship that captures the dynamics of the vessel [2]. Additionally, it is crucial to test these controllers in a real-world environment to validate their performances under realistic conditions. HIL simulations become a valuable asset at that point. HIL infrastructure provides efficient validation strategy for the autopilot system prior to implementation in the real platform by means of testing real-time controller parameters within a simulated environment that mimics real-world scenarios including environmental aspects.

It has been conducted extensive research on the HIL applications to test the control systems in many areas such as aerospace [3], [4], [5], [6], [7], [8], power systems [9], [10] and many other fields of engineering focused on advanced vehicles or systems. The HIL applications on the marine control systems, however, is restricted. Dubey and Subramanian focus on a HIL implementation of a free-running ship model by using the cRIO embedded controller device [11]. They manufacture a ship model and conduct set of experiments. The data obtained via experiments is compared with the simulation data. They design PID and LQR controllers and compare the performances of the controllers in simulation environment [11]. Johansen et. al. design a dynamic positioning HIL vessel simulator by also including the simulations of on-board systems such as thrusters, sensors, and other actuation mechanisms. They also use experimental data to obtain the parameters of the simulation [12]. Hwang et. al. design a hardware-in-the-loop simulation for an underwater vehicle. They use TCP/IP protocol to communicate between PC and controller. They use PD controllers to control the vehicle [13].

Testing the controllers in real-world environment might be time-consuming, expensive and even dangerous. HIL simulations create an environment that the parameters can be controlled and manipulated without conducting real-world tests. In this research, our main purpose is to leverage HIL simulation setup in order to develop and evaluate an efficient and reliable control system for autonomous marine vehicles.

The outline of the paper is presented as follows: In the second section, mathematical modeling of a ship has been conducted by using proper differential equations and assumptions. At the end of this section, a linear state-space model is obtained. Third section reveals the LQR-type controller, in which the mathematical background of the controller is explained and a controller is designed for the model obtained in the second section. In the fourth section the hardware-in-the-loop test structure is explained. A HIL simulation is conducted and the results are shared. Fifth section analyses the results of the study and proposes possible future improvements.

2. Mathematical modeling

For an autonomous system, it is crucial to have a mathematical representation of the system prior to design of the proper controller. One can analyze the system by conducting simulations in the computational environment thanks to having an accurate model.

Consider generic 6-DoF equations of motion which can be represented as follows [14]:

$$
\begin{aligned}
&m[\dot{u}-rv+wq-x_G(q^2+r^2)+y_G(pq-\dot{r})+z_G(pr+\dot{q})]=X\\
&m[\dot{v}-wp+ur-y_G(r^2+p^2)+z_G(qr-\dot{p})+x_G(qp+\dot{r})]=Y\\
&m[\dot{w}-uq+vp-z_G(p^2+q^2)+x_G(rp-\dot{q})+y_G(rq+\dot{p})]=Z\\
&I_x\dot{p}+(I_z-I_y)qr+m[y_G(\dot{w}-uq+vp)-z_G(\dot{v}-wp+ur)]=K\\
&I_y\dot{q}+(I_x-I_z)rp+m[z_G(\dot{u}-vr+wq)-x_G(\dot{w}-uq+vp)]=M\\
&I_z\dot{r}+(I_y-I_x)pq+m[x_G(\dot{v}-wp+ur)-y_G(\dot{u}-vr+wq)]=N
\end{aligned}
\tag{1}
$$

where X, Y, Z denote the translational motions namely surge, sway, and heave, while K, M, N represent the rotational motions: roll, pitch, and yaw. The linear velocities are given by u, v, w, and the angular velocities by p, q, r, with x_G, y_G, z_G representing the coordinates of the center of gravity. The terms I_x, I_y, I_z are the moments of inertia about the respective principal axes.

For slow-speed displacement vessels, sway, heave, roll, and pitch motions are typically negligible. Consequently, terms such as Z, K, M and w, p, q along with their derivatives can be disregarded. Considering the geometric symmetry of conventional ships on the xz-plane, we can assume y_G, = 0. These assumptions simplify the original 6 DOF model to a 3 DOF model:

$$
\begin{aligned}
&m(\dot{u}-rv-x_G r^2)=X\\
&m(\dot{v}+ur+x_G\dot{r})=Y\\
&I_z\dot{r}+mx_G(\dot{v}+ur)=N
\end{aligned}
\tag{2}
$$

Given that sway rate v and yaw rate r are minimal in slow-speed displacement vessels, the nonlinear terms rv and r^2 in Eq. (2) can be simplified to zero. This leads to the following equations:

$$
\begin{aligned}
&m\dot{u}=X\\
&m(\dot{v}+r+x_G\dot{r})=Y\\
&I_z\dot{r}+mx_G(\dot{v}+r)=N
\end{aligned}
\tag{3}
$$

Following a first order Taylor's series expansion, as detailed in [14], the forces X, Y, and moment N can be approximated as:

$$
\begin{aligned}
&X\approx X_{\dot{u}}\dot{u}+X_u u+X_\delta\delta+X_p\\
&Y\approx Y_{\dot{v}}\dot{v}+Y_v v+Y_{\dot{r}}\dot{r}+Y_r r+Y_\delta\\
&N\approx N_{\dot{v}}\dot{v}+N_v v+N_{\dot{r}}\dot{r}+N_r r+N_\delta
\end{aligned}
\tag{4}
$$

It is also obvious that the relation between yaw angle and yaw rate is:

$$
r=\dot{\psi} \tag{5}
$$

Where ψ is the yaw (heading) angle. The total equations motion can be represented in a matrix form as:

$$
\begin{bmatrix}1&0&0&0\\0&m-X_{\dot{u}}&0&0\\0&0&m-Y_{\dot{v}}&mx_G-Y_{\dot{r}}\\0&0&mx_G-N_{\dot{v}}&I_z-N_{\dot{r}}\end{bmatrix}\begin{bmatrix}\dot{\psi}\\\dot{u}\\\dot{v}\\\dot{r}\end{bmatrix}=\begin{bmatrix}1&0&0&0\\0&X_u&0&0\\0&0&Y_v&Y_r\\0&0&N_v&N_r\end{bmatrix}\begin{bmatrix}\psi\\u\\v\\r\end{bmatrix}+\begin{bmatrix}0\\X_\delta\\Y_\delta\\N_\delta\end{bmatrix}\delta+\begin{bmatrix}0\\X_P\\0\\0\end{bmatrix}
\tag{6}
$$

This leads us to the state-space representation of the linear ship motion model:

$$
\begin{bmatrix}\dot{\psi}\\\dot{u}\\\dot{v}\\\dot{r}\end{bmatrix}=\begin{bmatrix}1&0&0&0\\0&m-X_{\dot{u}}&0&0\\0&0&m-Y_{\dot{v}}&mx_G-Y_{\dot{r}}\\0&0&mx_G-N_{\dot{v}}&I_z-N_{\dot{r}}\end{bmatrix}^{-1}\left(\begin{bmatrix}1&0&0&0\\0&X_u&0&0\\0&0&Y_v&Y_r\\0&0&N_v&N_r\end{bmatrix}\begin{bmatrix}\psi\\u\\v\\r\end{bmatrix}+\begin{bmatrix}0\\X_\delta\\Y_\delta\\N_\delta\end{bmatrix}\delta+\begin{bmatrix}0\\X_P\\0\\0\end{bmatrix}\right)
\tag{7}
$$

The surge motion is clearly separate from the other two states (sway and yaw), which are mutually dependent. As per [14], the ship's surge speed exhibits minimal nonlinear variation, remaining within approximately 4% of the nominal speed during maneuvers. Therefore, we assume a constant surge speed u of 1 nondimensional unit. The reduced model, focusing on sway rate, yaw angle and yaw rate, is then given by:

$$
\begin{bmatrix}\dot{\psi}\\\dot{v}\\\dot{r}\end{bmatrix}=\begin{bmatrix}1&0&0\\0&m-Y_{\dot{v}}&mx_G-Y_{\dot{r}}\\0&mx_G-N_{\dot{v}}&I_z-N_{\dot{r}}\end{bmatrix}^{-1}\left(\begin{bmatrix}0&0&1\\0&Y_v&Y_r\\0&N_v&N_r\end{bmatrix}\begin{bmatrix}\psi\\v\\r\end{bmatrix}+\begin{bmatrix}0\\Y_\delta\\N_\delta\end{bmatrix}\delta\right)
\tag{8}
$$

Incorporating parameters from [15], the final state-space representation of the system becomes:

$$
\begin{bmatrix}\dot{\psi}\\\dot{v}\\\dot{r}\end{bmatrix}=\begin{bmatrix}0&0&1\\0&-0.524&0.135\\0&-3.707&-1.254\end{bmatrix}\begin{bmatrix}\psi\\v\\r\end{bmatrix}+\begin{bmatrix}0\\-0.207\\1.421\end{bmatrix}\delta
\tag{9}
$$

3. Control system design

Optimal controllers are widely used since they convert the control problem into an optimization problem. The most fundamental optimal control strategy is Linear Quadratic Regulator (LQR) controller which is based on constructing a cost function and finding the minima of that cost function under given controller requirements. For an LQR control problem, one can define a cost function, J to be minimized as [16]:

$$
J=\int_0^\infty (x^TQx+u^TRu)dt \tag{10}
$$

Where Q and R are the positive definite matrices, that are the weights used to penalize the changes in tracking error and control input, respectively. The control law can be explained as a basic state feedback control law, $u = -Kx$, where K is the gain matrix that is calculated as a result of solution to the optimization problem given in (10) [17]. The optimum K value can be calculated by using the equation:

$$
K=R^{-1}B^TP \tag{11}
$$

P is found as the solution of the algebraic Ricatti equation:

$$
PA+A^TP-Q+PBR^{-1}B^TP=0 \tag{12}
$$

Since the usage of LQR requires the system to be controllable, one needs to check the state space equations. The controllability matrix for the state space system given in (9) is found as:

$$
\begin{bmatrix}0&1.420&-1.014\\-0.207&0.300&-0.294\\1.421&-1.014&0.158\end{bmatrix}
\tag{13}
$$

Since the rank of the controllability matrix is 3, which is equal to the number of states, one can say that the system is fully controllable and the LQR controller can be applied.

4. Hardware-in-the-loop simulation design

In order to test the controller structure in a real-time environment, a hardware-in-the-loop (HIL) structure has been utilized. The core part of the HIL structure is the cRIO-9045 controller device manufactured by the National Instruments company. The cRIO device is equipped with an Intel CPU and 2 GBs of RAM. It has numerous real-time embedded features thanks to the implementation of GPIO pin module, CAN bus communication module, current output module, relay output module and serial interface module. For the sake of this research, the NI cRIO HIL device is used as a real-time control unit to test the performance and behavior of the LQR strategy. The main HIL structure consists of a PC (equipped with Intel CPU and 16 GBs of RAM) and the CompactRio rack. Communication between the PC and cRIO is utilized by an ethernet cable that uses TCP/IP protocol.

The state-space equations are constructed in the PC environment by the usage of LabVIEW software. On the other hand, LQR controller is embedded to the CompactRIO device. Q and R weights were equally chosen as 0.3. The optimal gain matrix was calculated as $K = [1\ \text{-}1.547\ \ 0.837]$. System output is calculated by the simulation conducted in the PC environment. The cRIO device calculated the required control input to be given into the ship simulation. Thus, a closed loop control structure has been utilized. The closed loop control diagram that elaborates the structure of LQR controller is given in Figure …. cRIO controller is utilized in the controller part of the block diagram. Prior to evaluation of the control process executed in cRIO, the error that is the difference between the reference and current heading of the ship is calculated. Subsequently, the rudder angle command was produced by the embedded controller to be sent to the actuator. Ship model calculates the expected heading angle output of the ship for the given sampling time by using proper mathematical model explained in previous sections. Additionally, the physical HIL facility constructed for the heading fixed autopilot design in the lab can be seen in Figure 2.

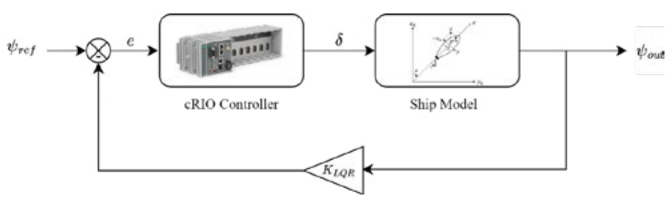

Figure 1. Control block diagram.

A simulation is done to evaluate the performance of the controller. During the simulation, a random reference heading angle is applied to the system. The cRIO device computed the control input that corresponds to the output heading angle of the system at a sampling rate of 100 Hz. The input signal and its input rate are saturated to replicate the conditions of real-world actuators. The result of the Hardware-in-the-Loop (HIL) simulation is presented in Figure 2. The system clearly demonstrates its ability to accurately track the provided heading reference.

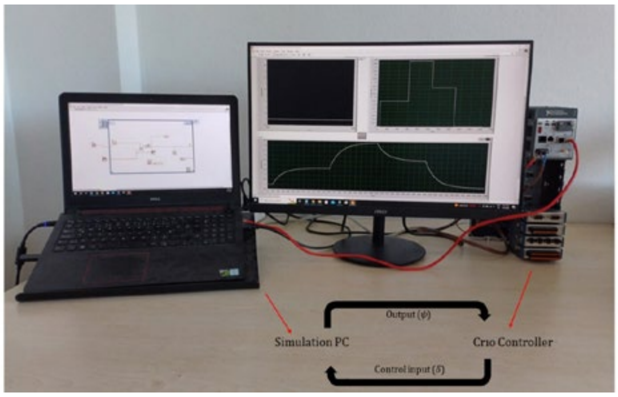

Figure 2. HIL structure.

As shown In Figure 3, the transient behavior of the ship is fairly slow due to the physical restrictions of the ship geometry and actuator limitations. It is possible to trade-off between the response time and overshoot profile of the controller performance by manipulating Q and R weights of the LQR controller. The primary objective of the controller was determined as the accurate tracking of the given heading angle. Thus, no-overshoot profile was preferred than a faster response. It is also essential for a ship to move relatively slow for the sake of providing a more comfortable driving profile. Figure 4 shows the ruddle angle change of the ship during the HIL simulation given in Figure 3.

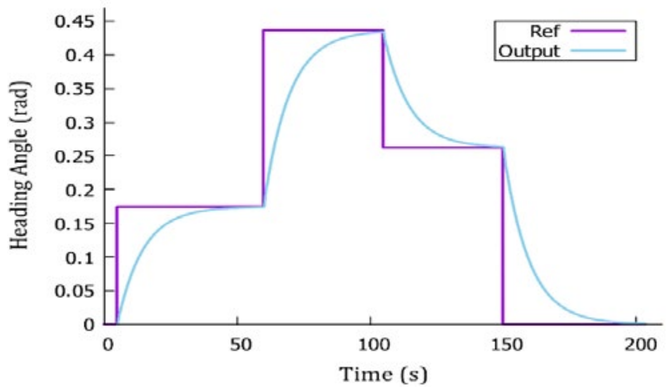

Figure 3. HIL simulation output.

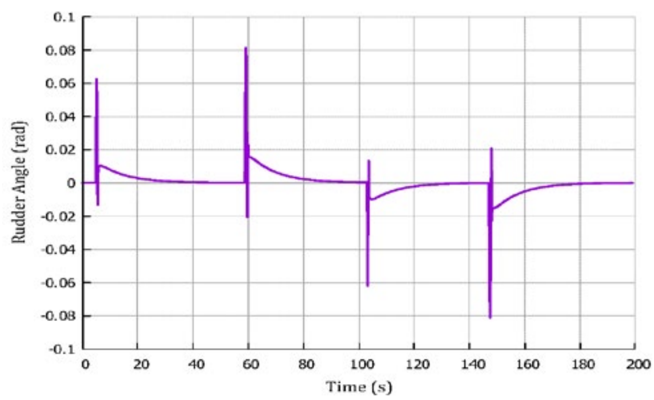

Figure 4. Rudder angle time history during the HIL simulation.

5. Results and Future Work

It has been successfully proved through the use of the HIL simulation that the system is able to track a reference heading angle by utilizing the LQR controller for this simplified ship model. A visual confirmation of this capacity can be seen in Figure 2, which shows that the output of the system is closely following the required heading angle with a reasonable degree of accuracy.

Since the scope of this research primarily focuses on a simplified linear model, the future aspect may involve the implementation of a more sophisticated model such as a nonlinear model. This is because the linear model is the primary research emphasis. This model ought to incorporate the actuator system, disturbances, and other degrees of freedom that are still available. Furthermore, the performance of the various controllers might be compared in terms of disturbance rejection, trajectory tracking, and other similar aspects. An implementation of a filter structure, such as a Kalman filter, may be carried out in order to completely eliminate the existence of disturbance. A real-world actuator test setup, real sensors, and a variety of peripherals can also be added to the HIL setup in order to provide additional development opportunities.

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Reinforcement Learning-Based Vessel Route Optimization with Continuous Obstacle Avoidance by Using DDPG Algorithms

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Abstract

This paper presents a novel approach to vessel route optimization by employing machine learning techniques, specifically the Deep Deterministic Policy Gradient (DDPG) algorithm. The research aims to address the challenge of continuous obstacle avoidance for vessels while optimizing their routes. The proposed methodology utilizes DDPG algorithms to develop an intelligent decision-making system that allows vessels to navigate efficiently while continuously avoiding obstacles. The study begins with the collection and pre-processing of data, including vessel characteristics, meteorological information, and obstacle positions. The pre-processed dataset is then used to train the DDPG model, enabling it to learn the optimal vessel behavior in different scenarios. To validate the proposed methodology, extensive simulations are conducted with varying obstacle positions and environmental conditions. The results demonstrate improved route efficiency and obstacle avoidance rates compared to traditional navigation systems, showcasing the effectiveness of the machine learning-based approach. Furthermore, the trained DDPG model exhibits enhanced generalization capabilities, effectively adapting to dynamic situations and unencountered obstacles. In conclusion, this paper presents a novel application of DDPG algorithms in vessel route optimization, introducing an intelligent decision-making system capable of continuously avoiding obstacles. The findings contribute to the advancement of autonomous vessel navigation, providing a more efficient and safe maritime transportation system. Future research avenues include optimizing the DDPG algorithm further, integrating real-time sensor data, and considering multi-vessel interactions in route planning.

Keywords: *Reinforcement Learning, Machine Learning, DDPG, Route Optimization, ASVs*

1. Introduction

Machine learning has become a powerful tool in the field of robotics, enabling robotic vessels to avoid obstacles and navigate complex environments with ease. This technology has the potential to revolutionize the way maritime operations are conducted, improving safety, efficiency, and reliability.

One of the key applications of machine learning in vessel navigation is obstacle avoidance. By using sensors such as radar, lidar, and cameras, robotic vessels can detect obstacles in their path and make decisions on how to navigate around them. Machine learning algorithms can analyze sensor data in real-time to recognize different types of obstacles, predict their movement patterns, and determine the best course of action to avoid them [1].

Machine learning algorithms used for obstacle avoidance in vessels can be trained using a variety of techniques, including supervised learning, reinforcement learning, and deep learning. Supervised learning involves training the algorithm on a labeled dataset of sensor data and corresponding actions, while reinforcement learning involves training the algorithm through trial-and-error interactions with the environment. Deep learning techniques, such as convolutional neural networks, can be used to extract complex features from sensor data and make more accurate predictions [2].

In addition to obstacle avoidance, machine learning can also be used to optimize vessel navigation in dynamic and uncertain environments. By analyzing historical data on sea conditions, traffic patterns, and weather forecasts, machine learning algorithms can make predictions on the best route to take to reach a destination safely and efficiently. These algorithms can continuously adapt and learn from new data to improve their navigation performance over time [3].

Machine learning has the potential to transform vessel navigation by enabling autonomous and intelligent decision-making in real-time. By combining sensor data with powerful algorithms, robotic vessels can navigate complex environments with greater precision and reliability, ultimately improving safety and efficiency in maritime operations. As research in this field continues to advance, we can expect to see more sophisticated and capable robotic vessels that leverage the power of machine learning to navigate the seas with precision and confidence [4].

The efficiency and safety of maritime transportation have become increasingly important in recent years, prompting the exploration of advanced technologies to optimize vessel route planning. Traditional navigation systems often struggle to address the challenge of continuous obstacle avoidance, particularly in dynamic and unpredictable environments. In response, this paper presents a novel approach to vessel route optimization using machine learning techniques, specifically the Deep Deterministic Policy Gradient (DDPG) algorithm [5]. By developing an intelligent decision-making system that enables vessels to navigate efficiently while continuously avoiding obstacles, the research aims to revolutionize autonomous vessel navigation and enhance overall maritime transportation system productivity [6]. Through extensive simulations and validation tests, the proposed methodology demonstrates superior route efficiency and obstacle avoidance rates compared to conventional systems, highlighting the effectiveness of the machine learning-based approach. The study's findings contribute to the advancement of autonomous vessel navigation and offer promising avenues for future research in optimizing the DDPG algorithm, incorporating real-time sensor data, and considering multi-vessel interactions in route planning [7].

One recent advancement in the DDPG algorithm that contributes to the advancement of autonomous vessels is the integration of reinforcement learning techniques. By incorporating reinforcement learning, DDPG algorithms can better adapt and learn from the environment, leading to more efficient and effective decision-making in autonomous vessel operations [8].

Additionally, researchers are exploring novel ways to train DDPG algorithms using simulation environments. This allows for extensive testing and fine-tuning of the algorithm before deploying it in real-world applications, ultimately improving the safety and performance of autonomous vessels [9].

Furthermore, advancements in sensor technology and data processing techniques have enabled DDPG algorithms to better interpret and respond to complex environmental cues, such as weather conditions or other vessels in the vicinity. This enhanced situational awareness improves the overall autonomy and reliability of autonomous vessels in various operating conditions [10].

Overall, these updates in DDPG algorithm development are propelling the evolution of autonomous vessels, making them smarter, more adaptable, and safer for use in maritime operations [11].

2. Methodology

The Deep Deterministic Policy Gradient (DDPG) algorithm is a model-free, off-policy reinforcement learning algorithm that is commonly used in training autonomous vessels. This algorithm is particularly well-suited for continuous action spaces, making it ideal for controlling the movements of an autonomous vessel [12].

The DDPG algorithm uses two neural networks: an actor network and a critic network. The actor network is responsible for learning the policy function, which maps states to actions. The critic network, on the other hand, is used to evaluate the actions chosen by the actor network and provide feedback on their quality [13].

During training, the actor network aims to maximize the expected return by searching for the optimal policy. The critic network is used to estimate the value function, providing the algorithm with a measure of how good the actions chosen by the actor network are in a given state.

The DDPG algorithm follows a stochastic gradient ascent approach to updating the actor network and the critic network. This involves computing the gradient of the expected return with respect to the parameters of the actor network and the critic network, and then updating these parameters in the direction of the gradient [14].

DDPG (Deep Deterministic Policy Gradient) algorithm is a popular reinforcement learning algorithm that combines deep learning techniques with deterministic policy gradients to learn a continuous action space in an environment. When applied to autonomous vessels, DDPG can be compared to other similar methodologies such as DQN (Deep Q-Network), SAC (Soft Actor-Critic), and PPO (Proximal Policy Optimization) [15].

1. DQN (Deep Q-Network): DQN is another reinforcement learning algorithm that uses a deep neural network to approximate the Q-function in a discrete action space. DQN is suitable for environments with discrete action spaces, whereas DDPG is more appropriate for continuous action spaces. In the context of autonomous vessels, DDPG may perform better in scenarios where precise control of continuous actions is required [16].

2. SAC (Soft Actor-Critic): SAC is a variant of the actor-critic algorithm that uses soft value function updates to stabilize the learning process. Compared to DDPG, SAC typically achieves better performance in terms of sample efficiency and stability. In the context of autonomous vessels, SAC may be preferred over DDPG for scenarios where robust and stable learning is crucial [17].

3. PPO (Proximal Policy Optimization): PPO is a policy optimization algorithm that uses a surrogate objective function to update policies in a more stable and efficient manner. In comparison to DDPG, PPO is known for its simplicity and ease of implementation. While DDPG may offer better performance in terms of accuracy and precision, PPO could be a better choice for scenarios where simplicity and efficiency are prioritized [18].

In conclusion, DDPG is a powerful methodology for training autonomous vessels to navigate continuous action spaces efficiently. However, depending on the specific requirements of the application, other algorithms such as DQN, SAC, and PPO may also be considered for their unique advantages in terms of stability, efficiency, and simplicity. Ultimately, the choice of methodology should be based on the specific goals and constraints of the autonomous vessel project.

In the context of autonomous vessels, the DDPG algorithm can be used to learn the optimal control policy for navigating a vessel through complex environments. By training the algorithm on data collected from a vessel's sensors and feedback from its environment, the autonomous vessel can learn to make decisions that are both safe and efficient.

Overall, the DDPG algorithm provides an effective methodology for training autonomous vessels to navigate and operate effectively in dynamic and challenging environments. By leveraging the power of reinforcement learning, the DDPG algorithm enables vessels to learn from experience and adapt to changing conditions, making them more capable and reliable in real-world applications.

4. Application

The DDPG (Deep Deterministic Policy Gradient) algorithm is a reinforcement learning algorithm that can be applied to solve complex decision-making problems, such as route planning for autonomous vessels. In the context of autonomous vessel route planning, the DDPG algorithm can be used to generate optimal routes by learning a policy that maps observations of the environment to actions that maximize a long-term objective, such as reaching the destination in the shortest amount of time while avoiding obstacles and adhering to safety regulations [19].

The DDPG algorithm works by training a neural network to approximate the optimal policy for selecting actions at each time step. The neural network takes observations of the environment (such as the vessel's current position, speed, heading, and sensor readings) as inputs and outputs a continuous action vector that represents the desired control inputs for the vessel (such as steering angle and throttle setting). Through a combination of exploration and exploitation, the algorithm learns to select actions that maximize a given reward function, which is designed to encourage the vessel to reach its destination efficiently and safely [20].

To apply the DDPG algorithm to autonomous vessel route planning, the following steps [21] can be taken:

1. Define the state space: Identify the relevant environmental variables that the algorithm will use to make decisions, such as the vessel's position, velocity, heading, and sensor readings.

2. Define the action space: Determine the set of possible control inputs that the algorithm can select to navigate the vessel, such as steering angle and throttle setting.

3. Design a reward function: Define a reward function that incentivizes the vessel to reach its destination quickly and safely, while penalizing actions that deviate from the desired route or pose a risk to the vessel or other maritime traffic.

4. Train the neural network: Use historical data or simulation environments to train the neural network to approximate the optimal policy for selecting actions that maximize the reward function.

5. Evaluate and fine-tune the policy: Test the trained policy in various scenarios and adjust the parameters of the algorithm to further improve its performance in route planning tasks.

By leveraging the capabilities of the DDPG algorithm, autonomous vessels can efficiently and effectively plan routes that optimize for safety, efficiency, and compliance with maritime regulations. This methodology enables autonomous vessels to navigate complex and dynamic environments with greater precision and reliability, ultimately enhancing the overall performance and autonomy of the vessel [22].

1. Define the problem: The first step in the DDPG algorithm for an autonomous vessel is to clearly define the problem that the vessel is trying to solve. This could be anything from navigating to a specific location to avoiding collisions with other vessels.

2. Set up the neural network architecture: The next step is to set up the neural network architecture that will be used to train the vessel to make decisions. This will typically involve setting up two neural networks - one for the actor (which selects actions) and one for the critic (which evaluates the actions taken).

3. Initialize the networks: The next step is to initialize the weights of the neural networks. This can be done randomly or using a pre-trained model.

4. Initialize the replay buffer: The replay buffer is a memory that stores experiences (state, action, reward, next state) that the vessel can use to learn from past experiences. This buffer is typically implemented as a FIFO queue.

5. Train the neural networks: The next step is to train the neural networks using the DDPG algorithm, which involves updating the weights of the networks based on the experiences stored in the replay buffer. This is done through a process of gradient descent, where the networks are updated to minimize the difference between the predicted and actual values.

6. Update the target networks: To stabilize training, the target networks (which are copies of the actor and critic networks) are periodically updated to match the main networks.

7. Select actions: Once the networks have been trained, the vessel can use the actor network to select actions based on the current state of the vessel.

8. Implement the actions: Finally, the vessel can implement the selected actions, such as adjusting its course or speed, in order to achieve its objective.

9. Evaluate performance: The performance of the vessel can be evaluated by measuring how well it is able to achieve its objective, such as reaching a specific location or avoiding collisions. This can be done by comparing the vessel's actions to the optimal actions that would achieve the objective.

5. Conclusion

As research and development in the field of autonomous vessels continue to progress, the integration of cutting-edge algorithms like DDPG will play a crucial role in realizing the full potential of autonomous navigation. By harnessing the power of artificial intelligence and reinforcement learning, autonomous vessels are poised to revolutionize the way we approach maritime transportation, setting new standards for safety, efficiency, and reliability in the maritime industry.

With advancements in technology and the implementation of algorithms like DDPG, the maritime industry is poised to witness a transformation in how vessels navigate and operate. Autonomous vessels equipped with sophisticated route planning capabilities can significantly improve operational efficiency, reduce the risk of accidents, and ultimately pave the way for a more sustainable and efficient maritime transportation system.

The successful completion of the project using the DDPG algorithm for autonomous vessel control demonstrates the effectiveness and efficiency of this methodology in designing and implementing autonomous systems. The algorithm's ability to learn and adapt to changing environments and situations resulted in a high level of autonomy and reliability in the vessel's operation. This project highlights the potential of DDPG in revolutionizing autonomous systems across various industries, paving the way for safer and more efficient operations in the future.

In conclusion, the DDPG algorithm offers a powerful solution for autonomous vessel route planning by enabling the vessels to make intelligent decisions based on a deep understanding of their environment and the desired objectives. By leveraging neural networks to approximate optimal policies for decision-making, autonomous vessels can navigate with efficiency and safety, while adapting to changing conditions in real-time.

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Productivity, Efficiency and Ergonomics in Shipyards

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Abstract

Man - Machine systems in shipyards, generally have crucial features. Scientific study of these systems, especially using ergonomic and methods study principles gives us the opportunity to increase productivity and efficiency. Unfortunately in Turkey, a superficial survey shows that many shipyards in Turkey don't apply this kind of scientific solutions consciously. According to our mind, in every man machine system in shipyards must be considered with this reality.

In many engineering problems, it is a real fact that in Turkey ,the responsible managers are not taking into account the Work Analysis Principles including ergonomics.

Unfortunately, according to our experience, we noticed that in many shipyards they don't use and apply Industrial Engineering solution methods. We assume that using the Industrial Engineering methods, especially through benefits of ergonomic principles it is possible to increase efficiency and productivity up to 30 %.

Using Ergonomic principles in shipyards we are able to determine stress level, identify basic human limitations in perception, decision making and control. Ergonomics can make huge contribution towards minimizing many of the difficulties. Guidance can also be provided in the improvement of new marine systems to tackle the weak points in Micro Man- Machine Systems.

The aim of this paper is to show how can we increase productivity and efficiency in Turkish shipyard. Manual Material Handling Process, Cognitive Ergonomics, Antropometric Design, Macro Ergonomics, Improving Environmental Conditions are some of important points in this issue. Our survey in each work station shows us that it is easily possible to work more scientifically in Turkish shipyards and to compete with other shipyards in the World as well.

Keywords: *Macro Ergonomics, Micro Ergonomics, Work Analysis, Ergonomic Principles,*

Productivity and Efficiency

1. Introduction

1.1. Ergonomics and Work Study in General

Ergonomics can be defined in different ways. It is an optimization of man, machine and environment. Environment can be physical or pshyco- social. Workers satisfaction, qualitative work, productivity and efficiency are sum of major components in every kind of man – machine systems. Ergonomics makes it possible the payment of the worker in minimum level. In Turkey, the ergonomic problems in industry and in service sector are well-known. But in shipyards so far we know it is not applied in scientific level and importance. The necessary improvement in shipyard will help a lot to solve efficiency and productivity problems. To our minds shipyards in Turkey do not use Industrial Engineering solving methods. Each shipyard generally in the World, naturally has its own different way of building ships or repairing process. To improve the necessary process, to measure and to implement ergonomic solution methods are a very important.

We believe that continuous improvement and using industrial engineering methods could be very useful in shipyards. This scientific way of production helps also to compete with other shipyards in the World. In Turkey, work accident frequencies is also too high . To prevent a fatal accident is also only possible if we use scientific methods in extension of the concept of providing a good safe and comfortable working environment for the operator. More efficient working environment enables us to create improved work conditions high worker moral and naturally to decrease member of accidents.

A very simple survey shows us what are the necessary measures to have a high moral in shipyards. For example, Accident prevention is a composition of controlling working methods to apply ergonomic principles and controlling materials , tools and equipment. In the first step accident prevention is the identification of factors, collect data, analyze them and to understand the main causes of accident. In many cases they may be several solutions but every time ergonomics is the main fundamental area we have to deal with. Of course, Ergonomics play a major role also in designing of man machine systems scientifically [1].

1.2. Productivity and Efficiency in Industrial Engineering

Ergonomics can be defined as a scientific man – machine system analysis which makes it possible to decrease the payment of human being. To increase man machine system performance and to create a system more human. Regarding psychological and physiological characteristic of human being has to be considered absolutely.

Many of industrial engineering technique can be applied also in shipyard.

In shipyards any system which can be a new design or maintenance system, can be handled according to Ergonomic Principles. This system has to be studied within human capacity. At the end of working time the person in the system has not to feel to be exhausted. Performance rating coefficient has to be 1 all the time. If it is more than 1, one has to have a incentive wage system.

Generally, in the literature productivity and efficiency used in the same meaning but we will define them little bit differently:

- Productivity = Output/ One of the production elements(n)

- Efficiency = Output / Input (%)

1.3. Ergonomic Design

Every work system can be checked according to ergonomic principles. Personal characteristics and job requirements have to be verified every work system. Besides this principles physical and socio-technical conditions have to be considered according to human well-being. In this point ergonomic checklist and subjective questionnaire can help a lot. In fact, an ergonomic culturally background is necessary for every company.

In any kind of work system designing process; workplace, tools equipment and physical and socio-technical work environments must be checked. Physical and mental capabilities and limitations of human are always mature factors to apply work design processes. Appropriate checklist to facilitate the use of design principles can be very helpful. Taking a shipyard a comprehensive macro man-machine system, all kind of design principles have to be considered precisely. This approach will assist also to apply method analysis in designing the work places equipment and to meet simultaneously to increase production and efficiency to decrease injury rates for human operator is also important.

1.4. Antropometric Design

In antropemetric design, we have some ergonomic principles: Every man – machine system has to be designed according to %90 percent of Antropometric population distribution. If possible, every system should be adjustable: For example, Table height and Chair. Statistically, we are able to design for any kind of percentage of the population.

Wrong Antropometric design can destroy human health quality and quantity of the produced item. We consider male or female population or both. For each population the mean value and the standart deviations are important. It is always preferable maintain natural postures minimize repetions to use power grips and pinch grips. Because of financial reasons it is not possible to take %100 of population into considerations in designing processes. A well-designed man - machine system is suitable for human being and also is providing to increase efficiency and productivity.

Man machine systems have to be established and developed to serve some specific shipyard purposes. The system approach has to be made in every procedure.

Antropometric design and preventing musculoscelaticale disorderare very often met in work stations. The development of muscular work needs to be improved after any experience. Job evaluation and establishing of standardize time systems is necessary for every kind of man machine systems in shipyard. If we are able to standardize every kind of work in shipyard may be incentive bonus salary system can be designed later. Regulation of working hours, digital transformation within the company can be developed by the time.

1.5. Work Environment Design

Physical and psychosocial environment design is also of great importance. Illumination, noise, heat, stress, radiation, ventilation, chemicals and toxic materials are sum of work environment elements to design scientifically. For health conditions, we don't permit to excess some numerical values of this physical environment conditions.

Besides physical environmental design a model of human information processing is also important in man machine system design. Human memory, perception, decision and response selection, response execution, working memory and long term memory are sum parameters in mental work design.

General environmental conditions are very inconvenient in shipyards. Vibration, noise, dust, chemicals, electricity, metal welding conditions are very tough in shipyards. They have to be improved in a very superficial survey shows that there are so many hazardous point to be improved. One can say that the managers are not aware of ergonomics. It is necessary day by day to improve working conditions to increase responsibility of the first and middle line managers.

1.6. Ship Building Processes and Work Flows

Ship production has some sub processes to built a ship. It covers generally three consecutive and overlapped sub processes, hull construction, outfitting of this hull and launching the ship from land into the water

For known standards ship specific materials and other equipment's are made with manufacturers as sub contractors. After production, the erection of the blocks forms the entire ship hull. In accordance with ship design projects still cutting is executed. Hull production is a key part in shipyard. We know that blocks construction starts with plate cutting and profile processing. The next step for the blocks is blasting and painting at given standards. The size and mines all hull shops are related with shipyards lifting capacity. If it is possible two or more blocks are combined two form a huge block around 300 tonnes or mega blocks more than 300 tonnes [2].

1.7. Work Analysis and Design in Shipyard

In Shipbuilding processes detailed information is necessary.

Project and contract, proposal preparation, contract negotiation, contract effectiveness and ship building processes are some of these processes in shipbuilding.

In many cases, manipulating tasks, dynamic motions and static muscular work has to be designed according to work simplification, method study and ergonomic principles. If we divide main movements into basic parts, we can distinguish the use of human body as upper and lower extremities.

Generally, in Turkey, first line and middle line managers omit scientific methods in practices. Furthermore, the traditional principles of motion economy and work simplification can be applied in many cases. Human body is able to produce movements because of the complex system of muscal and bones as we called the whole system as musculoscelaticale.

A basic supervision in shipyard shows us in many cases we can increase productivity and efficiency in many simple or complex work stations .

1.8. Work Organizations in Shipyards

The general work organization in shipyard is of great importance. Within the company rules and according to productivity principles the managers are responsible to plan in each work procedure. Generally, leadership of qualified management can analyze all kind of work station correctly and offer appropriate solutions. In each projects, data processing systems have to be considered within technological strategies. The creative approaches of companies have the potential in the global market. Correct processing , work flow and work simplifications are some technological tools to be applied. To increase the understandability among different departments is necessary.

.19. Implementation of Ergonomic projects in shipyards

Education and training for all levels in company,

- To apply and ergonomic project in any shipyard, it is necessary to educate all level company workers, supervisors and managers. The essential ideas of ergonomics have to be given to all people in the company according to their educational level. For example, for the blue color people an education of four hours can be assumed sufficient. For supervisors and White color people may be six hours education is necessary. In managerial level, according to their time an education for three hours can be enough.

In all cases, top management support is essential without any support of management to implement a project cannot be succeeded.

Selecting pilot work stations,

- In education and training periods, the people from all departments of the company assumed to participate. This group can help to find the most problematic work stations

Application,

- The most problematic work station has to be studied by a group who has already necessary basic knowledge in Ergonomics and Work Analysis and Design. During this team work all related factors has to be considered precisely.

Control,

- After application, it is necessary to control whether obtained results are valid or not. This control period gives a chance to improve the important points.

Generalizations,

- If everybody agrees what achieved in this implemented project than the obtained results can be generalized in the whole company. It helps also to create a general culture in company.

1.10. Fundamental Efficiency Culture of Shipyards

The shipyard work environment is generally very complex and have a variety of vessels Cargo carriers military ships and some of different type product. Comparatively with other industrial companies shipyards perform different types of work such as new ship construction repair maintenance and demolition.

Man Machine systems in shipyards are typically work stations which involves fabrication and forming of large still plates and pipes as well as painting and coating operations. In addition, electrical work, metal sheet work and welding are sum of common job in shipbuilding. Grinding and chipping of metals are also typical operations in shipyards. Moreover, more shipyards workers work outdoor and mainly exposed of adverse work conditions. For these reasons health and safety problems have to be taken into consideration carefully. Work related musculoskeletal disorders are common health problems in shipyards.

The development of preventation musculoskeletal and cumulative trauma disorders can be prevent in using PPE (Personal protection Equipment). Certain risk factors are related in general education and training. From this point of view, we have in Turkey many differently structured shipyards very advanced and very primitive.

1.11. Standard Times in Work Stations

To measure the performance of Man Machine systems, it is necessary also in shipyards to have standard times of every activities. We have generally three methods to determine time standards:

- Stop-watch
- Work Sampling
- Predetermined time standards

In stop-watch, it is necessary to determine actual time performance rating coefficient and allowances. The general formula is like the following:

$$T_n = T_a \,.\mathrm{H} \qquad (1)$$

$$T_s = T_n + T_n.\mathrm{P} \qquad (2)$$

$$T_s = T_n \ (1 + \mathrm{P}) \qquad (3)$$

$$0{,}05 \leq \mathrm{P} \leq 0{,}20 \qquad (4)$$

Denotation of the symbols on Eq1,2,3 and 4. as follows,

- T_n : Normal Time
- T_a : Actual Time
- H : Performance Rating Coefficient
- T_s : Standard Time
- P : Allowances

In work sampling, we observed Man – Machine system in random times and analyze to determine time standard. Predetermined time standards are established in micro levels. Every micro element can be established from predetermined tabular form.

In work sampling, we have some important formulas:

$$n = z^2 . \frac{1-p}{(h_p)^2 . p} \tag{5}$$

$$0{,}01 \leq h_p \quad \leq 0{,}10 \tag{6}$$

$$T_{S:} \ \frac{T.H_a.p}{N}(1+P) \tag{7}$$

Denotation of the symbols on Eq5,6 and 7. as follows,

- n : observation number
- h_p : Relative Error
- T : Observation Time
- H_a : Average Performance Rating Coefficient
- N : Produced Item Number

1.12. Work Station and System Safety In Shipyards

Generally, Work accidents result from a sequence of events with multiple causes in shipyards. We have to examine accidents by using job safety analysis. In this area, fault tree analysis can help to detail the accident sequences. In the same time we have to consider trade- offs varies corrective actions by using cost benefit analysis. The responsible managers in shipyards have to be familiar with safety requirements. At the end of detailed analysis, sometimes we eliminate some work elements, limit the energy levels, we use isolations, design fail – safe equipment and finally minimize failure through increased reliability and safety factors [3].

In shipyards unsafe conditions due to job factors such as inadequately work standards and pure working conditions are some factors of work accidents. In many cases, lack of maintenance is also another important factor to be considered.

Macro Ergonomic principles will be very useful in job organization to achieve the intended results. In macro level ergonomics we have to asses overall conditions in shipyards and every elements in production should be properly identified. In many cases, we have to take actions as early as possible.

2. Conclusion

Every industry business and service organizations must work more and more effectively in Turkey. Because every organization must increase intensity of cost reduction and quality improvement working with advanced technologies. Human centered design Man Machine systems, product reliability without accessing human capability and limits are important keys to successful activities in all areas of business industry and government. Industrial Engineering Methods can help a lot for an efficient work design. In our days, machine and equipment we use grow increasingly, complex and semi-automated or fully automated. From ergonomics point of you, it is important to study both the manual components and the cognitive aspects of work and in the same time to take into consideration safety and health conditions. The operator must understand and interpret large amount of information, make critical decisions and control all advanced technological equipment both quickly and accurately. In shipyards also jobs have shifted gradually from manufacturing to the service sectors. For this reason information processing and decision making have to be considered together associated modern technology. The same efficiency and work design cannot be considered without scientific ergonomic principles. Using advanced technology and scientific ergonomics principles one can believe that our shipyards can be much more competitive with other shipyards in the World. In collaboration with University Industrial Engineering Departments and shipyards in Turkey have to work together and to develop scientific projects.

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Thermodynamic Analysis of an Organic Rankine Cycle System Integrated with a Condensation Chamber Working Under Vacuum Conditions

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Abstract

This study aims to thermodynamically analyze the integration of a condensation chamber placed after the expander and operated under vacuum conditions in an organic Rankine cycle system of a marine vessel. The proposed system was designed to substantially reduce the evaporation pressure; therefore, the system can be established with cheaper components. The waste heat sources of jacket cooling water (JCW) and exhaust gas (EG) of the main engine were utilized. The condenser was cooled by sea water. The organic fluids were selected as acetone, isobutane, isopentane, and benzene. Most of the working fluids utilized in conventional waste heat recovery (WHR) systems were not included in the analyses due to their improper thermodynamic properties for the condensation state. A parametric study was carried out for main engine MCR loads of 50% and 100% under conditions where the high-pressure pump mass flow rate was theoretically varied between 4 kg/s and 7 kg/s, and condensation tank pressure was reduced to 55 kPa. The results showed that the highest energy efficiencies for all organic fluids were achieved with 50% MCR engine load and 7 kg/s high-pressure pump mass flow rate. The best performance was yielded with acetone with 18.83% thermal efficiency for 800 kPa evaporation pressure.

Keywords: *Waste Heat Recovery, Organic Rankine Cycle, Thermodynamic Analysis, Vacuum, Marine Engineering*

1. Introduction

Global environmental pollution has become a serious problem in recent years. Main engines have ~35% efficiency and the rest of the energy is released as waste heat [1]. The waste heat is discharged to the environment along with EG, JCW, scavenge air, etc. ~96% of installed produced energy on ships is generated by diesel engines that mostly operate around 50% efficiency [2]. According to the Carnot theorem, the high thermal efficiency of diesel engines is near the greatest value of approximately 50 % [3]. As a result, further improving the in-cylinder power cycle would not result in a gain in engine efficiency. Because about 50 % of the fuel energy is lost to the environment, WHR has been proposed and tested as an effective approach to generate extra power without consuming additional fuel. WHR systems are reasonable answers to increase efficiency and reduce emissions especially when EEXI (Energy Efficiency Existing Ship Index) mandated by IMO is considered [2,4]. Specific emissions of nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM) are reduced as a result of reduced fuel usage. As a result, WHR ensures compliance with severe emission regulations. WHR has emerged as a critical approach for environmental preservation, energy conservation, and the reduction of carbon dioxide emissions.

The ORC design has a huge capacity for producing power of WHR systems while utilizing waste heat from low and medium temperatures. It has been observed that ORC systems provide meaningful results when used in WHR systems [5]. Lyu et al. [6] developed a WHR system that extracts waste heat from a container ship's engine EG during a voyage cycle. Chen et al. [7] studied a WHR system based on a marine engine's waste heat. WHR system is based on ORC. R245fa is used as the working fluid. Mariani et al. [8] studied on WHR system based on the ORC for marine engines and found that R601 outperformed R1223zd.

The literature review ensures that multiple WHR systems for marine engines employing various waste heat sources are shown. Determination of the WHR potential and selection of the organic working fluid for the ORC system has been presented in the papers as mentioned earlier. Pesyridis et al. [5] investigated the implementation of WHR systems, specifically utilizing an organic Rankine cycle (ORC), in marine diesel engines to address rising fuel prices and stricter emissions regulations. The research aims to improve fuel consumption efficiency, which has become a primary focus for R&D departments in maritime applications. Lan et al. [9] employed the energy, exergy, economic, and life cycle climate performance method to analyze the comprehensive performance of three systems (ORC, Kalina cycle (KC), and thermoelectric generator (TEG)). Ahamed et al. [10] researched EEG recovery Rankine cycles in heavy-duty diesel engines. According to the investigation, up to 20 % of waste heat from the heavy-duty diesel engine can be recovered. Aryanfar et al. [11] researched assuming a two-stage ORC and LNG recovery mode, the energy efficiency of the SFGC will increase from 0.2023 to 0.3863 when using R227ea and R116 working fluids, Lyu et al. [12] studied a twin-loop ORC system to generate power. Exhaust heat is collected and used for power generation, creating 253kW power with cyclohexane and achieving a thermal efficiency of 18.5% with benzene. Dadpour et al. [13] propose a novel WHR system installed on a ship that can produce power and cooling by WHR. Yang et al. [14] proposed a new energy generation system for LNG-fueled ships that integrates LNG cold energy and waste heat of the main engine while taking into account the LNG pressure. The results show that the net output power, thermal efficiency, exergy efficiency, EPC, payback period, and CO_2 emission reduction of the system are 336.3 kW, 39.38%, 44.38%, 0.043 USD/kWh, 2.68 years, and 21,540 tons, respectively. Tian et al. [15] also researched thermo-economic analysis and optimization of a combined ORC system with LNG cold energy and WHR of a dual-fuel marine engine. This innovative approach aims to enhance energy efficiency and cost-effectiveness in maritime applications. By incorporating LNG cold energy and WHR, the system offers a novel solution to address environmental concerns and improve overall performance in marine propulsion systems. Furthermore, the research delves into a comprehensive thermo-economic analysis of the combined ORC system, evaluating various working fluid combinations to optimize system performance. Konur et al. [16] have added the integration of waste heat from the cargo oil pump turbine to the thermal design and analysis of an ORC system in a large tanker ship, building upon previous research. By incorporating the previously unexplored waste heat from the cargo oil pump turbine, the study seeks to improve energy efficiency and reduce carbon footprints in the maritime industry.

The literature review shows that the condensation tank in vacuum condition design and thermodynamic model of a vacuum ORC system have not yet been introduced in the preceding studies of marine ORC-integrated WHR systems that utilize different kinds of waste heat sources. This study aims to thermodynamically analyze the integration of a condensation chamber placed after the expander and operated under vacuum conditions in an organic Rankine cycle system of a marine vessel. The proposed system was designed to substantially reduce the evaporation pressure; therefore, the system can be established with cheaper components.

2. System Description

The established WHR system primarily consists of thermal oil, transferring engine JCW and main engine EG waste heat, the ORC, and the cooling water loop. Components in the ORC system include an ORC turbine for power generation, a condensation tank, a high-pressure pump, a low-pressure pump, a cold heat exchanger, and an evaporator. The condensation tank in the ORC system operates under vacuum conditions to enhance the thermal efficiency of the cycle. Before the system operates, the condensation tank is brought into a vacuum state with a vacuum pump, as shown in Figure 1.

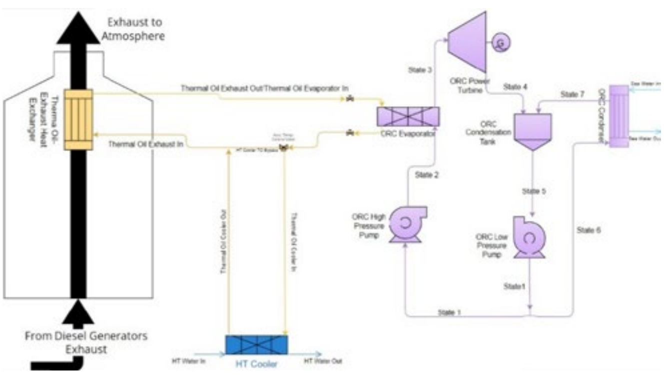

Figure 1. Model of ORC system for the marine vessel

In the evaporator, the working fluid pressurized by the high-pressure pump absorbs heat transferred from thermal oil and reaches the saturation boiling temperature. While heat transfer occurs between thermal oil and the organic working fluid, some heat losses occur due to the evaporator material. The heat loss from the evaporator was assumed to be 1% for the established ORC system. The heat transfer process was calculated with an HT water inlet temperature of 90°C, an HT water outlet temperature of 60°C, and EG temperatures that can vary depending on the main engine load values. The entrance temperature of the thermal oil to the evaporator was calculated as 200°C as given in Table 1.

Table 1. Input parameters for thermal oil waste heat source and seawater for cold heat exchanger

Input Parameters	Thermal Oil	Seawater for cold heat exchanger unit
Mass flow rate, kg/s	64,34	105
Inlet temperature	200	10
Target outlet temperature, °C	-	25
Average specific heat, kJ/kg K	1,73	4.195
Pressure, kPa	300	170
Substance	Oil	Water

The working fluid continues to be heated and becomes superheated vapor until the evaporator outlet. After the expansion process of the superheated vapor working fluid in the turbine, it separates as a mixture of saturated liquid and vapor at low pressure and temperature. Since some work loss occurs during the expansion process of the working fluid, the isentropic efficiency of the ORC turbine was assumed to be 0.80, as given in Table 2. The vacuum pressure inside the condensation tank was taken at 55 kPa, and the condensation temperature (T_{sat}) corresponds to 55 kPa for each organic working fluid. When compared to the condensation temperature corresponding to the turbine outlet pressure, the condensation temperature in the vacuum condition of the condensation tank is lower. Therefore, the condensation process at a lower temperature provides higher network output.

Table 2. Input parameters of the ORC system

Parameters	Value	Unit
The pressure of the working fluid entering the ORC evaporator	200-800	kPa
The isentropic efficiency of the ORC high-pressure pump	0.80	[−]
The isentropic efficiency of the ORC low-pressure pump	0.80	[−]
The isentropic efficiency of the ORC turbine	0.80	[−]
The heat loss from the heat exchangers	0.01	[−]

The properties of working fluids affect the energy conversion efficiency and environment greatly. It is essential to seek the suitability of working fluid for the ORC system. Wang et al.

(2018) investigated the effect of superheat degree of organic working fluids on the efficiency of the ORC system. It concludes that; If the superheat degree of dry working fluids increases, thermal efficiency rises. Furthermore, organic working fluids that are used in ORC systems must have relatively low ozone depletion potential (ODP) and low global warming potential (GWP). Therefore, they are selected as candidates in ORC, and the influences of working fluids properties on the system performance are investigated and compared. A review of the literature above shows that seven working fluids of R152a(difluoroethane), R245fa (Pentafluoropropane), R600 (butane), R1234yf (Tetrafloroehane), R134a (Tetrafluoroethane), R236fa (Hexafluoropropane), and R236ea (Hexafluoropropane) are widely used in the field of WHR for the Internal Combustion Engine (ICE)s.

Table 3. Properties of the organic working fluids

Organic working fluid	GWP[a]	ODP[b]	ASHRAE 34[c]	Critical temperature, °C	Critical pressure, kPa
Acetone	-	-	-	235	4800
Benzene		0	-	288.95	4894
Isopentane	11	0	A3	187.8	3381

[a]GWP: global warming potential, relative to CO2.
[b]ODP: ozone depletion potential, relative to R11.
[c]ASHRAE Standard 34—Refrigerant safety group classification. 1: nonflammable; 2L: mildly flammable; 2: lower flammability; 3: higher flammability; A: lower toxicity; B: higher toxicity.

3. Thermodynamic Modeling

The formulas written below are used in the thermodynamic calculations of the system. The whole cycle is considered a steady-state operating condition. The steady-state energy balance formula is used to find the enthalpy change of organic working fluids as given in Equation 1.

$$0=\dot{Q}_{CV}-\dot{W}_{CV}+\sum_i \dot{m}_{in}(h_{in}+\frac{1}{2}V_{in}^{\ 2}+gz_{in})-\sum_e \dot{m}_{out}(h_{out}+\frac{1}{2}V_{out}^{\ 2}+gz_{out}) \quad (1)$$

Turbine power is calculated as given in equation 2.

$$\dot{W}_{turbine}=\dot{m}\times\eta_{turbine}\times\left(h_{turbine,in}-h_{turbine,out}\right) \quad (2)$$

The power of the high pressure (HP) pump is calculated as given in Equation 3.

$$\dot{W}_{HPpump}=\frac{\dot{m}(h_{evap,in}-h_{HP,pump,in})}{\eta_{HPpump}} \quad (3)$$

The power of the low pressure (LP) pump is calculated as given in Equation 4.

$$\dot{W}_{LPpump}=\frac{\dot{m}(h_{LPpump,out}-h_{condenser,out})}{\eta_{LPpump}} \quad (4)$$

The net power output of the system is calculated as given in Equation 5.

$$\dot{W}_{net}=\dot{W}_{turbine}-(\dot{W}_{HPpump}+\dot{W}_{LPpump}) \quad (5)$$

The thermal efficiency of the system is calculated as given in Equation 6.

$$\eta_{th}=\frac{\dot{W}_{net}}{\dot{Q}_{ORC,evap}} \quad (6)$$

4. Result and Discussion

The formulations provided below are utilized in the thermodynamic calculations of the system. The entire cycle is considered under steady-state operating conditions. The steady-state energy balance formula is employed to determine the enthalpy change of organic working fluids, as given in Equation 1. The performance of the ORC system is significantly affected by the evaporator outlet pressure (evaporation pressure). A parametric study was conducted for various organic working fluids with low ozone depletion potential (ODP) and low global warming potential (GWP), as presented in Table 3. The thermal efficiency of the ORC system was investigated for the evaporator outlet pressure and engine load values, varying between 200 and 800 kPa and from 50% to 100%, respectively. For all candidate working fluids, the impact of evaporator outlet pressure (evaporation pressure) on thermodynamic performance was compared using parametric calculations in the system. The chosen performance parameter is the thermal efficiency of the ORC system. The maximum and minimum values for the evaporator pressure are considered 800 and 200 kPa, respectively. The engine load values are set to their maximum and minimum, which are 100% and 50%, respectively.

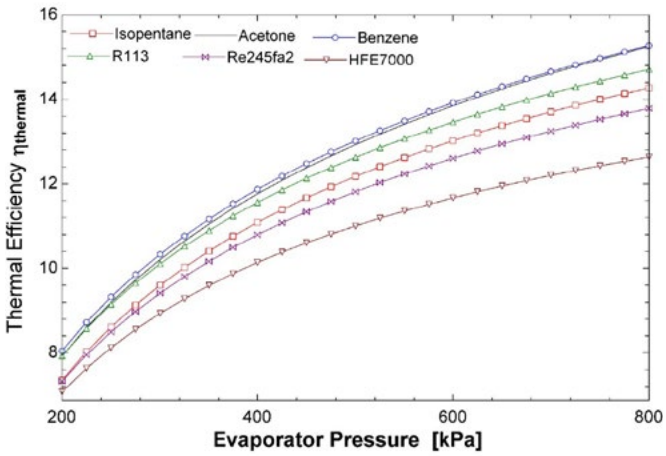

Figure 2. The effect of evaporator pressure on the thermal efficiency of the ORC (ORC) system for different ORC working fluid types

Figure 2 illustrates the effects of evaporation pressure on the system performance for the selected working fluids. With the given constant evaporation temperature, the thermal efficiency always increases as the evaporator outlet pressure (evaporation pressure) rises for all working fluids. The thermal efficiency of all working fluids continues to increase until the last value of the evaporator outlet pressure (evaporation pressure), which is 800 kPa.

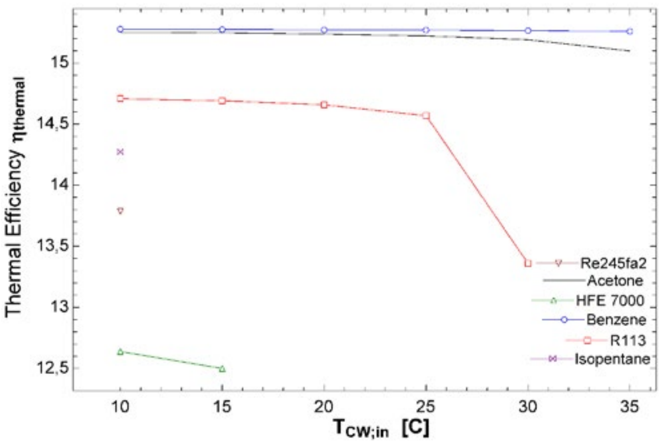

Figure 3. The effect of temperature of the sea water on the thermal efficiency of the ORC system for different working fluid types.

The variation in thermal efficiency of all working fluids according to sea water temperature values is shown in Figure 3. As observed in the graph, the thermal efficiency decreases at certain temperature values while it's higher at certain other temperature values. Among the selected organic working fluids, benzene, acetone, and R113 reach the maximum thermal efficiency in Figure 2. To operate effectively at values greater than the specified optimal evaporation temperature values for these fluids, the given evaporation temperature value should be increased. The thermal efficiencies of working fluids continue to increase for evaporator outlet pressures (evaporating pressures) until the last value of 800 kPa. The results of parametric studies show that the type of ORC working fluid has a significant effect on the performance of the ORC, as shown in Figure 2. Additionally, based on temperature values from 10 °C to 35 °C, high-pressure pump flow rate values were calculated for maximum efficiencies, as shown in Table 4. According to these calculations, it was observed that benzene achieves the highest efficiency at a high-pressure pump flow from 43.62 kg/s to 32.58 kg/s at various load values.

Table 4. The varying values of high-pressure pump flow rates for maximum efficiency values of acetone, benzene, and R113 liquids at 20C sea water temperature.

Working Fluid	Efficiency%	Load%	HP Pump Flow Rate (kg/s)
Acetone	15.24%	100%	43.62
		85%	38.19
		75%	37.12
		50%	32.58
Benzene	15.27%	100 %	50.76
		85%	44.44
		75%	43.19
		50%	37.91
R113	14.66%	100%	129.1
		85%	113
		75 %	109.9
		50%	96.42

5. Conclusions

In this project, parametric calculations for the ORC system and vacuum condition analysis of the condensation tank were conducted for WHR. Two WHR systems were used during this study. The WHR design utilized the main engine JCW temperature, main engine EG waste heat temperatures, and seawater cooling characteristics. A main engine complying with the design conditions was selected. Thermodynamic models for the ORC system were designed. The effects of evaporator outlet pressure and working fluid properties on system performance were investigated. Parametric optimization of thermal efficiency was determined for ORC system evaporator outlet pressures, high-pressure pump flow rates, and main engine loads. Suitable working fluids were selected through objective evaluations. The main results can be summarized as follows:

- For, isopentane, R113, benzene, and acetone, there exists an optimal evaporative pressure under specific input parameters. An ORC system with the optimal evaporative pressure exhibits maximum thermal efficiency. Optimal evaporative pressure ranges between 200 kPa and 800 kPa for these organic liquids.
- For all working fluids, the highest thermal efficiency was initially calculated between 200 kPa and 800 kPa, with the highest thermal efficiency determined at 800 kPa. The evaporator outlet pressure operating at 800 kPa was chosen to compare all ORC fluid types. Among the ORC fluid types, it was observed that acetone provided the best performance for the specified temperatures and operating pressures, by its thermal efficiency of 15.27%.

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Section 5

Marine Environment and Technologies

What are the Main Drivers of Sustainable Development Goals in the Maritime Industry? An analysis of Liner Shipping Companies

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Abstract

The Sustainable Development Goals (SDGs) are a broad agenda that has been agreed upon globally and aim to emphasize a wide range of sustainable development subjects. The maritime sector is a major stakeholder and makes a significant contribution to global sustainability. Relevant literature, however, demonstrates that studies pertaining to the maritime industry lack SDG research. From this vantage point, the goal of the study is to conduct a document analysis to ascertain the extent to which shipping companies consider the 17 SDGs established by the UN. The research sample comprises 29 liner shipping companies that are listed in the Alphaliner Top 100. The sustainability reports, Corporate Social Responsibility (CSR) reports and Environmental, Social, and Governance (ESG) reports of liner shipping companies that prepared according to the Global Report Initiative standard between 2018 and 2022 have been examined. The findings showed that the main goals of these companies were responsible, climate action, life below water and responsible consumption and production. The results demonstrate that the businesses have tried to achieve at least zero hunger, no poverty, and life on land. The study's conclusion is that liner shipping companies must create comprehensive policies that address every sustainable development goal.

Keywords: *SDGs, Liner Shipping Companies, Sustainability, United Nations, Maritime Industry.*

1. Introduction

Sustainable development has been one of society's main objectives, if not the sole one, since the turn of the twenty-first century. A widely accepted interpretation of sustainable development is growth that meets present needs without jeopardizing the capacity of future generations to meet their own aspirations for growth [1]. With the publication of the Earth Charter and a conference on environment and development in 1992, the United Nations (UN) projected and established an equal, sustainable, and peaceful world in the twenty-first century [2-3]. Since that time, the three pillars of sustainable development - the economic, social, and environmental dimensions - have been recognized.

Businesses are under pressure to implement sustainability practices as a result of public and institutional guidance, as sustainability gains importance for state authorities as well as private and public institutions. To achieve global sustainability, the shipping industry has been a crucial player. The shipping industry, a conventional business-to-business sector that supports global trade, is also making investments in sustainability [4-5]. The major shipping lines transport more than 3% of the global gross domestic product, while maritime transportation distributes over 80% of the world's traded goods by weight and 70% by value [6]. Apart from to the maritime transportation market's significant economic impact, there is also a notable environmental impact. The health and standard of living of coastal communities, as well as economic operations, are negatively impacted by pollution, invasive marine species, and global warming all of which are triggered by shipping activities [7]. Major challenges concerning security, health and safety, business ethics, and social responsibility are also affecting the maritime industry [8].

For the first time, a comprehensive global agenda has been agreed upon, which may inspire activities toward social, environmental, and economic sustainability in 2015 with 17 SDGs [9]. The container shipping industry is associated with each SDG by the roles of transporting semi-manufactured and manufactured goods directly relevant to people's daily lives. In this context, container shipping industry, which is essential part of maritime transportation, is in a struggle for disclose their sustainability condition precisely and correctly [10]. From this point forth, this research aims to conduct a document analysis to understand how and to what extent liner shipping companies take into account the 17 SDGs established by the UN. With the motivation of contributing to the literature gap on SDGs in maritime-related studies, this study analyzed the sustainability reports, CSR reports and ESG reports of liner shipping companies. The following section presents the SDGs concept and review of the maritime related SDGs studies. The methodology section includes the information of the sample of the study and steps in applying the document analysis. Finally, the findings are addressed concerning related studies found in the literature and suggestions for future studies are offered.

2. SDG and Maritime Industry

Since the awareness of social and environmental issues has grown, governments and individual businesses have created regulations requiring businesses to prioritize social and environmental goals in addition to financial earnings. The UN published the significant document "Transforming our world: The 2030 agenda for sustainable development" in 2015. The SDGs of the UN are an international political agenda that focus on taking collective action to create a better and more sustainable future for all. It had 169 targets and 17 SDGs. Based on the Millennium Development Goals (MDGs), the 2030 Agenda for Sustainable Development adds a new dimension to global sustainable development with its 17 SDGs, which are dedicated to addressing issues related to global development and creating favorable conditions that are crucial to global development [11-12].

Global agreement has been reached on a comprehensive agenda for the first time with the 2030 Agenda for Sustainable Development, which may inspire action toward social, environmental, and economic sustainability [9]. According to [13-14], the 17 SDGs together provide a common normative framework for players at all levels, including governments, civil society, and the private sector. Additionally, the Agenda defined the five pillars (5Ps) of people, planet, prosperity, peace, and partnership as areas of fundamental importance [15]. Numerous environmental challenges, including pollution, global warming, waste disposal, overpopulation, ocean acidification, and biodiversity loss, are included in the Agenda. In addition, there exists a broad range of social challenges, including but not limited to social exclusion, public health, age discrimination, social inequality, education, and the unequal position of women in the economy [16]. But there are significant obstacles to overcome, underscoring the significance of the interactions between individuals, sectors, and nations with varying degrees of economic growth [17]. Furthermore, it is possible to highlight the close connections that exist between the outcomes of each goal and how the accomplishment of one will affect the achievement of the others [18]. Therefore, it is important for academics to evaluate the state of SDG research because of the complexity of these interrelationships. Table 1 illustrates the UN SDGs with 5Ps classifications.

Table 1. UN SDGs with 5Ps [15].

Goal	Title	Targets	Indicators	5Ps Classification
1	"No poverty"	7	13	People
2	"Zero hunger"	8	13	People
3	"Good health and well-being"	13	28	People
4	"Quality education"	10	12	People
5	"Gender equality"	9	14	People
6	"Clean water and sanitation"	8	11	People, Planet
7	"Affordable and clean energy"	5	6	Prosperity, Planet
8	"Decent work and economic growth"	12	16	Prosperity, people
9	"Industry, innovation and infrastructure"	8	12	Prosperity
10	"Reducing inequalities"	10	14	Prosperity, people
11	"Sustainable cities and communities"	10	15	Prosperity
12	"Responsible consumption and production"	11	13	Planet
13	"Climate action"	5	8	Planet
14	"Life below water"	10	10	Planet
15	"Life on land"	12	14	Planet
16	"Peace, justice, and strong institutions"	12	14	Peace
17	"Partnerships for the goals"	16	24	Partnership

The collaboration of numerous stakeholders, including governmental and business sectors, will be necessary to achieve the SDGs. As a result, all organizations should take steps to help achieve the SDGs [19-20]. The negative environmental, social and negative impacts might be enormous in the maritime industry [21]. Therefore, the maritime industry needs to accurately and completely declare its sustainability status [10]. Container shipping companies, which is essential part of maritime transportation highlight this issue in their annual reports or sustainability reports to boast about their sustainability achievements. In this context, container shipping companies clearly include information about their sustainability status in their regularly published reports and focus on the comments of their stakeholders.

The existing literature on the sustainability of maritime transportation has mainly focused on the goals, crucial success variables, and the connection between sustainability and corporate performance [7-22]. Researchers have recently become interested in stakeholder management and sustainability disclosure in the maritime sector. For example, social media has been used to study stakeholder engagement in container shipping [23]. Also, the significance of fostering sustainable business practices and involving stakeholder participation in environmentally friendly maritime transportation by [24]. Moreover, [25] investigated sustainability reports from the Mediterranean Shipping Company (MSC) and A.P. Moller-Maersk (Maersk) and found that "social inclusion," "protection of the environment," "occupational health & safety," and "business ethics and protection of human rights" are the four pillars of MSC's sustainability system. "Support to decarbonize logistics," "help to halving food loss," "support multiply the benefits of trade," and "address change in the ship recycling industry" are the four sustainability precedence of Maersk. Furthermore, the maritime industry's potential to meet SDGs was investigated through a content analysis of sustainability reports from container shipping companies and terminal operators by [26]. Additionally, [10] used a text-mining approach to investigate the sustainability disclosure framework of the container shipping industry. The findings emphasize three main dimensions: sustainable business management, sustainable employee training and management, and sustainable shipping operations. Lastly, [27] conducted comprehensive literature review to provide an extensive overview of the SDGs in maritime transport and aims to connect each of the reviewed articles to the SDGs. The findings show that the SDGs—which address "gender equality", "climate action", and "life below water"—are widely implemented in the maritime transportation sector.

3. Methodology

The purpose of the study was to ascertain how much international shipping companies consider the UN Sustainable Development Goals. In this context, among the liner shipping companies published by Alphaliner top 100 on November 20, 2023, those with sustainability reports, CSR reports and

ESG reports prepared according to the GRI (Global Report Initiative) standard between 2018 and 2022 were examined. The sample of the study consists of 29 liner shipping companies. The companies in the sample and the years in which their reports were published are displayed in Table 2. Over a five-year period, a total of 101 reports were reviewed.

Table 2. Research Sample (1/2).

Company (n = 29)	2018	2019	2020	2021	2022
MSC	-	-	√	√	√
MAERSK	√	√	√	√	√
CMA CGM	√	√	√	√	√
COSCO	√	√	√	√	√
HAPAG	√	√	√	√	√
ONE	√	√	√	√	√
EVERGREEN	√	√	√	√	√
DEL MONTE	√	√	√	√	-
SAMSKIP	-	-	-	√	-
NEPTUNE	-	-	-	√	-
PAN OCEAN	-	-	-	-	√
BOLUDA	-	-	√	√	√
TRANSWORD	-	-	-	-	√
CROWLEY	-	-	-	√	√

Table 2. Research Sample (2/2).

Company (n = 29)	2018	2019	2020	2021	2022
DOLE	-	-	√	-	√
EIMSKIP	√	√	√	√	√
MERATUS	-	-	-	-	√
SİNOTRANS	√	√	√	√	√
SAMUDERA	√	√	√	√	√
GRIMALDI	-	-	-	√	√
MATSON	√	√	√	√	√
SWIRE	√	√	√	√	√
ZHONGGU	-	-	-	√	√
X-PRESS	-	-	√	√	√
SITC	-	-	-	√	√
PIL	-	-	-	√	√
ZIM	√	√	√	√	√
YANG MING	√	√	√	-	-
WAN HAI	√	√	√	√	-
HMM	-	√	√	√	√
NUMBER OF REPORTS	15	16	20	25	25

One qualitative research method used in the study was document analysis, which is how data were gathered. Qualitative research is more in-depth and comprehensible than quantitative research in that it aims to answer questions about an event, a person, or a phenomenon, including how and why, rather than quantifying attributes like quantity, average, and number [28]. The document review process developed by [29] was adapted to this study as follows[29]:

1. Choosing a research topic, approach, and technique (document selection, access, and restriction): The study's data comes from corporate social responsibility, sustainability, and environmental reports that businesses post on their websites.

2. Ensuring the documents' authenticity by trying to comprehend them and reading them carefully and thoroughly: The UN's 17 SDGs served as a framework for analyzing the reports.

3. Content Analysis: The 17 SDGs were used to determine categories and themes. The categories and themes are coded based on whether or not they are mentioned in reports on environmental management or sustainability.

4. Evaluating documents using the data and deciphering the study's findings: Code frequency analysis was performed after the themes and categories were coded. The outputs in Table 3 are displayed in a table along with percentages and frequencies.

4. Findings and Discussion

The studies and strategies used by liner shipping companies to develop SDGs were evaluated annually and by company, using the 17 SDGs as a basis. The SDGs that companies include in their reports are given as frequency and percentage values. The frequency value provides information on how many companies mentioned the target on a yearly basis. Percentage values according to the total number of reports on a yearly basis are given in Table 3.

"SDG 1 - No Poverty", goal's is to eradicate poverty worldwide in all of its manifestations. SDG 1 was mentioned in 27% of liner shipping companies' 2018 reports that were examined. It can be observed that in 2020, this percentage rose to 40%. Upon analysis of the results, it becomes evident that liner shipping companies have few strategies or give this UN-developed target little weight. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- Cosco works to build relationships with the community, encourage social harmony, and actively participate in community initiatives like street volunteers, poverty alleviation, and other philanthropic programs. Cosco invested RMB8.87 million 3 in initiatives aimed at reducing poverty. 2018: Put specific measures for reducing poverty into action (Yongde Country)
- Del Monte: By 2025, assist with their surrounding areas' green economic recovery from COVID-19. The GIZ Project increased activity, and the El Tigre Reserve Project persisted.

- Dole: Measure business multi-dimensional poverty by 2030 to help alleviate household poverty and have an impact on at least 20,000 individuals in Dole Latin America (Guatemala, Honduras, Costa Rica, and Ecuador) by 2040.
- X-Press: Their social commitment to the community is to support the education of the most marginalized impoverished children in order to provide them a better future. More than 5 million people have left Ukraine for other nations since the crisis began, and an additional 6 million are thought to be internally displaced. The residents' humanitarian needs are drastically increasing.
- Wan Hai has always been worried about the weaker segments of society. The Wan Hai Charity Foundation has established several initiatives, including the "Education Grant Project" and the "Emergency Relief Project." In recent years, they have also increased their donation to Africa.
- Neptune: The Social Welfare Company 'SYN-ENOSIS' was founded by the Union of Greek Shipowners members. Neptune Lines has been in favor of SYN-ENOSIS since its founding. They support its diverse efforts to provide effective relief to those in need throughout Greece through their corporate membership.

The examples show that 27% of liner shipping companies create plans to combat and prevent poverty in specific areas. Additionally, these businesses donate to charities, projects, and funds that support efforts aimed at preventing poverty.

"SDG 2 - Zero Hunger", goal's objectives are to end hunger, achieve food security, improve nutrition, and advance sustainable agriculture. Studying the liner shipping companies' 2018 reports, we found that 13% of them mentioned SDG 2. It can be observed that in 2021, this percentage will rise to 16%. Upon analysis of the results, it becomes evident that liner shipping companies have few strategies or give this UN-developed target little weight. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- HMM: Assistance with the international delivery of aid to the Philippines, Jordan Kimchi Sharing Event, and one-on-one sisterhood relationships with children living abroad.
- Two international alliances were formed by Maersk to target weak places in the food supply chain.
- CMA-CGM: Annas Linnas: purchase of a school bus to enable Syrian refugee children in the area to attend school and engage in recreational and athletic endeavors. Food assistance will also be distributed via this bus.
- Crowley's employees at Crowley utilized their qualified vacation time (VTO) during the program's inaugural year to volunteer for groups like the USO, K9 For Warriors, Habitat for Humanity, and many food banks.
- Matson funds hunger relief and food bank initiatives to build stronger communities.
- X-Press Feeders is contributing to the situation by helping the refugees in Poland. Coworkers from the Southampton, Hamburg, and Barcelona offices brought essentials to their respective offices, including personal care products, long-term meals, and medical aid.

Table 3. Findings of the Study (2/2)

	"SDG 1: No Poverty"		*"SDG 2: Zero Hunger"*		*"SDG 3: Good Health and Well-Being"*		*"SDG 4: Quality Education"*		*"SDG 5: Gender Equality"*		*"SDG 6: Clean Water and Sanitation"*		*"SDG 7: Affordable and Clean Energy"*		*"SDG 8: Decent Work and Economic Growth"*		*"SDG 9: Industry, Innovation, and Infrastructure"*		*"SDG 10: Reduced Inequalities"*	
Year	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
2018	4	27%	2	13%	11	73%	9	60%	8	53%	11	73%	11	73%	7	47%	8	53%	7	47%
2019	4	25%	2	13%	14	86%	12	75%	10	63%	10	63%	10	63%	8	50%	8	50%	8	50%
2020	5	25%	3	15%	15	75%	12	60%	14	70%	6	30%	12	60%	9	45%	10	50%	11	55%
2021	10	40%	2	8%	17	68%	17	68%	15	60%	11	44%	17	68%	21	84%	17	68%	9	36%
2022	4	16%	4	16%	16	64%	16	64%	14	56%	11	44%	16	64%	17	68%	14	56%	13	52%
Total	27	27%	13	13%	73	73%	66	66%	61	61%	49	49%	66	66%	62	62%	57	57%	48	48%

Table 3. Findings of the Study (2/2).

	"SDG 11: Sustainable Cities and Communities"		"SDG 12: Responsible Consumption and Production "		"SDG 13: Climate Action"		"SDG 14: Life Below Water"		"SDG 15: Life on Land "		"SDG 16: Peace, Justice, and Strong Institutions"		"SDG 17: Partnerships for the Goals"		Number of Firms
Year	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N
2018	7	47%	10	67%	11	73%	12	80%	8	53%	4	27%	11	73%	15
2019	6	38%	13	81%	12	75%	13	81%	7	44%	6	38%	12	75%	16
2020	5	25%	17	85%	20	100%	17	85%	4	20%	12	60%	15	75%	20
2021	11	44%	19	76%	25	100%	22	88%	9	36%	10	40%	15	60%	25
2022	10	40%	16	64%	25	100%	22	88%	9	36%	12	48%	16	64%	25
Total	39	39%	75	75%	93	93%	86	86%	37	37%	44	44%	69	69%	101

Food loss is a topic that is appropriately at the center of the shipping industries social and economic agendas, despite the fact that food and the shipping industry are unrelated [26]. A 5-year analysis of liner shipping companies' data reveals that 13% of the sample's businesses engage in food safety and hunger prevention initiatives, often with the assistance and collaboration of their local community's similar to [26].

"SDG 3 - Good Health and Well-Being", objectives of this goal are to guarantee healthy lives for all people and to promote wellbeing at all ages. In order to accomplish SDG 3, shipping companies have typically created targets. With an 86% mention rate, 2019 was the year this issue was brought up the most. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- HMM is implementing a comprehensive health check-up system, lighting children - solar lantern support, America Headquarters Dallas Heart Walk Event, and enhancing the health monitoring of offshore personnel.
- MSC aspires to lead the global recovery from pandemics since they think this is the only path to a "healthy planet with healthy people." The MSC Foundation never stopped working to help underprivileged children and adults. In partnership with the Andrea Bocelli Foundation, it supported healthcare for over 4,000 direct beneficiaries in Haiti and made it possible for over 3,000 severely malnourished children in Malawi to receive life-saving treatment.
- Cosco says, "Prosperity for all is impossible without health for all." Poor health and medical issues are a common problem in impoverished places. They participated in the "Kindness Project Hearing Aid Action" in 2019 and gave hearing aids to Yiyang City, Anhua County, Yuanling County, and Yongde County in the province of Hunan, as well as training for hearing aid specialists and hearing checks.
- Pan Ocean: The proliferation of contagious illnesses and the application of the Serious Accident Punishment Act underscore the escalating apprehensions regarding health and safety.
- Swire: By ensuring the health and safety of all of their workers and stakeholders and by fostering continuous safety excellence, CNCo prioritizes reducing the negative impact on SDG 3.
- Zhonggu: Establish a robust internal safety management framework, an occupational health assurance system, and a range of safety and health training programs in order to increase employee awareness of safety.
- SITC: Case: In order to visit children in foster families, SITC Container Lines Thailand's staff members raised money and purchased essentials.
- Neptune Lines has been supporting Axion Hellas since 2017. It is a non-profit, nongovernmental organization that is solely funded by its members, the people who participate in its actions and missions, as well as through donations from businesses and individuals. Axion Hellas is an initiative based on collective action with the goal of supporting society and especially communities in remote and inaccessible areas of Greek islands and the mainland.

Well-being and leading a healthy lifestyle are important to 73% of the sampled companies. Examining the implemented practices revealed that attempts were made to guarantee a healthy lifestyle for both employees and residents of particular areas. Applications typically involve social responsibility initiatives concerning children's unhealthy eating habits. It is evident from this context that they collaborate with non-governmental groups.

"SDG 4 - Quality Education", ensuring inclusive, equitable, high-quality education and promoting opportunities for lifelong learning for all are the objectives of this endeavor. In general, the businesses in the sample have created plans and procedures with the aim of achieving high-quality education. The topic of high-quality education was brought up in 75% of the reports published in 2019. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- Wan Hai offers programs for higher education and educational subsidies, spanning employee and employee-child scholarships. In addition, the Wan Hai Charity Foundation's "Hot Air Balloon Launching Project" provides long-term assistance for rural children' education.
- HMM operates a Company-wide talent training system and career development program.
- A bus was bought as part of the CMA-CGM initiative to transport Syrian refugee children from school to their destination and back, enabling them to take part in recreational and athletic events. Food help will also be distributed via this bus.
- Hapag Lloyd offer inclusive, egalitarian, high-quality education that encourages possibilities for lifelong learning for all. It provides a variety of training and continuing education opportunities to its workforce, including global staff development initiatives including's Talent Development Program (TDP) and the Agile Leadership Program (ALPHA).
- Evergreen provides thorough training for both onshore and onboard staff, as well as promoting marine education. With equal career possibilities, the company is constantly seeking new individuals to provide vitality and excitement to their team.
- Zhonggu create a framework of diverse talent cultivation to assist staff in enhancing their skills and worth as professionals.
- SITC successfully held Shandong Foreign Trade Vocational College's "SITC Class" graduation ceremony and "SITC Scholarship" awarding event.
- Neptune provides maritime education with the capabilities to enhance the caliber of cadet instruction while also upgrading the technological apparatus and infrastructure of the Merchant Marine Academies.

It can be observed that 66% of the sample companies create practices, activities, and team up with one another in order to provide high-quality education. Because of the nature of the industry, it is evident when we examine the practices in this context that maritime education is the primary focus. Both an internal and external analysis can be conducted on quality training practices independently. It is evident that the majority of the sampled companies collaborate with educational institutions and create internal strategies and practices similar to SDG 4.

"SDG 5 - Gender Equality", SDG 5 aims to empower all women and girls and attain gender equality. By 2020, 70% of businesses would have expressed interest in adopting gender equality policies and practices, compared to 53% in 2018. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- In accordance with the "Act of Gender Equality in Employment," Wan Hai established a system for reporting and stopping sexual harassment in addition to fostering an equitable work environment.
- HMM contributes to the strengthening of the social assistance system for the protection of motherhood, the prohibition of discrimination by creating a Human Rights Management policy, and the internalization of human rights awareness (human rights education, campaigns, etc.).
- D&I culture will be ingrained in all business processes at Swire. They will make an investment in their staff members and provide them the know-how and tools they need to thrive in their current and future environments. They'll make sure that CNCo upholds labor laws and enforces anti-modern slavery policies in their supply chains and operations.
- Zhonggu encourages workplace equity and offers equal development chances and platforms to both male and female employees.
- Transworld is committed to creating and maintaining a welcoming work environment by prohibiting harassment and discrimination on the basis of gender. Transworld seeks recourse and restitution for cases of sexual harassment in complete compliance with the Sexual Harassment of Women at Workplace (Prevention, Prohibition and Redressal) Act, 2013.

Reports from 61% of the sampled companies contained gender equality strategies and practices. Examining the practices brings to light concerns about harassment and discrimination, human rights awareness, equal employment, and a fair workplace. Automation technology has a rapidly increasing impact on the maritime industry, especially the employment of female seafarers [33].

"SDG 6- Clean Water and Sanitation", SDG 6 seeks to guarantee that everyone has access to and sustainable management of water and sanitation. Looking at the reports, we find that the issue of clean water was mentioned in 73% of them in 2018, a number that has been declining annually.

- Wan Hai assists Africa in drilling wells to reduce the amount of contaminated effluent that escapes and ensure that everyone has access to clean water.
- Washwater Filtration (WWF) systems have been installed on the Grimaldi Euromed-owned Cruise Barcelona, Cruise Roma, Cruise Smeralda, Cruise Ausonia, and Cruise Bonaria ro-pax ships in order to further protect the maritime environment. With a specific filter for polycyclic aromatic hydrocarbons, these devices can be activated in territorial waters and during maneuvers to enhance the quality of scrubber treatment water.
- To improve the scientific and coordinated administration of the Company's water-related projects, Zhonggu develops the Water Resources Administration Plan for Ships as well as other guidelines and policies.
- By switching to filtered water from bottle water in the United Arab Emirates, Transworld was able to lower its carbon footprint by 21.06 tons.
- Dole conducts water risk assessments and implements improved water practices in high-risk areas of its farms, packaging, and processing facilities.

49% of companies mentioned regional clean water needs, water filtration, management plans and improved water practices related to SDG 6.

"SDG 7 - Affordable and Clean Energy", SDG 7 aims to guarantee that everyone has access to modern, affordable, dependable, and sustainable energy. An average of 66% of the sampled companies included practices and projects in their reports to help them reach this goal. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- By implementing the Ship Energy Efficiency Management Plan (SEEMP), adhering to CII and EEXI rules, and increasing investment in environmentally friendly facilities, HMM promotes SDG 7.
- Wan Hai takes a practical approach to creating renewable energy sources and increasing the effectiveness of current machinery. Solar panels are installed at the exclusive ports, and outdated reefer containers are gradually replaced.
- In order to lower oil consumption and carbon emissions, Evergreen outfits ships with air lubrication systems (ALS), the newest low-friction and anti-fouling coating, and alternative maritime power (AMP).
- Swire is going to maximize energy efficiency and decarbonize. They will push for a reasonable carbon price to incentivize the required behavioral adjustments.
- In compliance with national environmental regulations, Zhonggu uses premium gasoline for all of its own ships, and it consistently lowers ship fuel use.
- Underlying goals to which ONE makes a contribution (7.2) Increase the proportion of renewable energy in the world's energy mix significantly by 2030. They are creating a roadmap for alternative fuels to replace traditional marine fuels as part of their green strategy.
- X-Press Feeders is utilized Retrofit initiative in 2023, they plan to implement a retrofit program that includes installing variable frequency drives (VFDs) on four vessels.

The sample companies are striving to meet their targets for "Affordable and Clean Energy" by addressing topics like ship fuel consumption, port panels, air lubrication systems, energy efficiency similar to [26], and green strategy.

"SDG 8 - Decent Work and Economic Growth", goal's is in favor of equitable employment opportunities, steady, inclusive economic growth, and full and productive employment for all. Upon examining the sample companies, it is evident that in 2021, this issue has gained more importance. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- Wan Hai actively broadens the scope of their business and offers superior services to foster socioeconomic development.
- HMM, which is currently rated as the eighth-best container shipping firm in the world (2021), has formed a joint venture (JV) in order to expand into the container storage and shipping industries.
- CMA CGM: To identify potential discriminatory practices and to organize team activities to advance diversity and inclusion, C-Box Diversity was introduced. A C-Box is a facilitation kit that gives teams the tools they need to solve a particular problem. Any employee can lead a session in complete autonomy for up to three hours with the materials in the box.
- D&I culture will be ingrained in all business processes at Swire. They'll make sure that CNCo upholds labor laws and mandates compliance with anti-modern slavery regulations in their supply chains and operations.
- Zhonggu establishes and enhances its internal benefit and compensation plan based on workers' performance and competencies while taking market rates into account.
- In order to enhance safety performance and advance the company's work-life balance policy, Zim implements preventive actions.
- X-Press Feeders actively encourages all employees to maintain a healthy work-life balance and takes proactive measures to guarantee that their employees achieve that balance.

SDG 8-related strategies and practices have been adopted by 62% of the sampled companies. Businesses typically focus on work-life balance, competency-based pay, regulating working hours, and promoting socioeconomic development similar to [26].

"SDG 9 - Industry, Innovation, and Infrastructure", SDG 9 encourages innovation, inclusive and sustainable industrialization, and the development of robust infrastructure. On average, 57% of businesses create policies and procedures in this area. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- HMM is supporting Myanmar with humanitarian cash and expedited shipping of COVID-19 medical supplies (Oxygen Station Donation Programme) to India.
- Zhonggu increases R&D spending while promoting the shift to digital shipping with a focus on informatization, digitalization, and intellectualization.
- In collaboration with the Shanghai Maritime University College of Information Engineering, SITC developed software, bringing practical project training into the classroom and advancing the information architecture of higher education institutions.
- Initiatives for maritime decarbonization are supported by ONE both within and outside of their own business. In addition to alternative fuels, ONE is investigating carbon capture and storage (CCUS) technology as a means of lowering emissions from their fleets.
- Zim makes business easier with creative digital solutions and streamlined procedures.

Because of the nature of the maritime industry, the companies in the sample place a high value on innovation. It addresses topics like rising R&D costs, initiatives, apps, software, digital transportation, environmental sustainability-related technologies, and digital solutions in this context similar to [26]. A business model centered on top-notch infrastructure promoting economic development and investment in R&D in developing countries needs to be put forth in order to effectively support SDG 9 [31].

"SDG 10 - Reduced Inequalities", half of the sample's maritime companies were interested in SDG 10, which aims to lessen inequality both within and between nations, and they concentrated on this problem. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- HMM and the Korea SMEs and Startups Agency inked a "Business agreement for long-term transportation support for small and medium-sized exporters" in April 2021.
- Swire will invest in its personnel and teach them the information and skills they need to succeed in their current and future environments. They will also instill a D&I culture throughout all business activities.
- Zhonggu aspires to the distribution rationality I employee gender, age, and region by fostering a varied and equitable work environment where all employees have fair and equal employment chances.
- Transworld Group is committed to providing equal job opportunities and is a firm believer in just and fair labor practices. As a global shipping firm, they currently employ a diverse staff at all levels, representing over 15 different countries.

The companies in the sample conducted studies, presentations, and startups across various nations in order to accomplish the goal.

"SDG 11 - Sustainable Cities and Communities" which aims to make human settlements and cities inclusive, safe, resilient, and sustainable, was covered in the reports of 39% of the sampled companies. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- HMM's assistance with the international delivery of humanitarian supplies to the Philippines and Jordan, as well as the renovation and relocation of office buildings (July 2022).

- Zhonggu is actively putting the "shipping loose cargo via containers" idea into practice and accelerating the development of sustainable communities.
- By uniting local communities, easing access to a worldwide market, and assisting clients through robust and disruption-free supply chains, MSC is in a unique position to create value.
- Del Monte's strategy is centered on teamwork; to optimize the results of their endeavors, they collaborate with nearby community-based NGOs and governmental entities.
- A key strategic goal of the Grimaldi Group has always been to distribute value locally, including through donations of community infrastructure.

The sample companies concentrate on building renovations, delivering humanitarian supplies, promoting sustainable community development, providing local communities with market access, and donating social infrastructure abroad.

"SDG 12 - Responsible Consumption and Production" is to ensure sustainable patterns of production and consumption; 75% of the sampled companies have included this goal in their reports. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- Studies like the revision of the sustainable procurement policy, the growth of the ESG sector through the amendment of the common standard contract's terms, and the implementation of the e-Service restructuring project have all been conducted by HMM. Furthermore, the business was granted the 'Participation Award' in the 2021 Korea Ocean Business Corporation-hosted Excellent Case Competition for Win-Win Cooperation between Shippers and Ship Owners.
- Through ethical and responsible purchasing of goods and services, Swire will enhance its supply chain and develop, operate, and transfer its assets in a sustainable manner.
- To protect the rights and interests of customers, Zhonggu established a reliable system for shipping services and container management.

To accomplish SDG 12, the sample companies concentrated on topics like win-win cooperation, ethical purchasing, and customer rights and interests similar to [26].

"SDG 13 - Climate Action", 93% of businesses have acted quickly to mitigate the effects of climate change. In 2020, 2021 and 2022, all companies in the sample set targets in connection with SDG 13. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- A Fleet Efficiency Management Team has been established by Wan Hai to carry out different energy-saving and carbon-reduction initiatives.
- HMM operates and takes part in the CDP Climate Change information disclosure Evergreen Ship Energy Efficiency Monitoring System
- Swire will promote a reasonable carbon pricing to incentivize the required behavioral adjustments, decarbonize, and maximize energy efficiency.
- Zhonggu builds green ships and strictly complies with emission regulations from different nations and areas to minimize emissions of hazardous and greenhouse gases.
- ONE's goal to lead the shipping industry in decarbonization is very clear. They pledged to achieve net zero emissions by 2050 and signed the Call to Action for Shipping Decarbonization in 2021.
- Zim's rigorous adherence to the global ship fuel sulfur quota of 0.5% and the NOx emission standards
- Samskip's goal is to drastically cut CO2 emissions by using renewable and alternative fuel-powered vessels and an inventive approach to ongoing research and development.

The sample companies have experience with topics like energy efficiency management for fleets similar to [26], decarbonization, zero emissions similar to [34], ship energy efficiency monitoring systems, and climate change disclosures.

"SDG 14 - Life below Water" which aims to safeguard and use oceans, seas, and marine resources sustainably for sustainable development—has drawn the interest of 86% of maritime companies. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- Wan Hai is responsible for safeguarding aquatic life as part of her role as a front-line ocean navigator. Wan Hai is actively reacting to international initiatives to safeguard life below the water, in addition to implementing the ships' waste management and ballast water management plans.
- Grimaldi promote the protection of biodiversity with Life Conceptu Maris, Oceanpod and Marevivo projects.
- Evergreen is involved in global initiatives, such as the commitment to refrain from using Artric shipping routes and to slow down vessels in order to preserve whale populations. The proclamation from Buckingham Palace was likewise signed by the Company.
- ONE is dedicated to safeguarding the oceans from pollution resulting from unintentional spills and operating emissions. In order to avoid detrimental effects on marine ecosystems, they collaborate closely with ship-owners to ensure adherence to international conventions on ballast water management, anti-fouling systems, and effluent discharge. This is done in accordance with their strict Vessel Quality Standard (VQS).
- Zim participates in the ECHO program to lessen marine pollution and the harmful environmental effects of vessel operating, as well as preventive actions to minimize the threat that shipping poses to whales.
- In order to avoid the ocean echo system from becoming unbalanced, Yang Ming has installed ballast water treatment systems (BWT) on 11 of its own vessels. These systems remove all plankton from the water.
- Meratus strives for biodiversity conservation with several partners as Komunitas Penjaga Laut, Sambangan Coral Guardian, and Carbon Ethic.

Businesses implement programs and initiatives to safeguard undersea life, manage waste similar to [32], control ballast water similar to [31], safeguard the population of marine life, lessen marine pollution similar to [35], and collaborate to meet ship quality requirements, lessen environmental effects, and variation of biodiversity similar to [13].

"SDG 15 - Life on Land", the goal of SDG 15 is to safeguard, replenish, and encourage the sustainable use of terrestrial ecosystems. Additionally, it aims to accomplish objectives like managing forests sustainably, preventing desertification, stopping the loss of biodiversity and stopping the degradation of land. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- For the crops and farming activities it owns, Dole creates a framework for sustainable farming.
- MSC connects African farmers and small businesses to global markets by transporting a variety of commodities, including cotton, cocoa, tea, coffee, and cacao, which are important contributors to national and regional GDP. This ensures the businesses' continued operations amid the disturbances.
- Scientists and researchers at Del Monte are assiduously striving to advance and discover new farming techniques that will maximize their harvests while safeguarding and maintaining their growing areas. They center on how they might use technology, such as drones and smart farming, to advance the circular economy on their farms.

The businesses in the sample concentrated on issues related to ecosystems, such as new agricultural techniques, smart agricultural technologies, crop cultivation areas and productivity increase, support for farmers and small businesses, product diversification for regional economic contribution, and sustainable agricultural practices.

"SDG 16 - Peace, Justice, and Strong Institutions", 44% of maritime companies guarantee that everyone has access to justice, encourage inclusive and peaceful societies for sustainable development, and create inclusive, accountable, and productive institutions at all levels. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- Human rights impact assessment plans are carried out by HMM, which also prepares the questionnaire for the assessment.
- Swire aims to enhance its supply chain by procuring services and products from ethical and responsible sources.
- To strengthen the basis for sustainable development, Zhonggu enhances corporate governance, fortifies anti-fraud management, promotes supplier integrity, and engages in anti-corruption public relations.
- Neptune's moral operations support the sub-target "to significantly reduce corruption and bribery in all their forms" as well as the main objective of "Promoting, peace, justice, and strong institutions."
- Matson expanded their caring for Alaska program, which awards grants to eligible nonprofits that arrange and carry out clean-up, rehabilitation and infrastructure improvement projects in Anchorage, Kodiak and Unalaska.

The companies in the sample conduct research on topics like plans for human rights impact assessments, moral supply chain conduct, corporate governance, drug and pirate attacks similar to [36] and the battle against fraud and corruption similar to [26], and infrastructure development initiatives.

"SDG 17: Partnership for the Goals", 69% of businesses collaborate in an effort to fortify implementation instruments and resurrect the Global Partnership for Sustainable Development. The strategies and practices used by companies to achieve the relevant target are outlined below with examples:

- An organization requires partners in the age of globalization in order to maximize its influence. In both business and public welfare, Wan Hai collaborates with partners that share her values.
- Ballast water management strategies are established and approved by HMM for implementation.
- CMA CGM has made the decision to join and support this effort by partnering with the Marseille school.
- In order to advance sustainability-related issues, Zim collaborates with stakeholders to support local initiatives in agencies and operating sites around the globe. It also forges alliances and partnerships with peers to support the development and improvement of sector-specific issues.
- Grimaldi collaborates with Life Conceptu Maris, Oceanpod and Marevivo projects.

According to [26] and [30], the maritime sector is actively working with other chain participants to accomplish sustainability objectives.

Examining the 17 SDGs, it is evident that 93% of the companies in the sample implement strategies, practices, and projects related to "climate action" (SDG 13). "Life below water" (SDG 14), "responsible consumption and production" (SDG 12), "good health and well-being" (SDG 3), "partnerships for the goals" (SDG 17), "quality education" (SDG 4), and "affordable and clean energy" (SDG 7) can be seen to follow these. It is evident that the reports give the least attention to the following sustainable development goals: "zero hunger" (SDG 2), "no poverty" (SDG 1), "life on land" (SDG 15), "sustainable cities and communities" (SDG 11), "peace, justice and strong institutions" (SDG 16), and "reduced inequalities" (SDG 10). It appears that over 50% of the sample has created plans, procedures, and initiatives pertaining to SDGs "decent work and economic growth" (SDG 8), "gender equality" (SDG 5), and "industry, innovation and infrastructure" (SDG 9). In contrast to the study by [26], the study carried out using Alphaliner 2019 top container liners and analyzing 56 reports reveals that SDG 8, 9, and 11 are the most frequently met goals. SDGs 1, 2, and 5 are mentioned at a rate of less than 1%, as can be observed. In the study analyzed by [31], the sustainable development goals were identified with the following: SDG 11, 12, 8, 7, 6, 3, 15 and 17.

5. Conclusion

Since the turn of the twenty-first century, one of society's primary goals, if not the only one, has been sustainable development. Sustainable development is generally understood to mean growth that satisfies current needs without endangering the ability of future generations to fulfill their own growth ambitions. Governments and individual companies have developed regulations requiring businesses to prioritize social and environmental goals in addition to financial earnings as awareness of social and environmental issues has grown. The important document "Transforming our world: The 2030 agenda for sustainable development" was released by the UN in 2015.The maritime sector is interested in the topic of sustainable development. In this regard, businesses incorporate the UN-published SDGs into their sustainability reports.

Finding out how much international shipping companies take into account the UN SDGs was the aim of the study. In this regard, the liner shipping companies that had sustainability reports, CSR reports, and ESG reports prepared in accordance with the GRI standard between 2018 and 2022 were scrutinized. These companies were determined by the Alphaliner Top 100 list published on November 20, 2023. There are 29 liner shipping companies in the study's sample. 101 reports were reviewed in total over a five-year period.

It is clear from looking at the 17 SDGs that 93% of the sampled companies carry out policies, procedures, and initiatives about climate action. Liner shipping companies have an effort in decarbonization, zero emissions, ship energy efficiency monitoring systems, energy efficiency management for fleets, and "climate change" disclosures. These can be seen as following "life below the water", "responsible consumption and production", "good health and well-being", collaboration for the goals, high-quality education, and accessible, clean energy. It is thought that these efforts of liner shipping companies will continue to increase in line with the strict practices of IMO (International Maritime Organization) and other international rule-makers on reducing emissions from maritime transportation.

"Zero hunger", "no poverty", "life on land", "sustainable cities and communities", "peace, justice, and strong institutions", and decreased inequality are clearly the goals that receive the least attention from the reports. These subjects receive little attention because it is believed that they have no direct bearing on the maritime sector. Liner shipping companies are paying greater attention to marine and marine-related matters. For example, liner shipping companies' missions, education strategies, practices, and projects focus on maritime education. However, in the future, it is expected that liner shipping companies will pay more attention to these issues with the social responsibility projects that are given more and more importance.

The importance of the SDGs in creating a sustainable maritime industry is persuasively demonstrated by this study. With thorough examples and a cohesive framework, this study presents the prominent liner shipping companies' sustainability planning strategies, practices, and projects. Also, it provides a perspective on how each of the SDGs is being implemented for maritime literature. In addition, the study conducts an international analysis instead of a regional perspective, which provides a more comprehensive view for the relevant literature. It is thought that the obtained results will be useful for policy makers in the maritime industry. Moreover, it is thought that this study will be beneficial as it contributes to the relevant literature by identifying the prominent SDGs and reveals the areas that should be focused on for academics who want to work in this field. However, it is important to point out the study's limitations. Various comparisons can be made within the framework of a wider sample by including maritime transportation types other than liner shipping in the sample. Also, published official reports other than Sustainability, CSR and ESG reports, website contents and social media posts can also be analyzed within the scope of SDGs. Lastly, apart from content analysis, various analyzes can be made using different quantitative and qualitative methods and the results can be compared.

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Maritime Sustainability Plan in Shipyards

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Abstract

The life cycle of ships consists of construction, operation, maintenance and disposal phases. With the addition of new technologies, the impact of the operation phase of the ships, which has the greatest impact on climate change, has decreased, but the impact of shipyards on the climate, where the construction, maintenance and disposal phases are carried out, is economical. Shipyards are metal-intensive open production areas with intense energy consumption and thousands of inventories. In order to efficiently use the resources used in these areas, it has become mandatory to conduct digital monitoring of objects and process, energy management, lean production and carbon footprint measurement studies in shipyards. In this way, it is possible to create a sustainable process in shipbuilding in a shorter time and with fewer resources, with higher quality ships and more environmentally friendly. The aim of this study is to reveal the processes that resist the climate crisis by applying digitalization, energy management, lean production and carbon footprint measurement to shipyard under the umbrella of sustainability. The implementation plans of Sedef Shipyard, a shipyard where these processes are actively carried out, will be examined in this direction.

Keywords: *Industrial Sustainability, Shipyard, Sustainability Plan*

1. Introduction

The shipbuilding industry is one of the important maritime areas with the highest costs. In recent years, there has been an increase in ship construction costs worldwide. There has been a 50% increase in tanker prices since 2020. New construction prices have shown a higher upward trend, especially in 2022. This situation has also caused an increase in second-hand ship prices. Despite cost increases, investments in new shipbuilding continue [1]. You can see the increase in new construction prices since 2020 in the Figure 1 below [2].

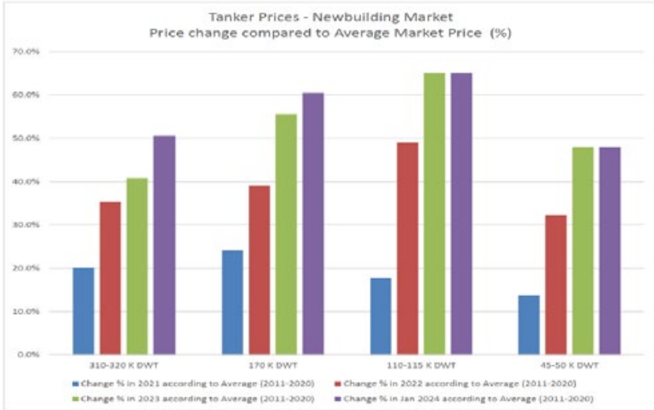

Figure 1. Newbuilding Market Prices Change Compared To Average Market Price [2]

In addition to price increases in the newbuilding sector, the operating costs and sustainability of these ships are also taken into account. Japan, which has the largest ships in the world, has the fleets with the highest value in terms of volume, with LNG and LPG ships worth US$ 37.8 billion and US$ 13.4 billion, and 202 LNG ships and 344 LPG ships [3].

Policies implemented to reduce carbon emissions in ship operations also find their place in ship construction. The use of alternative fuels aims to reduce transportation emissions. For example; although green methanol significantly reduces SOX and NOX emissions, it is not carbon-free. However, although this fuel is an alternative sustainable fuel, since it is liquid at ambient temperature, it is cheaper to store than other alternative fuels such as LNG or Ammonia, which require cryogenic tanks. It is not surprising that methanol does not perform well compared to MGO in terms of energy density; the energy density of methanol is 15.8 GJ/m3, while that of MGO is 36.6 GJ/m3, so methanol takes up 2.4 times more space on the ship than its conventional counterpart. In addition to requiring more space on board, green methanol is expensive compared to VLSFO. Green methanol priced on a VLSFO equivalent basis is currently 4-5 times more expensive. This gap could be closed by an increase in the supply of green methanol and higher carbon prices. For example, the volume occupied by MDO and Fuel Diesel fuels used in conventional ships is 2-3 times less than methanol. When environmentally friendly fuels are used, NRT (Net Tonnage) in shipbuilding will therefore decrease.

When the concept of sustainability is examined by taking into account the parameters that constitute shipbuilding and shipyards, it means meeting the current needs in the future and using resources in the most efficient way for quality work output and protecting the nature. While the World Shipping Council recognizes that ocean-going ships are a significant emitter of greenhouse gases and that people see the devastating effects of climate change every day, it is trying to find a way to invest in green fuels without imposing an undue cost on the global economy. According to the WSC, the "Green Balance Mechanism" could achieve this balance by charging fossil fuel-burning ships and allocating them to green alternatives so that the average fuel cost is equal. The group said this approach would make it "economically rational and attractive" for both ship owners and energy providers to invest in fuels and technologies that deliver deep reductions in greenhouse gases.

Due to the cost increases in ship construction in recent years, it is of great importance for shipyards to work on process and energy management, sustainability and preparation of sustainability plans.

2. Methods

The issue of sustainability ecosystem has been examined in a comprehensive end-to-end manner by listing the methods applied in the new shipbuilding industry. The analysis is based on examining the work carried out and planned in the last decade in the complex shipyard environment.

2.1. Digitalization

Shipbuilding processes consist of project-based assembly processes. The fact that automation systems are of great importance in assembly lines reveals the need for digitalization. The efficiency and flexibility provided by digitalization provide shipyards with an increase in market share. It provides cost advantage in quality control systems compared to traditional production systems. In order to provide all the advantages of digitalization, there is a need for a system in which space, equipment and other resources can communicate with each other and give and receive commands. This system is made possible by an infrastructure that will enable information collection, sharing and processing of all collected data. This system, referred to as the industrial internet of things, aims to optimize the process regardless of human influence as it makes existing processes visible. The first step in ensuring correct resource use, which is one of the basic building blocks of sustainability, is to implement digital monitoring.

2.1.1. Digitalization of Shipbuilding Area

The first step of digitalization is to ensure that the production lines, semi-finished and finished products are capable of transmitting the collected data. The area is made fully capable of broadcasting with location sensors, gateways, servers where information will be collected, wired and wireless communication networks, and protective and auxiliary equipment that will ensure the smooth and flexible operation of all these equipment. This condition applies not only to the shipyard environment but also to all other sectors where digitalization will take place. With this infrastructure, the data of all assets expected to be monitored will be collected on the main server. You can briefly examine the communication infrastructure in the Figure 2 below [4].

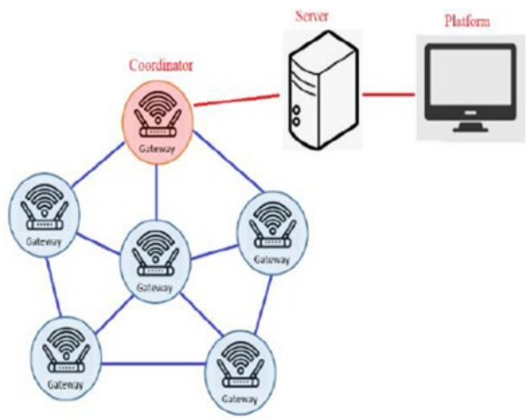

Figure 2. Mesh Network Communication Infrastructure [4]

In addition to being a great opportunity in terms of efficiency and safety for the shipyard sector, which has complex processes, the fact that the production area is mostly an open manufacturing area and the fact that this manufacturing area is metal-intensive are among the difficulties that must be overcome. The production area is considered as a closed and open environment. Determining and defining locations in shipyards is necessary to ensure workflow. In shipyards, in addition to the shipyard campus, the ship and the blocks that make up the ship are also taken into account as the production area. These areas can be marked as a location and workflows in the areas can be followed. Blocks, which we can describe as semi-finished products, can be evaluated as both a monitored asset and a production location throughout the entire process. Likewise, the ship should be marked as a location to ensure traceability of the equipment processes that continue after the block construction of the ship, which is a finished product. In order to digitally monitor metal-framed closed areas, different communication techniques will need to be used.

2.1.2. Sensor Installation

Sensors are electronic components that collect data according to their structural features. A digital production area is ready to collect data from sensors. At this stage, in order to make the assets and the data we want to monitor visible in the digital environment, sensor installations must be made without damaging the structure and functioning of the asset.

In shipyards; location, temperature, air quality (smoke, particles, humidity, etc.), vibration, impact, pressure, energy, consumables, image, operator ID, applied process, etc. data can be received. This data is associated with region and business processes. In this way, the data were correlated with each other and new data was created. For example; with location sensors, security vulnerability, vehicle tracking systems and forklift route optimization can be achieved. With the sensors in the welding machine, how much welding wire is consumed for which job, how much is wasted, how much affects the work processes, how much energy is spent for this process, operators and the operation management can be determined.

We think about ships and blocks, the number of people in the closed area, their vital conditions and the suitability of working conditions can be controlled. It helps prevent an emergency and gives time to intervene in a possible situation. The important point at this stage is to correctly define the processes expected to be followed and mount the appropriate sensor.

2.1.3. Production Data Collection

The sensor located in the production area broadcasts live in real time. Receivers collect this data and convert it into Bluetooth 5.0 data depending on the RSSI values. Sensor data received via Bluetooth is sent to the main servers via the Wi-Fi network via gateways. Raw data on the servers is processed, monitored and evaluated on a digital platform.

However, the gateways inside the ship and the block cannot be connected to the Wi-Fi network because they are located in a metal ship body frame. For this reason, the data collected in the metal frame is collected by the method called mesh network and transmitted to the server. In outdoor areas, signal reflections may occur due to metal density in the shipyard production area. For this reason, location sensors were tested and installed on floor, pole and wall platforms, taking into account the coverage areas and the electromagnetic noise in the region where they are located.

Collecting big data will provide the ability to make predictive comments together with machine learning in the future. This study, which is implemented for the first time in the shipbuilding sector, will bring knowledge to the sector. You can see the Sedef Shipyard production area data collection points in Figure 3 below [4].

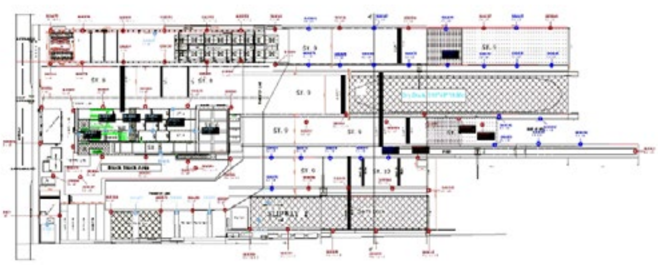

Figure 3. Shipyard Data Collection Points [4]

2.2. Energy Management

One of the factors that determine international balances today is energy. Energy is the largest consumable resource affecting production and economy. Shipyards, like all industrial enterprises, must be successful in competition and use their capital resources in the most efficient way. Since there are no major changes in the prices of machinery and materials used in the shipbuilding sector, which is a global industry, production costs need to be reduced in order to be successful in competition. Energy management, one of the most important steps of the sustainability plan, is important for both efficiency and eliminating negative environmental effects.

In order to manage energy in a shipyard, it must first be included in company policies. Afterwards, energy gap analysis should be performed to see the current energy and energy consumption of the shipyard. Thus, the shipbuilding industry, which is an energy-intensive sector in metal processing, should optimize consumption by identifying important energy consumption sources and prevent losses and fugitives.

2.2.1. Locating Main Consumption Sources

To ensure energy management, a detailed inventory and energy analysis of a shipyard or facility must be made. This analysis identifies important consumption areas, gives investment advice within the specified scope, suggests improvements and makes a savings forecast. After reviewing the shipyard's need points with this analysis, optimization is achieved by measuring the distribution and consumption lines at these points with industrial equipment. There is an energy manager at the shipyard for this process. It monitors the entire system in an energy management program and identifies important consumption sources in distribution centers.

Since high-consuming resources directly affect the production process, it is assumed that it works efficiently and smoothly, but when it was analyzed whether the system was working correctly or not, it was seen that efficiency was increased with small improvements. Cranes, compressors, welding machines and pumps in shipyards are examples of machines that consume high energy.

2.2.2. Detection of Losses and Fugitives

The increased need for energy has led to an increase in energy production. Shipyards, where heavy energy consumption is required, must prevent losses and leaks in order to manage energy.

Losses and leaks are energy losses that cause some disruptions in the service provided by the systems without any problems. These systems are losses that occur when energy is released into the environment while it should be converted into value. These losses occur when energy is released into the environment while it should be converted into value. These losses must be prevented in order for uninterrupted energy to be transformed into value. For example; heat losses, air losses and outdated machinery and equipment directly affect productivity. Since shipyards are areas where heavy metals are processed, failure to operate the machines at the correct load will reduce both the consumption and the life of the machine.

2.3. Lean Production

Lean manufacturing techniques, which are developing in the automotive industry, are applied in shipyards as well as in many other sectors. The main purpose of lean production is to reduce production costs and do better quality work in less time, which is one of the foundations of efficiency and sustainability. This method, which is easy to apply in industrial sectors that carry out mass production, requires some adaptations in its application for shipyards that do unique work.

2.3.1. Process Monitoring

Shipyards are large production areas. Even if there is no mass production in these areas, there are similar processes applied for each project in shipbuilding processes. Optimizing these processes directly affects the construction time of a ship. All details of the processes must be recorded in order to see the improvement areas of operational processes, to identify investment areas and to prevent waste. Process data is recorded with flow charts and value analysis forms.

2.3.2. Problem Detection

In industrial systems, lines that produce output generally appears smoothly without any problem. The flow charts and value analysis forms prepared during the process monitoring process are reviewed together with the process owners. During the examinations, spaghetti diagram, time recording, etc. used in lean production techniques were used. These methods determine where the problem is. It is very important to detect the problem in order to manage it.

2.3.3. Recreation Process

After a process is reviewed and problems identified, problem solutions are discussed. Once the most appropriate solution is determined, a new process is created with this solution. Especially in shipyards, there is limited space and limited lifting capacities. For this reason, the production area has become available with maximum efficiency by creating new processes with line balancing, reducing waste, and creating new tools etc.

2.4. Measuring Carbon Footprint

Reducing the carbon footprint, one of the stages of sustainability in production, has gained importance in these days when we are experiencing a climate crisis. In accordance with the updated rules, it has become almost mandatory to use products that emit less carbon to nature. The most striking step at this stage is the natural resources spent during the production phase of the products. This situation has indirectly revealed the necessity of measuring the carbon footprint at the production stage.

3. Results

Shipyards, like all other sectors, want to continue their existence. For this reason, they have to fulfill the requirements of sustainability. It must try to survive by reducing waste, adapting to new technologies and taking into account the sanctions of the climate crisis. This study examined the sustainability steps that shipyards should follow in order to maximize their life cycle and continue their existence in the future. In this study, the efforts made by Sedef Shipyard for sustainability in the last ten years are summarized.

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Determining Factors Shaping Garbage Generation on Cruise Ships in the Arctic Region through Advanced Deep Learning Models

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Abstract

The Arctic Region is experiencing a surge in tourism, fuelled by cruise expeditions organized by tour companies, indicating a growing tourism sector. Climate change has rapidly altered the Arctic, reducing sea ice cover and opening new sea routes, making it more accessible. However, cruise ships, crucial for Arctic tourism, pose environmental challenges, notably in garbage generation. Waste disposal is governed by the MARPOL agreement and the Polar Code, with regulations on garbage discharge. Storing waste onboard until reaching designated port facilities presents challenges. This study utilized PAME-provided data on passenger ship garbage generation, employing deep learning methods to analyse factors like gross tonnage, fuel quality, passenger capacity, distance travelled, and date of build. K-means clustering categorized garbage values into 'less' and 'more' clusters, and models with various feature combinations were created. The combination of distance travelled, passenger capacity, and gross tonnage yielded the highest test success (F1 = 0.94) with the fewest attributes. The study concluded by estimating garbage generation by cruise ships in the Arctic.

Keywords: *Arctic, Deep Learning, Garbage Generation, Cruise, MARPOL*

1. Introduction

The Arctic region is known for its exceptionally low temperatures, distinctive ecosystems, and expansive ice cover, creating a unique and formidable setting. The distinctive nature of this region captures the interest of both nations and individuals, notwithstanding the challenging conditions it presents. With the rapid rise of attractiveness in the Arctic Region, tourist flow triggered by tour companies organizing cruise expeditions. The rising prevalence of cruise shipping indicates the development of an expanding tourism sector in the Arctic. The Arctic, frequently acknowledged as being on the edge of the world both spatially and traditionally, entices visitors mainly through nature-oriented attractions such as hiking, hunting, fishing, marine adventures, and winter sports, with a focus on immersing oneself in the indigenous culture [1-4]. Simultaneously, due to its environmental features, the Arctic region has tender conditions and is the most vulnerable region significantly impacted by the effects of global warming [5-7].

The Arctic region is experiencing rapid change caused by climate change, resulting in a decrease in sea ice cover and the opening of new sea routes with increased accessibility. In light of this transformation in the Arctic climate, where rapid changes have led to a decline in sea ice and the opening of new navigable routes, not only facilitates maritime journeys but also enhances the comfort of cruise ships, allowing for extended tourist seasons in the region. Over the past few years, there has been a consistent rise in popularity for significant Arctic cruise destinations like Greenland, Alaska, and Svalbard [8]. Prior to the outbreak of the COVID-19 pandemic, Alaska annually hosted around one million cruise passengers, while Svalbard attracted approximately 75,000 visitors, Greenland recorded approximately 25,000 annual tourists, and the Canadian Arctic received nearly 5,000 visitors each year [9 -11]. The rise in Arctic tourism, driven by the increasing favor for cruises, not only results in economic advantages for the region but also fosters heightened awareness and admiration for its distinctive ecosystems and indigenous cultures [12]. This, in turn, creates avenues for sustainable development opportunities in the Arctic [13].

Alongside the beneficial impacts of burgeoning tourism in the Arctic region and the subsequent rise in the number of cruise ships in the Arctic region can have several negative impacts on the environment and local ecosystems. Currently, waste disposal from ships in the Arctic region is governed not only by the MARPOL agreement, which regulates such matters in other regions, but also by the Polar Code [14]. The main issue confronting ships in the Arctic is the restriction on discharging waste, leading to the necessity of storing waste until it can be appropriately disposed of at a port reception facility [15, 14]. This gives rise to multiple challenges, including the need for ships to be constructed with greater capacity for managing onboard waste following MARPOL regulations. Moreover, the extended distances between ports, possible disruptions due to unfavorable weather conditions, and restrictions on ocean discharge, especially in icy areas, enhance the overall intricacy of the situation. Moreover, challenges are exacerbated by the difficulty of accessing specific ports due to shallow or uncharted channels and the insufficient port infrastructure for waste disposal from anchored ships, presenting obstacles for both ships and ports operating in Arctic waters.

The prohibition of garbage discharge, excluding food, in polar regions is regulated by MARPOL Annex V [16]. It also highlights the specific restriction on discharging food near the ice edge, as stipulated by the Polar Code Amendments to Annex V in 2013. In the event of it not being possible to discharge waste, it must be stored on board until reaching a designated port facility, presenting an added challenge for both ships and Arctic ports. Given these factors, waste management in the Arctic and nearby ports will face challenges due to the heightened transportation activities to and from the Arctic Ocean. As a result, the growing interest in the Arctic region leading to a proportional increase in the number of cruise ships arriving will further compound this already complex and challenging situation.

In conclusion, this study aims to address the complex challenges arising from the intersection of burgeoning Arctic tourism, propelled by the increasing popularity of cruise expeditions, and the escalating issue of waste management. The Arctic's unique attractions have not only stimulated economic benefits and sustainable development opportunities but have also heightened environmental concerns. The growing number of cruise ships in the region amplifies the waste disposal challenge, as stipulated by MARPOL and the Polar Code. To shed light on this complicated scenario, the study utilized advanced deep-learning models and PAME-provided data to explore the factors influencing garbage generation on cruise ships in the Arctic region. The findings underscore the pressing need for effective waste management strategies, given the restrictions on waste discharge and the multifaceted challenges posed by extended distances between ports, adverse weather conditions, and limited ocean discharge in icy areas. As the Arctic undergoes rapid environmental changes, this research seeks to contribute valuable insights to guide the development of sustainable practices, ensuring a harmonious coexistence between Arctic tourism and the preservation of its fragile ecosystems.

2. Materials and Methods

This study utilized cruise ship garbage production data provided by PAME to identify factors affecting garbage production on ships traveling to the Arctic. Simultaneously, information such as passenger capacity, travel distance, and gross tonnage (GT) was also incorporated into the analysis. A model was created using qualitative data analysis and deep learning methods. In the initial stage, factors influencing garbage production on ships traveling to the Arctic were determined through qualitative data analysis. Subsequently, a deep learning model was developed, and 1000 experiments were conducted to evaluate the performance of this model. Continuing the study, the qualitative data analysis method was employed to calculate seasonal garbage production per capita on ships traveling to the Arctic between 2013 and 2019. In Figure 1 all steps of algorithm are shown.

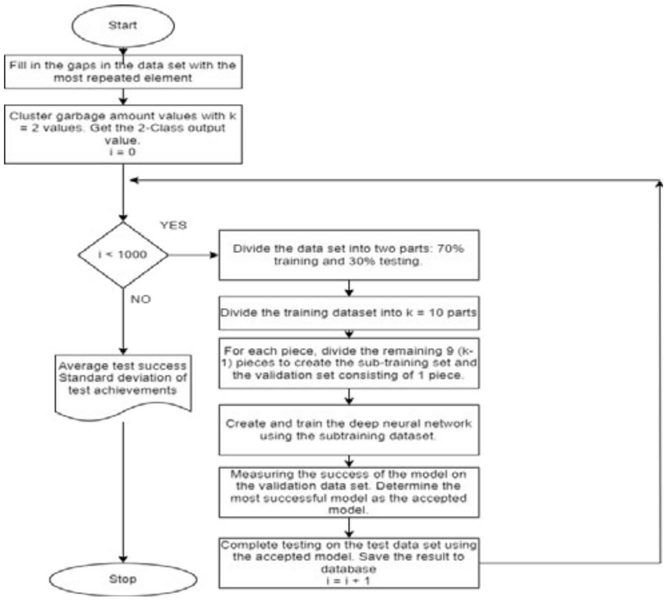

Figure 1. Explained Steps of the Method.

The methodologies employed in this study can be examined in three successive stages: pre-processing, creating the dataset through clustering, and classification.

a.) Pre-processing Step: Each of the date of build, distance traveled, fuel quality, and garbage values, which will constitute the input of the model in the dataset, has been individually scanned, and missing rows have been identified. The missing values in the sequence have been filled with the most frequently occurring element.

b.) Generation of the Output Value: The magnitudes of the garbage quantity in the raw dataset are presented as vector magnitudes. While these magnitudes are suitable for regression analysis, they are deemed inappropriate for a classification problem. To address this issue, recourse has been made to the k-means algorithm, one of the fundamental clustering algorithms, to transform the data into a format more amenable to classification analysis.

c.) K-Means Algorithm: The main idea of this algorithm is to partition the data into a specified number of clusters [17]. To run the algorithm, two hyperparameters are required. These are the number of clusters, denoted as 'k', and a distance function that measures the distance of each example to the center. Once these hyperparameters are obtained, the function is iteratively executed until the cluster centers are determined. Below is the pseudocode for this algorithm.

1. Select and designate k points randomly as cluster centers.

2. While the total (change in cluster centers) is not equal to 0:

2.1. Calculate the distance of each element to the cluster centers and include it in the nearest cluster.

2.2. Redefine each cluster center as the average of the new elements.

In this research, a k value of 2 was chosen, given the need to categorize garbage into small and large clusters. Moreover, Euclidean distance was employed for distance calculations.

2.1. Classification

Size Group GT, Fual Quality, Passenger Capacity, Distance Travelled, Date of Build values were examined together on the scatter diagram (Figure 2).

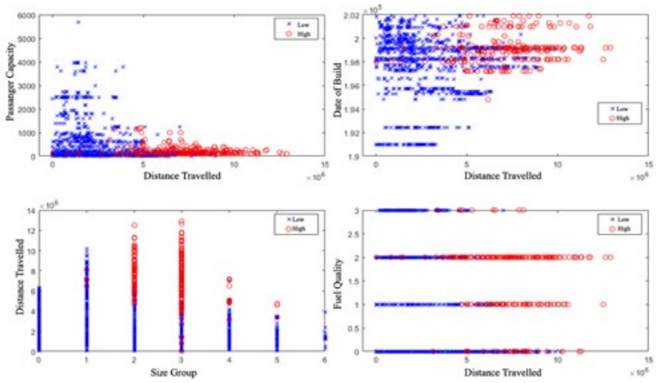

Figure 2. Scatter Diagram.

Upon a comprehensive analysis of these diagrams, it becomes apparent that the data does not lend itself to linear separation. This underscores the necessity for a non-linear classifier. Accordingly, diverse input-output combinations were addressed through the utilization of deep neural networks.

The dataset, for each input-output pairing, was partitioned into 70% for training and 30% for testing purposes. The establishment of the classifier model involved the execution of the system in adherence to the k-fold cross-validation technique.

2.2. Deep Learning Model

In this study, a deep learning model was configured with a network architecture consisting of 1 input layer, 3 intermediate layers, and 1 output layer. The intermediate layers encompass 100, 50, and 100 neurons, respectively. The resulting deep neural network model is illustrated in Figure 3.

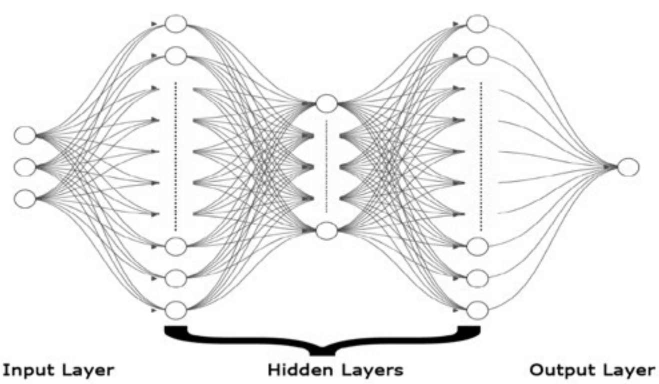

Figure 3. Deep Neural Network Model.

The activation function employed for the middle layer was rectified linear unit (ReLU), while the softmax function was utilized for the output layer. The training of the network was conducted using the limited-memory Broyden–Fletcher–Goldfarb–Shanno algorithm (LBFGS) method, chosen for its efficient memory utilization [18].

2.3. Model Evaluation and Success Metrics

The model evaluation and success measurement were conducted using the k-fold cross-validation method. This method is frequently used in statistics to construct and real assess a model. According to this approach, the training data is divided into k equal parts, and the model is retrained k times, using (k-1) segments for training and the remaining 1 segment for validation in each iteration. The average validation successes provide insights into the training performance. The model yielding the best validation success among the k models is considered the final model. The ultimate model is applied to the test dataset, unseen by the classifier during training, and the success of the test dataset is acknowledged as the most reliable performance metric evaluating the model's competence. Figure 3 depicts the overall schematic of this model.

Success evaluation employed two metrics: accuracy and F1 score. Accuracy, widely utilized, represents the ratio of correct decisions to the total observations. While accuracy is commonplace and applicable in daily scenarios, it may falter in cases of imbalanced class distribution, as depicted in Figure 1 for the dataset in this experiment. Therefore, the F1 score was also employed, relying on four measurements: true positive (TP), true negative (TN), false positive (FP), and false negative (FN). True positive denotes instances where the model correctly diagnoses positivity, and true negative represents accurate negative diagnoses. False positives occur when the model wrongly identifies positivity, whereas false negatives arise from incorrect negative diagnoses. The F1 score calculation involves two essential metrics: precision (1) and sensitivity (2) (see below).

$$\text{Precision}=TP/\ (TP+FP) \qquad \textbf{(1)}$$

$$TPR=TP/\ (TP+FN) \qquad \textbf{(2)}$$

Utilizing these considerations, the F1 criterion is computed using formula (3).

$$F1=2^*\ (\text{Precision}^*\ \text{Sensivity})/(\text{Precision}+\text{Sensivity}) = (2^*TP)\ /(2TP+FP+FN) \qquad \textbf{(3)}$$

3. Findings

The study aimed to quantify ship garbage based on diverse inputs, leading to separate model training and testing for distinct input combinations. For each combination, 1000 experiments were conducted, wherein training adhered to the k-fold cross-validation parameters outlined in the methodology. Subsequently, testing was executed post-training. The outcomes of the experiments' success are presented in Table 1.

Table 1. Experiment's Success Ratio.

Criterion Name	Average Accuracy	Standard Deviation of Accuracy	Maximum Success	Minimum Success	Test F1 Score
'Date of Build', 'Distance Travelled', 'Fuel Quality', Passenger Capacity, 'Size Group GT'	0.940	0.010	0.970	0.920	0.910
'Distance Travelled', 'Fuel Quality', Passenger Capacity, 'Size Group GT'	0.930	0.011	0.950	0.910	0.920
'Date of Build', 'Distance Travelled', Passenger Capacity, 'Size Group GT'	0.910	0.013	0.950	0.890	0.900
'Date of Build', 'Distance Travelled', 'Fuel Quality', Passenger Capacity	0.900	0.012	0.940	0.850	0.880
'Date of Build', 'Distance Travelled', 'Fuel Quality', 'Size Group GT'	0.870	0.015	0.930	0.930	0.850

4. Discussion and Conclusion

Our research delved into the intricate factors influencing the generation of waste on cruise ships in the Arctic, particularly in the context of the surge in tourism driven by cruise expeditions. The Arctic, renowned for its unique ecosystems and challenging conditions, has experienced heightened accessibility due to climate change, leading to an increased presence of cruise ship activities. While the upswing in tourism offers economic benefits and encourages sustainable development, it also intensifies environmental concerns, especially regarding waste management. Navigating waste disposal challenges in the Arctic involves adherence to the MARPOL agreement and the Polar Code, with regulations mandating strict limitations on garbage discharge and the necessity to store waste on board until reaching designated port facilities. These challenges are compounded by extended distances between ports, adverse weather conditions, and restricted discharge options in icy areas, presenting intricate issues for both ships and Arctic ports. To tackle these multifaceted challenges, we employed advanced deep learning models, utilizing data provided by PAME on passenger ship garbage generation. Our study probed into the influence of various parameters such as gross tonnage, fuel quality, passenger capacity, distance traveled, and date of build on garbage generation. Employing k-means clustering, we strategically categorized garbage values, leading to the creation of deep neural network models with distinct feature combinations. The outcomes underscored the effectiveness of combining distance traveled, passenger capacity, and gross tonnage, achieving the highest test success (F1 = 0.94) with minimal attributes. The integration of the F1 score, alongside accuracy, offered a comprehensive assessment of the model's performance, addressing potential imbalances in class distribution.

In summary, our research provides nuanced insights into the intricate intersection of increasing Arctic tourism, cruise ship activities, and the challenges associated with waste management. The findings emphasize the imperative need for robust waste management strategies in the Arctic, crafted with due consideration for unique environmental and regulatory constraints. As the Arctic undergoes rapid environmental changes, our study aspires to guide the development of sustainable practices, ensuring the harmonious coexistence of Arctic tourism and the preservation of its delicate ecosystems.

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Review on Inorganic and Hybrid Absorbent Materials Developed to Prevent Marine Pollution Caused by Ship Leak

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Abstract

This research is dedicated to exploring the application of absorbent materials in reducing marine pollution caused by oil spills. The scarcity of organic materials, critical in addressing this environmental challenge, represents a significant obstacle. This scarcity is particularly acute in regions like Türkiye, where the cultivation of certain organic absorbents, such as coconut fiber, is hindered by unsuitable climatic conditions. The primary objective of this study is to bridge the existing gaps in the literature concerning absorbent materials and to highlight ongoing research within this field. To achieve this, the study meticulously evaluates the characteristics, benefits, and limitations of both organic-inorganic and inorganic-synthetic composite materials. For instance, it examines the comparative absorption capabilities of organic versus inorganic cellulose. Through an exhaustive analysis of these materials' properties, the research aims to provide strategic insights into their optimal application. Furthermore, it includes a review of the literature on selecting the most appropriate absorbent materials based on the types of oil prevalent in marine vessels. This comprehensive compilation seeks to lay the foundation for the sustainable and efficient use of absorbent materials, thereby informing future scientific inquiries and technological advancements.

Keywords: *environmental effect, hybrid sorbents, oil spill, organic sorbents*.

1. Introduction

Oceans and seas are fundamental ecosystems, pivotal to the sustenance of natural life. However, these crucial habitats are increasingly threatened by industrial activities, including maritime transportation and oil extraction, which risk polluting them through leaks and spills. Specifically, the discharge of hazardous substances, such as petroleum and various chemicals, can cause profound harm to marine life and, by extension, the broader aquatic ecosystem. Such leaks often result in the formation of a thin, obstructive layer on the water's surface, necessitating prompt and effective cleanup measures. The Deepwater Horizon oil spill of 2010 illustrates the severity of this issue, with a petroleum layer spreading over more than 112,000 square kilometers of the ocean surface. Despite efforts involving dispersants and controlled burns, only a fraction—approximately 15% to 25%—of the spill was prevented from reaching the shores. Moreover, the disruption of enzymes critical for petroleum breakdown further exemplifies the spill's detrimental impact [1].

Given these challenges, there is a clear and urgent need for the development of innovative and more efficient cleanup technologies. These technologies need to be efficient, economically viable, and harmless to the environment. This study focuses on exploring organic-inorganic and inorganic-synthetic hybrid absorbents, as well as purely inorganic absorbents that have undergone specific chemical modifications to enhance their efficacy. The aim is to contribute to the advancement of solutions capable of mitigating the environmental impact of such spills, thereby safeguarding marine ecosystems.

2. Various classes of sorbent materials

In 1998, Toyoda and colleagues pioneered the use of exfoliated graphite (EG), obtained by treating graphite with sulfuric acid at 1000°C. Their subsequent research in 2000 further diversified the applications of EG by employing natural graphite and sulfuric acid to modify the material's properties. This led to the production of two distinct types of exfoliated graphites, characterized by their varying viscosities. The studies highlighted the critical role of pore volume and bulk density in determining the materials' absorption capacity. It was observed that a lower bulk density, specifically 0.006 g/cm^3, facilitated the absorption of 83 g of Class A heavy oil per gram of expanded graphite, with the highest absorption efficiency recorded within 60 seconds of exposure at a controlled temperature of 25°C [2]. In their 2010 study, Wang et al. contrasted the absorption performances of magnetic exfoliated graphite and traditional EG. MEG, synthesized via the citric acid sol-gel method, demonstrated superior absorption capacities compared to EG when tested with various oils. Specifically, MEG and EG exhibited absorption capacities of 48.93 g/g and 41.46 g/g for motor oil, respectively. However, these capacities declined with diesel and gasoline, indicating the materials' selective efficiency based on the oil type. The study also reported average recovery rates for oils, underscoring an efficient recovery process across different oil types [3]. In 2011, Qi and associates introduced an inorganic absorbent by integrating commercial oil-absorbing felt (OAF) with expanded graphite (EG), aiming to overcome the challenges posed by EG's low density. Their innovation, dubbed NOAF-1, achieved an optimized density of 0.0087 g/cm^3, thereby enhancing the absorbent's performance. They determined that the optimal thickness for the OAF was approximately 1 mm, which represented a significant improvement in absorption capacity compared to standalone OAF or EG. Notably, this development holds promise for enhancing the efficiency of disposing and recovering EG in marine environments [4].

In 2005, Sayed and Zayed explored the use of mud, primarily composed of calcium aluminum silicate, obtained from water treatment processes in petroleum refineries and power plants, for oil spill remediation. They chemically modified this mud to boost its oil removal efficiency. Such modification significantly enhanced the mud's absorption capacity, underscoring the potential of repurposing waste by-products in environmental cleanup efforts [5]. In 2013, Nguyen et al. developed a cellulose-based aerogel through an innovative alkaline/urea method, presenting an environmentally sustainable approach to crude oil spill remediation. This aerogel demonstrated remarkable absorption capacities across a range of crude oil types, showcasing the potential for using sustainable materials in environmental cleanup. The research highlights the aerogel's versatility and efficiency in addressing different oil spill scenarios, further emphasizing the value of sustainable technologies in environmental protection efforts [6].

In 2007, Rajakovic et al. conducted a comparative study on the efficiency of wool-based sorbents and sepiolite, a natural clay mineral, in oil spill cleanup efforts. Despite the high absorption capacity of sepiolite, the wool-based sorbents outperformed it under bulk tank conditions, indicating that these organic materials are not only viable but also potentially superior for oil remediation purposes. This observation indicates that wool-based absorbents may provide a better response in situations reflecting actual oil spill conditions, underscoring the significance of investigating organic alternatives for environmental remediation tactics [7]. In 2011, Arbatan and their team developed a superhydrophobic and oleophilic material using calcium carbonate powder that was treated with fatty acids to enhance its oil removal efficiency. This modification turned the material into an environmentally friendly solution, thanks to its basis in readily available and non-toxic components. It proved to be highly effective in separating oil from water, presenting a cost-effective and environmentally sustainable solution for oil spill cleanup, offering significant promise for real-world application in environmental preservation efforts [8]. The discovery of carbon nanotubes (CNTs) in 1991 revolutionized the field of oil absorption materials, offering unprecedented properties. Xuchun and colleagues advanced this area by developing a CNT sponge via chemical vapor deposition, showcasing not only superior oil absorption capabilities but also notable thermal insulation properties. This innovation, indicative of the material's versatility, opens doors to various environmental and industrial applications[9]. Subsequently, in 2013, Kızıl, Karadağ, and their team introduced poly(alkoxysilanes), a polymer distinguished by its remarkable oil absorption and reusability. Synthesized through a straightforward condensation reaction, this material emerged as a potential solution for the efficient removal of organic pollutants from aquatic environments [10].

In 2017, Li Yan and their colleagues synthesized an oil-absorbent resin through suspension polymerization, a process that involved coating cotton with hydrophobic Bio-MgO (biologically derived magnesium oxide). This method resulted in a material characterized by rapid oil absorption rates and pronounced hydrophobic properties, making it exceptionally suited for oil spill remediation. The innovation lies not only in the use of sustainable materials but also in the material's efficiency, which could significantly improve the effectiveness of cleanup operations in marine and freshwater environments [11]. In 2003, Roulia et al. conducted a study on the use of expanded perlite for oil absorption. Their research demonstrated that expanded perlite is highly efficient in absorbing various types of oil, even though it has a propensity to absorb water. This characteristic presents both a challenge and an area for further innovation in its application for oil spill cleanup. The findings suggest that, with further refinement to reduce water absorption, expanded perlite could be a viable option for effectively addressing oil spills [12].

Loh and their team delved into the performance of wool aerogels in oil absorption, specifically examining how variations in wool fiber or Polyvinyl Alcohol (PVA) concentrations influence efficiency. Their findings, which highlight the significance of material composition, contribute valuable insights towards optimizing cleanup technologies[13].

Table 1. Absorption capacity of wool aerogel at various fiber levels [13]

	Fiber (wt%)	PVA (wt%)	Absorption Capasity, Qmax (g/g)
W2	0,1	0,1	136,2 ± 11,0
W3	0,1	0,5	48,3 ± 4,0
X4	0,1	1,0	32,5 ± 3,0
X5	0,5	0,1	96,0 ± 7,1
X6	0,5	0,5	46,2 ± 3,6
Y6	0,5	1,0	30,6 ± 1,5
Y7	1,0	0,1	63,6 ± 1,5
Y8	1,0	0,5	42,5 ± 5,6
Y9	1,0	1,0	26,3 ± 1,3

This revision ensures a comprehensive and coherent presentation of the research findings, structured to emphasize the progression in the development of absorbent materials for oil spill cleanup. It aligns with academic standards, providing clear and concise descriptions of each study's contributions to the field. These studies collectively underscore a continuous pursuit of innovative materials that enhance oil spill remediation efforts, demonstrating the field's dynamic evolution and the growing understanding of material science's impact on environmental sustainability.

3. Conclusions and perspective

Figure 1 shows the absorption capacities of different inorganic materials on diesel fuel. An optimum inorganic material selection was also made for other oils and fuels.

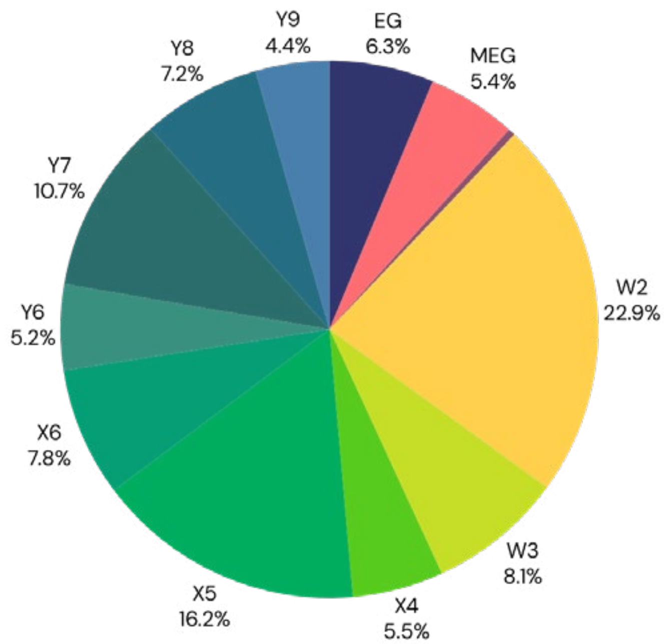

Figure 1. Oil absorption capacities for diesel fuel

Despite disposal considerations, the study identifies wool aerogel, fabricated with 0.1% fiber and 0.1% PVA concentrations, as the most effective absorbent material for remediating diesel fuel spills. Following wool aerogels, exfoliated graphite (EG) and magnetic exfoliated graphite (MEG) are identified as the next most effective options. Notably, MEG shows superior absorption capacities for both crude oil and motor oil, making it a particularly advantageous material for these types of spills. In the context of motor oil spill remediation, MEG is found to have the highest absorption efficacy. If a single absorbent material is required for three different oil types, magnetic exfoliated graphite would be the preferred choice. Alternatively, combining wool aerogels and MEG could offer synergistic benefits.

Considering disposal, the use of NOAF addresses the limitations inherent in both EG and MEG. Furthermore, the potential for using sludge cycles amenable to carbonization processes opens a promising avenue for future research. Applying carbonization techniques can increase the carbon values of sludge cycles, turning them into fuel. This area presents a significant gap in the existing literature, highlighting the need for further academic investigation. Additionally, exploring materials such as cellulose and calcium carbonate treated with fatty acids could provide valuable insights into their disposal efficacy. Although fatty acid-treated calcium carbonate has potential as a topic of scholarly interest, research in this area is currently underdeveloped. The environmental friendliness and low production costs of Cellulose Aerogel and Wool Aerogel suggest a promising future for addressing ship leakage incidents.

The comparative analysis between organic and inorganic wool-based materials necessitated a careful review of the literature on organic wool aerogel. This review focused on selecting experiments conducted under similar conditions. In the empirical investigations by Alina et al. regarding natural wool, the material was evaluated in a packetized form. The absorption capacities for natural wool were quantified as 11.76 g/g at a packet density of $\rho b0=0.33$ g/cm³, 8.094 g/g for $\rho b0=0.66$ g/cm³, and 10.88 g/g for $\rho b0=0.99$ g/cm³. In contrast, the study led by J.W. Loh on wool aerogel reported a minimum absorption capacity of 26.3 ± 1.3 g/g, thus demonstrating the superior efficacy of hybrid absorbents over their purely organic counterparts [14].

A parallel investigation into the absorption capacities of organic-based materials for cellulose revealed that cellulose aerogel exhibited a superior oil absorption potential relative to natural cellulose-based materials, as documented in the study by Chau M. in 2021. Furthermore, cellulose aerogel demonstrated a propensity to absorb more oil than cotton in numerous studies, surpassing the latter's performance [15]. The research conducted by Zheng et al. on the Calotropis gigantea (Giant milkweed) plant indicated a higher absorption capacity compared to cellulose aerogel. Nonetheless, the geographical limitation of this plant's habitat to Southeast Asia poses challenges to its accessibility and, by extension, its utility in oil spill remediation efforts [16].

This concluding section synthesizes the insights obtained from the preceding analyses, highlighting the nuanced considerations required for selecting the most effective absorbent materials for mitigating marine pollution caused by oil spills. It underscores the critical need for continued research to innovate and assess various materials and their combinations, focusing on sustainability, economic viability, and practical applicability in a marine context.

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Techniques and Methods for the Analysis of Micro Plastics from Marine Sediments

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Abstract

There are many methods of extracting micro plastics, but procedural differences prevent meaningful comparisons between datasets. There is an abundance of micro-, mezo- and macro plastic in the western Black Sea .The development of methods to address a wide range of sediment and plastic matrices has resulted in a wide variety of extraction techniques. Procedural differences include sediment sample mass, sample preparation, and sample handling. The effectiveness of the method often depends on the composition of the sediments. This paper aims to present the evaluation of five current methods for the extraction and isolation of micro plastics from marine sediments. In order to process the samples in the laboratory, a combined method was used to extract the micro plastic from the sample by the density separation method using a saturated NaCl solution, followed by the use of sieves with variable mesh sizes (0.02 mm...2 mm), in order to extract and analyse both macro plastic and micro plastic. For the sediment sample, the sampling was done in the area of Pasarela in the Mamaia resort, in the coastal area of the Romanian shore, from the surface of the sand, in the immediate vicinity of the supralittoral floor. The sampling was done on an area of approximately 50 cm^2. The collected samples were contained in a glass container to avoid contamination with other materials or substances.Given that beaches and coastal tidal habitats are dynamic systems with continuous and seasonal erosion of sediments, micro plastics can become buried in sediments during periods of accumulation. Laboratory analyses were carried out on the samples taken, namely: sorting (visually and with a binocular microscope), mixing and sieving, as well as microscopic identification of the micro plastics in the marine sediment. To avoid sample contamination, a series of safety measures were taken both during sampling and laboratory analysis. The results of visual identification revealed an average concentration of approximately 7 particles/m^3, predominating in fibbers (~75%), followed by foils (~15%) and fragments (~10%), being very few spherical particles. The areas with an abundance of plastic materials identified were: the N-W area of the study location, the S-E area, towards the port of Constanta and towards the border with Bulgaria.

Keywords: *sediment, micro plastic, separation, sorting, sieving, extraction*

1. Introduction

Over 8,3 billion tones of plastic have been produced worldwide since 1950's. Plastic consumption has exceeded the capacity of modern recycling infrastructure, leading to waste mismanagement and environmental pollution. It is estimated that 8 million tones of plastic end up in the oceans every year via land-based sources.[1] However, floating plastics account for only 1% of those 8 million.[2] Much of the remaining 99% of plastic is expected to brake down into fragments smaller than 5mm, known as micro plastics (MS), through a series of physical, chemical and biological processes and eventually accumulate in sediments.[3]

Micro plastic is often defined as particles smaller than 5 mm. Particles between 5 and 1 mm in size are described as large micro plastics and particles that are 1 mm or smaller are described as small micro plastics. Particles smaller than 100 nm are nano plastics, according to Keolmans et al.. [4]

In addition, plastic particles between 5 and 25 mm in size are described as mesoplastics, and particles larger than 25 mm as macroplastics.[5]

A wide variety of shapes is also present within micro plastics such as: spheres, irregular shapes, flakes or fibers that have very little mass-to-surface ratios.[6] Although several studies have been published on methodologies for the identification and quantification of micro plastics in the marine environment, sediments, biota or soils, there is still no standardized method for sampling and sample preparation.[7]

Several studies have been published regarding methodologies for the identification and quantification of micro plastics (MPs) in various environments such as the marine environment, freshwater environments, sediments, biota or soils. The basis for representative results of micro plastic studies is the choice of sampling location. Only a part of the particles are transported to surface waters. Both transport and deposition in the marine environment depend on the characteristics of the particles. Compared to sediment mobility, the transport behavior of micro plastics differs in terms of particle shape, density and effects such as biofouling.

The main layers in which sampling is carried out in the marine environment are:

- Surface waters
- Water column
- Sediments
- Biota

Sampling micro plastics in the main layers previously mentioned requires different approaches. Thus, 3 main sampling strategies are distinguished, as follows:

- Selective sampling
- Volume-reduced sampling (by volume reduction)
- Bulk sampling

Selective field sampling. Consists of direct extraction from the environment of elements that can be recognized by the naked eye, usually from the surface of sediments.

However, when micro plastics are mixed with other debris or do not have a characteristic shape (irregular, rough, angular), there is a high risk of overlooking them. Therefore special care should be taken when selectively sampling in the field.

Bulk sampling. This refers to the method in which the entire sample volume is collected without reducing it during the sampling process. Bulk sampling is most appropriate when micro plastics cannot be easily identified visually because they are covered by sediment particles, their abundance is low and requires sorting and filtering of large volumes of sediment or water, or they are too small to be identified by the naked eye.

Volume reduced sampling. Reduced volume sampling, both for sediment and seawater samples, refers to samples where the volume of the bulk sample is usually reduced during sampling, keeping only that part of the sample that is of interest for further processing.[8]

In the case of sediment analysis, samples may be sieved directly on the beach, whereas in the case of seawater sampling, volume reduction samples are usually obtained by filtering large volumes of water through nets (neuston/plankton nets). Both bulk sampling and volume reduction samples require further processing in the laboratory.

- ***Extraction of micro plastics from water surface and water column samples***

For these layers, water sampling is done using a neuston or plankton net.

- *Neuston net*

The most common method of sampling the sea surface is by using a neuston net. This method captures micro plastic from large volumes of water and, although widely used, is specifically designed for the study of plankton ecology.[9] Its effectiveness for micro plastic research is limited by the mesh size of the net as well as the likelihood of contamination. It is generally attached to a research vessel, and in combination with a digital flow meter it can determine the amount of organisms per unit volume.

- *Plankton net*

A plankton net is a piece of equipment used for collecting plankton samples from still bodies of water. Plankton nets are considered one of the oldest, easiest and least expensive methods of sampling plankton.

It consists of a towing mechanism attached to a nylon mesh net at the end of which is located an outlet valve and a collecting cylinder.

The toweling mechanism represents the upper part of the plankton net and consists of a nylon rope or a chain attached to the rest of the nets body.

Nylon mesh net represents the middle part of the plankton net and it is used to filter plankton from the water sample in accordance with the mesh size. In addition, its funnel shape makes it possible to catch plankton of different sized effectively. There are different mesh sizes depending on the targeted microorganisms to be collected and the condition of the water body. The smaller the mesh size, the smaller the plankton in the water sample.

- ***Methods for processing samples in the laboratory***

Laboratory processing and subsequent sorting of micro plastics is essential for bulk and reduced volume samples. Four main types of steps can be distinguished during laboratory processing of samples: density separation, filtration, sieving and visual sorting.

- *Separation by density difference*

The specific density of plastic particles can vary considerably depending on the type of polymer and the manufacturing process. Density values for plastics range from 0.8 to 1.4 g/cm^3:

- for polypropylene from 0,85 to 0,94 g/cm^3,

- for polyethylene from 0.92 to 0.97 g/cm^3,

- and for polystyrene from <0,05 to 1,00 g/cm^3.[11]

Typical density for sand or other sediments is 2.65 g/cm^3.

This difference is used to separate lighter plastic particles from heavier sediments by mixing a sample of sediment with a saturated solution and stirring it for a period of time.

After mixing, the sediment is expected to settle quickly to the bottom, while the lower-density particles remain in suspension or float to the surface of the solution. Afterwards, the supernatant containing plastic particles is extracted for further processing.[8]

The most commonly used method involves using a saturated NaCl solution of 1.2 g/cm^3.

- *Filtering*

The plastic particles are separated from the supernatant obtained from the density separation by passing the solution containing the plastic particles through a filter, usually using a vacuum device.[8] Some studies specify the porosity of filter papers of 1 to 2 µm.

In a study in which density separation was performed with fresh water, micro plastics were collected using tweezers from the surface of the aqueous supernatant. To sort larger particles before the filtration step, water samples can first be sieved through a 500 µm mesh sieve, or through a series of sieves with different mesh sizes, starting from the largest to the smallest.

- *Sieveing*

Micro plastics can be separated from samples using mesh screens of varying sizes. Materials retained in the sieve are collected (and sorted), while those that pass through are usually discarded. The use of sieves with various mesh sizes allows us to differentiate between different micro plastic sizes and categories them.[8]

- *Visual sorting and separation*

In all the studies reviewed, visual examination of concentrated sample residues is a mandatory step. Careful visual sorting of the residues is necessary to separate plastics from other materials, such as organic debris (shell fragments, animal parts, dried algae or seagrass, etc.) and other items (layers of metallic paint, tar, glass, etc.). This is done by examining the sample directly with the naked eye or using a microscope.

Most sea-surface studies have separated micro plastics by visual sorting of particles that have been retained in the collecting cylinder attached to the end of the net.[8]

In conclusions:

Previously isolated plastic fragments can also be washed to remove other substances adhering to their surface (such as sand and soil); for example, by ultrasonic cleaning in a liquid medium or deionized water. Samples can be kept in their original form without initial sorting or can be sorted immediately to retain only the plastics in the original sample. Plastics separated from the sample should be dried and stored in a dark, temperature-controlled environment (stable room temperature) to reduce degradation during storage.

To avoid misidentification and underestimation of micro plastics, it is necessary to standardize the selection of plastic particles following certain criteria to ensure correct identification. This is particularly important when it is not possible to use more precise methods such as Fourier transform infrared spectroscopy.[8]

2. Sampling techniques and sample preparation methods for the analysis of micro plastics in sediment

There is an extensive list of published methods for isolating MPs from sediments, thus the variety of published procedures reflects the unique challenges associated with isolating MP from sediments.

Differences between extraction and isolation procedures ultimately determine the ability to accurately recover and quantify different MPs. It is therefore difficult to compare micro plastic recovery rates (number of plastic particles per sample) between samples using different procedures. Procedural differences include sediment sample mass, sample preparation and sample handling. Sediments may undergo pre-treatment steps, including oven drying, pre-sampling of coarse or fine materials or chemical oxidation. The effectiveness of the method often depends on the composition of the sediment. The properties of the sediment, such as grain size, organic matter content and mineralogy, greatly affect the results and the complexity of the method. Differentiation between plastic and non-plastic particles in environmental samples is another major obstacle in the isolation and visual identification of micro plastics.

Most of the techniques used to isolate MP from marine and estuarine sediments involve density separation (i.e. flotation) by stirring sediment samples with aqueous salt solutions. Methods that rely on flotation separation are restricted by the density of their respective salt solutions. Common plastics range in density from 0.8 – 2.35 g/cm3. Low density salt solutions, such as sodium chloride, may be insufficient to separate higher density plastics from sediments. However, high density salts (e.g. NaBr, NaI, ZnCl2) may not allow differentiation between plastics and other sediment components, making separation from sediment particles difficult. In addition, the different salts used in density separation methods vary greatly in price, toxicity, reactivity and waste disposal. These considerations can be restrictive or prohibitive for laboratories wishing to use higher density salts.12

In this study, we will experiment with the density separation method, using a concentrated sodium chloride solution and mixing it with the sediment sample, followed by the sieving method with different sieve mesh sized, starting from the largest to the smallest.

3. Collecting samples from the surface waters of the Black Sea for analysis

3.1. Presentation of the site

The location chosen for the study is the coastal are of the Black Sea, specifically in the area of the Mamaia Footbridge, 70 meters from the shore. A plankton net was used to take a sample of approximately 500 ml using the volume reduction method (Figure 1).

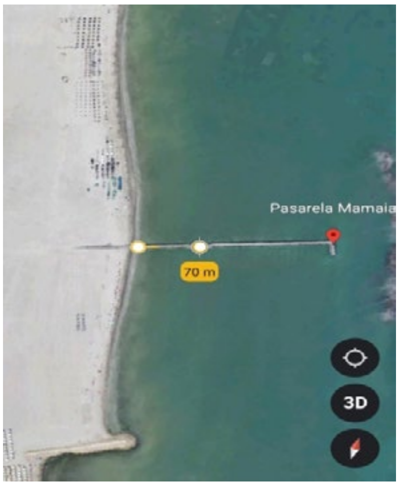

Figure 1. Mamaia footbridge: Sampling distance from the shore.

3.2. Sampling method

A water sample was taken from the water surface at a depth of approximately 30 cm using the volume reduction method by using a plankton catch net.

Reduced volume samples, for both sediment and seawater samples, refer to samples where the volume of the bulk sample is usually reduced during sampling, keeping only that part of the sample that is of interest for furter processing. [8]

In this case, for our study it used a plankton catch net with a mesh size of 80 µm, a net opening area of 130 mm (13 cm) and a ring diameter of 180 mm (18 cm). The length of the net is 65 cm and it is equipped at the end with a cylindrical collecting container and an outlet valve.

The net consists of 3 parts, as follows:

- *The towing mechanism* represents the upper part of the plankton net and consists of a chain attached to the net by a carabiner.
- *The nylon mesh* net represents the middle part of the plankton net and is generally used to filter plankton from the water sample depending on the mesh size. In addition, its funnel shape mekes it possible to effectively capture microplastics of different sizes.

At the bottom of the net, at the end of the funnel, there is a cylindrical collecting container and a valve that allows for the collected sample to drain.

Although this type of net is designed for plankton sampling, it can also be used for microplastic sampling.

The main advantage of using a net is that large volumes of water can be sampled quickly, keeping only the reduced volume sample of interest.

The most important characteristics of the sampling net are the mesh size and the opening area of the net. Most studies have used nets with mesh sizes between 50 and 3,000 µm (0.05 - 0.3 mm), but for our study we used a net with a mesh size of 80 µm (Figure 2).

Figure 2. Plankton collecting net with a mesh size of 80 µm

In marine waters, samples are generally taken from the surface layers because most mass-produced polymers (polyethylene and polypropylene) are initially buoyant and accumulate at the surface. Density values range from 0.85 to 0.95 g/cm^3 for polypropylene and from 0.92 to 0.97 g/cm^3 for polyethylene. Many other polymers (PVC, polycarbonates) are denser and more likely to sink.

The collected samples were stored in a glass container to avoid contamination with other materials or substances. Both the container and the catch net were rinsed with distilled water before sampling.

3.3. Preventing micro plastic contamination

Synthetic polymers are omnipresent in our daily lives. It is therefore of utmost importance to prevent samples from being contaminated during sampling, preparation and analysis by, for instance, laboratory equipment, synthetic fibres, clothing fibres, or airborne plastic particles that have a high potential to contaminate samples.

In order to avoid contamination of the samples, a number of safety measures have been taken both during sampling and laboratory analysis.

- All fluids used for sample preparation should be filtered and all laboratory equipment and materials should be thoroughly rinsed with pre-filtered deionised water or 35% ethanol 35% water before and during all work steps.
- To prevent airborne contamination, all materials and samples were covered with aluminum foil or glass covers during non-treatment phases.
- To avoid potential sources of contamination, all plastic equipment should be replaced with glass or metal equipment (including caps; be aware that seals may be made of synthetic polymers).
- Only non-synthetic polymer-based clothing and 100% cotton should be used in the laboratory.
- It is mandatory to work only in a clean environment (clean the laboratory of any dust).[13]

3.4. Sample processing in the laboratory

In order to process the samples in the laboratory, a quantity of approximately 300 ml of water sample taken from the area of the Mamaia Footbridge was weighed and a saturated solution of 500 ml NaCl was added on top (Figure 3).

Figure 3. Water sample collected from the Mamaia Footbridge area

To obtain the saturated solution, I weighted 180 g of salt with a laboratory precision scale. Before weighing, I placed the empty glass container on the scale and pressed the TARE key to bring the scale to 0 in order to exclude the weight of the container for proper sample preparation. I then added the salt over 500 ml of water and waited for it to dissolve. After the salt completely disolved, I added the saturated NaCl solution over 300 ml of water sample and shook it vigorously for 30 seconds, after witch I allowed the sand to settle down for 5 minutes.

Since the density of plastics (0.8 g/cm3 - 1.4 g/cm3) is much lower than that of sediments (2.65 g/cm3), the use of a saturated NaCl solution to promote the deposition of heavier sediments and the lifting of lighter plastic particles is commonly used in studies regarding the separation of plastics from fluids. After stirring, the sediments are prone to settle rapidly to the bottom of the container, while the lower density particles remain in suspension or float to the surface of the solution. Subsequently, the supernatant with the plastic particles is extracted for further processing.

- *Sieving*

Following the density separation process I sieved the sample through a sieve with a mesh size of 0.02 mm.

Although some studies use a sieve stack with varying sieve mesh sizes, for this study I chose only one sieve with a mesh size of 0.02 mm because the sample contained no visible particles of belonging to the macroplastics class.

After sieving the sample, we rinsed the sieve with distilled water and obtained a small amount of fragments which we scraped off the surface of the sieve with a stainless steel spoon (Figure 4). We rinsed with distilled water and dried a small glass continer into which i transferred the sample for further analysis using a binocular microscope.

Figure 4. Transfer of sieved sample for futher sorting and analysis

- *Sorting and visual separation*

Visual examination of concentrated sample residues is a mandatory step. Careful visual sorting of the residues is necessary to separate plastics from other materials, such as organic debris (shell fragments, animal parts, dried algae or seagrass, etc.) and other items (metallic paint, coating, tar, grass, etc.). This is done by examining the sample directly with the naked eye or using a binocular microscope. Further processing involves extracting the fragments of interest using tweezers to analyze them under the microscope in order to determine whether they belong to the category of micro plastics or not.

Some particles in the sample were identified as pieces of expanded polystyrene and degraded plastic sheets (Figure 5), both falling into the category of micro plastics with lengths smaller than 5 mm.

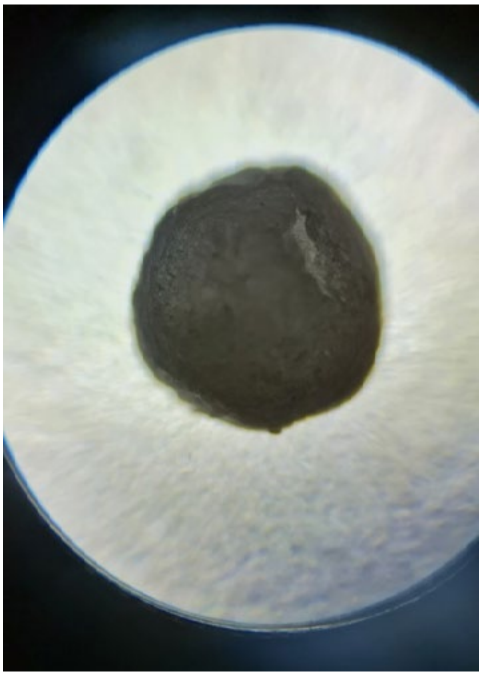

Figure 5. Expanded polystyrene viewed under the microscope

4 Sediment sampling from the Black Sea sandy beaches for micro plastic analysis

4.1. Presentation of location

For the sediment study, sampling was also conducted in the Mamaia Footbridge area, in the littoral zone, from the sand surface, in the immediate vicinity of the supralittoral floor. The supralittoral zone is made up of areas of the shoreline covered or splased by waves. Due to its nature, the area has high humidity, flooding, generally high or at least significant amounts of organic matter carried by waves or local origin.

Sandy beaches are cherecterised by their uncontrollable dynamic nature and their structure is influenced by wind, sand, precipitation, varying rates of sun exposure, sea wave action and constantly moving water. Marine beaches and costal areas are very often subjected to considerable anthropogenic pressure due to their recreational function and the holiday activities of millions of tourists, mainly in the summer season.14

All these factors contribute firstly to the pollution of beaches with plastic material, either carried by waves or originating from land, and secondly to the fragmentation of these materials and their distribution caused by both site-specific weather conditions and the natural regime of the sea and waves.

Therefore, a significant amount of plastic materials can be found on sandy beaches and the phenomena contributing to their degradation are of significant importance in terms of the distribution and size of these debris.

4.2. Sampling method

Sampling was conducted on an area of approximately 50 cm2 using an iron shovel and the sample was places in a glass container. Both the container and the shovel were previously rinsed with distilled water.

Since beaches and tidal coastal habitats are dynamic systems with continuous and seasonal erosion of sediments, microplastics may be buried in the sediments during periods of accumulation.

4.3. Sample processing in the laboratory

A combined method of extracting plastic from the sample by the density separation method using a saturated NaCl solution, followed by the use of sieves with variable mesh sizes (0.02 mm to 0.02 mm), was used to process the samples in the laboratory in order to extract and analyse both macroplastic and microplastic.

The sediment sample was weighted using a laboratory scale. The total weight of the sample was 411 g. Before weighing, we placed the empty glass container on the scale and pressed the TARE key to bring the scale to 0 to exclude the weight of the container for proper analysis of the sample (Figure 6).

Figure 6. Total weight of the sediment sample

For further laboratory analysis it used about half of the original sample, meaning 200g (Figure 7).

Figure 7. Sample used for further analysis

180 g of NaCl were weighed in a glass container using the same method and prepared a saturated solution of NaCl by pouring the previously weighted salt into 500 ml of water. Saturated sodium chloride solution was poured over the sediment sample and stirred with a glass rod to propel the micro- and macro-plastics to the surface (Figure 8).

Figure 8. Sample obtained after mixing and settling

The sieve stack was prepared as follows: the 2 mm mesh sieve was placed over the 0.02 mm mesh sieve. Both were then placed on top of a stainless steel container to sift out the micro and macro plastics and also to collect the saturated solution. The collected solution will be used to repeat the process from the beginning to get as much plastic as possible.

The saturated solution mixture was poured over the sieve stack, allowing only the floating mixture to be sieved, and the deposited sediment was kept in the original glass container for further processing. Over the settled sediment remaining in the container, the saturated solution remaining after the first sieving was poured and mixed again with the glass rod to release any particles that may have been contained (Figure 9).

Figure 9. Sediment sample in saturated solution and sieve stack

This process was repeated 3 times until no more fragments were visible on the surface of the solution (Figure 10).

Figure 10. Sieving the sample through meshes of 2 different sizes

4.3. Visual sorting and separation and by using a binocular microscope

After sieving, the surface of the sieves together with the contained fragments was rinsed with distilled water. The visible plastic pieces were separated from the organic matter with a trivet and collected in a smaller glass container (Figure 11).

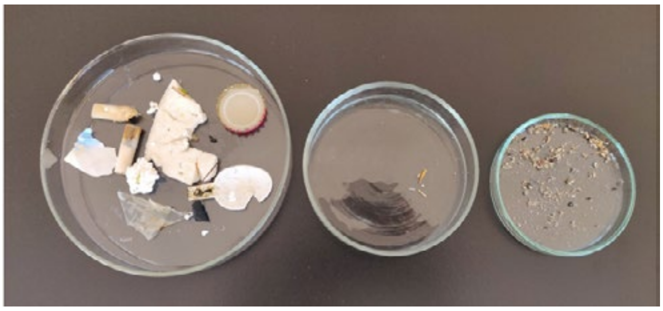

Figure 11. Separating macro and micro plastics

The same process was repeated for the 0.02 mesh sieve, then the remaining fragments were scraped from its surface with a spoon and then everything was transferred to a smaller glass container for further microscopic analysis.

A binocular microscope with 10X, 40X, 100X magnification was used to identify and sort the micro plastics (Figure 12).

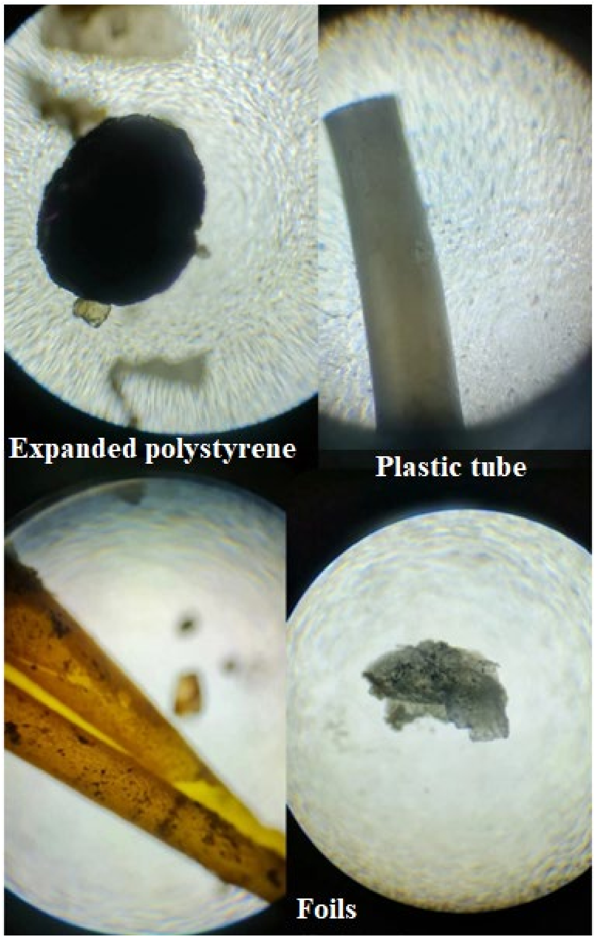

Figure 12. Micro-plastic identification under the microscope

Plastic particles predominantly found were represented by polystyrene foam, shredded plastic sheets and other plastic items such as tubes or microfibres. Most of the identified plastics belonged to the category of macroplastics wih sizes larger than 5mm. Also, considerably more plastics were found in the sandy environment compared to the marine environment.

Sampling of both sand and water took place in June, at the beginning of the summer season. Altough not much time has passed for plastic articles to accumulate on the beaches as a result of anthropogenic activities, a considerable amount of plastic has nevertheless been found on a relatively small area, thus emphasising the seriousness of the human impact on the environment.

The lack of higher quantities of plastics in the marine environment can be attributed to a number of factors such as: weather conditions, state of the sea, season, sampling location, sampling only from one location etc..

This study aimed to experiment with the main methods for filtering and determining the presence of plastics in both fluids and sediment. The results confirmed the presence of plastics in both environments, with the sandy environment accumulating considerably more plastics than the marine environment. However, the overwhelming presence of micro and nano plastics in the marine environment proven by countless studies cannot be overlooked.

Therefore, the development and standardisation of techniques for collecting and determining the presence of plastics in all types of media is absolutely necessary and more studies need to be carried out in this regard.

5. Conclusions

The methods used were those mentioned in most of the studies as being the least expensive and most convenient and involved sampling methods using common equipment found both in the laboratory (plankton net, sieve) and in most homes (shovel, glass containers, spoon, tweezers). The method of separating microplastics by density using a saturated NaCl solution was one of the most commonly used methods in all studies,, both for water samples extracted from the surface and for sediment.

Although some studies have presented much more advanced methods for separating microplastics from sediments and water, the method chosen has had clear results in confirming their presence.

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System design and implementation of modular offshore marine buoy to collect environmental marine data

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Abstract

With the development of today's technology, the need for unmanned or remotely controlled systems is increasing. With this development in the maritime sector, unmanned or remotely controlled designs used for military and civilian purposes have emerged in recent years. Under the Scientific and Technological Research Council of Türkiye (TÜBİTAK) 2209-B project, this study has been carried out to provide a more detailed and dependable collection of maritime environmental data. The primary goal of this study is to develop and deploy smart buoys that can continuously monitor environmental conditions. The novel and intelligent buoy gathers information on variables like humidity, air temperature, atmospheric pressure and light intensity near the sea surface and communicates with a central system. The marine buoy is outfitted with meteorological sensors and communication devices. Air and water temperature, humidity, air pressure, and light intensity were measured simultaneously and transmitted to the station on land. The data obtained were processed and analyzed comparatively. At the same time, thanks to its modular structure, this buoy is upgradable and aims to support local production by supporting the infrastructure of other autonomous systems.

Keywords: *Marine buoy, Intelligent system, Sensor, Weather data*

1. Introduction

In contemporary times, the real-time monitoring of weather and environmental conditions holds immense significance across various sectors. Particularly within the maritime domain, the ability to predict fluctuating weather patterns and access instant weather data is crucial for ensuring safe navigation, efficient ship operations, and overall maritime industry functionality. Within this framework, the implementation of smart buoy systems, aimed at collecting, analyzing, and disseminating marine weather data, emerges as a robust solution.

Leveraging meteorological observation technology embedded within marine buoys will not only advance the theoretical understanding but also foster technical advancements in marine meteorological detection, thereby addressing the evolving dynamics of weather and climate environments. By enhancing the capacity for marine meteorological monitoring and forecasting, the initiative seeks to bolster protection against severe weather conditions, mitigate atmospheric environmental degradation, and facilitate the rational utilization and development of climate resources and meteorological conditions [1,2]. Weather monitoring stations]3] are located near the coasts of Türkiye as shown in Figure 1.

Figure 1. Weather monitoring stations

Furthermore, the establishment of an academic exchange platform facilitates the exploration of novel ideas, methodologies, and technologies in this domain. The project's innovative features include a modular structure allowing for easy sensor replacement, smart data processing enabling instant analysis and alert generation, remote access and monitoring capabilities, durability, adaptability to varying sea conditions, and seamless data integration. Figure 2 shows the concept design of the weather monitoring station. These attributes positively impact industrial R&D endeavours, enhancing the technological value and quality of weather measurement systems. Ultimately, the outcomes of this project hold significant implications for the maritime sector, weather forecasting agencies, and coastal safety measures. Wireless sensor networks have emerged as a promising technique for monitoring marine environments, owing to their advantages such as easy installation, real-time monitoring, automatic operation, and cost-effectiveness [4,5]. Weather monitoring station concept design is demonstrated in Figure 2.

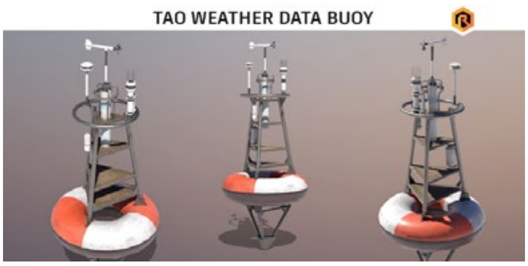

Figure 2. Weather monitoring station concept design [6]

2. Methodology

This research involved conducting solid modelling, installing electronic systems, integrating sensors, and conducting tests. Subsequently, the experimental setup underwent rigorous testing, leading to the acquisition of experimental data.

2.1. Solid Modelling and Stability

The model can be analyzed in three distinct sections: the top floor, the electronics floor, and the reel part, arranged from top to bottom. Figure 3 illustrates the solid model of the platform along with its design components. Stability calculations for the platform were performed using the stability software. The densities of the various components of the platform were inputted into the program, and the results are presented in Figure 4. The seawater density used for these stability calculations was determined to be 1025 kg/m³.

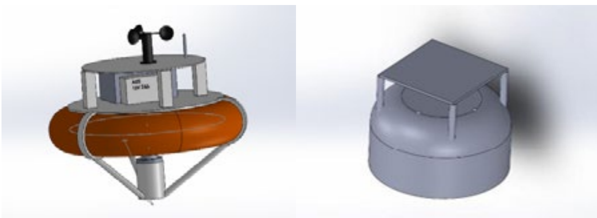

Figure 3. Platform solid model and design [6]

	Measurement	Value	Units
1	Displacement	12,57	kg
2	Volume (displaced)	0,012	m^3
3	Draft Amidships	0,295	m
4	Immersed depth	0,295	m
5	WL Length	0,717	m
6	Beam max extents o	0,717	m
7	Wetted Area	0,459	m^2
8	Max sect. area	0,026	m^2
9	Waterpl. Area	0,262	m^2
10	Prismatic coeff. (Cp)	0,650	
11	Block coeff. (Cb)	0,081	
12	Max Sect. area coeff	0,835	
13	Waterpl. area coeff.	0,509	
14	LCB length	0,000	from z
15	LCF length	0,000	from z
16	LCB %	-0,001	from z
17	LCF %	-0,003	from z
18	KB	0,262	m
19	KG fluid	0,310	m
20	BMt	0,917	m
21	BML	0,914	m
22	GMt corrected	0,869	m
23	GML	0,866	m
24	KMt	1,179	m
25	KML	1,176	m
26	Immersion (TPc)	0,003	tonne/c
27	MTc	0,000	tonne.
28	RM at 1deg = GMt.Di	0,191	kg.m

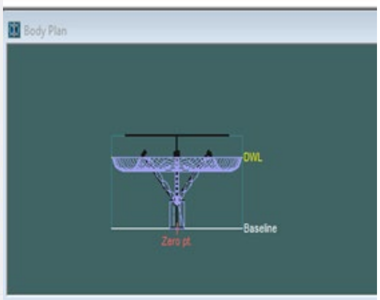

Figure 4. Stability calculations and results of the design

2.2. Electronics and Software

The sensors and additional electronic elements designed for the platform were predetermined and subjected to individual testing. Subsequently, all electronic components were integrated, and requisite software was developed to ensure their synchronized operation. For humidity and temperature measurements, the DHT22 sensor was employed [7]. Before constructing the circuit, a schematic diagram was drafted using Fritzing software for microcontroller [8], as depicted in Figure 3.

2.3. Sensor Data Acquisition and Testing

Once the circuit diagram was finalized, the circuit was assembled to verify its functionality. Initially, the power supply necessary for sensor operation was connected, followed by establishing the connections enabling communication between the sensor and the microcontroller. Subsequently, the interface was linked to one of the analog input ports of the Arduino controller. Finally, a USB cable was employed to connect the Arduino to the computer for programming and configuring the sensor. Subsequently, the coding process commenced using the Arduino IDE software. Essential libraries were downloaded to facilitate the reading of data transmitted from the established circuit. The required code was structured based on relevant examples sourced from online resources. This software primarily interprets the analog pin values. Data retrieved from the sensor was then displayed on the serial port screen. It was observed that the readings were accurate, affirming the successful operation of both the sensor and software. Following the completion of the circuit diagram (Figure 5), all components were interconnected as per the schematic to verify the system's functionality.

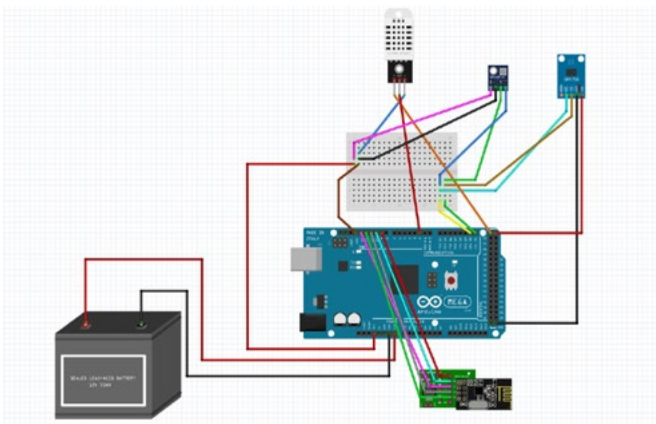

Figure 5. Sensor circuit diagram of transmitter side

3.2.4 Data Transfer

Radio frequency (RF) communication was chosen as the method for data transmission. To accomplish this, NRF24L01 receiver and transmitter modules were utilized. Circuit schematic for these modules were designed using Fritzing software. Subsequently, the necessary components were gathered and transported to the project site, where their connections were established with the aid of cables. This process enabled the creation of circuit diagrams for both the transmitter and receiver modules, as depicted in Figure 6.

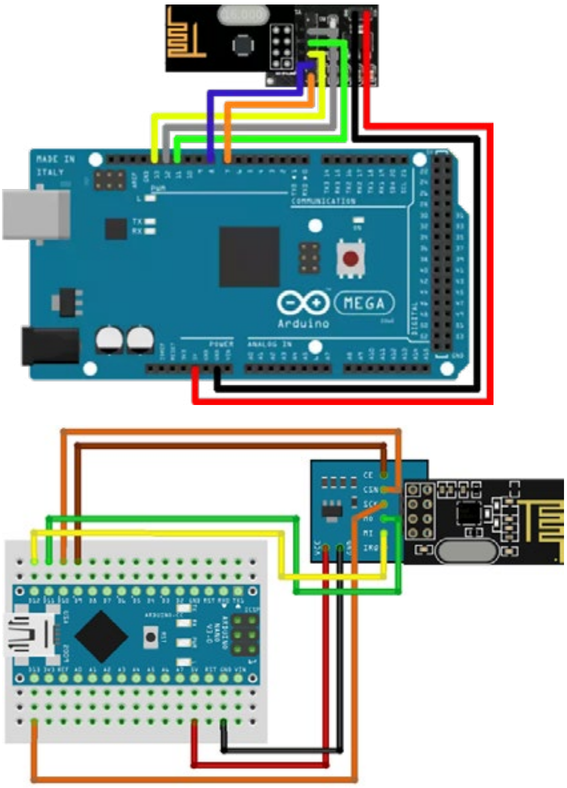

Figure 6. Transmitter and receiver circuit diagram

Following the completion of the circuit diagrams, the transmitter and receiver circuits were assembled to verify the functionality of the system. Pins on the NRF module were connected to the respective ports of the microcontroller using cables. Subsequently, a connection was established between the microcontroller and the computer to proceed with the coding phase. Arduino IDE was utilized for coding, and the necessary libraries required for circuit operation were incorporated beforehand. Pins were defined according to the specifications outlined in the circuit diagram. Additionally, the communication channel through which the modules would interact with each other was specified. Finally, a message was transmitted from the transmitter module and successfully displayed on the serial port screen of the receiving module, affirming smooth and accurate transmission.

4. Results

Within the scope of the study, the aim is to conduct measurements using sensors with the assistance of electronic components. These measurements encompass humidity, wind, air and water temperature and light intensity. Initially, these values were measured at the seashore, and the data obtained from the sensors was wirelessly transmitted to the remote user as previously planned. Values sent by the data platform initial and measurement with time intervals are shown in Table 1 and Table 2, respectively. The obtained data were processed and evaluated.

Table 1. Initial Actual Data Log from Transmitter of Microcontroller

No	Time	Temperature (C)	Humidity (%)	Pressure (hPa)	Light Intensity (lux)
1	10:04:18	14.10	67.3	1016.63	97.50
2	10:04:28	14.10	67.3	1016.60	107.50
3	10:04:38	14.10	67.4	1016.58	138.33
4	10:04:48	14.10	68.1	1016.58	115.00
5	10:04:58	14.10	69.1	1016.60	162.50
6	10:05:08	14.10	70.5	1016.65	155.00
7	10:05:18	14.20	69.4	1016.62	20.00
8	10:05:28	14.20	68.5	1016.64	41.67
9	10:05:38	14.20	68.3	1016.66	115.83
10	10:05:48	14.30	68.8	1016.67	106.67
11	10:05:58	14.30	68.5	1016.65	149.17
12	10:06:08	14.40	68.2	1016.63	145.00
13	10:06:18	14.50	68.0	1016.65	145.83
14	10:06:28	14.50	68.1	1016.63	140.00
15	10:06:38	14.60	67.8	1016.58	119.17
16	10:06:48	14.60	67.3	1016.63	140.00

Table 2. Data Log deviation points with time intervals

No	Time	Air Temperature (°C)	Water Temperature (°C)	Humidity (%)	Pressure (hPa)	Light Intensity (lux)
1	10:05:08	13.10	14.46	70.5	1016.65	155
2	10:10:08	12.90	14.55	68.2	1016.61	5848
3	10:15:08	12.20	14.54	70.5	1016.79	5699
4	10:20:08	12.20	14.60	70.1	1016.76	6763
5	10:24:17	12.20	14.68	69.9	1016.75	5915
6	10:30:17	12.20	14.68	69.9	1016.75	5680
7	11:50:08	17.90	15.88	57.9	1016.19	2235
8	11:55:18	18.00	16.00	52.9	1015.17	33314
9	12:00:28	19.40	16.10	49.9	1015.10	32585
10	12:20:11	22.20	16.14	41.2	1016.23	12938
11	12:25:01	21.30	15.90	54.0	1016.58	5151
12	12:30:51	20.40	15.74	56.9	1015.22	47357

Marine buoy on the sea, data logging process and position data image are shown in Figure 7.

Figure 7. Marine buoy on the sea, data logging process and position data image

Measurements were taken at 10-second intervals and saved to an Excel file for 2 hours and some regions which has more deviation in temperature measurement are chosen for graphs to see the change in weather situation. The temperature was measured with an external thermometer and a difference of 0.5 °C was observed between the temperature sensor values. This can be considered as tolerance. Looking at the humidity data from meteorological sources, the measured location had humidity levels around 55%-70%. This margin of error is also acceptable given the conditions at the time. The values obtained from the sensors in seashore conditions were satisfactory. Collected data samples are shown below in Figures 8, 9, 10, 11, and 12.

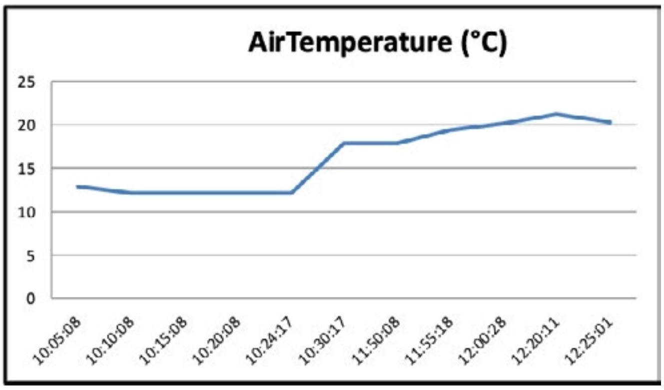

Figure 8. The air temperature for a 2-hour timeline taken from the data log

In Figure 8, temperature increases in a 2-hour time interval as expected.

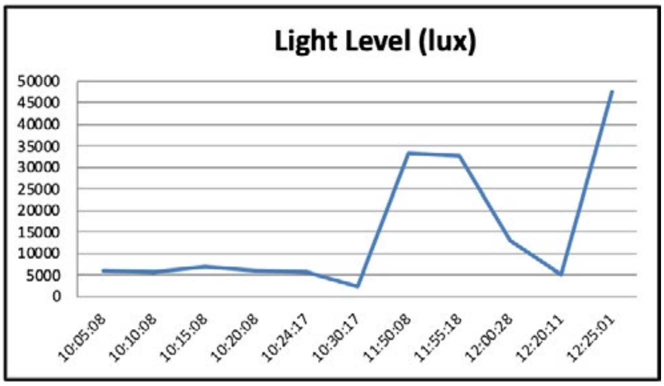

Figure 9. The light intensity for a 2-hour timeline taken from the data log

In Figure 9, it has been observed that the values we take from the light sensor, which gives low values when the weather is cloudy, increase when the weather is clear. The next step will be adding a UV intensity sensor for UV light measurements.

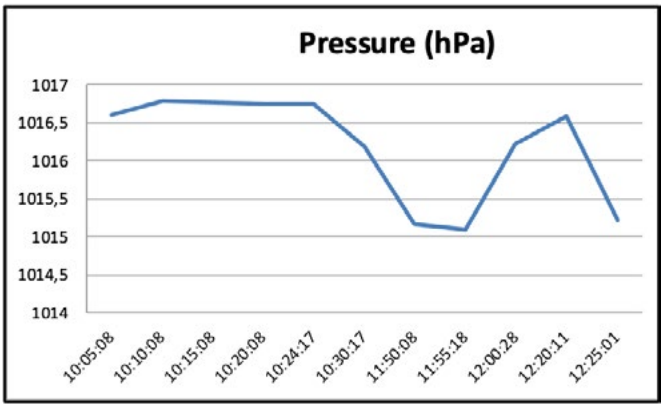

Figure 10. Pressure for a 2-hour timeline taken from the data log

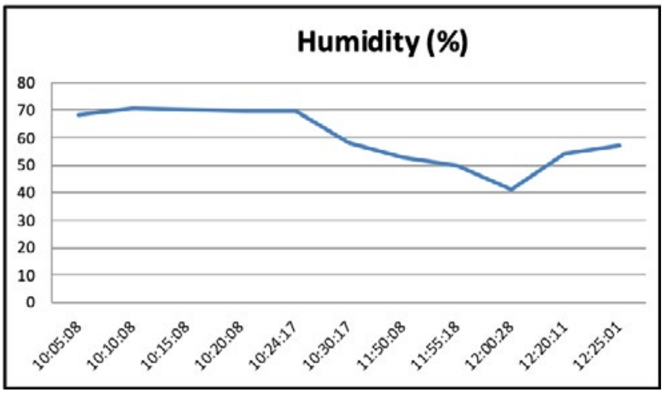

Figure 11. Humidity percentage for a 2-hour timeline taken from the data log

When the data shown in Figures 10 and 11 were analyzed together, the reliability of the sensors was tested, considering the weather conditions during the measurement process.

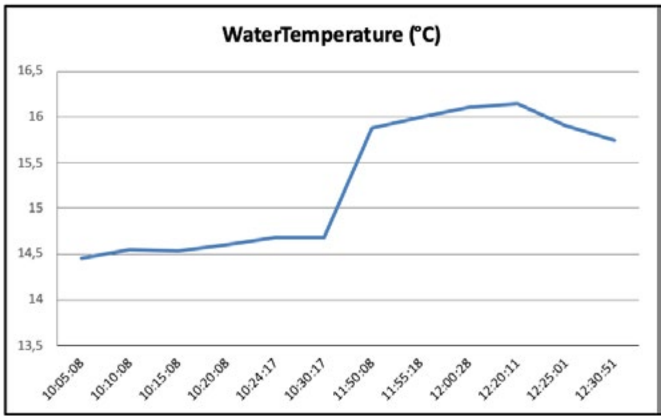

Figure 12. Water temperature for a 2-hour timeline taken from the data log

The water temperature rises as the air temperature increases but as shown in Figure 12 this process is very small (due to the specific heat of water) compared to air temperature.

5. Conclusion

The study and project aimed to enhance data accessibility in maritime operations by addressing challenges in data transfer through modern technology. By establishing a system for remotely accessing weather data from any location, the project sought to streamline access to real-time weather conditions. The study involved a thorough examination and installation of individual sensors and followed by comprehensive testing of wireless communication in diverse environments. Sensors were evaluated under various conditions and times to ensure accuracy. Field testing at sea was conducted to assess the platform's performance, including buoyancy and waterproofing tests. Data regarding temperature, wind speed and humidity were collected under offshore conditions. The project also proposed future developments including modular enhancements to the buoy platform for overall improvement. Additionally, there are plans to explore electricity generation from water tides for battery charging in future iterations. It aims to benefit Turkish marine transportation.

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Comparing the Ship Recycling Process for Different Countries: A Comparative Study of Türkiye, Bangladesh, and India

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Abstract

The process of ship recycling involves extracting the ship's raw material and making it usable, a task that requires a significant amount of energy. This process also poses a threat to public health and the environment due to the emission of harmful gases. To mitigate these risks, old (completed economic life) scrapped ships are recycled in ship recycling yards, where ready-made raw materials are reused. This practice, prevalent in the ship dismantling sector and many other sectors, is crucial for reducing the environmental impact of ship recycling.

The fact that current problems in ship recycling are on the public agenda from time to time and that this agenda has a direction that will affect decisions in ship recycling is one of the situations that reveals the importance of the study. This paper uses SWOT analysis to examine ship recycling processes in Türkiye, Bangladesh, and India, recognised as prominent nations in the recycling industry. This study compares and evaluates the present dismantling procedures, and the objective is to identify the best practices and areas that need development in these countries. Implementing universal and effective ship recycling protocols globally can decrease environmental consequences and enhance the sector's competitiveness. The comparative analysis serves as a crucial initial step in comprehending the disparities and advancements in sustainable ship dismantling on a global scale.

Keywords: *Ship recycling, dismantling, Sustainable ship recycling, Comparative analysis.*

1. Introduction

The shipping industry plays a great role in global trade, transporting goods worldwide. The importance of the sector can be emphasized by reminding the information that 80% of the trade is done by sea, which adorns the beginning of many articles written about the maritime sector [1]. According to the UNCTAD (2023) report, global shipping markets are affected by various factors that determine the demand for shipping in 2022 and early 2023, such as ship-carrying capacity, economic developments, market sentiment, freight rates, financial liquidity, shipbuilding capacity and ship recycling activity [1]. The global economy's slow recovery and the influx of newly constructed ships, commissioned before the financial crisis, have led to a significant downturn in the shipping sector, resulting in a surplus shipping capacity and a robust growth of the ship recycling industry [2].

On the other hand, due to the challenging environment of the ship's lifecycle, when it comes to its end, dismantling and recycling vessels has become a crucial concern within the maritime domain, affecting the environment, health, and economy. Ship recycling may contribute to a circular economy; however, concerns arise when developing countries engage in shipbreaking activities without adhering to established ecologically favourable ship recycling standards [3].

Ship recycling also mitigates the environmental impact and ecological harm resulting from mining raw materials. Ship recycling is regarded as an ecologically sustainable sector and is recognised as a green industry by the International Maritime Organisation (IMO)[4]. Ship recycling allows for extracting materials from many ship components, including the hull, steel superstructure, decks, structural bulkheads, hatches, holds, supports, masts, control surfaces, cargo machinery, and other equipment. Research on the ship recycling design approach indicates that 96% of the entire weight of ships may be recycled [5]. The ship recycling sector, which stands out with its high tempo, also fosters competition. Ship recycling is considered among the industries that protect the environment as a "green industry", and it is stated that it plays an active role in preserving the ecological balance. The conversion process is the most "Environmentally Friendly" way to dispose of ships that have reached the end of their operational life. It is possible to recycle almost all the materials in the ship or reuse all the materials removed. While ship recycling provides positive added value to economies, it poses serious risks to health and safety. Around 90% of ship recycling operations worldwide are in Bangladesh, China, India, Pakistan, and Türkiye [6].

This study uses a comparative analysis of the ship recycling industry in India, Bangladesh, and Türkiye. The strengths and weaknesses of the ship dismantling sector in these countries will be emphasised, and the sector's opportunities and threats will be evaluated under these countries' conditions. A study from the field of law examining the place of ship recycling in India in the current legal regime states that it does not conflict with the Hong Kong Convention [7]. However, it is a matter of debate whether ship recycling in India fully complies with the principles that are the target of the Hong Kong Convention.

Despite its rudimentary nature and lack of human and environmental safety measures, Bangladesh and India employ beach dismantling as a ship dismantling method. Despite their negative impact on the environment and worker safety, these countries' low labour prices, geographical circumstances, and geological features make them desirable for ship recycling operations [8]. On the other hand, Türkiye (and China) are pioneers in establishing reasonably reliable criteria for security measures and environmental protection [9].

2. Literature Review

The ship recycling industry has seen significant advancements in recent years, with international organisations like the International

Maritime Organisation (IMO), the International Labour Organisation (ILO), and the European Union (EU) addressing pollution prevention, safety assurance, and human health protection. The Basel Convention, implemented in 1989, addresses regulations for transferring dangerous substances from dismantling ships [10]. However, it is considered inadequate because it lacks a comprehensive deconstruction process. In response, the IMO adopted the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (HKC) in 2019, which covers all aspects of ship recycling, including disposal and transportation of hazardous materials, working conditions at recycling facilities, and environmental effects [11]. The HKC will require stricter procedures for both ship recycling facilities and commercial ships, including the implementation of the Ship Recycling Facility Plan (SRFP), contingency plans, systematic information documentation, and an integrated framework for recording and communicating emissions, accidents, incidents, occupational diseases, and adverse effects on worker safety and the environment.

The literature examines ship recycling activities with various focal points. These focal points contribute to the research by providing the opportunity to examine the subject more holistically.

Past and recent studies with an economic perspective provide important data on the state of the market. In one of these studies, Knapp and her colleagues (2008) applied econometric modelling to the data set they obtained to provide information about the dynamics of the ship recycling market. The data set in the modelling applied in this study conducted in 2008 contains information about 51,112 ships over 100 GT and covers 748,621 events over a 29-year period [12]. At the end of this comprehensive analysis, it was predicted that the possible implementation of the contract valid at the EU level would most likely affect Türkiye, and failure to approve one of the major flags would most likely affect China or Bangladesh. In another comprehensive literature study, sixteen active authors in ship recycling research were divided into four stages according to the number of publications; Kurt R.E is ahead with eight releases [13]. Starting the literature review from the old date allows us to purify our research from similar mistakes by seeing which mistake was made if a wrong prediction was made and by having the opportunity to verify or falsify the predictions and predictions reached as a result of the research.

In another study examining the research in the literature, Rahman (2020) concluded that environmental, economic and social dimensions should be considered together in terms of the sustainability of the shipbreaking sector [14]. In the 183 articles examined, it is seen that there are two types of headings expressed as “ship recycling” and “ship breaking”. A broader search can be performed by adding “ship dismantling” to this heading. In addition, this study points out that policy developments in the sector are limited due to the lack of interdisciplinary studies. Therefore, more research is needed to understand the sustainability dimensions in the sector better and improve policy developments.

When existing studies are categorized, the subject is examined under environmental sciences, environmental engineering safety management, and economics. In addition, developing a model that considers social, economic, and environmental dimensions will contribute to the reliability of the research.

Various procedures were followed in the studies. Some tools were used to facilitate the literature search. Using Nvivo qualitative data analysis software, the scope of the study was determined, a literature review was carried out, a category was selected, and the material was evaluated. In another study, Rahman (2020) states that the main criticism of the ship recycling industry is that the dismantling of end-of-life ships to meet the steel demand is mostly carried out in South Asian countries, and the environmental, social and economic sustainability dimensions of this process are not adequately addressed.

In another systematic review study, Dey et al. (2021) analysed 286 studies in the literature under the headings of “environmental, economic and social obstacles” regarding sustainability and “dimensions that facilitate implementation such as law-policy, technology and management”[15]. As a result of these analyses, it was determined that more interdimensional research is needed to develop policies and micro-management facilitators that facilitate circularity. The study also states that the ship recycling sector causes environmental damage and faces difficulties such as occupational health and safety risks and socio-economic injustices. Here, once again, the importance of making the perspective of our research inspired by a socio-technical perspective is understood.

3. SWOT Analysis

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is a widely used approach for the strategic planning tool, which gives a comprehensive analysis of processes or industries. This study used a SWOT analysis to evaluate and understand the ship recycling process for the prominent countries in the world ship recycling industry. Swot, used in studies in the ship recycling sector, allows the internal and external dynamics of the sector to be determined accurately [16].

SWOT is a comprehensive compilation of statements or factors that delineate the internal and external milieu’s present and future trajectory. Nevertheless, SWOT analysis provides a convenient method for comprehensively evaluating a situation. This aims to allow a particular focus group to assess the advantages, disadvantages, potential benefits, and potential risks associated with implementing a specific strategy [17].

Dyson (2004) claimed that the relationship between SWOT analysis and different techniques shows that SWOT is a flexible model that can be combined with newer approaches [18]. Therefore, using SWOT to evaluate their position in the analysis of facilities can continue for a long time [19]. Research in the field of literature supports the validity of this prediction.

This study uses expert interview methodology to collect information. The primary input of the SWOT analysis was obtained from information obtained from interviews with relevant experts and studies in the literature. Expert interviews are widely used to gather information. They offer valuable insights and knowledge in the relevant field and are considered an effective and focused data collection method, especially during the discovery phase. In this context, interviews were held with experts in ship recycling.

Various data sources, including public and research institutions, regulations, public information requests, and NGO reports, were used to assess the status of ship recycling using a broad methodology [20].

4. Comparative Analysis and Findings

This section provides an overview of the countries' practices in the ship recycling process. Then, the SWOT analysis of the ship recycling industry is evaluated to gain an understanding of this industry.

4.1. Overview of the Countries

These prominent countries in the ship recycling industry represent various approaches and processes in the maritime domain.

4.1.1. India

In 2019, and based on the Hong Kong Convention, 2009, the Ship Recycling Act 2019 was enacted, which covers aspects of ship recycling in India that are not covered by the 2013 Act. After it was declared that the ship recycling capacity in India would triple from 2021 to 2024, the number of ships imported from Europe and Japan increased [21].

The 2013 Rules mandate ship recyclers to comply with various laws and regulations. focuses on health and environmental compatibility. It also mandates the safe disposal of hazardous materials from ship recycling activities and requires State Pollution Control Boards to monitor air quality near ship-breaking facilities. The permitted beaching method for ship dismantling aligns with the Hong Kong Convention, 2009. However, India has not ratified the Basel Convention Ban Amendment, which does not apply to the ship recycling industry [7].

India's ship recycling market share has declined since 2016, while Bangladesh's has quadrupled due to regulatory restrictions and increased demand for steel scrap [22]. In Bangladesh, shipowners can recover 30-40% of a ship's value through recycling, compared to 1-2% in India. Three main initiatives are considered crucial to revive the demand in the ship recycling industry in India: relax BIS standards to increase steel production per tonne of scrap; redevelop the Alang areas and create a ship repair cluster; and establish a facilitation centre to promote the Indian ship recycling industry through trade fairs and exhibitions [23].

4.1.2. Bangladesh

Ship recycling includes disassembling a retired ship. The ship is stranded and cut, and precious materials are extracted and reused. Shipbreaking in Bangladesh began in 1960 when a powerful cyclone grounded the Greek ship MD Alphin near Shitakunda, Chattogram[24]. Chittagong Steel House bought and scrapped the ship after this tragedy. This started Bangladesh's shipbreaking industry. Karnaphuli Metal Works Limited bought Al-Abbas, a bombed Pakistani ship, in 1974, marking another milestone. This company scrapped the ship to start Bangladesh's commercial ship-breaking industry. In a study discussing Bangladesh's ship recycling prospects, the authors stated that almost 100% of materials and equipment collected from ship dismantling in Bangladesh are recycled. Regardless of the probability of this ambitious rate, such a high rate demonstrates the importance of ship recycling [25]. Another study studied the impact of mega-scale shipbreaking yards in Bangladesh on soil and product quality, revealing the spatial-temporal dynamics and associated health risks of metal/loid contamination [26]. The shipbreaking industry generates around 50,000 jobs, around 150 yards along the coast north of Chittagong. However, working in these yards is dangerous, involving human health risks, accidents, and a lack of basic equipment. Most workers are under 22 years old, illiterate, and have no other job alternatives. The government has not recognised the industry as an industry, and industry-based labour laws do not apply [27].

4.1.3. Türkiye

Türkiye, which has the world's fourth largest ship recycling facility, currently carries out ship dismantling activities using 22 systems in Aliağa District of İzmir. Türkiye has been granted an exemption under the European Recycling Regulation, which mandates that only EU-flagged ships can be dismantled if on the EU Ship Recycling list. Eight facilities are listed on the EU Commission Ship Recycling List, and an additional nine facilities have submitted applications for EU membership [28]. Türkiye has the potential to achieve sustainable ship recycling and steel production due to its geographical position and industrial capabilities. Nevertheless, more stringent regulation, enforcement, incentives, and a clear vision are needed to realise its potential fully. When comparing the active shipyards and ship dismantling facilities in Türkiye between 2003 and 2022, the number of shipyards, which was 37 in 2003, increased by 127% to 84 in 2022[29].

Table 1. Dismantling Statistics Per Year [30].

Year	Number of Ship	Gross tonnage
2009	73	557
2010	127	659
2011	238	1.067
2012	281	1.541
2013	232	1.370
2014	203	978
2015	113	752
2016	121	752
2017	189	971
2018	158	1.030
2019	128	1.060
2020	118	1.776
2021	112	1.441
2022	86	1.012
2023	66	564

4.2. SWOT Analysis Results

The SWOT analysis conducted on the ship recycling industries in Türkiye, Bangladesh, and India revealed valuable insights into the industries' strengths, weaknesses, opportunities, and threats. Table 1 evaluates the findings from the SWOT analysis.

Table 2. SWOT Analysis of Countries

SWOT	Bangladesh[31]	India[26]	Türkiye[32]
Strengths	• Lowest-cost global workforce. • Competitive prices at local shipyards. • Disciplined, diligent, hardworking maritime workforce. • Skilled labour produced by vocational training centres and technical institutes. • SMEs contribute to heavy industries. • Classification societies support export shipbuilding industry expansion.	• Countries such as India, Bangladesh, and Pakistan, which are developing economies in South Asia, benefit from their geographical advantage of having a high tidal level. • Availability of inexpensive labour • Environmental Policies and Regulations • Taxation Presence of ample open spaces • Support from government • Manage and operate large vessels	• Labor Potential and Worker Wages • Ship Recycling in Compliance with International Rules and Regulations • Use of Recycled Materials Proximity to Facilities and Sub-Industry • Waste Management
Weaknesses	• Gap between industrial needs and mass education curriculum. • Lack of awareness among policy planners and bankers. • Limited production of class approved MS plates, frames, beams, reinforcements, and longitudinals. • Image crisis in EODB discouraging foreign direct investment. • Lack of technical expertise and government financial support.	• Insufficient infrastructure • Inadequate training for the purpose of enhancing skills. • Insufficient criteria and recommendations • Lack of appropriate facilities for the disposal of hazardous materials • Financial support for enhancing organisational capabilities	• Insufficient public and press relations. • Premium shipping prices compared to South and East Asia. • Facility expansion response. • Insufficient funds and resources. • Opposition to global technological advancements. • Absence of government assistance.
Opportunities	• Potential for global market share capture and foreign currency earnings. • Increased employment opportunities with trainable workforce and abundant resources. • Potential geopolitical and financial crises to boost low-cost ship demand. • Growth of backup industries for local shipbuilding and foreign collaboration.	• SMEs directly demand ferrous and non-ferrous materials. • Indirect market opportunity • Decarbonisation is achieved by implementing sustainable practices in ship recycling. • Minimise the financial and legal responsibility associated with using new materials • Certification for ship recycling yards • Stimulate the economic growth at both the local and national levels. • Improve the overall prosperity of society	• Expected increase in ship scrap due to global slowdown. • Top facility for EU ship recycling regulation. • Exclusive European ship breaking industry due to geographical proximity. • Entrepreneurial structure of Turkish people. • Young population. • Increase in ship owners selling for recycling due to pandemic.
Threats	• Lack of government, stakeholder, private initiatives. • Potential threats: competition, reliance on imported raw materials. • Growing demand for new ships. • Image crisis, integrity concerns, bureaucratic issues. • Negative local investor attitudes. • High attrition rate of skilled personnel. • Inadequate infrastructure, energy supply, limited land availability.	• Insufficient ship availability due to regulatory failures. • Industrialized nations' environmentally-friendly ship dismantling practices. • Legal implications from lack of safety and health insurance provisions. • Developed countries' increased bidding value.	• Insufficient public and press relations. • Premium shipping prices compared to South and East Asia. • Facility expansion response. • Insufficient funds and resources. • Opposition to global technological advancements. • Absence of government assistance.

5. Conclusion

Extracting the raw materials needed to build ships uses a lot of energy, depletes energy resources, and releases harmful gases into the atmosphere that endanger human health. Because of this, the shipbuilding industry, like many other industries, recycles old (scrapped) ships by reusing ready-made raw materials through ship recycling facilities and businesses.

India's ship recycling sector, primarily Alang-Sosiya Ship Recycling Yard (ASSRY), faces land underutilisation, compliance costs, and high taxes. However, ASSRY's efforts in responsible ship recycling demonstrate India's potential[33]. Recent developments like the Maritime Amrit Kaal Vision 2047 reflect the sector's commitment to sustainable methods. Proposals to promote the industry, address environmental issues, and embrace circular economy concepts can enhance Alang's global standing, promote ethical ship recycling procedures, and align with India's marine sector objectives. Supporting India's ship recycling sector through changing regulations, redeveloping ship recycling infrastructure in Alang and creating a ship recycling cluster on the East Coast will benefit ship recycling in India.

Compliance with international standards has been accelerated in major ship recycling countries due to adopting the Hong Kong Convention of the International Maritime Organisation (IMO) and the EU Ship Recycling Regulations. Workers need to receive training in order to improve safety and compliance. It is necessary to make improvements to the ship recycling industry in Bangladesh, and a comprehensive training system has been developed by experts from both the local and international communities. For sustainability, it is necessary to have long-term training strategies and funding systems that are stable.

In light of the available data, it has been determined that there is a need to recycle ships that have completed their economic life to rejuvenate the Turkish Merchant Marine Fleet. When expert opinions and sector analysis reports were examined, it was seen that there were serious optimisation requirements for the rejuvenation of the Turkish

Maritime Trade Fleet the realisation of SR and the improvement in the sector. Türkiye has potential for sustainable ship recycling and steel production, but improved regulation, enforcement, incentives, and vision are needed. The EU can motivate ship recyclers, and recommendations include a comprehensive ship recycling standard, improved legal framework, and reassessment of the sector.

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Analysis of the Inadequacies Encountered by Ships in Port Reception Facilities Between 2019 and 2023

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Abstract

Waste management on board ships is a critical element in the maritime industry's sustainability efforts. Marine pollution crosses borders and has global impacts. In particular, the disposal of ship-borne wastes into the sea has the potential to harm large areas. Under the International Convention for the Prevention of Pollution from Ships and other international conventions on marine pollution, states parties are obliged to prevent the illegal disposal of ship-borne waste. However, various difficulties are encountered in the access of ships to port reception facilities and waste management.

This study analyses the inadequacies faced by ships in port reception facilities in world ports between 2019 and 2023. According to the International Convention for the Prevention of Pollution from Ships, state parties are obliged to always provide adequate port reception facilities. Port facilities should be equipped to cope with various types of waste from ships. In this study, the main difficulties encountered by ships regarding port reception facilities in ports are examined by analyzing the notification data that submitted to the International Maritime Organization regarding the situations where the port reception facilities required to be provided under the the International Convention for the Prevention of Pollution from Ships are insufficient.

Key factors such as lack of technical infrastructure, high costs and delays in port reception are emphasized in the analysis. In addition, the lack of coordination between stakeholders is also explicitly addressed and the inadequacies are also analyzed regionally. In conclusion, the study aims to contribute to understanding the difficulties in accessing port reception facilities for ships and to develop possible solutions to this issue which has global impacts.

Keywords: *Ship, Port, Port Reception Facilities*

1. Introduction

In 1967, the consequences of the Torrey Canyon accident brought the issue of marine environmental pollution due to the maritime sector to the top of the agenda (Cedre, 1999). This accident has caused developments that will affect the whole world. The necessity of international rules has emerged in order to reduce pollution and environmental damage caused by ship accidents and routine operations.

Within the International Maritime Organization (IMO), studies on the prevention of marine pollution and the elimination of damages that may occur as a result of marine pollution have gained momentum. Adopted on November 2, 1973, the International Convention for the Prevention of Pollution from Ships (MARPOL) aims to prevent marine pollution from ships. MARPOL has been updated with amendments over the years as a result of the lessons learned from tanker accidents and currently includes the following 6 annexes (IMO), n.d.);

- Annex I Regulations for the Prevention of Pollution by Oil
- Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk
- Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form
- Annex IV Prevention of Pollution by Sewage from Ships
- Annex V Prevention of Pollution by Garbage from Ships
- Annex VI Prevention of Air Pollution from Ships

Protection of the marine environment is also addressed under the United Nations Convention on the Law of the Sea (UNCLOS). Within the scope of UNCLOS, attention has been drawn to the need to carry out controls, carry out various activities, and construct the necessary facilities to reduce pollution and interference with the marine ecosystem on the coastline and in the sea (UNCLOS, 1982).

International conventions on marine pollution make waste management on ships a critical element for the sustainability of the maritime industry. Under MARPOL and other international conventions on marine pollution, States Parties are obliged to combat illegal disposal of waste from ships (IMO, n.d.).

Although IMO has helped to reduce ship-source pollution through the rules established by the MARPOL convention, which was adopted to prevent marine pollution and entered into force in 1973, there are a number of challenges that prevent the effective disposal of ship-source waste. In this context, IMO has identified the need for clear guidance on the disposal process. On March 1, 2018, the IMO published Consolidated Guidance for Port reception facility Providers and Users, which aims to provide a useful resource for both ship personnel and port facility staff, and to identify the competencies required to meet the needs of ships when calling at ports in order to comply with the provisions of MARPOL, which requires ships to have access to port reception facilities (PRFs). Therefore, the use and adequacy of PRFs is an important factor for keeping the seas clean. States parties to MARPOL are obliged to have PRFs to provide services in their ports (IMO, 2018).

The EU parliament enacted Directive 2019/883 in its updated final version to set out the principles for the application of international conventions (MARPOL, UNCLOS, etc.) in the ports of Member States ((On Port Reception Facilities for the Delivery of Waste from Ships, Amending Directive 2010/65/EU and Repealing Directive 2000/59/EC, 2019).

"Clause – 8. In order to ensure that the fees are fair, transparent, easily identifiable, non-discriminatory, and that they reflect the costs of the facilities and services made available, and, where appropriate, used, the amount of the fees and the basis on which they have been calculated shall be made available in an official language of the Member State where the port is located and, where relevant, in a language that is internationally used to the port users in the waste reception and handling plan."

Looking at the literature, Georgakellos (2007) examines the extent to which the deposit-refund framework can be used in the charging systems of PRFs within the scope of the repealed directive 2000/59/EC, while another study on the European Union (EU) directive analyzes the performance of the wastewater treatment plan in the port of Las Palmas and the success of the cost recovery system from a social benefit perspective (Martínez-López, Ruiz-García and Pérez, 2020).

Although the research on Port Reception Facility (Vaneeckhaute and Fazli, 2019) is port-oriented, Ball (1999) discussed the ways to ensure adequate provision of PRFs in the UK and mentioned the obligation of all ports and harbors to prepare a port waste management plan. However, there is no broader international approach to the challenges faced by ships in PRFs in the literature.

Khondoker and Hasan (2020) examined the feasibility of establishing a standardized and modern waste management system in Mongla port. While pointing out that there is a PRF for ship-borne wastes under MARPOL, the environmental importance of Mongla port as a location is also revealed as ships must pass through the United Nations Educational, Scientific and Cultural Organization (UNESCO) heritage site of Sundarban. They pointed out that none of the sea and inland ports of Bangladesh, which is a party to MARPOL, has yet to establish a PRF according to MARPOL rules and although there is a facility in Chittagong port, it is not sufficient. Mongla port, the second largest port of Bangladesh, does not have a waste management facility and therefore they investigated the technical and economic feasibility of establishing a waste PRF. The study shows that some ports of MARPOL signatory states do not provide adequate and efficient waste reception services, or the services provided are not adequate.

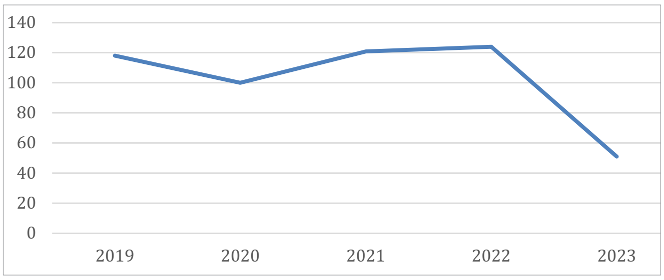
In order to overcome this deficiency, the data obtained from the notifications entered into the IMO GISIS system between 2019 and 2023 were analyzed and it was aimed to evaluate the challenges encountered on a global scale.

2. Methodology

Cross tabulation analysis allows us to examine and analyze the relationship between two categorical variables from various angles in cases where the sample size is not large, and the variables used do not show a normal distribution (Özbay, 2008). Frequency is the frequency of observation of a value, the number of repetitions. Tables of statistical data are often called frequency tables. The frequency table shows what measurements were observed and the number of repetitions of each of them, and how many individuals took which measurements (Arıcı, 1998). Frequency analysis is a statistical analysis technique used to examine the frequency and percentage distribution of variables in a data set.

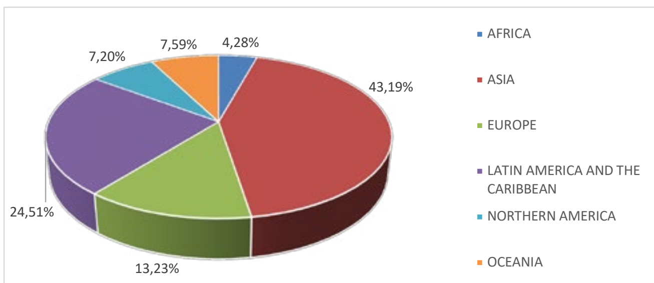
Information on the adequacy of the PRF can be obtained from port state authorities, port agents or ships calling at the port. IMO has organized a page on the Global Integrated Ship Information System (GISIS) with information on PRFs and ships can obtain PRF information for the ports they want from this page. This system also allows masters, owners and operators to report deficiencies or problems they encounter in ports (IMO, 2018). The notification data on PRF to IMO were obtained from the IMO GISIS web database. In this research, only the notifications made between 2019-2023 were taken into consideration in order to obtain information about the changes in the problems encountered over the years.

Graph 1. Number of Notifications Made to GISIS Database in 2019-2023



In the GISIS system, there were 118 notifications in 2019, 100 in 2020, 121 in 2021, 124 in 2022 and 51 in 2023. Although the number of notifications made in 2019-2022 are quite close to each other, there is a significant decrease in the number of notifications in 2023. In the research, it is aimed to statistically analyze the inadequacies encountered through the notification data made to IMO regarding PRF. In the analysis, the distribution of difficulties according to the regional classification of the United Nations (UN), the distribution according to waste types, the difficulties experienced by years and the relationship between waste types and difficulties were examined.

Graph 2. Regional Group Table of Port Authorities



The United Nations has established regional groups to facilitate the fair geographical distribution of seats among member states. The port authorities included in the declarations are grouped into 6 regions as Africa, Asia, Europe, Latin America and the Caribbean, North America and Oceana, taking into account the regional groups published by the United Nations (United Nations, n.d.).

Table 1. Distribution of the Number of Notifications by Regional Classification

Geographic Regions	Frequency	Percent
Africa	22	4,30%
Asia	222	43,20%
Europe	68	13,20%
Latin America and Carribbean	126	24,50%
Nouthern America	37	7,20%
Oceania	39	7,60%
Total	514	100%

The distribution of 514 reports made to the GISIS database between 2019 and 2023 on the basis of classified regions is shown. It is seen that the highest reporting rate is 43.19% for ports in the Asia Region. The Asia Region is followed by Latin America and the Caribbean Region with 24.51%. In addition, the lowest reporting was made for ports in the African Region with 4.28%.

Table 3. Distribution of Notifications by Waste Types

Waste Type	Frequency	Percent
Annex I	75	14,60%
Annex II	4	0,80%
Annex IV	8	1,60%
Annex V	424	82,50%
Annex VI	3	0,60%
Total	514	100%

When the distribution of notifications according to waste types is analyzed, MARPOL Annex V is the most common waste type with 82.5%. When it is evaluated in which waste types the difficulties encountered in PRFs are experienced more frequently, it is seen that after Annex V, Annex I, IV, II and VI, respectively. There is no notification for BMW Sediment category in the data.

Table 4. Distribution of Reports on Difficulties Experienced in PRFs by Categories

Inadequacies	Frequency	Percent
A. No Facility Available	326	63,40%
B. Undue Delay	5	1%
C. Use of Facility Technically Not Possible	4	0,80%
D. Inconvenient Location	5	1%
E. Vessel Had to Shift Berth Involving Delay/Cost	6	1,20%
F. Unreasonable Charges for Use of Facilities	62	12,10%
G. Others	106	20,60%
Total	514	100%

Table 2. Waste Type Classification Table MEPC.1/Circ.834/Rev.1

Annex I	Annex II	Annex IV	Annex V	Annex VI	Ballast Water Management
Oily bilge water	Category X substance	Sewage	A. Plastics	Ozone-depleting substances (Annex VI)	Sediments (BWM Convention)
Oily residues (sludge)	Category Y substance		B. Food wastes	Exhaust gas-cleaning residues (Annex VI)	
Oily tank washings (slops)	Category Z substance		C. Domestic wastes		
Dirty ballast water	Other Substances		D. Cooking oil		
Scale and sludge from tanker cleaning			E. Incinerator ashes		
Other			F. Operational wastes		
			G. Animal carcasses		
			H. Fishing gear		
			I. E-waste		
			J. Cargo residues (non-HME)		
			K. Cargo residues (HME)		

Within the scope of MARPOL, waste types are categorized as shown in table-2. The notification screen in the IMO GISIS database also used the categorization based on waste types as specified in MARPOL.

The types of challenges indicated in the table are the options presented during the submission to the GISIS database. The most common challenge faced by PRFs is the lack of a suitable waste reception facility. Lack of a suitable waste reception facility is the most common type of challenge. Another type of challenge that ships face more often is the high cost of waste reception. When the rate of the type of difficulty related to the lack of a suitable facility is compared to the total rate of the other types of difficulties, it is seen that it is reported approximately 2 times more.

Table 5. Distribution of Types of Difficulties Encountered by Year

Years	No Facility Available	Undue Delay	Use of Facility Tech-nically Not Possible	Incon-venient Location	Vessel Had to Shift Berth Involving Delay/Cost	Unrea-sonable Charges for Use of Facilities	Others
2019	27,90%	0%	0%	0%	0%	21%	23%
2020	16,90%	40%	0%	40%	16,70%	19%	19,50%
2021	21,50%	40%	75%	40%	33,30%	19%	23,50%
2022	23,60%	20%	25%	20%	50%	26%	24,10%
2023	10,10%	0%	0%	0%	0%	15%	9,90%
Total	100%	100%	100%	100%	100%	100%	100%

The numerical distribution of the challenges reported in this context by year is shown in Table-5. Lack of a suitable facility as the most common challenge increased after 2020 but did not reach the highest level in 2019. Especially in 2022, there was an increase in the reporting of waste reception costs. Undue delay, use of facility technically not possible, inconvenient location and vessel had to shift berth involving delay/cost were the least reported in all years.

3. Discussion

In the conducted literature review on this topic, it has been observed that the majority of research focuses specifically on individual ports, with scant global assessments available. Despite the limited number of comprehensive studies, the volume of reports suggests that there is a significant need for further research in this area.

The International Maritime Organization (IMO) is actively implementing measures to promote environmental sustainability within the maritime industry. Under the leadership of the IMO, the sector has begun to emphasize the enhancement of energy efficiency standards, the promotion of alternative fuel use, and the reduction of the carbon footprint in maritime transport. A multitude of policies and measures has been developed, with a clear timeline set for industry response and action plan implementation. However, findings indicate that the existing Port Reception Facilities (PRFs) are inadequate in supporting sustainable waste management aimed at protecting the marine environment.

Furthermore, while it is mandatory for member states of the IMO to ensure the availability of PRFs capable of meeting local demands at every port, practical implementation shows significant shortcomings, and PRFs often fail to meet the necessary demands. The requirement for PRFs to handle all types of waste imposes a substantial financial burden on ports. Passing these costs onto vessels could increase operational expenses and, in the long term, negatively impact trade due to rising costs. The establishment and operational costs of PRFs should not solely be the responsibility of ship operators; within the framework of sustainability, governments should also support these facilities. Although the IMO has not established a fee structure for waste at ports, initiating studies to create a sectoral balance in this regard would be appropriate.

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Design of Floating Platform for Ship Recycling Activity (case study: Indonesia)

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Abstract

Indonesia is strategically positioned in the maritime sector due to its expansive Exclusive Economic Zone territory and 17,500 islands, necessitating a robust inter-island connectivity transportation network. With the largest shipping cabotage principle in the world, Indonesia maintains control over its domestic maritime transportation, fostering a strong, self-sufficient shipping industry. Furthermore, the Indonesian government substantially supports the marine industry, promoting infrastructure development, fostering innovation, and implementing policies to ensure growth and prosperity.

However, 1739 Indonesia-flagged ships (3,917,461 GT) operated for 25 years or more in 2019, highlighting the need for ship dismantling facilities, while Indonesia only possesses three ship recycling yards. One innovative solution proposed in this paper involves suggesting floating platforms as a potential remedy to mitigate traditional ship dismantling processes' environmental and social impacts. The novelty of floating platforms lies in their capacity to provide a safer, more efficient, and environmentally friendly approach to handling end-of-life ships, thereby addressing the pressing need for sustainable ship recycling practices in Indonesia. The study explores the design of a floating platform for ship recycling activities, addressing traditional ship dismantling processes' environmental and social impacts. This design process uses a method that entails establishing the size of the floating dock platform by calculating the average size of the target ship being disassembled. Following this, the requirements and capacity of the floating platform facility are determined. As a result of this paper, it is predicted that the design of a floating platform for ship recycling activities will be obtained. This design will include the floating platform lines plan, general arrangement design, construction profile, and 3D modelling. The study also identifies the challenges and opportunities for their adoption in Indonesia, emphasising the need for thorough planning, regulation, and stakeholder coordination. The recommendations provide valuable insights for future research and policy, aiming to promote sustainable and responsible ship recycling practices in Indonesia and beyond.

Keywords: *floating platform, ship recycling, Indonesia, ship, ship dismantling*

1. Introduction

Indonesia, comprising over 17,500 islands, heavily relies on sea transportation [1]. As ships reach the end of their operational life (typically around 22 years or older), they become uneconomical to maintain and are retired. These end-of-life vessels are sold for scrap, leading to ship recycling activities. However, the current ship-breaking practices in Indonesia fall short of international and national regulations, posing threats to worker well-being and environmental health [2].

Ship recycling is a critical industry with both economic potential and environmental challenges [3]. As a nation with the vast maritime territory, abundant ship supply, and competitive labour costs, Indonesia is well-positioned to develop a thriving ship recycling sector. However, this industry also presents significant risks to worker safety, environmental pollution, and human rights violations. The impending enforcement of the Hong Kong Convention in July 2025 underscores the need for sustainable and safe ship recycling practices.

Indonesia has significant potential to play an important role in sustainable ship recycling. As an emerging maritime power, Indonesia has seen a rise in its domestic ship fleet, much of which will eventually require responsible end-of-life recycling [4]. However, Indonesia still faces challenges in fully implementing sustainable ship recycling practices and regulations. Continued efforts to improve standards, infrastructure, and worker training will be significant for Indonesia to become a leader in responsible ship recycling [5].

The research on green ship recycling yard design covers a range of innovative approaches. [6] proposes converting an idle ferry port in Madura Island, Indonesia, into a green ship recycling yard, with the design including three slipways to lift ships onto land for safe and environmentally friendly dismantling. Another study [4] aims to design an environmentally friendly ship recycling yard with a capacity of up to 30,000 DWT ships or 330 ft barges and tugs, using a docking process to ensure no waste contaminates the sea during the recycling. A third research study focuses on designing an environmentally friendly or "green" ship recycling yard, drawing on existing literature and regulations [7]. Additionally, a PhD thesis develops a simulation framework to design and optimise ship recycling yards, to increase productivity and cost-efficiency while meeting new environmental and safety regulations [8]. Finally, a review paper [9] summarises the current state of research on green ship recycling yard design and discusses recent efforts to improve the sustainability and efficiency of ship recycling facilities.

One significant challenge during ship recycling is the vessel draft issue. Traditional ship recycling methods require vessels to be grounded on shores, limiting access to certain facilities, while creating extensive environmental damage. The beaching method, where end-of-life vessels are intentionally grounded on tidal beaches, has been a prevalent practice in countries with significant ship recycling industries, such as India, Bangladesh, and Pakistan [10], [11]. This method, while cost-effective and labor-intensive, raises substantial environmental and safety concerns. The vessel draft issue is central to the beaching method, as it limits the recycling process to facilities that can accommodate the grounding of large vessels. This restriction not only constrains the industry's capacity but also exacerbates environmental degradation, including soil and water contamination from hazardous materials like asbestos, heavy metals, and oil residues.

A more innovative approach is necessary to overcome this limitation and damage caused by industry such as dry-docking and the use of slipways, present viable alternatives to the beaching method. Dry-docking involves transferring vessels to a dry platform, allowing for safer and more environmentally friendly dismantling [12]. This method significantly reduces the risk of environmental contamination, as hazardous materials can be controlled and treated more effectively in a contained environment. Similarly, slipways offer a method to haul vessels out of the water, providing better access for recycling operations and minimizing direct impacts on the marine ecosystem.

Floating dry-docks represent another innovative solution, particularly for locations where permanent dry-dock facilities are not feasible. These mobile platforms can be submerged to allow a vessel to be positioned over them, then raised to lift the vessel out of the water. This method offers flexibility in terms of location and can be adapted to different vessel sizes, addressing the draft issue by eliminating the need for grounding on shores.

Therefore, this paper explores the conceptual design of a floating platform as a novel solution to address the limitations of traditional beaching methods for ship recycling. The proposed platform offers a safer and cleaner alternative, mitigating health and safety risks while maintaining environmental integrity. Additionally, its mobility and flexibility enhance operational efficiency.

2. Methods

The conceptual design of the floating platform for ship recycling was developed through a systematic process involving various key steps. Firstly, an identification of the average characteristics of ships undergoing dismantling was conducted to understand the specific requirements of the recycling process. Subsequently, precise calculations were carried out to determine the optimal dimensions of the floating platform. Following this, a detailed evaluation was performed to identify and assess the design requirements and capacities of the facility.

By integrating insights from these studies and conducting detailed analyses on ship dismantling practices and waste management, a comprehensive conceptual design for the floating platform dedicated to ship recycling activities in Indonesia was formulated. This design included main dimensions, a lines plan, a general arrangement, midship section details, a construction profile, and a 3D model representation. The development of this conceptual design aimed to enhance the efficiency and sustainability of ship recycling processes in Indonesia.

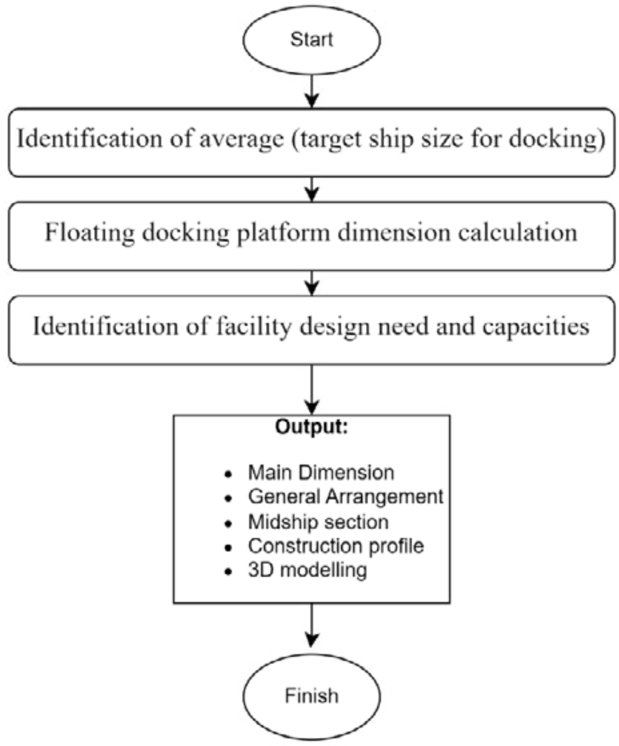


Figure 1 Research method flowchart.

The methodology employed in crafting the conceptual design of the floating platform for ship recycling activities is elucidated in the research flowchart depicted in Figure 1. The sequential stages of the conceptual design process are outlined as follows:

1. Identification of the average size of ships to be dismantled.

   This step involves assessing and analysing the typical size range of ships that will undergo dismantling on the floating platform. It requires gathering data on various types of vessels commonly found in the region where the platform will operate. Factors such as length, width, draft, and displacement of ships are considered to determine the average size. This information is crucial for designing a platform that can accommodate different sizes of ships efficiently and safely.

2. Calculation of the dimensions for the floating platform.

   Once the average size of the ships is determined, the next step is to calculate the dimensions of the floating platform. This involves considering factors such as the size and weight of the ships to be dismantled, operational requirements, stability, and safety regulations. Engineers use naval architecture principles to determine the optimal dimensions of the platform, including length, width, draft, freeboard, and buoyancy. The goal is to ensure that the platform can effectively support the weight of the ships and provide a stable working environment for recycling activities.

3. Identification of facility design elements and their respective capacities.

   This step entails identifying the necessary infrastructure and facilities required on the floating platform to support the ship recycling process. It involves determining the layout of the platform, including areas for dismantling, sorting, and processing various materials, as well as storage spaces for equipment and recyclable materials. Additionally, it involves assessing the capacities of these facilities, such as the maximum weight they can handle, the volume of materials they can process, and the environmental impact mitigation measures they incorporate. This step ensures that the floating platform is equipped with all the necessary resources and facilities to efficiently carry out the ship recycling activities while adhering to safety and environmental standards.

This paper delivers a comprehensive output in the form of a conceptual design for the floating platform tailored for ship recycling endeavours. The components of this design include main dimensions, lines plan, general arrangement, midship section, construction profile, and 3D modelling.

3. Result

1. Ship dimensions.

The first step to designing the floating platform is to determine the potential end of life ship's dimensions. The method of comparison of ship dimensions has a capacity above 70.000 DWT until 100.000 DWT is operated in Indonesian waterways. The specified range is selected due to the presence of only one floating dock and one graving dock with capacities exceeding 70,000 DWT, primarily due to draft restrictions, which are exclusively dedicated to ship repair services. These facilities are located on Batam Island[13], [14]. The next step is the ship dimension from the regression result of the ship's sample. The steps of ship dimension calculation are as follows:

a. First, 40-60 ships with the matching Deadweight Tonnage (DWT) were obtained ranging from 70,000 to 100,000 DWT. Then, ship data was used to create the graph with DWT on the horizontal axis and the main ship dimensions like LBP, B, T, and H on the vertical axis.

b. The next step is determining the linear regression equation to obtain the best R^2 value.

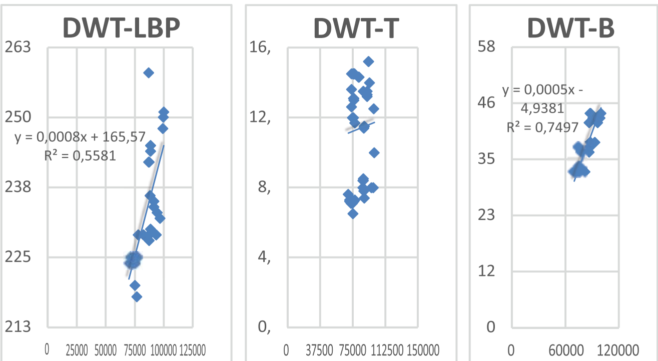
c. By inputting the desired DWT, we can obtain the ship's main dimensions that can be recycled.

Table 1 Ship sample to determine ship's dimension.

No	Name of ship	DWT	L	B	T
			(meters)		
1	Victory union	70000	224	32	7.6
2	Andhika nareswari	71290	225	32	7.2
3	Andihika athalia	71298	225	32	7.3
4	Andhika kanishka	73220	225	32	7.1
5	Aliyah pertiwi	73461	225	32	14.5
6	Kartini samudra	73592	224	32	13.6
7	Andhika paramesti	73726	225	32	12.6
8	Anggrek laut	74716	225	32	7.1
9	Manalagi prita	74759	225	32	12
10	Jaka tarub	74999	224	37	7.3
11	Prima andalan i	75162	220	33	6.5
12	Prima spirit	75511	225	32	14.5
13	Lumoso damai	75632	225	32	14.5
14	Cm laurencia	75698	225	32	12
15	Kartini baruna	75698	225	32	13.1
16	Chandra kirana	75700	225	32	7.2
17	Prima pioneer	75729	225	32	14.5
18	Andhika alisha	75785	225	32	14.5
19	Bulk batavia	76243	225	32	7.2
20	Peony laut	76302	225	32	14.5
21	Lumoso pratama	76536	225	32	14.5
22	Arimbi baruna	76588	218	32	13
23	Bulk nusantara	76596	225	32	13.1
24	Karunia gemilang ii	76737	225	32	14.5
25	Sinar kintamani	76830	225	32	14.5
26	Emerald indah	77734	229	36	7.3
27	Ruby indah	77775	229	36	11.7
28	Lumoso kasih	82133	229	32	14.3
29	Lumoso sayang	82133	229	32	14.3
30	Zaleha fitrat	82208	229	32	14.3
31	Pertamina abherka	86866	258	42	8
32	Gunung kemala	86962	242	42	8.4
33	Muhasyir	87052	228	36	8.5
34	Gebang	87069	242	42	8.4
35	Sinar komodo	87334	229	37	13.5
36	Sinar kuta	87334	229	37	13.5
37	Manalagi asta	88005	236	38	7.8
38	Manalagi asti	88018	236	38	11.4
39	Gamkonora	88258	245	44	11.5
40	Gede	88312	244	44	11.5
41	Manalagi dasa	88315	230	38	7.4
42	Galunggung	88322	245	44	11.5
43	Gamalama	88322	245	44	11.5
44	Hammada	91438	234	43	13.3
45	Maria nashwah	91439	235	43	13.2
46	Amanah morowali amc	91439	235	43	13.5
47	Ims jakarta	93313	229	38	15.2
48	Golden rose	93318	229	38	15.2
49	Ratu nusantara	94225	233	43	14
50	Federal ii	96759	232	42	8
51	Success challenger xxxvii	98880	248	43	8
52	Habco ankaa	99347	250	43	12.5
53	Golden splendor	99999	251	44	10

The table above displays the findings from gathering data on ships ranging from 70,000-100,000 DWT and flagged under Indonesia. It reveals the diverse range of ship sizes in Indonesia, with lengths spanning from about 218 meters to approximately 258 meters and the most comprehensive ship reaching 44 meters.

After obtaining the ship dimension data (LBP- Length between Perpendicular, B-Breadth, and T- Draught) with a range of 70,000-100,000 DWT, the next step is to form a graph showing the relationship between DWT-LBP, DWT-B, and DWT-T. The graph is as follows:



(a) (b) (c)

Figure 2 Plotted DWT-LOA (a) DWT-T (b) and DWT-B (c)

After obtaining the linear regression equation to determine the ship's main dimensions, the next step is to input the DWT of the intended ship. In this case, the target ship size has a maximum capacity of 100,000 DWT. As a result, the following ship data is obtained:

- Length Between Perpendicular (Lbp) = 245.57 meters
- Breadth = 45.0169 meters
- Draught = 11.6904 meters

2. Floating dock dimension

After determining the maximum ship dimensions for recycling, the next step is to calculate the main dimensions of the floating platform. Similar to ships in general, floating platforms come in various sizes, which can be adjusted based on existing platform designs or the capabilities of the floating platform. The main dimensions of the floating platform (principal dimensions) determine the size of the platform. These main dimensions also determine the floating platform's ability to lift cargo on it, often called its lifting capacity. The main dimensions of the floating platform consist of the platform length (LD), internal width (BInt), external width (BExt), height (H), floating draft (T1), submerged draft (T2), and others.

After the data calculation, the next step involves calculating the Ton Lifting Capacity (TLC). The following are the results of the TLC calculation for the floating dock:

Table 2 Ton lifting capacity calculation

Ton Lifting Capacity (TLC)		
Displacement	=	DWT +LWT
LWT	=	Displacement- DWT
	=	(LPPxBxTxρxCb) - DWT
	=	(245.57 x 45.02 x 11.69x1.025x1) – 100,000
	=	132,756.975-100000
	=	32,756.98 ton
TLC	=	LWT*1.025 + margin 10%
	=	33575.9 +3357.6
	=	36933.49 ton

After determining the Ton Lifting Capacity (TLC), the next step involves detailed calculations Tto determine the main dimensions of the floating platform for ship recycling. the floating platform length (Ld) is the length of the bottom caisson or the distance from the aft end of the aftermost pontoon to the fore end of the forward pontoon, excluding non-integral end platforms or swing bridges. To calculate the floating platform length, the distance from the end of the floating dock to the collision bulkhead and the stern bulkhead of the transported fishing vessel is measured, and the total dock length is formulated by adding the ship's LBP of 237 meters with a 21,5x2 meter margin length, resulting in a total floating length (LD total) of 280 meters. The floating platform breadth (Bd) is the moulded breadth in meters, and the floating platform height (Dd) is the vertical distance from the lowest point of the bottom framing to the lower surface of the uppermost deck plating. The freeboard to the pontoon deck at the centerline of the dock when supporting a ship having a displacement equal to the lifting capacity is to be not less than 300 mm, and when the pontoon deck at the inner side walls is lower than at the centre, the freeboard to the pontoon deck at the inner side walls is to be not less than 75 mm, with the freeboard at the centerline being not less than 300 mm. The floating dock draught (Td) is the distance between the floating platform height (Dd) and the freeboard, and the light displacement includes the structural weight of the dock complete with all machinery, crane(s), equipment, fresh water, fuel oil for the use of the dock, compensating ballast water (if required), and rest-water. The volume displacement is the volume of water displaced by the submerged portion of the dock, and the keel block height is the height of the keel block in meters.

Table 3 Principal dimension summary

Principal Dimension		
Main Dimension	**Qty**	**Unit**
LD	280	m
BD (Int)	47	m
BD (Ext)	55	m
T FD	6.2	m
H Safety Deck	8.39	m
H Ponton	10	m
Side Wall	2	
Lifting Capacity	67.000	Ton

3. Facility and capability

The approach taken in analysing the requirements and facilities of the floating platform is based on the recycling process. The ship recycling process, as an integral part of this approach, describes the steps necessary to achieve this goal.

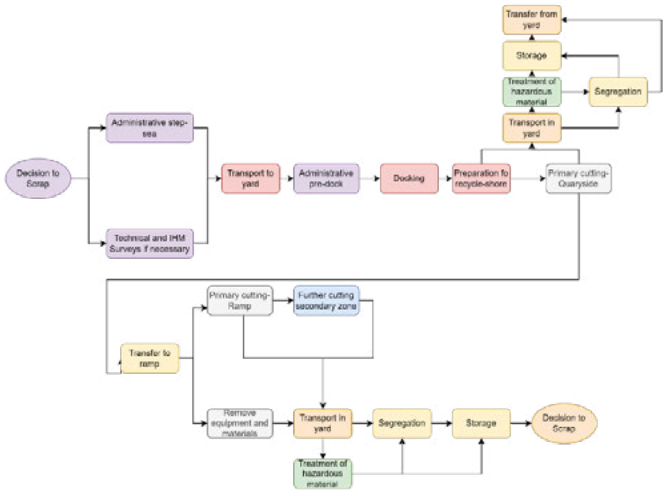


Figure 3 Simplified ship recycling activity approach by **[8]** .

Based on Figure 3, the ship recycling process can be broadly divided into the following steps:

1. Administrative Process
   This includes the technical and Inventory of Hazardous Materials (IHM) survey, if necessary before the ship can be approved for recycling.
2. Docking
   The ship is docked at the ship recycling facility, typically in a dry dock or on a slipway, to allow for safe and efficient dismantling.
3. Primary Cutting
   The initial cutting and dismantling of the ship's structure, starting from the upper decks and superstructure.
4. Segregation
   The various materials and components removed from the ship are segregated and sorted based on their composition, such as metals, plastics, hazardous waste, etc.
5. Secondary Cutting
   Further cutting and dismantling of the ship's hull and other larger components to facilitate the efficient handling and processing of the materials.
6. Treatment of Hazardous Materials
   Any hazardous materials, such as asbestos, heavy metals, or other toxic substances, are carefully identified, removed, and treated in accordance with environmental regulations.
7. Scrap
   The segregated materials, including metals, plastics, and other recyclable components, are processed and prepared for sale or further recycling.

After understanding the ship recycling process, the next step is to identify the facilities and activities typically used in a ship recycling yard. This identification aims to determine the facilities and capabilities of the floating platform for ship recycling. Table 4 presents the results of the identification carried out by [8].

Table 4 Facilities and activities in ship recycling process

Facilities	Activities
Quay	IHM Preparation Detailed SRP Decontamination Removal of equipment, machinery and furniture Primary cutting and removal of superstructure
Ramp	Primary cutting of blocks
Crane	Transfer from the primary zone to secondary zone /segregation room
Chain puller	Transfer from quay to ramp
Offices	Administrative works
Secondary cutting zone	Further dismantling of blocks
Segregation zone for non-hazardous material	Non-hazardous material segregation
Storage zone for non-hazardous material	Storage for different material: steel, rare metals, machinery, other material etc.

Because there are differences in the facilities of the ship recycling yard on land/onshore and the floating platform, it is necessary to adjust the placement of the facilities that will be placed on the floating platform. The approach method for facility deployment adopted from [15] and can be identified through

Table 5 Identifying Facility and capability of floating platform.

Ship recycling process		**Admin-istrative Process**	**Docking**	**Primary cutting**	**Segrega-tion**	**Secondary cutting**	**Treatment of Hazard-ous Mate-rials**	**Scrap**
Area capacity		Wing wall area	Dock area			Secondary cutting area	Double bottom HM area	Scrap Area
					Material storage		Waste man-agement	
Facility	**Main**	Office facility	Docking Block, pump	Cutting machine		Cutting machine		
	Sub		Movable Jib crane					
	MHS		Transporter, Forklift, container					

The key design requirements and environmental, economic, and social considerations for a floating ship recycling platform in Indonesia are:

Design Requirements:

- Modular Design: The floating platform should be constructed in separate modules or pieces to allow for easier manoeuvrability, maintenance, and reconfiguration. [16]
- Buoyancy and Stability: The platform must be designed with an appropriate float size and configuration to ensure sufficient buoyancy and stability to support the weight of ships, accounting for factors like water depth, tidal ranges, and wind/wave conditions.[17]
- Design considerations must incorporate mechanisms for the containment and treatment of contaminants like oil, asbestos, heavy metals, and other dangerous substances frequently encountered in ships. This entails using non-porous surfaces to avert the pollution of soil and water, alongside provisions for the secure storage and handling of waste. Within this framework, liquid contaminants and hazardous materials are to be initially held in double-bottom compartments before being transferred to tanks for conveyance to onshore facilities specialised in hazardous waste management. Meanwhile, solid hazardous materials are to be contained within designated containers.
- Given the hazardous nature of ship recycling, the platform must incorporate safety measures such as fire-fighting systems, emergency evacuation routes, and personal protective equipment. Health facilities should be available to treat injuries and exposure to toxic substances. The clinic facility will be located on the wing wall.
- The layout should facilitate the efficient dismantling of ships, sorting materials, and storing reusable components and scrap. This includes the placement of cranes, cutting stations, and storage areas to minimise transport distances and handling times.
- The design should adhere to international guidelines and conventions, such as the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, ensuring that recycling practices meet global environmental and safety standards.

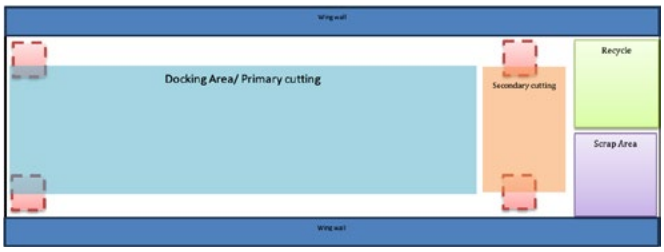


Figure 4 Layout design of floating platform for ship recycling

4. Floating platform design

After designing the layout for a floating platform intended for ship recycling activities, which can accommodate ships up to a maximum of 100,000 DWT with dimensions of approximately LOA=237 m, B=43 m, and T=11 m, the platform is equipped with facilities based on referenced standards, comprising:

1. Docking and Primary Cutting Area

   This area is designed as a docking space, measuring 240 m x 54 m. Its length is determined based on the maximum length of the ships and the additional space required for operational clearance.

2. Secondary Cutting Area

   An open space measuring 30 m x 54 m is allocated for further cutting of large sections into smaller pieces following the primary cutting process.

3. Recyclable Parts Storage

   A designated area for storing components that can be recycled, such as engines, fittings, and electronics, with dimensions of 30 m x 27 m.

4. Scrap Area

   An open space for storing scrap materials, also measuring 30 m x 27 m.

5. Lifting and Transportation Facilities

   The platform has two jib cranes, each with a lifting capacity of 50 tons, and three forklifts for material handling.

6. Waste Storage

   Two forty-foot containers are utilised to temporarily contain solid hazardous wastes, including materials containing asbestos. Additionally, there are four separate tanks for storing various liquids such as fuel oil, lubricating oil, and contaminated water. These hazardous wastes are transported to a specialised disposal facility managed by the industrial estate on land.

7. Safety and Support Facilities

   The platform includes safety equipment and facilities, fire prevention tools, oil spill response gear, and other necessary safety appliances.

8. Administrative and Ancillary Facilities

   The platform features office buildings, a dining hall, a medical clinic, a place of worship, and a power generator strategically located along the structure's wing wall.

5. Linesplan

The lines plan is a collection of schematics that illustrate the three-dimensional contours of a floating platform, detailing its length, width, and depth. These schematics are composed of various curves that outline the platform's hull shape. The lines plan is essential for predicting the platform's performance in aquatic environments, encompassing its stability, buoyancy, and hydrodynamic characteristics. When designing a floating platform for ship recycling purposes, the lines plan must consider the unique requirements, such as the ability to support various ship sizes, maintain stability throughout the dismantling process, and provide adequate access for personnel and machinery.

The design process for the lines plan was carried out using Maxsurf software, resulting in a detailed lines plan for a floating platform tailored to ship recycling activities, as depicted in Figure 5.

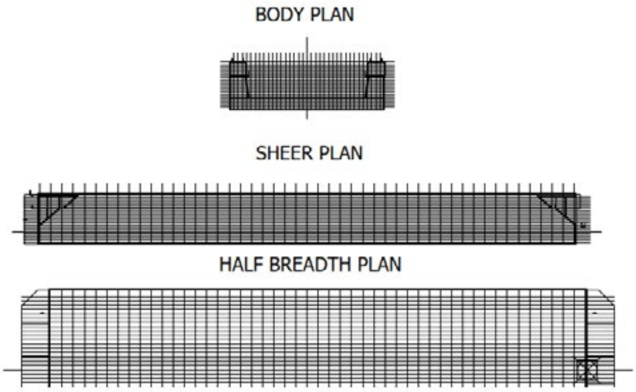


Figure 5 Floating platform linesplan

6. General arrangement

The general arrangement (GA) plan provides a comprehensive overview of the layout and spatial organisation of the floating platform. It includes the positioning of key areas, such as docking area, primary cutting and secondary cutting, storage areas for recycled materials, equipment rooms, and crew accommodations. The GA is essential for ensuring efficient workflow, safety, and compliance with environmental regulations. In the context of Indonesia, considerations might also include adaptability to local weather conditions and tides and integration with local infrastructure. The detailed layout of the floating platform's general arrangement can be examined in Figure 6

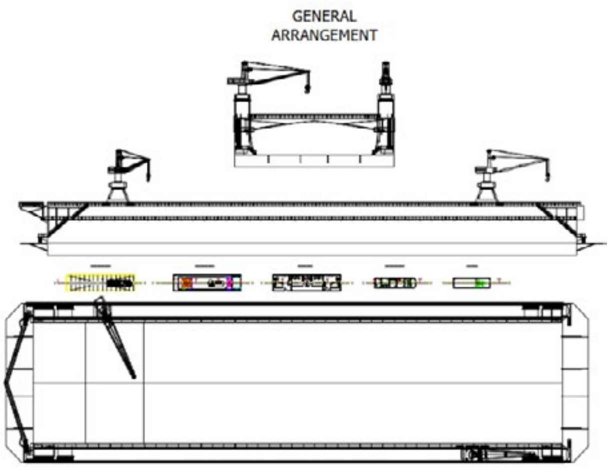


Figure 6 Floating platform general arrangement.

7. Midship section & construction profile

The midship section is a detailed cross-section of the widest part of the platform, providing insights into its structural integrity and load-bearing capacities. This section includes details on the framing, bulkheads, deck arrangements, and any reinforcements designed to withstand the stresses of ship recycling activities. The construction profile outlines the methods and materials used in building the floating platform. It includes specifications for welding, materials for hull construction, and Calculation of construction profile using rules and regulations for Classification and Construction of Floating Docks BKI Volume II 2019. The construction profile can be depicted on Figure 7

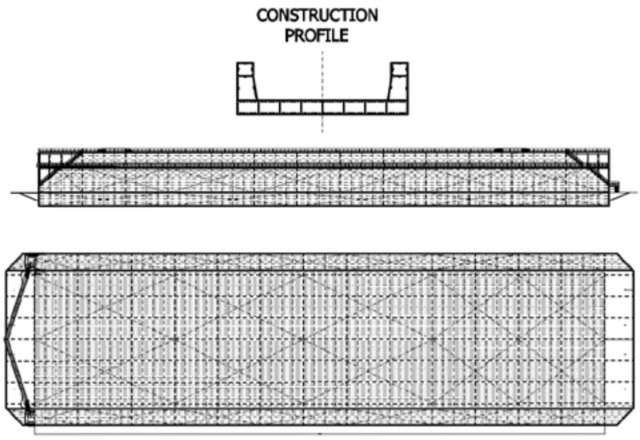


Figure 7 Floating platform construction profile.

8. 3D modelling

3D modelling combines all the previous stages into a detailed and interactive representation of the floating platform. It allows designers and engineers to visualise the platform in a virtual environment, identify potential issues, and make adjustments before construction begins. For ship recycling activities, 3D modelling can simulate operations, assess the platform's response to loads and environmental conditions, and plan for emergency situations. It's also a valuable tool for stakeholder presentations and obtaining necessary approvals and certifications.

9. Ship recycling process on a floating platform.

To visualise The conceptual design of a floating platform for recycling activities it can be explained as follows:

The floating platform is transported to a ship where the dismantling process will occur. The location is chosen based on the required draft or water depth to allow for docking. Once the platform is in position, mooring is carried out to secure it and prevent it from being affected by waves and wind, ensuring that the recycling process is not disrupted by external forces.

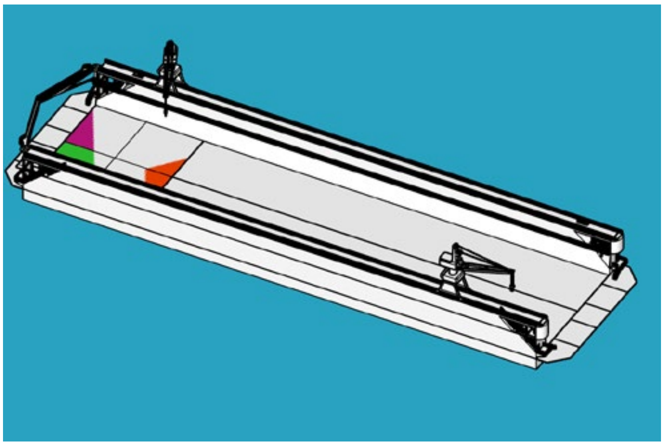


Figure 8 Floating platform transported and moored

Subsequently, thorough preparations and planning are set in motion upon the arrival and approach of the ship slated for recycling towards the floating platform. Before the vessel enters the floating dock, a thorough preparation phase ensues, necessitating the crafting of a comprehensive docking plan, scrutiny of the Inventory of Hazardous Materials (IHM) aboard the ship, and verification of all pertinent documents for the vessel recycling process. Before guiding the ship into the floating dock, meticulous arrangements are made, including the placement of keel blocks and readiness of lines and personnel, ensuring the smooth handling of the vessel.

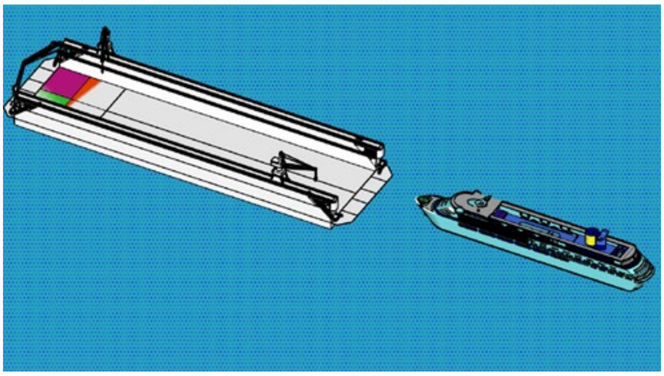


Figure 9 Ship approaching the floating platform.

Once the floating dock is prepared, the docking process commences by pumping water into the tanks of the floating platform. This action causes the floating platform to descend and reach the desired draft, enabling the ship slated for dismantling to enter the floating platform.

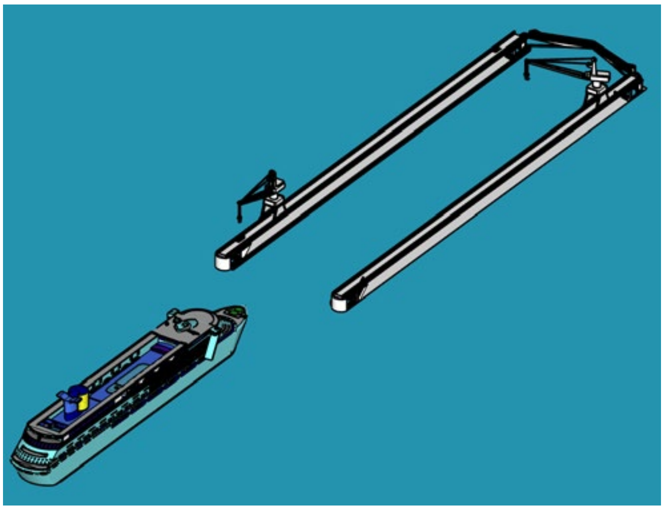


Figure 10 Docking process in the floating platform

The ship designated for recycling enters the floating platform, aligning with the predetermined docking plan. After ensuring all is secure, the next step involves pumping water out from the tanks of the floating platform. This action causes the floating platform to ascend, allowing the ship to settle onto the pre-arranged blocks.

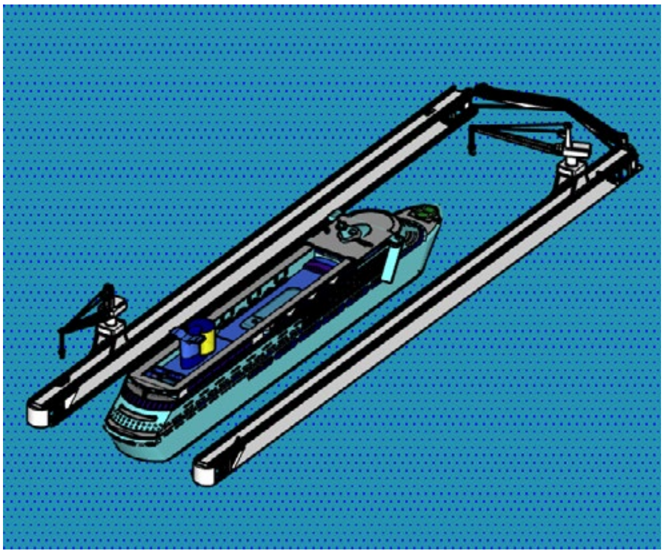


Figure 11 Ship entering floating platform and sitting on the blocks

Once at the floating platform, the ship is securely moored. This ensures that the ship remains stable during recycling, preventing accidents or unwanted movements. The next step is removing hazardous materials such as asbestos, heavy metals, and hydrocarbons. This step must be taken carefully to prevent exposure and environmental contamination. Hazardous materials are safely stored in designated containers and transported to approved disposal facilities.

The ship is dismantled in a pre-determined sequence to ensure structural stability. The process starts from the upper structures and progressively moves downwards. Various cutting techniques are employed, such as gas torches or mechanical cutters. The choice of technique depends on the materials being cut and the need to minimise environmental impact. Some of the cutting techniques in ship recycling facilities has been discussed in the [18]

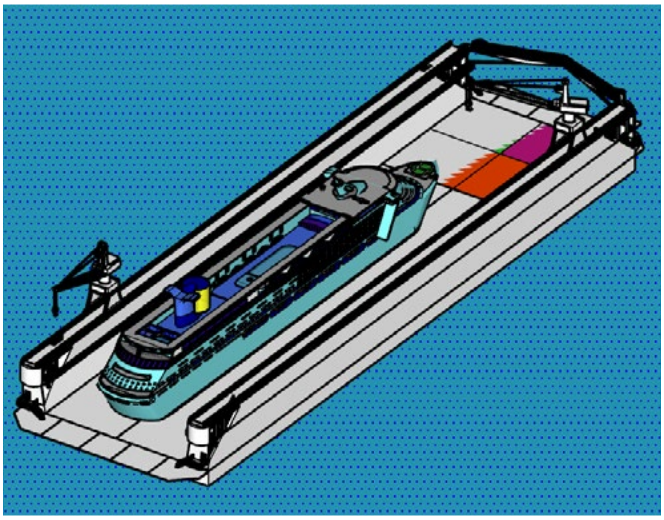


Figure 12 Ship ready to dismantle.

Materials undergo segregation according to their types, distinguishing between metals, plastics, wood, and other categories. This systematic sorting process enhances the effectiveness of recycling efforts and waste management practices. Recyclable materials are directed to their respective recycling facilities, where they undergo processing for reuse. Meanwhile, non-recyclable materials are managed following stringent environmental protocols for safe disposal, ensuring minimal impact on the environment.

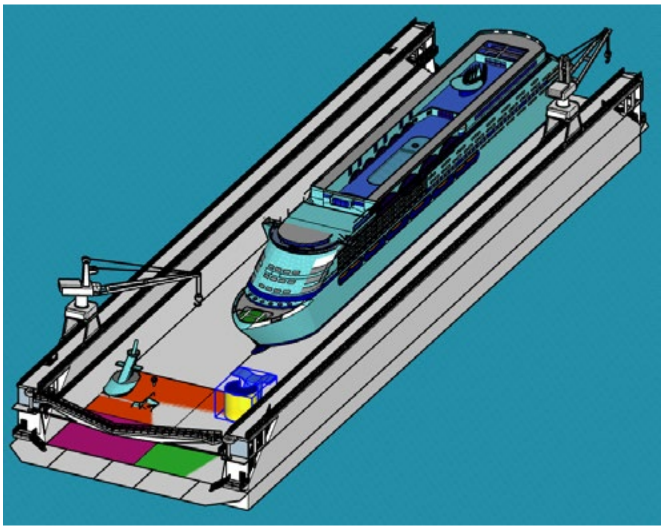


Figure 13 Segregation on floating platform

Materials undergo meticulous sorting and staging based on their intended destination and handling prerequisites. Recyclable materials, non-recyclable waste, and hazardous substances are methodically segregated. Prior to loading, stringent safety measures are implemented to ensure proper containment and labelling of hazardous materials in compliance with international transport regulations. Utilising cranes and other lifting equipment, materials are loaded onto propelled barges with careful consideration given to balancing the barge and securing all cargo for transport.

Throughout the transportation phase, stringent measures are in place to prevent spillage or environmental contamination, particularly concerning the transport of hazardous waste.

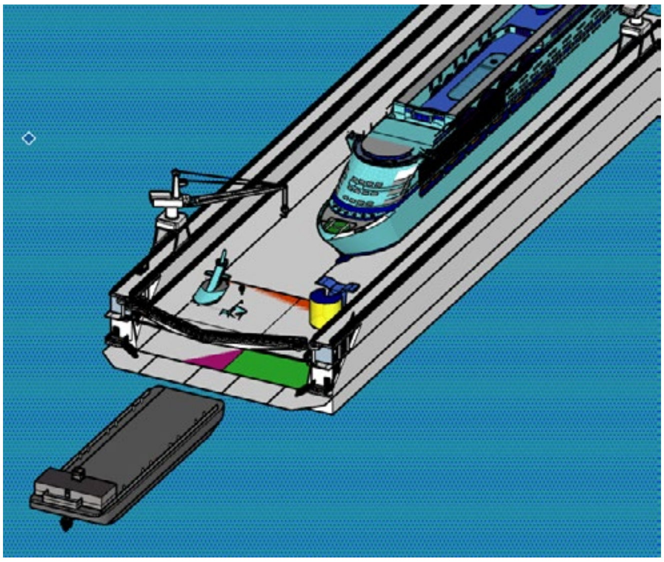


Figure 14 Loading material to propelled barge

Upon arrival at shore, the unloading of barges necessitates coordinated efforts to direct materials to their designated facilities, be it recycling plants, waste management centers, or hazardous waste disposal sites.

Onshore facilities include:

- Recycling Facilities are specialized centers where recyclable materials are processed and transformed into new products, contributing to the principles of the circular economy.
- Waste Management Centers: Facilities tasked with handling non-recyclable materials following local environmental regulations, typically involving safe landfilling or incineration with energy recovery.
- Hazardous Waste Disposal: Certified facilities responsible for safely disposing or treating hazardous materials, ensuring they pose no threat to the environment or public health.

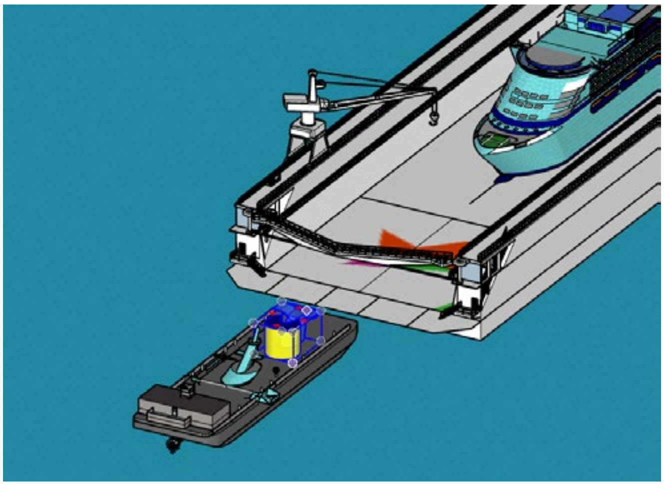


Figure 15 Propelled barge go to shore facilities.

10. Conclusion

In conclusion, this study has meticulously explored the design and implementation of a floating platform for ship recycling activities specifically tailored to the Indonesian context. It has addressed the pressing need for sustainable and environmentally responsible ship dismantling methods by proposing an innovative floating platform. This platform is designed with a focus on adaptability, efficiency, safety, and environmental protection, marking a significant step towards redefining ship recycling practices. The proposed design can recycle ships up to a maximum capacity of 100,000 DWT. Comprehensive details such as the facilities, layout, lines plan, general arrangement, construction profile, and 3D modeling have been thoroughly provided, alongside an in-depth explanation of the ship recycling process. Recommendations for stakeholders underscore the importance of collaboration, policy support, and investment in green technologies to foster the industry's evolution.

Future research in the ship recycling industry should prioritize the development of comprehensive safety protocols and training programs, focusing on the safe handling of hazardous materials, the use of PPE, and emergency response procedures. The integration of advanced technologies like robotics and automation is also recommended to reduce human exposure to dangerous conditions. Additionally, the creation of evacuation models tailored to the ship recycling environment is essential for the safety of workers, with the potential for enhanced effectiveness through real-time monitoring and wearable technologies.

Environmental considerations are equally important, with future studies needing to conduct thorough environmental impact assessments for ship recycling activities. These should assess pollutant release, marine biodiversity effects, and the efficiency of waste management. Innovative methods to reduce the environmental footprint, including green technologies and materials recovery, should be explored.

Economic analysis is necessary to evaluate the cost-effectiveness of sustainable ship recycling, including the proposed floating platform. Research should identify financial incentives for stakeholders, analyze market demand for recycled materials, and consider the economic advantages of green technologies. The development and use of sustainable materials and technologies, such as non-toxic coatings, renewable energy, and advanced waste treatment, should also be a focus of future research efforts.

This study not only contributes to maritime engineering and environmental sustainability but also sets a transformative agenda for the global ship recycling industry, advocating for practices that are safe, efficient, and environmentally conscientious.

11. Acknowledgments

We extend our deepest gratitude to LPDP Indonesia for their generous financial support, which was instrumental in the realization of this research project. Their commitment to advancing knowledge and fostering innovation has been a cornerstone of our study's success.

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Section 6

Naval Architecture & Offshore Technologies

Investigating the Impact of Propeller Pitch, Blade Area Ratio, Skew, and Rake Angle on Cavitation

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Abstract

Cavitation, a phenomenon characterized by the formation and collapse of vapor bubbles in a liquid, poses significant challenges to the efficiency and longevity of marine propulsion systems. In this study, the effects of propeller design parameters (especially Pitch, Blade Area Ratio (BAR), Skew, and Rake) on cavitation were investigated through Computational Fluid Dynamics (CFD) analysis. To ensure the accuracy of the CFD calculations, the open water and cavitation tunnel test results of the VP 1304 test propeller were taken as reference. After the validation studies, an initial propeller geometry was developed based on the VP 1304 propeller geometry used in the SVA PPTC 2011 Symposium. Subsequently, four different propeller designs were created by changing the Blade Area Ratio (BAR), Pitch (P), Skew, and Rake parameters of this initial propeller. The effect of each parameter on cavitation was evaluated separately and based on the data obtained, a new propeller geometry was developed with better cavitation performance compared to the first propeller. It was found that while improving the cavitation performance of the propeller, the open-water propeller efficiency decreases. The goal of the research is to provide a comprehensive understanding of how these design parameters influence cavitation inception, growth, and mitigation strategies.

Keywords: *Propeller, cavitation, pitch, BAR, skew, rake, CFD*

1. Introduction

Energy efficiency is becoming increasingly important in every aspect of today's world. Designing propulsion systems that operate more efficiently not only reduces fuel consumption, but also extends the life of the platform. This is a factor to consider for propeller design, which is an integral part of both commercial and military ship propulsion systems.

In propeller design, having low cavitation is one of the greatest challenges encountered in designing an efficient system [1]. Cavitation arises from pressure differences between propeller blade surfaces, and this can be reduced by making changes to propeller design parameters [2]. These design parameters include blade number, blade area ratio, rake, skew, and pitch [3]. For example, increasing propeller skew angle affects cavitation dynamics by reducing pressure fluctuations [4], [5], [6], while increasing the number of blades can decrease propeller cavitation and noise by reducing the force on each propeller blade [7].

In this study, the influence of propeller design parameters, especially Pitch, Blade Area Ratio (BAR), Skew and Rake, on cavitation was analyzed using Computational Fluid Dynamics (CFD) analysis. The open water and cavitation tunnel test results of the VP 1304 propeller geometry used at the SVA PPTC 2011 symposium were utilized in the study to verify the accuracy of the CFD calculations. Following the validation studies, an initial propeller geometry was developed based on the VP 1304 propeller geometry. Subsequently, four different propeller designs were created by changing the Blade Area Ratio (BAR), Pitch (P), Skew, and Rake parameters of this initial propeller. Propeller-1 was designed by increasing the Skew parameter by 20%, Propeller-2 was designed by increasing the BAR parameter by 20%, Propeller-3 was designed by increasing the Pitch parameter by 20%, and Propeller-4 was designed by increasing the Rake by 20%. The effect of each parameter on cavitation has been evaluated separately, and parameters that positively influence the cavitation performance of the initial propeller have been applied to the new design propeller, which is named 'developed.' Lastly, the cavitation performance of the developed propeller geometry has been compared with the initial propeller geometry.

2. Method

The non-dimensional performance coefficients that define the general performance characteristics of a propeller are the thrust coefficient (K_T) (1), the torque coefficient (K_Q) (2), and the advance coefficient (J) (3). These non-dimensional coefficients are calculated as follows based on the inputs of thrust (T), torque (Q), fluid density (ρ), rotational speed (n), propeller diameter (D), and advance velocity (V_a). Using these coefficients, the open-water efficiency (η_0) (4) can be found. The cavitation number (σ_n) (5), which predicts the onset of cavitation at a reference point on the propeller blade, depends on factors such as hydrostatic pressure (P_{st}) and saturation pressure (P_v) [8].

$$K_T = \frac{T}{\rho n^2 D^4} \tag{1}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \tag{2}$$

$$J = \frac{V_a}{nD} \tag{3}$$

$$\eta_0 = \frac{K_T}{K_Q}\frac{J}{2\pi} \tag{4}$$

$$\sigma_n = \frac{P_{ST} - P_V}{0{,}5\rho n D} \tag{5}$$

3. SVA Potsdam VP 1304 PPTC and CFD Validations

This section includes a CFD validation study based on the experimental results of the SVA Potsdam VP 1304 propeller. The aim of this validation study is to compare the results obtained from the CFD simulations with those obtained from the cavitation tunnel experiments. The VP 1304 standard test propeller is a 5-blade propeller with a diameter of 0,25 m and a 0,3 hub-to-diameter ratio with a skewness angle of 18,837° [9], and the images of the pitch-controlled propeller are shown in Figure 1.

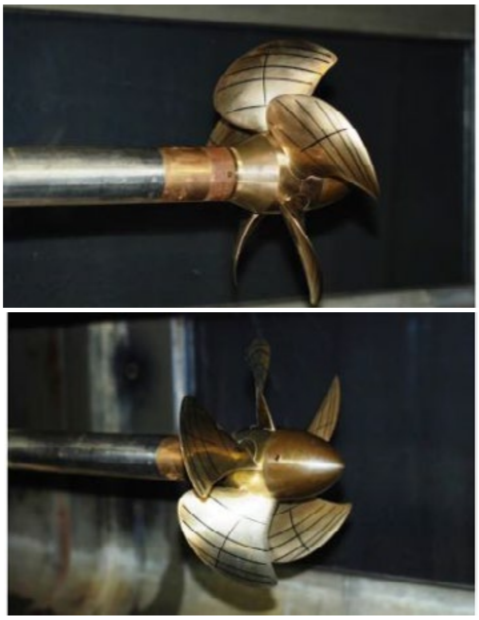


Figure 1: VP 1304 Propeller at the SVA 2011 Symposium [9]

The geometric characteristics of the propeller are shown in Table 1

Table 1: Characteristics of the VP1304 Propeller [9]

Properties	**Symbol**	**Value**
Diameter	D (m)	0,25
Pitch @ r/R	$P_{0,7D}$	1,635
Blade Area Ratio	A_E/A_0	0,7789
Chord Length @ 0,7R	$C_{0,7}$	0,1041
Skewness	$\Theta_{EXT}^{(°)}$	18,837
Hub/Diameter	d_h/D	0,3
Number of Blades	Z	5
Rotation Side	-	Right
Type	-	Pitch Controlled Propeller

3.1 PPTC 2011 Test Conditions

The tests were performed under 3 different conditions. Details are shown in Table 2.

Table 2: Flow Conditions for VP1304 PPTC 2011 Case Analysis [9]

Parameters	Case 1	Case 2	Case 3
Tunnel Water Temperature (°C)	23,2 °C	23,2 °C	23,2 °C
Hydrostatic Pressure of the Tunnel (Pa)	42207	30528	41872
Vapor Pressure of Water (Pa)	2818	2818	2869
RPM (rps)	24,987	24,987	25,014
Propeller Diameter (m)	0,25	0,25	0,25
Density of Water	997,44	997,44	997,37
Propeller Advance Coefficient (J)	1,019	1,269	1,408
Water Velocity (m/s)	6,365	7,926	8,804

3.2 Domain and Boundary Conditions

The geometry of the PPTC VP 1304 propeller was created in the Rhinoceros CAD program and transferred to the Ansys CFX program. The process of subtracting the propeller geometry from the control volume was performed using the Ansys Design Modeler module. The created propeller geometry model is shown in Figure 2.

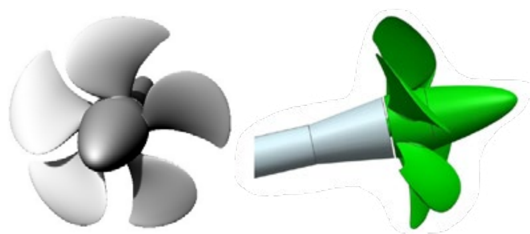


Figure 2: VP 1304 CAD Model [9]

For CFD analyses, the initial and boundary conditions should be defined carefully depending on the flow problem. Correct boundary conditions lead the analysis to accurate results and prevent the unnecessary computational costs [10]. The computational domain consists of rotating and static regions. The inlet and outlet surfaces are velocity inlet and pressure outlet, respectively. The common surfaces between these regions are defined as interfaces. The propeller blades, hub and the shaft are defined as non-slip wall. Detailed information about the boundary conditions applied in the analyses can be found in the guide tutorials of the commercial CFD solver [11]. As boundary conditions for the external domain, the inlet velocity side is positioned at 2 propeller diameters, the outlet pressure side is at 4 propeller diameters, and the propeller circumference is at 8 propeller diameters. According to the ITTC standard [12], the maximum y+ value is intended to be 100 to accurately model the boundary layer around the propeller blade and hub. Therefore, a boundary layer tetrahedral mesh consisting of 12 layers with a maximum thickness of 4.8 mm around the propeller and growing at a rate of 1.2 per layer has been generated. Analyses were carried out using a total of 7,2 million solution meshes in the solution domains, and boundary conditions applied to the computational domain are given in Figure 3.

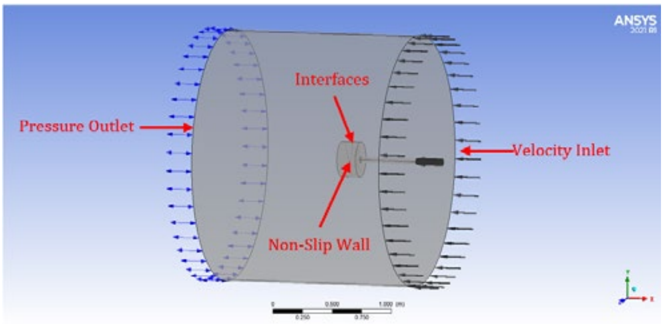


Figure 3: Boundary Conditions

3.3 Sensitivity Analysis

According to the standard document [13], a convergence study was carried out with ratios of the differences between the results obtained using different mesh sizes. When the result of the analysis with a fine number of mesh is S_{k1}, the result of the analysis with a medium number of mesh is S_{k2}, and the result of the analysis with a coarse number of mesh is S_{k3}, Changes between medium-fine ($\varepsilon_{i,21}$) (6) and coarse-medium ($\varepsilon_{i,32}$) (7) solutions are used define the converge ratio.

$$\varepsilon_{i,21} = \acute{S}_{i,2} - \acute{S}_{i,1} \tag{6}$$

$$\varepsilon_{i,32} = \acute{S}_{i,3} - \acute{S}_{i,2} \tag{7}$$

The convergence rate (R_i) (8) is expressed as:

$$R_i = \frac{\varepsilon_{i,21}}{\varepsilon_{i,32}} \tag{8}$$

According to this definition, three different convergence states can be formed:
Monotonous Converge: $0<R_i<1$
Oscillation: $R_i<0$
Diverge: $R_i>0$

Sensitivity analyses was performed J=1,019 advance coefficient and case 1 for VP 1304 Propeller. Thrust coefficient parameters obtained from the analysis are given in Table 3.

Table 3: Parameters Obtained from Sensitivity Analysis

	Mesh Size (mm)	Total Mesh (million)	CFD-K_T	EFD-K_T	Relative Difference (%)
$\acute{S}_{i,1}$	0,65	10,3	0,3728	0,3725	0,08
$\acute{S}_{i,2}$	0,92	7,1	0,3745		0,54
$\acute{S}_{i,3}$	1,3	5,5	0,3766		1,1
$\varepsilon_{i,21}$	0,0017				
$\varepsilon_{i,32}$	0,0021				
R_i	0,81				

In the sensitivity analysis, εk_{21} was calculated as 0,0017, εk_{23} was calculated as 0,0021. Consequently, Rk=0,81 and convergence has been achieved.

The image of the mesh structure used in the propeller is shown in Figure 4.

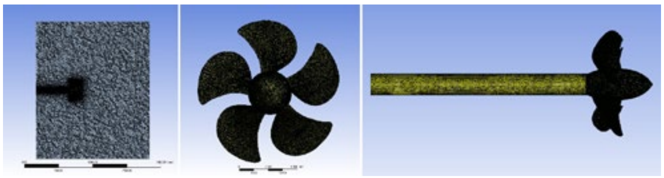


Figure 4: Mesh View of PPTC VP 1304 Propeller

3.4 Solution Methods

To eliminate the sudden changes in pressure momentum and continuity that will occur at the beginning of the analysis, the analysis was started as steady. It was later resumed as transient. Both steady and transient analysis was performed with two phases (water & water vapor). According to ITTC standard [14], in the transient analysis the propeller was rotated by 20° per time step. SST k-ω turbulence model with Raylight Plesset Zwart Cavitation method was used. In this validation study, the thrust force and cavity area values of the propeller blades were compared with the experimental results. The thrust coefficient and cavitation areas were calculated under three different flow conditions. The comparative CFD results with SVA experiments are summarized in Table 4. These analyses results are closely aligned with the cavitation tunnel test results.

Table 4: The Comparison of K_T Values at Different Advance Coefficient Values

	K_T Case 1	K_T Case 2	K_T Case 3
Advance Coefficient (J)	1,019	1,269	1,408
SVA-Experiment Result	0,3725	0,2064	0,1362
CFD-Result	0,3745	0,2021	0,1315
Relative Difference (%)	0,54	2,08	3,45

The cavity field patterns resulting from the analyses by Vapor Volume Fraction 50%, along with the cavity captures of the experimental comparative results, are comparatively presented in Figures 5, 6, and 7.

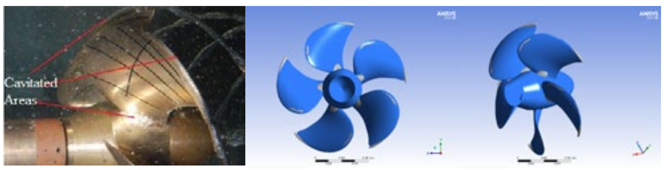


Figure 5: Case 1 Experiment and CFD Cavity Captures Comparison

As a result of the CFD analysis, it was seen that the cavitation patterns formed in the leading edge, tip and root region of the propeller blades are consistent with the experimental results in Figure 5.

Figure 6: Case 2 Experiment and CFD Cavity Captures Comparison

As seen in Figure 6, CFD analysis shows that the cavitation patterns formed in the suction and thrust side root regions of the propeller blades are consistent with the experimental results.

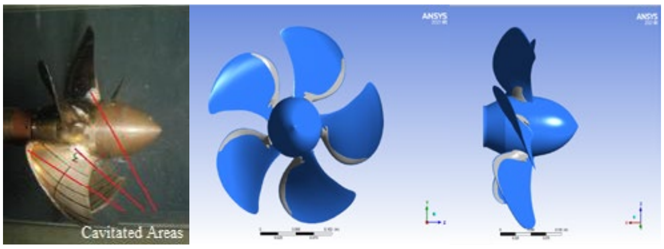


Figure 7: Case 3 Experiment and CFD Cavity Captures Comparison

As seen in Figure 7, the CFD analysis shows that the cavitation patterns formed in the root region of the suction side and the leading edge of the thrust side of the propeller blades are consistent with the experimental results. SVA VP 1304 PPTC 2011 experiment is the study used as a reference for the propeller cavitation validation study conducted at different advance coefficients. It has been observed that the propeller cavitation images, and performance coefficients obtained in the experiment were compatible with CFD. The reason for using this experiment in the study was that it allowed to validate the performance coefficients of the propeller and the cavity area by CFD. The fact that the CFD result was compatible with the experimental results gave the possibility for subsequent studies. The validation method in the experiment will be used in CFD calculations for investigating the impact of propeller pitch, blade area ratio, skew and rake angle on cavitation.

4. Parametrically Designed Propellers

As a result of the validation studies, it was determined that the results from the CFD were compatible with the experimental results. After the validation, an initial propeller geometry was designed based on the VP 1304 propeller geometry. Later, four different propeller designs were created by changing the Blade Area Ratio (BAR), Pitch (P), Skew, and Rake parameters of this initial propeller. Propeller-1 was designed by increasing the Skew parameter by 20%, Propeller-2 was designed by increasing the BAR parameter by 20%, Propeller-3 was designed by increasing the Pitch parameter by 20%, and Propeller-4 was designed by increasing the Rake by 20%. The effect of each parameter on cavitation and open water has been evaluated separately, and parameters that positively influence the cavitation and open water performance of the initial propeller have been applied to the new design propeller, which is named 'developed.' Lastly, the cavitation performance of the developed propeller geometry has been compared with the initial propeller geometry under the Case 1 cavitation tunnel condition at the SVA PPTC 2011 symposium. The geometric characteristics of the propellers were given in Table 5.

Table 5: Characteristics of Parametrically Designed Propellers

	D	P	P/D	BAR	Skew	Rake
Initial-Propeller	0,25	0,4	1,6	0,75	20	5
Propeller-1	0,25	0,4	1,6	0,75	24	5
Propeller-2	0,25	0,4	1,6	0,9	20	5
Propeller-3	0,25	0,48	1,92	0,75	20	5
Propeller-4	0,25	0,4	1,6	0,75	20	6

The parametrically designed propeller geometries were shown in Figure 8.

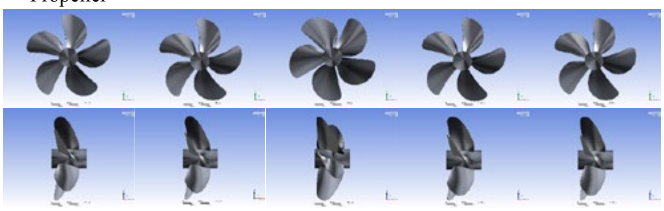


Figure 8: Parametrically Designed Propeller Geometries

4.1 Open Water and Cavitation Performance Analysis

To determine the efficiency of the propellers, open water performance tests were carried out initially. Following this, the cavitation behavior will be evaluated under case 1 conditions. The propeller open water flow conditions are presented in Table 6.

Table 6: Flow Conditions for Open Water Analysis

Parameters	Case 1
RPM (rps)	24,987
Propeller Diameter (m)	0,25
Density of Water (kg/m³)	997,44
Propeller Advance Coefficient (J)	1,019
Water Velocity (m/s)	6,365

Four propellers were parametrically designed in the PropCAD and Rhinoceros CAD program and transferred to the Ansys CFX CFD solver. The process of subtracting the propeller geometry from the control volume was performed using the Ansys Design Modeler module.

The location of the propeller inside the tunnel and the boundary conditions were determined similarly to section 3.2. In the analysis of the SVA VP 1304 PPTC 2011 symposium propeller open water and cavitation experiments, the size of the propeller blade mesh of 0.92 mm obtained from the sensitivity analysis of the validation study was used. A total of 7.3 million solution meshes were used in the solution regions.

When the open water characteristic results of the four propellers are compared with those of the initial propeller, it is observed that Propeller-3, with increased pitch, has the lowest efficiency (η_0) and the highest K_T. Additionally, when the results of the other three propellers are compared with those of the initial propeller, it is noted that only a 20% increase in one parameter leads to a slight decrease in overall open water propeller efficiency, while Propellers 1 and 2 show a slight increase in K_T values, and Propeller 4 exhibits a slight decrease. The comparative results for the propellers are summarized in Table 7.

Table 7: Open Water Performance of Parametrically Designed Propellers

	K_T	10 x K_Q	η_0	Relative Difference K_T - (%)		Relative Difference η_0 - (%)	
Initial Propeller	0,3570	0,890	0,6505				
Propeller-1	0,3580	0,903	0,6430	~0,3	↑	~1,2	↑
Propeller-2	0,3620	0,919	0,6388	~1,4	↑	~1,8	↑
Propeller-3	0,5172	1,483	0,5656	~45	↑	~13	↑
Propeller-4	0,3562	0,897	0,6440	~0,2	↓	~1,0	↑

The parametrically designed propellers were compared for cavitation tunnel performance after open water performance analysis. Case 1 conditions used at the SVA 2011 symposium were applied in cavitation tunnel analysis. Cavitation tunnel conditions for propellers are presented in Section 4.1 Table 6.

The thrust coefficients and cavitation areas were calculated according to analysis conditions. The comparative results are summarized in Table 8 and Figure 9.

Table 8: Cavitation Performance of Parametrically Designed Propellers

	Cavitated Area	Relative Difference η_0 - (%)	
Initial Propeller	0,00872		
Propeller-1	0,00834	~4,4	↓
Propeller-2	0,007352	~15,7	↓
Propller-3	0,0198	~127	↑
Propeller-4	0,008692	~0,3	↓

Figure 9: Cavitation Areas of Parametrically Designed Propellers

It is observed that Propeller-3, with an increased pitch, had the highest cavitated area. Additionally, the positive effect of the other parameters on the cavitation performance of the initial propeller is also noted. When the results of the open water and cavitation analyses of these propellers developed through parametric design study are evaluated together, it is observed that increasing the pitch significantly increases thrust and cavitation, while decreasing the efficiency of the open water propeller. However, an increase in the Blade Area Ratio (BAR), Skew, and Rake parameters has been observed to have a positive effect on cavitation performance, while causing a slight decrease in open water efficiency.

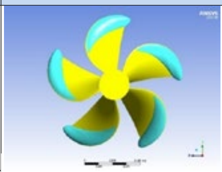
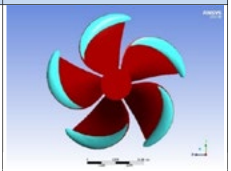
5. Results

The results of open water efficiency and cavitation performance for both the initial propeller and the four propellers designed parametrically were compared in Section 4.1. In the final design of the improved propeller form the parameters which increased the cavitation performance were selected. As understood from the previous section, increasing the propeller pitch has a negative impact on both open water efficiency and cavitation performance. Therefore, while the propeller pitch remained the same as the initial propeller in designing the developed propeller form, the other parameters (BAR, Skew and Rake) were increased by 20% and applied to the developed propeller design. This is because these parameters, despite causing a slight decrease in open water efficiency, provide a significant improvement in cavitation performance. To determine the efficiency of both the initial and developed propellers, open water performance tests were conducted initially. Subsequently, the cavitation behavior will be evaluated under again case 1 conditions. The cavitation tunnel and open water flow conditions for the propellers are mentioned in previous sections. Characteristics of propellers and comparative results for the propellers are summarized in Table 9 and 10.

Table 9: Characteristics of the Initial and Developed Propellers

	D	P	P/D	BAR	Skew	Rake
Initial-Propeller	0,25	0,4	1,6	0,75	20	5
Developed-Propeller	0,25	0,4	1,6	0,90	24	6

Table 10: Comparative Results for Initial and Developed Propeller

	Initial Propeller	Developed Propeller
		
Cavitated Area	0,00872 m^2	0,007117 m^2
K_T	0,3570	0,3636
K_Q	0,0890	0,0949
η_0	0,65	0,62

The results of the open water and cavitation analyses of these propellers are evaluated together, it is observed that increasing the Skew, BAR, and Rake decreases cavitation by around 19%. Additionally, alongside the approximately 2% increase in thrust coefficient, the torque coefficient also increased by around 7%, resulting in a loss of around 4,6% in the propeller's open water efficiency.

6. Conclusions

In this paper, computational analyses of the well-known VP 1304 propeller have been carried out. To validate the numerical method, CFD results have been compared with the available experimental data. Numerical calculations show that changes made to the Pitch parameter require special attention among all parameters. The reason for this is that altering the pitch can significantly affect both the efficiency of the propeller in open water and the occurrence of cavitation. For example, during the design process, an increase in the ship's weight or speed requirements can influence propeller design. In such cases, increasing the propeller pitch should not be the immediate solution. Instead, the necessary increase in thrust can also be achieved by increasing Skew or BAR. While an increase in pitch can easily meet the new thrust requirement, it also brings along the cavitation issue. As the pitch increases, the propeller generates more thrust, which increases the likelihood of cavitation formation. In fact, if more thrust is generated than necessary, the excess thrust will directly lead to cavitation. This situation can be likened to the wear on the tires of a skidding car.

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Optimization Model in Ro-Ro Vessel Operations

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Abstract

With the increase in international trade and short-sea shipping, problems related to planning and operational decision-making processes in port management are frequently on the agenda of the port industry. In addition to ports that specialize in handling the same type of cargo, there are also multi-purpose ports that handle cargo such as containers, ro-ro and general cargo. In this study, an optimization model has been developed in order to make the yard planning of a multi-purpose port where cargo such as container, roro, general cargo, bulk cargo and project cargo are handled more efficiently. In the model, answers are sought to the issues of how many cargoes to be discharged from Ro-Ro vessels or loaded to vessels will be taken to which areas and to which berth the vessel will be berthed. GAMS program was used to solve the established. In this model prepared with seven berths, eighteen yards and eight cargo types were aimed to minimize the discharging-loading operation times of the ro-ro vessel, to predict the port density according to the vessel schedule in the future and suggest a sustainable application.

Keywords: *Optimization, Yard Planning, Port Management, Mathematical Model, Ro-Ro*

1. Introduction

Product transportation is carried out by the most appropriate means of air, sea, road and railway transportation, taking into account different criteria such as the location of unloading and loading, load characteristics and transportation costs. Today, approximately 90% of trade activities are carried out by sea, but the rate of domestic transportation in our country utilizing maritime transportation is very low [1]. In this study, it is aimed to examine the processes of a multi-purpose port operation in Kocaeli and to transform the manually planned discharging and loading operations into a mathematical model with the data collected and to use the results obtained from the model solution. Maritime transportation is the most frequently used means of global trade, especially due to low costs. In Europe, short sea Roll-on/Roll-off (RoRo) shipping is a dominant transportation mode due to its flexibility and connectivity [2]. New vehicles, buses, trucks, pickup trucks, trailers, construction equipment, etc. Transportation of drivable loads is called Roll on-Roll off (Ro-Ro) transportation. Specially designed Ro-Ro vessels are used to easily transport these cargoes by sea. The fact that Ro-Ro vessels are like multi storey car parks, that they have adjustable height floors for non-standard loads, and that they have a high carrying capacity provide advantages in the transportation of these Ro-Ro loads. In order to get ahead of competitors in international Ro-Ro transportation, it is important to follow trends and increase process efficiency. Most terminal operation systems used to manage processes in ports where Ro-Ro cargo is handled cannot go beyond keeping operational and commercial records regarding discharge and loading. Since a serious software investment is required for an optimization-related study, port operators continue their planning processes manually. In this study, it is aimed to examine the processes of a multi-purpose port operation in Kocaeli and to transform the manually planned discharging and loading operations into a mathematical model with the data collected and to use the results obtained from the model solution. The questions of how much of the cargo to be discharged from Ro-Ro vessels will be taken to which areas and to which berth the vessel will berthed have been answered with a model established in the GAMS program. In the model, separate objective functions were written for each berth and the results were evaluated.

There are some optimization studies on Ro-ro processes in the literature. Chen et al. (2021), based on the Ro-Ro vessel stacking scheme, they proposed a car group concept that would reflect the loading order of cars onto a Ro-Ro vessel. Their numerical experiments show that the proposed method can effectively produce a satisfactory car assignment plan for the management of automotive Ro-Ro terminals [3]. Yan-ning et al. (2014), based on the analysis of ro-ro vessel loading characteristics, the ro-ro vessel loading problem for multiple ports is formulated by mixed integer programming, taking into account realistic constraints such as stability of vessels, loading efficiency and voyage revenue [4]. Øvstebø et al. (2011), modeled the problem of a ship navigating between two geographical regions, picking up cargo in the first and delivering it to the second, with a mixed integer program that was solved using Xpress [5]. Tang et al. (2015), considering that the scale of the parking lot has a significant impact on the efficiency of the entire roll-on/roll-off terminal (RORO terminal), they proposed a simulation model to simulate vehicles entering and exiting the RORO terminal with Arena software [6]. Øvstebø et al. (2011), have established a mathematical model that explains the problems of "which cargo to carry, how many vehicles of each cargo to carry, and how to stack the vehicles carried during the journey" with a ship that will travel according to a certain route. They used both a standard Mixed Integer Programming solver and a specially designed heuristic to solve the problem [7]. Dragović et. al. (2015), discussed the performance indicators and traffic analysis of the Ro-Ro automobile terminal, which has experienced rapid growth in recent years. They conducted a study on the traffic and frequency analysis of ships visiting the Port of Bar in 2013, and the detailed empirical analysis is based on the terminal traffic obtained during the period in question [8]. Zhang et. al. (2023) addressed a common scheduling problem of field section allocation and transfer manpower allocation at the macro level in automobile RO-RO terminals. They formulated the joint scheduling problem as a mixed integer programming model with the goal of minimizing the required total driving distance of vehicles and showed that the proposed algorithms can efficiently produce high-quality solutions and have great practical value in daily operations [9].

2. Methodology

The process flow in contracted ports with vessels begins with the vessel agency's notification of the vessel's Estimated Time of Arrival (ETA). By informing the estimated number of discharging-loading and load types of ro-ro vessels in the port, the port planning department determines which berth the vessel will berth at and which areas the vehicles to be discharged will be taken to. In field planning, planning is done according to the company information and special groupage requests of the vehicles. The team that will operate the vessel in the port management includes a driver, traffic person, shuttle services and drivers, stower, lashing personnel and a team leader. The operation is initiated following the berthing of the vessel and completion of its checks. Traffic officers are placed according to the vessel's decks and port route. Drivers carry the vehicles from the vessel to the yard or from the yard to the vessel, and shuttle vehicles take the drivers back to where they started from where they left off. While the vehicle parking operation is carried out with the stower personnel. Through stower personnel, parking between vehicles is narrow and possible damage is prevented. After the vehicles to be loaded are loaded according to the discharge port and cargo plan, lashing operations are carried out to prevent damage during the voyage. After the operations are completed, the vessel becomes ready for departure and takes off after the necessary permissions.

While yard planning is being done for the vehicles to be discharged from the vessel, the operation time is tried to be minimized. During the discharging process, construction equipment, trucks, trailers, etc. Since the driving speed of the loads is low, planning is required to the nearest yard. There are seven berths where Ro-Ro vessels can berth in the port facility where the study was carried out. The decision on which berths the Ro-Ro vessels will berth and to which areas the vehicles to be discharged from the vessel will be taken is determined by the planner. In the study, it was aimed to minimize the operation time, use the fields effectively and accelerate the planning processes with mathematical modeling. In a problem obtained from an example vessel data, there are eleven load groups to be discharged and they are construction equipment, parts, automobiles, trailers, trucks, etc. includes load types. Decision variables are defined as the number of loads to be taken to the fields of eleven groups. The distance from each berth to the sites was measured and tabulated as time (sec) according to load types. The restrictions are that the number of decision variables to be evacuated to the fields should not exceed the field capacities and that the full number of groups to be discharged from the vessel is used. In the modeling, separate operation times are calculated for each berth. Determining which berth the vessel will berth at and the number of field assignments by looking at these operation times provides visible data to the port management and planning team. In linear programming, results consist of positive numbers. In some problems, decision variables must be zero, one or integer. In such problems, integer programming must be used [10]. GAMS program, which is used for high-level mathematical programming and optimization, was used in the study. This system is designed for complex, large-scale modeling applications and allows the programmer to quickly adapt models to new situations. Complex integer models can be solved with the GAMS program.

3. Conclusion

In the modeling done with the GAMS program, separate results were found for each berth. It is envisaged that the operation of the R6 berth, which shows the minimum result compared to other berths, will be completed in nineteen hours, according to the current yard capacities. The table below shows how much loads of the Ro-Ro vessel berthing at R6 berth will be distributed to appropriate areas. When the work on the model is completed, an attempt will be made to demonstrate the optimum berthing, additional services and loading with integer modeling. The model used in the study can be integrated with the terminal operation system used in port operations and users can be offered the opportunity to manage operations through a single system.

Table 1. Assignment Results

R6 BERTH											
Yard/ Group	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11
C1											
C2											
C3											
VIP											
RA2											
B4											
B3		19	1000							46	
B2	500			100							
B1					31			2			
A3											
A2											
A1											
R8				77	38	142	5				
R7			138	12							
R6									15	11	7
R5											
VGA											
D3A											

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An experimental investigation about Vortex-Induced Vibrations of a single cylinder and two cylinders in tandem arrangement

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Abstract

VIV (Vortex-Induced Vibrations), a subheading of FIV (Flow-Induced Vibrations), is a phenomenon caused by the separation of flow from a bluff body while it oscillates. When vortices are shed at the wake of the structure, they cause it to move by exerting force. This movement generates new vortices, and the continuous motion induces vibrations. This experiment-based study investigates the VIV effects on a system, utilizing both a single cylinder and two cylinders in tandem arrangement with distinct characteristics. The objective of this research is to compare the amplitudes and frequencies of the responses at the same speeds. In the present scenario, two cylinders and two pairs of springs are used. The length of the rear cylinder is 1.345 m, while the other one is 1.423 m. The stiffness of the two pairs of springs are 766 N/m and 917 N/m. Both cylinders have a diameter of D=0.08 m. In the tandem cylinders experiment, the distance between the outer shells of the two cylinders is measured as 1D. Based on the results of the experiments, despite having similar characteristics in terms of mass ratio, length of the cylinder, and the type of spring used; the amplitude ratio of the rear cylinder in tandem cylinders is lower than that of the single cylinder. This difference is attributed to the influence of the front cylinder in tandem cylinders on the rear cylinder. Another observation from this experiment is that the synchronization range in tandem cylinders is wider than in the single cylinder. Additionally, the Upper Branch range of the front cylinder is larger than that in the rear and single cylinder. It can also be observed that the increase in the oscillation frequency of the single cylinder after the flow velocity of U=0.614 m/s, is greater than that of the tandem cylinders.

Keywords: *Vortex-induced vibrations, flow-induced oscillations, single cylinder, tandem cylinders*

1. Introduction

VIV (Vortex-induced vibration), a subheading of FIV (Flow-Induced Vibration), is a phenomenon that arises from the formation of vortices in fluid flow. When the fluid flows past the structure, it creates alternating areas of high and low pressure around the structure. These pressure differences lead to the generation of vortices, which are swirling regions of fluid motion. This phenomenon has been extensively researched by numerous scientists in recent years, and each study has contributed new findings to the literature. Despite all the conducted research, it is undeniable that the topic of VIV still requires further investigation. The event that first brought attention to VIV occurred in 1940 with the collapse of the Tacoma Narrows Bridge. Initially, VIV was predominantly discussed and researched for its harmful effects; however, researchers have increasingly explored its potential benefits over time. In 2005, a new method for energy harvesting from water currents through VIV was invented by Professor Bernitsas and his group at the University of Michigan. Overall, when considering VIV, it can be both a harmful and a beneficial phenomenon.

Cylindrical structures are frequently utilized in offshore engineering, such as platform legs, risers, seabed pipelines, etc. VIV affects numerous systems and structural models, and some of them include offshore platforms, ship appendages, bridge suspensions, towed cables, and marine pipelines. The presence of vibrations, when exposed to environmental forces like waves and currents, can cause structural fatigue. From one perspective, VIV of flexibly mounted bluff bodies, a significant challenge in the field of marine engineering, stands out as an important and attention-worthy research topic. This is especially notable due to the diverse dynamic characteristics, particularly for investigating the relationship between flow and structure. On the other hand, VIV can also be classified in the renewable energy category due to the vibrations it generates. The topic of renewable energy is gaining even more attention and importance as scientific evidence continues to demonstrate the various harms caused by other forms of energy to both nature and humanity. VIVACE (Vortex-Induced Vibration for Aquatic Clean Energy) serves as an illustrative example in the context of the discussed renewable energy topic [1], [2]. From a general perspective, minimizing the induced oscillation is desirable when investigating the detrimental aspects of VIV, aiming to reduce potential harm to the system. Conversely, in the context of discussing the beneficial impact of VIV on renewable energy production, it becomes crucial to emphasize and optimize the obtained oscillation for maximum energy conversion. In studies of both the harmful and beneficial effects of VIV, several known variables should be considered, including the amplitude of the motion, the frequency of vortex shedding, and the frequency of the oscillation. Figure 1 shows the shedding vortices around the stationary and moving cylinders, the separation point of each boundary layer, the boundary layer, and the wake region. This wake is known as von Kàrmàn vortex street. Figure 2 illustrates the schematic view of the single cylinder and tandem cylinders.

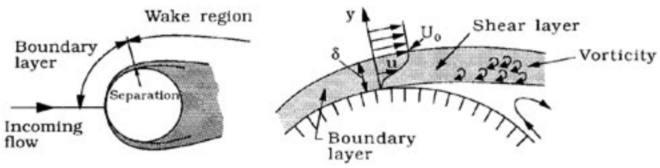

Figure 1. Schematically Representation of Boundary Layer and Wake Region [3].

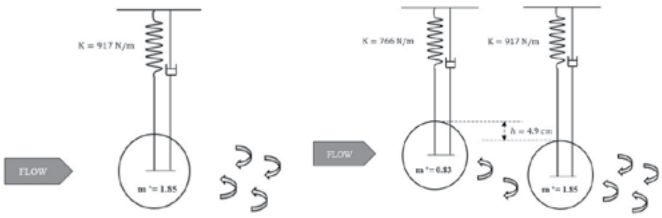

Figure 2. Schematic View of the Single Cylinder (Left). Schematic View of the Tandem Cylinders (Right)

In VIV systems, two types of responses exist, as indicated by [4], and these responses depend on the mass damping (m* ζ) and working fluid parameters [5]. The first type, which commonly uses air as its working fluid, is associated with systems characterized by a high mass-damping parameter and includes two branch responses named the "Initial" and "Lower" branches. The second type primarily utilizes water as its working fluid and has a third branch response named the "Upper" branch. This branch exhibits a higher amplitude response compared to the two branches described above [6]. Figure 3 shows four different areas of the amplitude response of a VIV system including the "Initial", "Upper", "Lower", and "Desynchronization" branches. Experiments generally include these four areas.

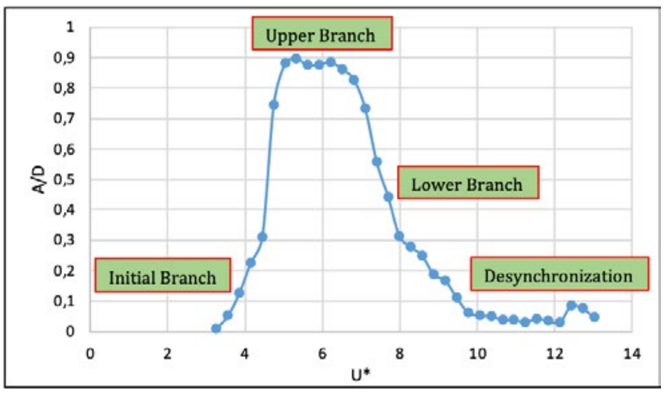

Figure 3. Motion Regions of the Amplitude Response of a VIV System

There are two common parameters that affect the VIV characteristics of the system: amplitude and frequency. These parameters also depend on certain details within the system, including spring stiffness, surface roughness, mass ratio, etc.

There is a situation that the experimental frequency at the point where amplitude ratio (A/D) is maximum, becomes close to the natural frequency of the system ($f_{n.w}$). This situation is called "resonance". However, in VIV, it is called "lock-in". The maximum movement is achieved at this point (1).

2. Experimental Setup

The experiments have been carried out in the circulation channel of ITU (Istanbul Technical University) Ata Nutku Ship Model Testing Laboratory located at the Ayazaga Campus of ITU Istanbul, faculty of Naval Architecture and Ocean Engineering. On the first floor of the two-story tunnel, there is an impeller on the first floor which circulates the water in the tunnel powered by a 67HP electrical motor (7). The test section, where the experiments are conducted, is located on the second floor. Figure 4 displays a CAD view of the circulation channel and also illustrates the channel in the laboratory. The channel has the ability to stream a uniform steady current in a flow velocity range of $0 < U < 2$ m/s.

First, the frame is mounted and moored on the sides of the channel. Later, the selected cylinders are screwed on the struts. They become just one component. The component is placed into rails over the wheels. Then, the springs are attached to the struts. Subsequently, the camera systems are positioned in the middle of the frame to measure the distance between the cylinders and themselves, which is referred to as amplitude. The VIV system is finally ready for experimentation.

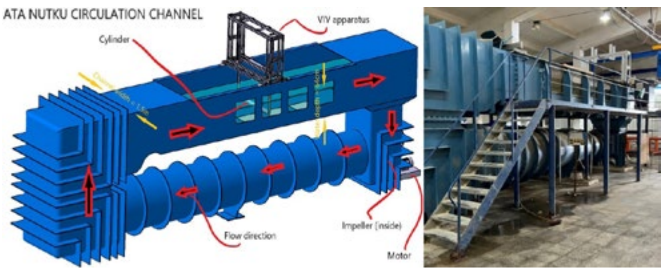

Figure 4. The CAD View of the VIV Prototype System (Left) (8). The Circulation Channel in Ata Nutku Ship Model Testing Laboratory (Right)

The experimental study was conducted in two main types. In the first experiment, a single cylinder was utilized, and two springs with the same stiffness value were attached to this cylinder. The purpose of the experiment was to investigate the VIV effects of a single cylinder. This research was conducted both without any flow entering the system and with the system exposed to a flow. In tests involving flow, the channel's flow was utilized. The flow velocity started at 0 m/s and progressed with an increment of 0.026 m/s. In this experiment, approximately 60 seconds were allotted at each specific velocity to obtain clear and accurate results, after which the system introduced the next velocity. In the second experiment, two different types of cylinders were used to harness the VIV effects of two tandem cylinders. In this experiment, two pairs of springs with different stiffness values were employed. The second part of the experiment commenced with channel flow starting at a speed of 0 m/s and continued with 0.026 m/s increments. Similar to the single cylinder test, a 60-second duration was allowed at each specific velocity to obtain clear and accurate frequency and amplitude responses of the cylinders. Upon examination of the results, both cylinders in this experiment began to move at a specific velocity. Over time, they were then subjected to progressively faster flows. Figure 5 illustrates the single cylinder and tandem cylinders system in the laboratory.

3. Components of the VIV System

The system used in all experiments is designed and developed in ITU Ata Nutku Ship Model Testing Laboratory and composed of several components. The components of the experimental setup include main frame, two identical compression springs, two cylinders with different features, two side struts, a pair of U groove guiding pulleys along with rails, and a sensor system that measure the distance between the cylinders and itself, referred to as amplitude. All the equipment has the advantage of providing low mechanical friction and a desirable low damping ratio (ζ).

Figure 5. The Experiment Setup of the Single Cylinder (Left). The Experiment Setup of the Tandem Cylinders (Right)

3.1. Springs of the VIV System

The two most common types of springs are extension and compression springs [9]. Extension springs are not suitable for the VIV system as they cannot be compressed, leading to a limitation where the motion of the cylinder does not continue upward beyond a certain point. Therefore, compression springs are selected for this case. To accurately determine the stiffness of the springs, the initial length of each spring was measured. Subsequently, various weights were sequentially added to the springs, and the length of each spring was measured after the addition of each weight. This sequential process facilitated the calculation of individual spring stiffness, revealing how each added weight affected the length of the springs (Figure 6).

Figure 6. Schematic View of a Spring Used in the Experiments

3.2. Sensors of the VIV System

The primary function of the sensor system is to detect, measure, and collect data based on the movement of the cylinders and transmit all of it. In the first part of the experiment, a single cylinder was used, so one sensor system was employed to measure its movements. In the second part of the experiment, with two cylinders, each exhibiting distinct movements, two sensor systems were added to the main frame. This allowed obtaining the values of the movements performed individually by each cylinder. Figure 7 shows one of the sensor systems used in the experiments.

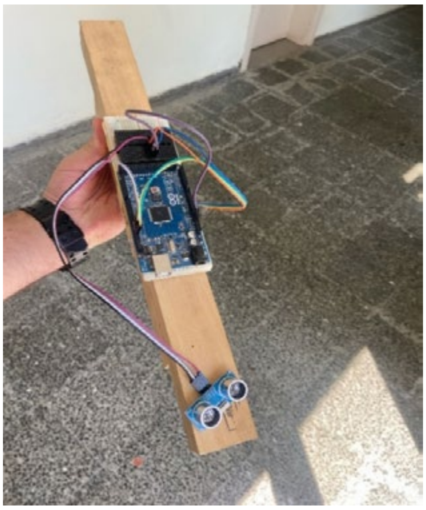

Figure 7. One of the Sensors Used in the Experiment

3.3 All Other Components of the VIV System

The VIV system used in the experiments comprises various components. Figure 8 illustrates all components connected to the cylinders.

Figure 8. All Other Components of the VIV System

4. Experimental Study

In this study, two main experiments have been conducted: one involving tests with a single cylinder, and the other involving tests with two cylinders in tandem arrangement. Each test comprises two parts: a free decay test and a test with flow. Free decay tests are conducted to determine the damping ratio, involving the application of an initial displacement to the cylinders. In tests with flow, the channel in Ata Nutku Ship Model Testing Laboratory is utilized, enabling the system to move by providing flow at different speeds.

4.1 Parameters of the VIV System

The design conditions of the experimental setup are listed in Table 1.

Table 1. Parameters of the VIV Setup

Parameters	Unit	Values
Stiffness of the springs	N/m	766 - 917
Length of the cylinders	m	1.345 - 1.423
Weight of the cylinders	Kg	4.45 - 2.7
Mass Ratios	-	0.83 - 1.85
Diameter of the cylinders	m	0.08
Water depth in the channel	m	0.63
Fluid density	kg/m³	999.72

4.2 Free Decay Tests

The results of the single cylinder tests and two cylinders in tandem arrangement are listed below.

4.2.1 Single Cylinder Free Decay Tests

Table 2 shows all the parameters of the single cylinder. The natural frequency ($f_{n,w}$) obtained from the experiments is 1.11 and the value obtained with formulas is 1.10. In addition, the damping ratio obtained from the experiments is 0.09.

Table 2. Parameters of the Single Cylinder

Parameter	Symbol	Unit	Value
Cylinder mass	m_{cyl}	Kg	4.45
Strut mass	m_{str}	Kg	8.05
Oscillation mass	m_{osc}	Kg	12.5
Displaced mass	m_{disp}	Kg	6.76
Added mass	m_{add}	Kg	6.76
Mass ratio	$m*$	-	1.85
Spring stiffness	K	N/m	917
Natural frequency of the system	$f_{n,w}$	1/s	1.10
Natural frequency from the experiments	$f_{n,w}$	1/s	1.11
Cylinder diameter	D	m	0.09
Cylinder length	L	m	1.345
Natural frequency in vacuum	$f_{n,v}$	1/s	1.36
Zeta	ζ	-	0.08
Reynolds number	Re	-	22,880 - 93,600
Reduced velocity	U*	-	3.25 – 13.31

4.2.2 Tandem Cylinders Free Decay Tests, Rear Cylinder

Table 3 shows all the parameters of the rear cylinder. The natural frequency ($f_{n,w}$) obtained from the experiments is 1.19 and the value obtained with formulas is 1.10. In addition, the damping ratio obtained from the experiments is 0.07.

Table 3. Parameters of the Rear Cylinder

Parameter	Symbol	Unit	Value
Cylinder mass	m_{cyl}	Kg	4.45
Strut mass	m_{str}	Kg	8.05
Oscillation mass	m_{osc}	Kg	12.5
Displaced mass	m_{disp}	Kg	6.76
Added mass	m_{add}	Kg	6.76
Mass ratio	$m*$	-	1.85
Spring stiffness	K	N/m	917
Natural frequency of the system	$f_{n,w}$	1/s	1.10
Natural frequency from the experiments	$f_{n,w}$	1/s	1.19
Cylinder diameter	D	m	0.08
Cylinder length	L	m	1.345
Natural frequency in vacuum	$f_{n,v}$	1/s	1.36
Zeta	ζ	-	0.07
Reynolds number	Re	-	22,880 - 135,200
Reduced velocity	U*	-	3.25 – 19.23

4.2.3 Tandem Cylinders Free Decay Tests, Front Cylinder

Table 4 shows the other parameters of the front cylinder. The natural frequency ($f_{n,w}$) obtained from the experiments is 1.21 and the value obtained with formulas is 1.22. In addition, the damping ratio obtained from the experiments is 0.07.

Table 4. Parameters of the Front Cylinder

Parameter	Symbol	Unit	Value
Cylinder mass	m_{cyl}	Kg	2.70
Strut mass	m_{str}	Kg	3.20
Oscillation mass	m_{osc}	Kg	5.90
Displaced mass	m_{disp}	Kg	7.15
Added mass	m_{add}	Kg	7.15
Mass ratio	$m*$	-	0.83
Spring stiffness	K	N/m	766
Natural frequency of the system	$f_{n,w}$	1/s	1.22
Natural frequency from the experiments	$f_{n,w}$	1/s	1.21
Cylinder diameter	D	m	0.08
Cylinder length	L	m	1.423
Natural frequency in vacuum	$f_{n,v}$	1/s	1.81
Zeta	ζ	-	0.07
Reynolds number	Re	-	22,880 - 135,200
Reduced velocity	U*	-	3.25 – 19.23

4.3 Comparison of VIV Responses

Figure 9 displays detailed results of both the single cylinder experiment and the tandem cylinders experiment. The primary objective of this graph is to compare the amplitude responses obtained from the experiments against increasing reduced velocity. Figure 10, on the other hand, is intended for comparing the frequency of oscillation results obtained from the conducted experiments. Looking at Figure 9, due to the differing characteristics of the front cylinder, the transition trend from the Initial branch to the Upper branch, as well as the duration of staying in the Upper branch, are different compared to the other two cylinders. This means that the front cylinder, compared to the other two, finishes the Initial branch and transitions to the Upper branch at a higher range of reduced velocity. However, upon entering the Upper branch, it stays in this region for a longer reduced velocity range before eventually transitioning to the Lower branch.

An important point to note here is that in the single cylinder experiment and the front cylinder of the tandem cylinders experiment, the amplitude responses decrease towards a minimum trend at maximum reduced velocity. However, in the tandem cylinders experiment, the rear cylinder's amplitude response shows an increase with increasing reduced velocity.

Additionally, looking at Figure 10, it is possible to observe that the frequency of oscillation results vary with increasing reduced velocity. Up to a reduced velocity of 5.33, the highest frequency of oscillation is associated with the front cylinder, while after a reduced velocity of 7.19, the highest frequency value belongs to the single cylinder. Generally, however, across all results, it is evident that the frequency of oscillation increases with increasing reduced velocity.

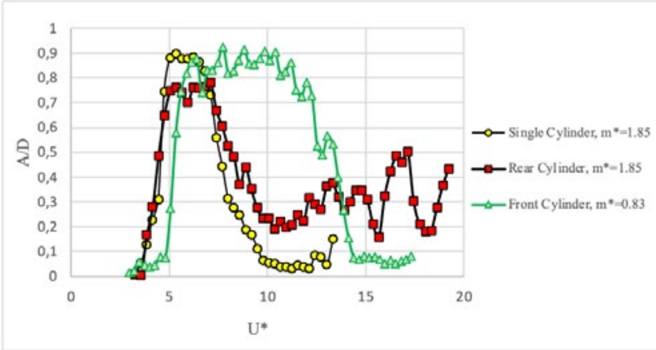

Figure 9. Comparison of Amplitude Responses of the Single Cylinder, Rear Cylinder, and Front Cylinder in Tests with Flow

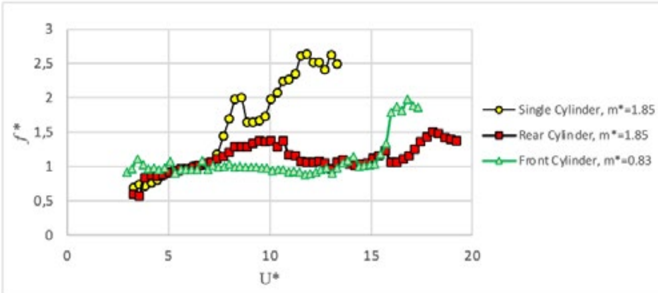

Figure 10. Comparison of Oscillation Frequencies of the Single Cylinder, Rear Cylinder, and Front Cylinder in Tests with Flow

Conclusion

In all situations, the data of the experiments are gotten from 220 rpm which equals to 0.286 m/s as the movement of the system in each test starts at this velocity. Fig. 9 shows that in the single cylinder's test, until the velocity of 300 rpm which equals to 0.39 m/s, the VIV system is in Initial Branch. Between 0.39 m/s and 0.65 m/s which equals to 500 rpm, the system is in Upper Branch. After this speed, the system enters to Lower Branch.

Fig. 9 also shows that in the rear cylinder's results of tandem experiment, until the velocity of 280 rpm which equals to 0.364 m/s, the VIV system is in Initial Branch and between 0.364 m/s and 0.702 m/s which equals to 540 rpm the system is in Upper Branch. After 0.702 m/s, the system enters to Lower Branch.

Fig. 9 shows that in the front cylinder's results of tandem experiment, until the speed of 360 rpm which equals to 0.468 m/s. the system is in Initial Branch. Starting from 0.468 m/s, the VIV system enters to Upper Branch up to the velocity of 1.222 m/s which equals to 940 rpm. After that velocity, the system enters to Lower Branch.

In tandem cylinders experiment, the amplitude response (A/D) of the rear cylinder reaches its maximum at the velocity of 480 rpm (0.624 m/s). In this velocity, the experimental frequency is 1.163563 Hz. Additionally, the natural frequency of the system is 1.098167 Hz. These two frequencies are close to each other. As described before, this situation is called "resonance".

Comparing these three amplitude responses (Fig. 9) gives that both single cylinder and rear cylinder enter the Upper Branch almost in the same range of reduced velocity ($U*$) and they both finish the Upper Branch at velocities close to each other. This is because the same cylinder is used in the single cylinder's experiment and the rear cylinder in tandem cylinders experiment. Differences between the amplitude responses of this cylinder in the single cylinder's experiment and the rear cylinder in tandem experiment, is due to the effect of the second cylinder (front cylinder) being used in the tandem cylinders experiment. As the cylinders face the incoming flow and the speed of this flow increases, the cylinders start to create vortices. The vortex created by each cylinder have an effect on the responses of the other cylinder. It is an undeniable fact that as the speed of the flow increases, the intensity of the vortex increases up to a certain level, and it is also observed during the experiment. In addition, the comparison of results in Fig. 9 indicates that the synchronization area in tandem cylinders (both rear and front cylinder), is wider than in single cylinder. Fig. 9 also shows that the Upper Branch area in the front cylinder is larger than the rear and single cylinder. Fig. 10 shows that the increase in the oscillation frequency of the single cylinder after the reduced velocity of U* = 7 is greater than that of the tandem cylinders. In general, the increasing trend in the oscillation frequency of the single cylinder is greater than that of the rear and front (tandem) cylinders.

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Numerical Investigation of different Length to Beam (L/B) Ratios on the Static Drift Condition of the Autosub Underwater

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Abstract

High maneuverability is a fundamental design principle in submarine design. The main parameters that shape the external configuration include the hull form, length-to-beam ratio (L/B), relative lengths of fore and aft ends, and form factors. Increasing hull elongation is expected to reduce form resistance, although it may lead to a larger wetted surface area and, consequently, increased friction resistance. The optimum hull elongation that minimizes resistance exists from a resistance perspective. Additionally, increased hull elongation affects the static and dynamic stability of a submarine. This study focuses on investigating the effects of different hull elongations (L/B) on the static drift of the Autosub underwater vehicle. Computational fluid dynamics analyses validate the static drift results against experimental data from the open literature, followed by generating geometries for various L/B ratios at constant displacement. The results are analyzed to draw conclusions about the impact of hull elongation on maneuverability.

Keywords: *maneuvring, static drift, underwater vehicle, Autosub*

1. Introduction

Maneuverability is crucial in the design of underwater vehicles. Calculating maneuvering coefficients from hydrodynamic effects is necessary to measure maneuver performance. These calculations must consider that underwater vehicles have six degrees of freedom in motion. Developing a mathematical model that includes forces and moments is essential for creating a control system. The maneuvering capability of underwater vehicles is influenced by hydrodynamic coefficients, which are part of the motion equations [1]. Accurate calculation of hydrodynamic coefficients is necessary to simulate or predict the movement of underwater vehicles accurately. Computational fluid dynamics, experimental, and empirical methods are used to examine hydrodynamic properties. Experimental or numerical simulations are common methods to obtain hydrodynamic coefficients. While coefficients can be directly determined through experiments, numerical simulations have become more popular due to cost and difficulty associated with experiments [2].

Both empirical and computational fluid dynamics methods, along with experimental techniques, are utilized to examine the hydrodynamic characteristics of underwater vehicles. The motion of the vehicle encompasses three main states: acceleration and steady rotation. Analyzing these states helps determine the maneuvering capabilities of the vehicle [3].

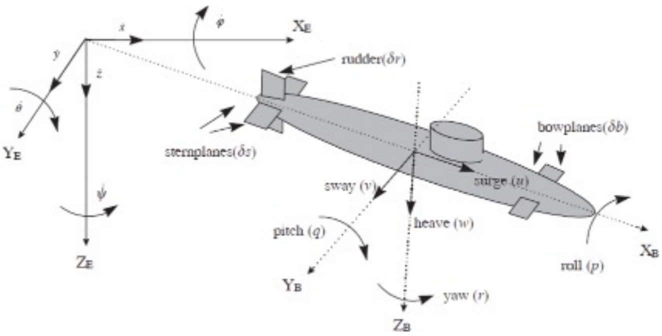
Planar motion mechanism experiments are employed to calculate hydrodynamic forces, while towing tank or towing tank experiments are used to calculate forces and moments during cruising. The effects of angular velocity are examined using a rotating arm experimental test setup. These test systems can be utilized to calculate hydrodynamic coefficients. The use of test setups is necessary to obtain the required hydrodynamic coefficients in underwater vehicle design [4]. The Autosub underwater vehicle (AUV), designed by the British National Oceanography Centre, is utilized in this study. Scientists frequently utilize this vehicle because it is equipped with a range of sensors to measure the physical, chemical, and biological properties of the underwater environment. Autosub can be deployed in various missions, such as exploring geological features like underwater volcanoes, canyons, and mountains [5]. It is also used to research and monitor underwater biological life. Additionally, it plays a significant role in studying natural disasters and human-induced pollution. Due to its ability to stay submerged for extended periods, Autosub has become a crucial tool in ocean sciences and has been employed in numerous research endeavors. It is also utilized for maneuvering studies, benefiting from comprehensive model test results shared in the open literature. In a study conducted by Kimber, hydrodynamic coefficients of underwater vehicles were calculated using a 3/4 scale model of the Autosub vehicle. Specific drag tests were conducted in these experiments, and the findings were elaborated in detail. An approach aimed at reducing the total resistance of the underwater vehicle, as demonstrated by Wu et al., involved simulations of microbubbles. These simulations revealed that the presence of microbubbles near the hull of the underwater vehicle could increase the total resistance by up to 50%. Phillips and other studies examined the hull resistance of three different Autosub underwater vehicles [6]. The resistance encountered by these vehicles during underwater missions was calculated based on their shapes and sizes. Researchers simulated the flow around the vehicle hulls using the HAD method and accurately determined the resistance values. The resistance values obtained from physical tests and measurements were compared. The results showed a positive agreement between the calculated and experimental resistance values, demonstrating the accuracy and reliability of the HAD method. Additionally, rotating arm and towing tank experiments were conducted to obtain hydrodynamic derivatives for the Autosub underwater vehicle. These experiments were conducted using a time-independent computational fluid dynamics method. The predictions made to estimate lateral forces were consistently accurate, but there were differences in predictions for induced resistance and yaw moments. Experimental measurements accurately determined the dynamic stability limits of the underwater vehicle using numerical methods. In another study, Phillips and others found the resistance and hydrodynamic coefficients of the Autosub model [7]. Horizontal towing tank and rotating arm experiments for a torpedo-style Autosub were successfully replicated, and the HAD method was utilized for steady-state conditions. While there was a very good agreement in predicting lateral force, it was found that the prediction for induced resistance and yaw moment was slightly higher [2][8].

2. Purpose of This Study

This research investigates the effects of L/B ratios on the hydrodynamic characteristics of AutoSub. Lateral displacement forces and yaw moments have been examined in this study. Static drift conditions for geometries with different L/B ratios and cruising conditions at various angles have been calculated.

In the first part of this study, a mesh independence and validation study were conducted using commercial software called Star CCM+, which utilizes computational fluid dynamics methods. The aim of this study was to determine an appropriate mesh structure and configuration settings. The software conducted resistance analyses at speeds ranging from 0 to 2 m/s and performed a validation study. In the second part, hydrodynamic analyses were carried out for various static drift angles independently of time. In this study, static drift angles of 0, 2, 4, 6, 8, and 10 degrees were utilized. Mesh independence and uncertainty analysis were employed to determine the mesh structure to be used in the analyses. For the mesh independence study, a six-degree static drift angle was selected. Five different mesh structures were created based on different mesh element sizes. The results of these five analyses were compared with experimental findings published by Alexander Phillips, Stephen R. Turnock, and Maaten Furlong. Following the mesh independence study and uncertainty analysis, the mesh structure was found to be consistent with the experimental results. The mesh structure selected for the other static drift analyses was utilized in the calculations. In the second part of the study, the drag force values were determined using the selected mesh structure. The final section of the study demonstrates the effects of the L/B ratio of the Autosub geometry on hydrodynamic forces and moments. Consequently, new geometries with different L/B ratios have been developed despite having the same displacement. These mesh structures utilized mesh element sizes selected for the mesh independence study. The study comprises 24 analyses, consisting of four different geometries with varying L/B ratios and six different static drift angles. Finally, an evaluation of the impact of the L/B ratio on hydrodynamic forces on Autosub is conducted at the end of the study.

3. Hydrodynamic Theory and Equations



Underwater vehicles can move with six different degrees of freedom. Translation in surge, sway, and heave motions are known as linear movements. However, yaw, pitch, and roll motions are identified as angular movements. Figure 1 illustrates a standard underwater vehicle and its axis system.

Figure 1. Six Degrees of Freedom Movements.

3.1 Rolling

The underwater vehicle rotates around the X-axis. The center of underwater volume and the center of gravity of the vehicle coincide vertically in calm water. If a wave crest approaches only one side of the vehicle, the underwater volume on that side increases. Consequently, the new center of underwater volume of the vehicle will move in the direction of the incoming wave. Due to this shift, the vehicle moves towards the side from which the wave is coming. As a result of this effect, the vehicle moves in the opposite direction of the direction of motion [8].

3.2 Pitching

The underwater vehicle rotates around the Y-axis. While the vehicle floats in calm water, the center of underwater volume and the center of gravity coincide vertically. However, as a wave crest approaches the front of the vehicle, the underwater volume at the front increases. In this case, the center of underwater volume of the vehicle shifts towards the front. However, the positions of the weights on the vehicle remain unchanged, thus the location of the center of gravity remains the same. Consequently, the center of underwater volume of the vehicle cannot stay at the same vertical level as the center of gravity. Therefore, the center of underwater volume of the vehicle changes the trim of the vehicle. Due to this trim change, the vehicle moves towards the bow or stern. When the wave crest approaches the stern of the vehicle, the vehicle tilts towards the bow [8].

3.3 Yawing

It is a rotational motion around the Z-axis. If a wave crest comes from the starboard bow of the vehicle, the bow is pushed to port. If a wave trough forms from the starboard bow, the vehicle slides towards starboard. A wave crest coming from the port bow has the opposite effect [8].

3.4 Heaving

It is a linear motion along the Z-axis. A wave trough pushes a vehicle downwards. When there are continuous waves in the environment where the vehicle is located, the Z-axis oscillates linearly [8].

3.5 Surging

It is a linear motion along the X-axis. Wave troughs push the vehicle in the direction of the wave, while wave crests pull the vehicle. In the presence of waves, the vehicle oscillates linearly along the X-axis [8].

3.6 Swaying

The underwater vehicle undergoes linear motion along the Y-axis. After passing the starboard side of the vehicle, a wave will push it towards the port side. Similarly, if there is a wave trough on the starboard side, the vehicle will move towards the trough. Conversely, if a wave crest emerges from the port side, the vehicle will move in the opposite direction. The vehicle oscillates linearly along the Y-axis if there are waves present.

Since the hydrodynamic equation group includes six degrees of freedom, fundamentally, six values are obtained. The hydrodynamic forces named surge, sway, and heave affect three axes denoted as X, Y, and Z. The other three values are hydrodynamic moments: K, M, and N, influencing roll, pitch, and yaw around three axes. Additionally, velocity expressions causing these values to change are used; these expressions can be linear, angular, or time dependent.

To mathematically describe nonlinear effects, Taylor series expansions are utilized. The Taylor series should employ dimensionless force and moment values. The underwater vehicle's length is dimensionless with the square of the length. Below are these dimensionless forces demonstrated [8].

Dimensionlessization of the surge force:

$$X' = \frac{X}{\frac{1}{2}\rho l^2 U^2} \quad \textbf{(1)}$$

Dimensionlessization of the sway force

$$Y' = \frac{Y}{\frac{1}{2}\rho l^2 U^2} \quad \textbf{(2)}$$

Dimensionlessization of the rolling force

$$Z' = \frac{Z}{\frac{1}{2}\rho l^2 U^2} \quad \textbf{(3)}$$

Dimensionlessization of the rolling moment

$$K' = \frac{K}{\frac{1}{2}\rho l^3 U^2} \quad \textbf{(4)}$$

Dimensionlessization of the pitching moment

$$M' = \frac{M}{\frac{1}{2}\rho l^3 U^2} \quad \textbf{(5)}$$

Dimensionlessization of the yawing moment

$$N' = \frac{N}{\frac{1}{2}\rho l^3 U^2} \quad (6)$$

Dimensionless velocities

$$u' = \frac{u}{U} \qquad v' = \frac{v}{U} \qquad w' = \frac{w}{U} \quad \textbf{(7)}$$

$$p' = \frac{pl}{U} \qquad q' = \frac{ql}{U} \qquad r' = \frac{rl}{U} \quad \textbf{(8)}$$

In these equations, ρ represents the density of water; l denotes the length of the vehicle; and U is the free stream velocity. This free stream velocity and vehicle length are expressed by Equation 9 and Equation 10.

$$U = u^2 + v^2 + w^2 \qquad l = u'^2 + v'^2 + w'^2 \quad \textbf{(9)}$$

The following equations are the result of these dimensionless transformations and findings obtained from other studies and will be used in the calculation of hydrodynamic forces and moments. These equations involve Taylor series expansions and the widely accepted six-degree-of-freedom motion problem in underwater calculations [9].

Surge Force Equation:

$$\begin{aligned} &\mathrm{M}[\dot{u}-vr+wq-xG(q2+r2)+yG(pq-\dot{r})+zG(pr+\dot{q})]= \quad \textbf{(10)} \\ &+\frac{p}{2}l^4\left[\mathrm{Xqq}'^{q^2}+\mathrm{Xrr}'^{r^2}+\mathrm{Xrp}'\mathrm{rp}\right] \\ &+\frac{p}{2}l^3[\mathrm{Xu\,u}+\mathrm{Xvr}'\mathrm{vr}+\mathrm{Xwq}'\mathrm{wq}] \\ &+\frac{p}{2}l^2\left[\mathrm{Xuu}'^{u^2}+\mathrm{Xvv}'^{v^2}+\mathrm{Xww}'^{w^2}\right] \\ &+\frac{p}{2}l^2u^2\left[\mathrm{X\delta e\delta e}'^{\delta e^2}+\mathrm{X\delta r\delta r}'^{\delta r^2}+\mathrm{X\delta a\delta a}'^{\delta a^2}\right] \\ &-(W-B)sin \end{aligned}$$

Sway Force Equation:

$$\begin{aligned} &\mathrm{m}[\dot{v}-wp+ur-Y_G(r^2+p^2)+Z_G(qr-\dot{p})+X_G(qp+\dot{r})]= \quad \textbf{(11)} \\ &+\frac{p}{2}l^4[\mathrm{Y\dot{r}}'\,\dot{r}+\mathrm{Y\dot{p}}'\dot{p}+\mathrm{Yp|p|}'\mathrm{p|p|}+\mathrm{Ypq}'\mathrm{pq}+\mathrm{Yqr}'\mathrm{qr}] \\ &+\frac{p}{2}l^4\,[\mathrm{Y\dot{v}}\,'\dot{v}+\mathrm{Yvq}'\mathrm{vq}+\mathrm{Ywp}'\mathrm{wp}+\mathrm{Ywr}'\mathrm{wr} \end{aligned}$$

4.Methodology

4.1 Main Equations

This problem is modeled using the Navier-Stokes equations. The Navier-Stokes equations, which form the backbone of fluid mechanics, consist of the equations of motion and continuity. These equations provide mathematical calculations for the conservation of mass, energy, and momentum. According to these equations, the total of forces acting on fluid particles equals the change in momentum [10].

Conservation of mass equation:

$$\frac{\partial\rho}{\partial t}++\nabla.(\rho U)=S_m \qquad \text{U= velocity vector, } \rho = \text{density, t = time} \quad \textbf{(12)}$$

Equation 12 is the most general form of the mass conservation equation. It is valid for both compressible and incompressible flows. If the problem we want to solve is not time-dependent and our fluid is incompressible, then the time derivatives and ρ are equal to zero. Equation 12 transforms into equation 13 for the problem addressed in this thesis, which is time-independent, and the flow is incompressible [10].

$$\frac{\partial \rho}{\partial t} + + \nabla.(\rho U) = 0 \tag{13}$$

When the fluid is assumed to be Newtonian and the viscosity remains constant throughout the flow, the momentum conservation equations transform into the following forms:

$$\nabla . U = 0$$

$$\frac{\rho Du}{Dt} = -\frac{\partial \rho}{\partial x} + \mu \nabla^2 u + \rho . fx \tag{14}$$

$$\frac{\rho Dv}{Dt} = -\frac{\partial \rho}{\partial y} + \mu \nabla^2 v + \rho . fy \quad \frac{\rho Dw}{Dt} = -\frac{\partial \rho}{\partial x} + \mu \nabla^2 w + \rho . fz$$

4.2 Reynolds Averaged Navier-Stokes (RANS) Equations

The motion of real fluids can generate laminar or turbulent flow depending on the Reynolds number. Due to the complex nature of turbulent flow, direct resolution using the Navier-Stokes equations is challenging. Flow parameters such as velocity and pressure in turbulent flow vary irregularly over time. Equation 13 expresses the total of the mean and instantaneous deviations of velocity and pressure at any given moment.

$$u = \overline{u} + u' \; v = \overline{v} + v' \; w = \overline{w} + w' \tag{15}$$

The equations can be obtained by substituting $\overline{u}$, $\overline{v}$, $\overline{w}$, representing the mean values of velocity and pressure, and u', v', w', representing the instantaneous deviations from the mean, into the continuity equations, and making necessary adjustments avs follows:

$$\rho\left(\frac{\overline{\partial u}}{\partial t} + \bar{u}\frac{\overline{\partial u}}{\partial x} + \bar{v}\frac{\overline{\partial u}}{\partial y} + \overline{w}\frac{\overline{\partial u}}{\partial z}\right) = fx - \frac{\overline{\partial_P}}{\partial x} + \mu \nabla \bar{u} - \rho\left(\frac{\overline{\partial u'u'}}{\partial x} + \frac{\overline{\partial u'v'}}{\partial y} + \frac{\overline{\partial u'\omega'}}{\partial z}\right) \tag{16}$$

$$\rho\left(\frac{\overline{\partial v}}{\partial t} + \bar{u}\frac{\overline{\partial v}}{\partial x} + \bar{v}\frac{\overline{\partial v}}{\partial y} + \overline{w}\frac{\overline{\partial v}}{\partial z}\right) = fy - \frac{\overline{\partial_P}}{\partial y} + \mu \nabla \bar{v} - \rho\left(\frac{\overline{\partial v'u'}}{\partial x} + \frac{\overline{\partial v'v'}}{\partial y} + \frac{\overline{\partial v'\omega'}}{\partial z}\right) \tag{17}$$

$$\rho\left(\frac{\overline{\partial w}}{\partial t} + \bar{u}\frac{\overline{\partial w}}{\partial x} + \bar{v}\frac{\overline{\partial w}}{\partial y} + \overline{w}\frac{\overline{\partial w}}{\partial z}\right) = fz - \frac{\overline{\partial_P}}{\partial z} + \mu \nabla \overline{w} - \rho\left(\frac{\overline{\partial w'u'}}{\partial x} + \frac{\overline{\partial w'v'}}{\partial y} + \frac{\overline{\partial w'\omega'}}{\partial z}\right)$$

4.3 Turbulence model

The (k-ω) model is the most popular turbulence model. This model uses two transport equations to determine the turbulence characteristics of the flow. This two-equation model addresses both dissipation effects and transport. Kinetic energy is the first transported variable and is denoted as k-ω. The second variable is the specific dissipation rate denoted by ω. This variable determines how intense the turbulence is. For this problem, the "k-ω SST" model is chosen. The (k-ω) SST model employs the vortex viscosity technique. Therefore, shear forces in the boundary layer are more accurately accounted for in the equations [11].

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial k_j} = Pk - \beta^{*} k \omega \frac{\partial}{\partial x_j}\left((v + v_t \sigma_k)\frac{\partial k}{\partial x_j}\right) \tag{18}$$

Specific Dissipation Rate:

$$\frac{\partial \omega}{\partial t} + U_j \frac{\partial \omega}{\partial k_j} = \alpha S^2 - \beta \omega^2 + \frac{\partial}{\partial x_j}\left((v + v_t \sigma_\omega)\frac{\partial k}{\partial x_j}\right) + 2(1 - F_1)\sigma \omega^2 \frac{1}{\omega}\frac{\partial k}{\partial xi}\frac{\omega}{\partial xi} \tag{19}$$

4.4 Finite volume method and solution algorithm numerical computations

The finite volume method is used to solve partial differential equations in numerical modeling. In short, the flow domain is discretized into small control volumes. Equations are solved separately for these volumes. The flow determines how the conditions in nearby volumes change from one volume to another. The finite volume method can solve for density, pressure, and other unknown fields in the flow domain over time. Equation 20 represents the integral form for the general transport equations [12].

$$\int_s \rho \emptyset V . ndS = \int_s F \nabla \emptyset . ndS + \int_\Omega q_\emptyset d\Omega \tag{20}$$

The coupled flow model solves the conservation equations of mass, momentum, and energy. Since the flow is independent of time, it does not require time steps. In this process, there is a linear relationship between the number of cells within the control volume and the solution time, so the solution time is not significantly affected by the quality of the grid structure.

5. Numerical Computations

Autosub, historical context of its performance and usage purposes has evolved over time. The National Oceanography Centre (NOC) at Wormley initiated a program aimed at developing scientific applications for autonomous underwater vehicles because of advancements in technology. The Autosub underwater vehicle is designed for various purposes with several different geometries. It has a length of 7 meters and a diameter of 0.9 meters. As seen in Figure 2, in this study, a 3/4 scale model of Autosub has been modeled and analyzed for use. The geometric properties of the underwater vehicle are shown in the table below.

Table 1. Geometric Features of Autosub Vehicle.

L_{oa} (Length Over All)	5.2 m
D (Underwater Vehicle Diameter)	0.669 m
L_n (Autosub Nose Length)	1.022 m
Nose Shape	Elliptical
L_b (Autosub Hull Length)	2.020 m
S_b (Hull Cross-Sectional Area)	0.352 m^2
L_{aft} (Aft Hull Length)	1.799 m
Cg_n (Center Of Gravity Distance From Nose)	2.310 m
B_T (Tail Clearance)	0.854 m
C (Tail Tip Veterinary Length)	0.200 m
Scan Angle (Leading Edge)	14.40°
Scan Angle (Trailing Edge)	0°
Tail Wing Profile	NACA0015

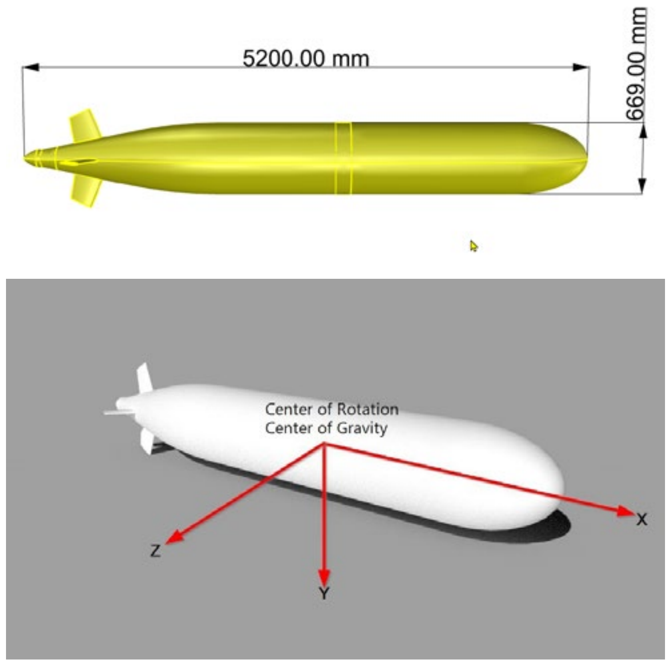


Figure 2. Geometric Views of Autosub Vehicle.

Our main goal was to conduct analyses with a healthy margin of error and to minimize computational costs by establishing a solution grid structure. To achieve this goal, we conducted a grid independence study first. The existing experimental data of the Autosub underwater vehicle formed the basis of this study. Experimental results were also utilized in the grid independence analyses. Therefore, a comprehensive examination was conducted to understand the impact and dependence of experimental data on the grid structure in order to obtain accurate and reliable results in the calculations.

To define boundary conditions, a rectangular prismatic volume structure was preferred. Assuming the geometric size of the underwater vehicle as L, the flow volume will be 3L at the front, 6L at the rear, and 3L at the bottom, top, and side. A velocity inlet was defined at the front face of this volume, while a pressure outlet with a value of 0 Pa was specified at the rear face. The side faces were designated as slip walls to avoid influencing the flow condition. The grid structure surrounding the Autosub model was refined. For each yaw angle condition, the model was rotated back to the center of the domain by the required angle from the center of gravity. Analyses were repeated without changing the model position or boundary conditions. The Star CCM+ program was used for defining flow volume and boundary conditions.

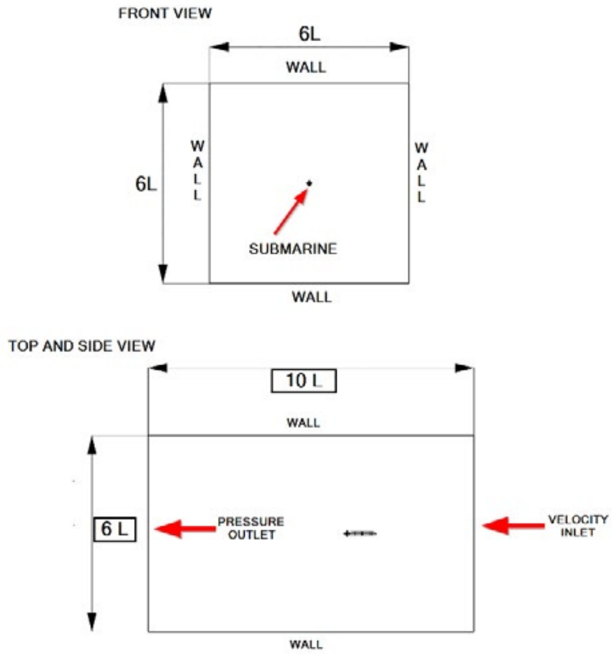


Figure 3. Boundary Conditions for Static Drift Analysis.

5.1 Design of the Physical Model mesh model and uncertainty analysis

In all flow analysis calculations, steady-state and stable Reynolds-Averaged Navier-Stokes (RANS) equations have been utilized. The RANS turbulence models, such as k-epsilon, k-omega, and SST models, have been predominantly employed for solving the Navier-Stokes equations. These models are preferred due to their low computational costs and reasonable accuracy and convergence capabilities. The STAR CCM+ software has been used for the analysis studies. Viscous effects were obtained using the wall function in the program, and the analyses were evaluated accordingly. The first layer thickness consists of y+ values in the range of 0 < y+ < 5. It has been calculated based on the Reynolds number and modeled as ten layers, as shown in the equation 23, which is used to calculate the thickness of the first layer [13].

$$\Delta y = L\Delta y^{+}\sqrt{80}R^{-13/14} \quad \textbf{(21)}$$

$$\delta = 0.035LR^{-1/7} \quad \textbf{(22)}$$

5.2 Mesh Model and Uncertainty Analysis

In this analysis study, analyses were conducted to optimize the mesh structure with five different mesh sizes. Figure 4 shows the surface meshes of the underwater vehicle. According to the rules and guidelines set by the ITTC (International Towing Tank Conference), the size difference between each mesh structure was changed by a factor of √2, and the convergence states of the resistance values were examined. It can be observed that the mesh is refined around the Autosub model, and it takes the lowest values at the bow and wing areas, as seen in the figures. The main purpose of this is to determine changes in the flow region effectively and to bring the resistance values to the closest position to the experimental data.

Different mesh sizes were analyzed to find the appropriate mesh structure, and the grid convergence index (GCI) method was used. Scenarios with five different mesh sizes were repeated at a 2° drift angle, and the data were compared. Table 3 shows the element numbers of the mesh structures and the analysis results of these mesh structures. Force and moment graphs are shown in Figure 5 and 6 according to experimental and analytical results.

Table 2. 2˚ Static drag for lateral displacement. (Y').

	Number Of Cells	Y Resistance Values	Y' Values	Error (Y'-%)	N' Values	Error (N'-%)
Mesh Type 4	16,029,425	92.8644	0.0009515	13.8209	0.0002079	-0.95548
Mesh Type 3	8,373,519	92.1753	0.0009444	12.9763	0.0002066	-0.31937
Mesh Type 2	4,886,657	93.8288	0.0009614	15.0030	0.0001973	4.21372
Mesh Type 1	2,886,470	97.0649	0.0009945	18.9693	0.0001920	6.75623
Mesh Type 0	1,692,539	96.389	0.0009876	18.1409	0.0001880	8.73725

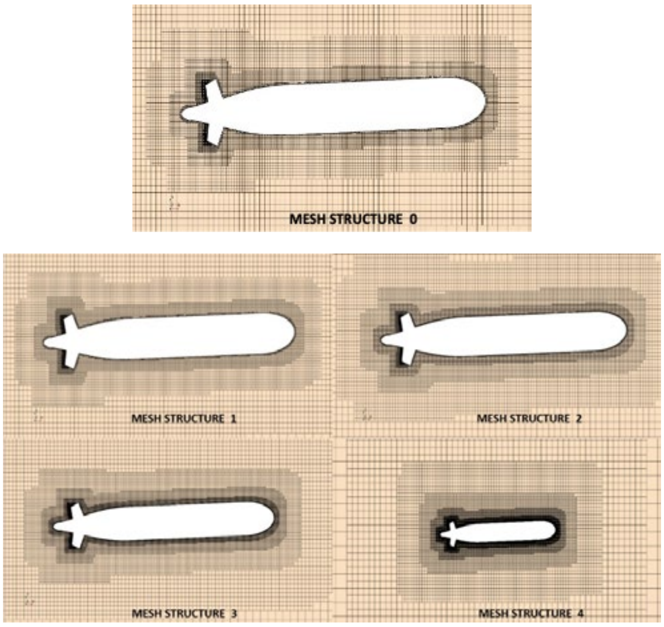


Figure 4. Mesh Structures.

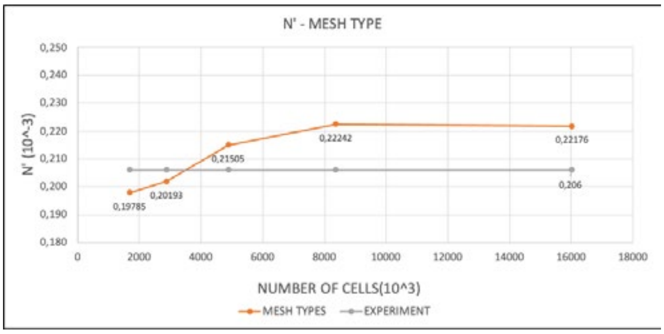


Figure 5. Yaw moment (N') for 2˚ static drift.

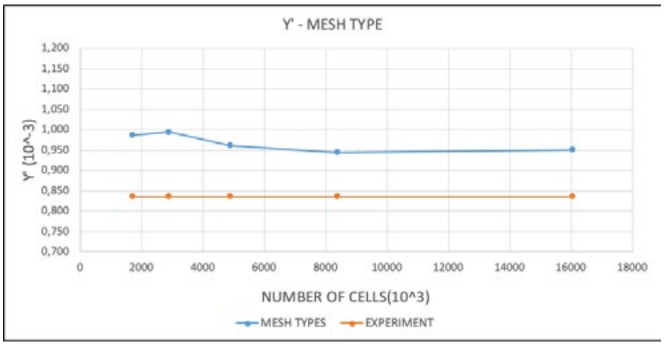


Figure 6. Displacement force (Y') for 2° static drift.

Grid Convergence Index (GCI) is commonly used in HAD (Hydro-Acoustic Dynamics) analyses to improve the grid structure. This method, offered to alleviate complexity in the grid structure, has been widely accepted by researchers and institutions. In this study, the GCI method has been utilized as follows.

$$h = \left[\left[\frac{1}{N}\sum_{i=1}^{N}(\Delta V_i)\right]\right]^{\frac{1}{3}} \tag{23}$$

In Equation 23, $\boldsymbol{V_i}$ represents the volume of cells, while N represents the number of cells. The values $\boldsymbol{h_1}, \boldsymbol{h_2}, \boldsymbol{h_3}$ represent the fine, medium, and coarse grid models, respectively, which are effective in the grid refinement factor.

$$r_{21} = \frac{h_2}{h_1}\ ; r_{32} = \frac{h_3}{h_2} \tag{24}$$

The R values represent the refinement factor, which is first calculated between the fine and medium grid models, and then between the medium and coarse grid structures.

$$p = \frac{1}{\ln \ln(r_{21})}\left|\ln \ln \left|\frac{\varepsilon_{32}}{\varepsilon_{21}}\right| + q(p)\right| \tag{25}$$

$$(p) = ln\, ln\left(\frac{r_{21}^{p} - s}{r_{32}^{p} - s}\right) \tag{26}$$

$$s = 1 * sgn\left(\frac{\varepsilon_{32}}{\varepsilon_{21}}\right) \tag{27}$$

$$\varepsilon_{32} = \emptyset_3 - \emptyset_2\ ; \varepsilon_{21} = \emptyset_2 - \emptyset_1 \tag{28}$$

$\emptyset_k$ contains the solution of the k-th square, but since we cannot obtain the calculation of each square, a scalar value such as lateral displacement force can be taken. Thus, it is used in the calculation of ε_{32} and ε_{21}. These are used in the calculation of R. If s takes a negative value, it means that it is oscillatory convergence.

$$R = \frac{\varepsilon_{21}}{\varepsilon_{32}} \quad \textbf{(29)}$$

$$\emptyset_{ext}^{21} = \frac{(r_{21}^{p}\,\emptyset_1 - \emptyset_2)}{r_{21}^{p} - 1} \quad \textbf{(30)}$$

In Equation 32, $\emptyset_{ext}^{21}$ represents the extrapolated scalar value of the chosen $\emptyset$.

$$e_a^{21} = \left|\frac{\emptyset_1 - \emptyset_2}{\emptyset_1}\right| \quad \textbf{(31)}$$

$$e_{ext}^{21} = \left|\frac{\emptyset_{ext}^{21} - \emptyset_1}{\emptyset_{ext}^{21}}\right| \quad \textbf{(32)}$$

$$GCI_{fine}^{21} = \frac{1.25 * e_a^{21}}{r_{21}^{p} - 1} \quad \textbf{(33)}$$

Finally, the Grid Convergence Index (GCI) can be determined according to the equation. The results based on the selected grid structures are provided in the table below.

Table 3. Uncertainty Analysis Results.

	Lateral Translation Force (Y) [N]	Yaw Moment (N) [N-m]
N_1	1692539	
N_2	2886470	
N_3	4886657	
N_4	8373519	
N_5	16029425	
r_{21}	1,4235	
r_{32}	1,1874	
$\emptyset_1$	92,864	111,541
$\emptyset_2$	92,175	112,876
$\emptyset_3$	93,828	115,137
p	3,2549	1,5316
R	-0,41681790	0,590446705
$\emptyset_{exp}^{21}$	93,183	109,686
e_a^{21}	0,74%	1,19%
e_{exp}^{21}	0,34%	1,66%
$GCI_{mesh_5}^{21}$	0,43%	2%

Table 3 shows the calculated GCI and sublevel values. Considering the processing time and cost, although there is not a significant difference between grid structure 3 and grid structure 4, the doubling of the grid structure leads to a significant increase in analysis time. Therefore, grid structure 3 was preferred due to its balanced performance, and these parameters were used for further analyses.

Table 4. Resistance Data's.

Velocity (m/s)	Exp. (Fallows)	Exp. (Kimber)	Empirical (Phillips et al.)	CFX (Phillips et al.)	CFD	Error % Empirical	Error % CFX
0,5	10,337	-	9,003	8,943	9,068	1,912	2,589
1	18,023	-	30,663	31,959	30,65	3,941	-0,270
1,5	100,017	-	64,242	67,926	68,24	4,801	-0,881
2	-	126,6494	108,228	115,53	113,92	5,683	-1,001

5.3 Autosub Vehicle Resistance Analyses

In the static drag analysis, a scaled model of the Autosub vehicle with a length of 5.2 meters was utilized. Analyses were conducted at different velocity units in the control volume created using mesh structure 3 at a 0° angle of attack, and the results were compared with experimental data. Experiment results, categorized into CFX, HAD, and others, are presented in Table 4, and the velocity distributions resulting from the analysis are depicted in Figure 7.

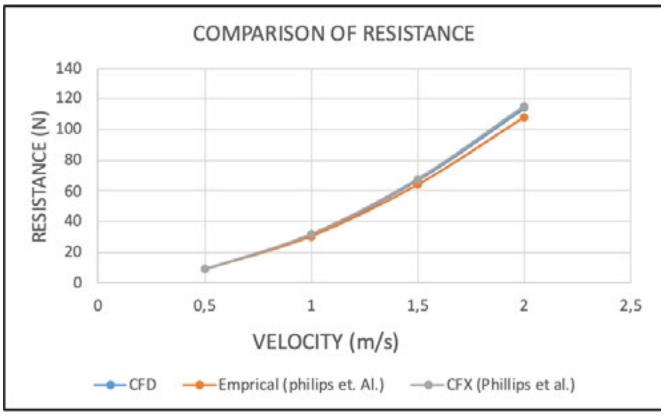


Figure 7. Comparison of Experimental and Analytical Data of the Autosub Vehicle.

As can be understood from the data in the table, the Fallow's test results differ from the others. One of the main reasons for this is the use of the model at a scale of 2.5 meters and the test setup pulling the model at a depth of 2.6 diameters from the water surface. In such cases, fluctuations that may occur on the water surface can adversely affect the test results. Pulling at high speeds and moving it with the help of an arm during the test increase the error percentage and affect the calculations. The error margin between HAD analyses and CFX is reasonable compared to the others and can be considered acceptable.

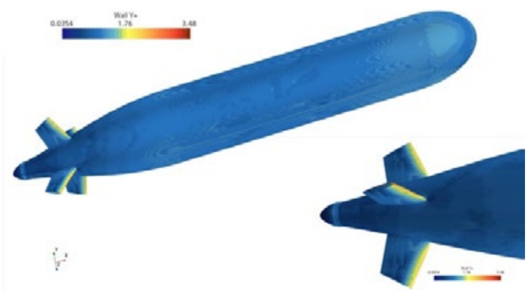


Figure 8. Average of Y+ Distribution.

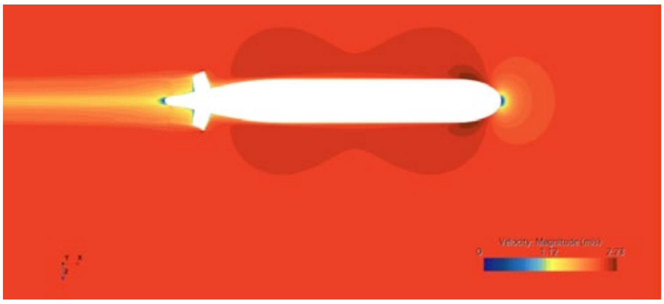


Figure 9. Velocity Distribution at 2 m/s.

5.4 Static Drift Analyses

In this section, unlike the previous one, the underwater vehicle model was analyzed at five different angles of attack, namely 2, 4, 6, 8, and 10, with a speed of 2.69 m/s. A comparison between the dimensionless values Y' and N', and experimental values is presented in Table 5. Additionally, Figures 9 and 10 illustrate the variations of moment and force values with drift speed. Here, the term dimensionless velocity refers to the velocity component corresponding to the Y-axis under the angle of attack.

Table 5. Static Drift Data.

Attack Angle (°)	Number of Cells	Velocity (m/s)	Average Y+	X Direction resistance	Y Direction resistance	Z Direction Moment (N)
0	2,824,367	1	0.5510	15.3025	0	0
	1,820,463	1.5	0.7870	34.1258	0	0
	2,824,367	2	1.018	56.9668	0	0
2	8,373,519	2.69	1.0249	96.6055	92.1753	112.8769
4	8,377,067	2.69	1.0260	104.6174	195.6180	216.4104
6	8,474,182	2.69	1.0239	115.4151	298.0363	311.1772
8	10,831,409	2.69	1.0222	120.5191	417.8219	351.1519
10	11,924,840	2.69	1.0266	140.7984	535.8303	411.6440
Attack Angle (°)	**Y'**	**Y' Exp.**	**N' (10^{-3})**	**N' Exp.**	**Y' Error (%)**	**N' Error (%)**
2	0.000944	0.000836	0.2224	0.000206	-12.976	-7.9726
4	0.002004	0.001913	0.4264	0.000391	-4.7787	-9.0629
6	0.003053	0.003032	0.6131	0.00054	-0.7208	-13.5507
8	0.004281	0.004305	0.6919	0.000652	0.5517	-6.1263
10	0.005490	0.005931	0.8111	0.000734	7.4282	-10.5100

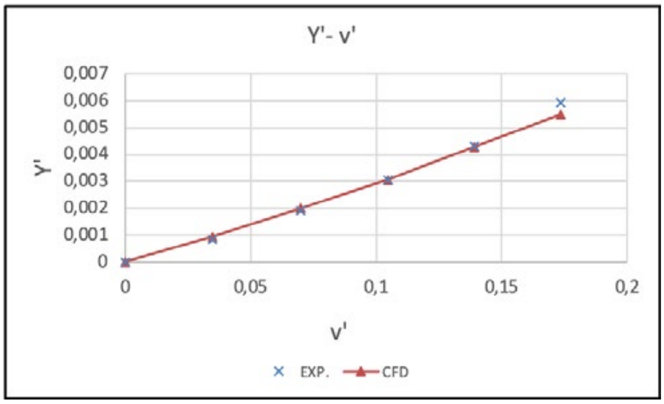


Figure 10. Lateral translational force – translational velocity graph.

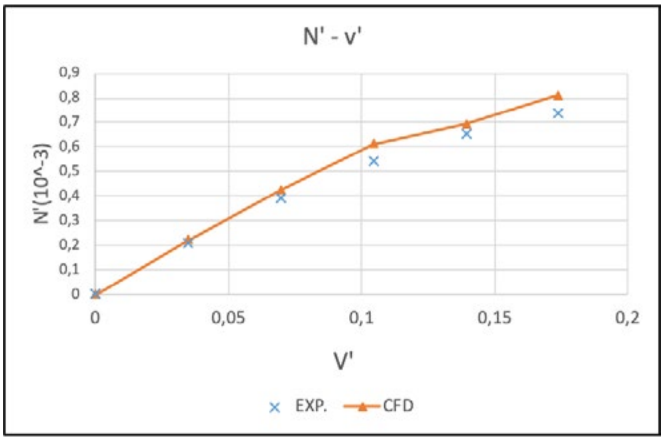


Figure 11. Yaw moment – translational velocity graph.

5.5 Different L/B ratios and static drag for the Autosub submarine

In this section, similar to the previous section, static drift analyses of the Autosub model were examined for 6 different L/B ratios. Six different models were produced with displacement volumes remaining constant, and a total of 32 analyses were conducted for these models at 0, 2, 4, 6, 8, and 10 degrees. In these simulations, the L/B ratios were selected as integers, and a reference B width was chosen to scale appropriately. Subsequently, the parallel hull length was adjusted to maintain displacement.

Table 6. L/B ratios and Geometries.

Length (m)	Width (m)	L/B
4.087	0.817	5
4.5	0.75	6
4.9	0.7	7
5.287	0.660	8
5.666	0.629	9
6.036	0.6031	10

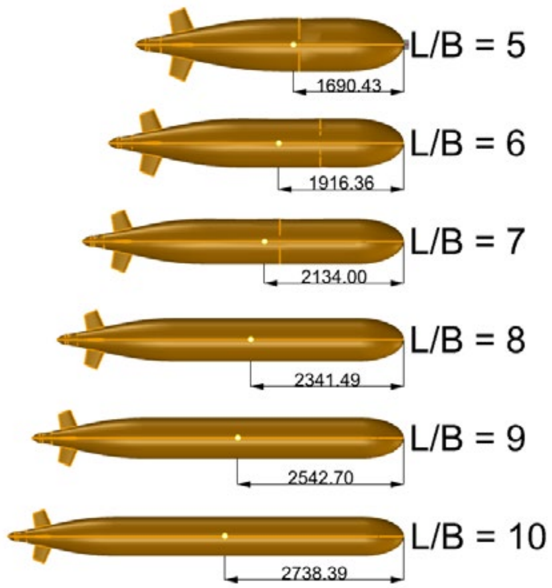


Figure 12. Different L/B Geometries.

As seen in the image, the positions of the volume (lift force) centers for different L/B ratios can be observed as mm. All models have been rotated from this point (volume center) to create varying angles of attack. In the generation of the grid structures for different L/B ratios, grid independence studies were considered, and the grid size and model used in previous sections were employed. Analyses were conducted with an average of 10,763,229 elements.

Graphs of analyses conducted with different L/B ratios are presented. They show the dimensionless drag coefficient and dimensionless yawing moment coefficient against the dimensionless drift velocity. The lateral force Y, yawing moment N, and drift velocity v were calculated using the equations provided in previous sections.

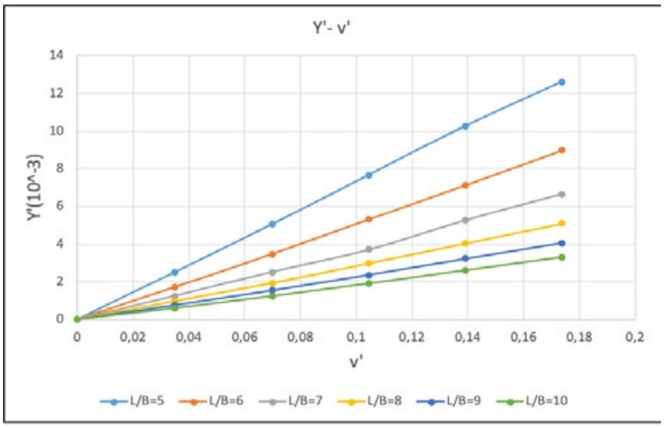


Figure 13. The Variation of Lateral Forces and Drift Velocities for Different L/B Ratios.

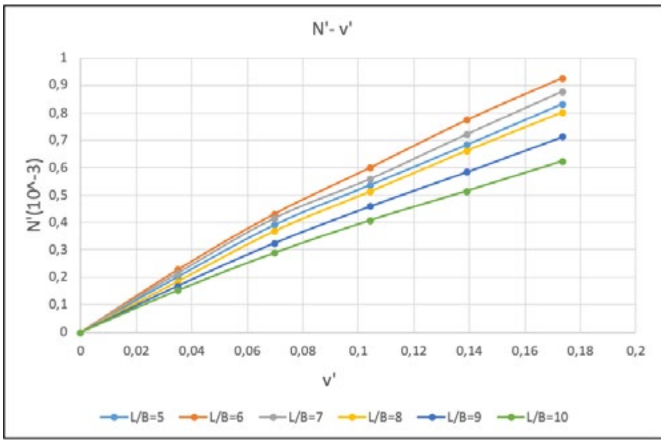


Figure 14. Variation of Yaw Moments and Drift Velocities for Different L/B Ratios.

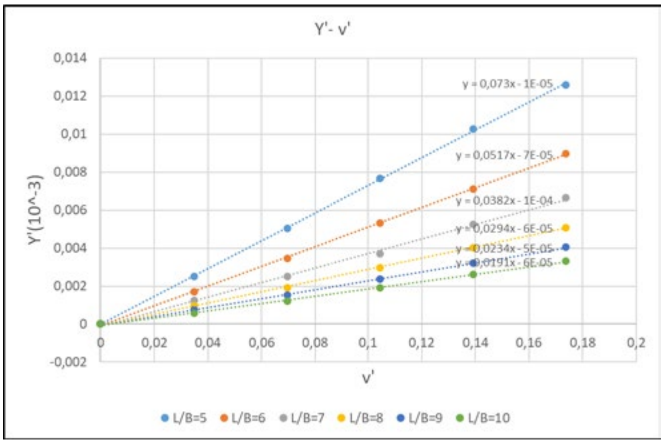


Figure 15. Dimensionless Coefficient Ratios (Lateral Drift Force and Yaw Moment).

Table 7. Dimensionless Ratio Coefficients (Lateral Translation, Yaw Moment).

L/B	$Y'_{v'}$	$N'_{v'}$
5	0,0730	0,0047
6	0,0517	0,0053
7	0,0382	0,0050
8	0,0294	0,0046
9	0,0234	0,0041
10	0,0191	0,0036

The table shows the values of the coefficient ratios. According to this table, as the underwater vehicle grows, there is an increase in the dimensionless coefficient ratio of lateral drift force (Yv) and a decrease in the dimensionless coefficient ratio of yaw moment (Nv). The length value is dependent on the scale ratio. Increasing the length of Autosub increases the dimensionless lateral drift force. However, as the length increases, the dimensionless yaw moment values decrease. Similarly, when the values are examined, it can be observed that force values increase while moment values decrease. This indicates that as the length increases, the point of force acting on the underwater vehicle approaches its center of gravity. Consequently, this should demonstrate that a longer Autosub, with the same static drift angle, experiences more lateral disturbing force and less disturbing moment compared to a shorter one. When designing a new geometry, reducing the L/B ratio should be aimed for as controlling lateral forces becomes more challenging. However, in cases where rotational effects are more significant, increasing the L/B ratio should still be the objective [14].

6. Conclusion

This study involves the calculation of forces and moments acting on the Autosub underwater vehicle model using defined scale and geometric properties. RANS equations and turbulence models, the main elements of fluid dynamics, were utilized in the calculations. Analyses were conducted at different angles of attack and at a cruising speed of 2.69 m/s, focusing on static drag and yaw moments. A mesh independence study was conducted using experimental results and calculated values for error rates and analysis. After determining the optimal mesh structure, analyses were completed for other angles, and the results were compared with experimental data. The study also conducted full-scale drag analyses using the same mesh sizes.

Open-source literature presents two experimental findings regarding resistance. In the initial study presented by Kimber and Marshall, a resistance value of 2 m/s was found, while Fallows has shown resistance values for a wider range. Fallows' experimental findings encompassed velocities ranging from 0 to 5 m/s for various model depths, thus including wave resistance values [6]. Consequently, there is a disparity between the HAD analysis and Fallows' experimental results. Similarly, when examining the empirical and experimental results previously obtained by Kimber and Marshall, this difference becomes apparent again. Phillips and others also addressed the cause of this discrepancy. Kimber and Marshall's experimental results are well aligned with static drift analysis conducted for various drift angles. While there is a lower deviation from experimental findings in lateral drift forces, the deviation is higher in moments. However, with a maximum error rate of ten percent, it is considered reasonable. The force and moment values obtained from static drift and resistance analyses are consistent with experimental and empirical findings in the literature, with an error rate ranging from 6% to 9%. The HAD method can accurately determine drift and yaw moments. In the final section of the study, the mesh independence and validation study results yielded mesh sizes and analysis setups, which were then used to analyze different geometries with varying L/B ratios. The evaluation of these analysis results demonstrates the impact of increasing L/B ratio on maneuver derivatives. As the L/B ratio increases, coefficients caused by drag force increase, while coefficients caused by yaw moment decrease.

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A Numerical Investigation of Airfoil Sections for More Efficient Horizontal Axis Hydrokinetic Turbine Design

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Abstract

Nowadays pollution is constantly increasing due to the energy provided by fossil fuels. Hence, the tendency to use renewable energy sources gain in to obtain eco-friendlier and from clean energy. Thus, energy and electricity produced using renewable energy sources are of greater importance every day. Hydrokinetic Turbine, which is a proper option for this purpose constitutes the main subject of this study. The orientation to these products shows an increase due to the need for electric energy generated in classical ways such as dams (barrages) and the fact that hydrokinetic turbines are more environmentally friendly and less costly compared to the technologies used. The main aim of this study is to investigate the different blade geometries that will be used to design a more efficient horizontal axis Hydrokinetic Turbine with optimized section profiles. For this purpose, firstly, the aerodynamic coefficient values of the Eppler 395 and S1210 airfoils which are the most common sections for hydrokinetic turbine design with higher performance efficiency compared with others in open literature. In the current study, these aerodynamic performance characteristics were calculated using Computational Fluid Dynamics (CFD) approaches and validated with experimental results. The preliminary results and comparisons present a good agreement for upcoming calculations with estimated deviations around 5-10% for the lift coefficient (CL) values for two-dimensional (2-D) analyses performed.

Keywords: *Hydrokinetic Turbine, Airfoil, CFD*

1. Introduction

Within the scope of this study, there are many academic studies in the literature about Hydrokinetic Turbines (HKTs), the design and optimization of which are aimed to be carried out. Before the design and optimization of a hydrokinetic turbine, the blade cross-sectional profiles that are often used in hydrokinetic turbines should be examined.

Many researchers have been involved in the design of a new blade cross-sectional profile (foil) for turbine blade design or have used existing designs. The researchers used the Eppler 420 hydrofoil at the optimum angle of attack for the Horizontal axis Hydrokinetic Turbines they designed [1]. In another study, NACA 4412 for turbine geometry, NACA 0006 for diffuser design and NACA 0012 and NACA 2412 blade cross section profiles were used for pre-vortex stator geometry in horizontal axis Hydrokinetic Turbine design [2]. The researchers selected The Eppler 395 hydrofoil for the turbine they designed, which has a high lift and drag ratio for Multi-Horizontal axis Hydrokinetic Turbines [3]. The Wortmann FX63-137 Hydrokinetic Turbine with airfoil blade geometry was used in the related study [4]. For the winglet-designed Hydrokinetic Turbine, the S814 airfoil blade geometry was used [5]. A diffuser was designed using the NACA 0012 airfoil for the Hydrokinetic Turbine previously used in the study [6]. The NACA 4415 airfoil profile was used for the design of the Horizontal axis Hydrokinetic Turbine modelled for use in experimental studies [7]. The researchers showed the pressure distribution at the near end of the turbine blade belonging to the NACA65(3)-618 airfoil they selected [8]. In this study, they compared the airfoil they designed using the optimization method with NACA63(3)-618, NACA 4418, RISO-A-18, NREL S825 and NREL S833 airfoils C_L, C_D and the ratio of lift and drag forces (L/D) ratio at different angles of attack [9]. To optimize the turbine blade, they created the turbine design by using NACA 9430, NACA 9425 and NACA 9420 hydrofoil profiles in different thicknesses [10]. In the study, 3 different turbines were analyzed and the FFA-W3-211 airfoil profile was used in the Horizontal axis Turbine design [11]. The researchers designed the turbine using the newly created DT0814 hydrofoil and preferred the NACA 0012 hydrofoil profile in the diffuser design [12]. The researchers designed the turbine using the classical Glauert optimization method and preferred NACA65(3)-618 hydrofoil as the blade geometry in the turbine design [13]. In the study, NACA 4412 and NACA 6411 hydrofoil profiles were selected for Hydrokinetic Turbine design [14]. To determine the optimum angle of attack in the turbine design, NACA0012, NACA 0015, NACA0018, NACA2412, NACA2415, NACA2418, NACA4412, NACA4415 and NACA4418 hydrofoil profiles determined the optimum angle of attack from the angles of attack where the C_L/C_D ratio is the highest [15]. In the study, a diffuser was designed for the turbine using NACA4412 foil, and NACA4418 airfoil and NACA 63-418 foil geometries were preferred for the turbine designs in the study [16].

As a result of a literature review on horizontal axis Hydrokinetic Turbine studies, one of the most important objectives of choosing Hydrokinetic Turbines is to use renewable energy sources and to obtain power through kinetic energy from Hydrokinetic Turbines, which is one of the methods of using these resources. Since this method of obtaining power is more environmentally friendly and there is a continuity of renewable energy sources found in nature, the importance of hydrokinetic Turbines is increasing. Many academic studies have been carried out in line with this need. The design parameters that are important for these studies have been examined by numerical and/or experimental methods to increase power and efficiency. Within the scope of this study, the parameters and geometry that are primarily studied and planned to be designed are the blade cross-sectional profile.

This study was started primarily by examining the blade cross-sectional profiles, which are often used in HKTs and where high power and efficiency values can be obtained. The geometric structure of these airfoils, the lift and drag forces they generate, and the efficiency values were investigated for this purpose. Among them, the geometries with the highest power coefficient and the most efficient in terms of performance were selected, and numerical analyses of these airfoils were performed. These verifications will constitute a preliminary study in terms of lift, drag forces and efficiency estimates for the new blade geometry to be designed with optimization studies planned to be carried out at later stages. The newly designed Horizontal axis Hydrokinetic Turbines will be designed using the newly designed blade profiles.

Within the scope of this study, detailed graphs of the C_L, C_L/C_D ratios of foils, which are often used in the designs of horizontal axis Hydrokinetic Turbines are presented in Section 2. The foil sections with high efficiency, power coefficient and performance have been selected and information about 2-D numerical analysis of these geometries has been given in Section 3. There are important outputs and findings obtained as a result of numerical verification studies (Section 4). In the last part of this study, the studies planned to be carried out in the future within the scope of this study are included.

2. Blade Cross-Sectional Geometries Used in Horizontal Axis Hydrokinetic Turbines

In order to determine the blade geometries in horizontal axis Hydrokinetic Turbine designs, the researchers applied to existing blade cross-sectional profiles (foils) or new blade profiles that they CFD designed themselves. The blades of horizontal axis Hydrokinetic Turbines are designed using the Blade Element Method with existing foils or newly designed blade profiles. As mentioned in the introduction section, the C_L and C_L/C_D aerodynamic coefficients of foils often used in horizontal axis Hydrokinetic Turbines are shown with the help of graphs in this section. These coefficient values are derived in the XFOIL source code under the conditions of C=0.1 m and Re=2x10^5. These aerodynamic coefficient data are taken from Airfoil Tools [17].

2.1 Evaluation of Aerodynamic Characteristics of Existing Airfoils (C_L and C_L/C_D)

The aerodynamic coefficients (C_L and C_L/C_D) of existing airfoils that the researchers have generally used in horizontal axis Hydrokinetic Turbines are presented in graphs with the data obtained from Airfoil Tools. The researchers determined the optimum angle of attack for the Horizontal axis Hydrokinetic Turbine they will design by using the C_L/C_D values depending on the angle of attack of the NACA profiles [15]. In another study, the researchers compared the S1223, S1210, S1221, SH3055, E387, SG6043 and FX 63-137 blade profiles and C_L and L/D values they designed for horizontal axis Hydrokinetic Turbine with Re=1x10^5 condition and values at different angles of attack [18]. The values of C_L and C_L/C_D of the airfoils used in the design of horizontal axis Hydrokinetic Turbines under the conditions C=0,1 m and Re=2x10^5 are given in Figure 1 and Figure 2.

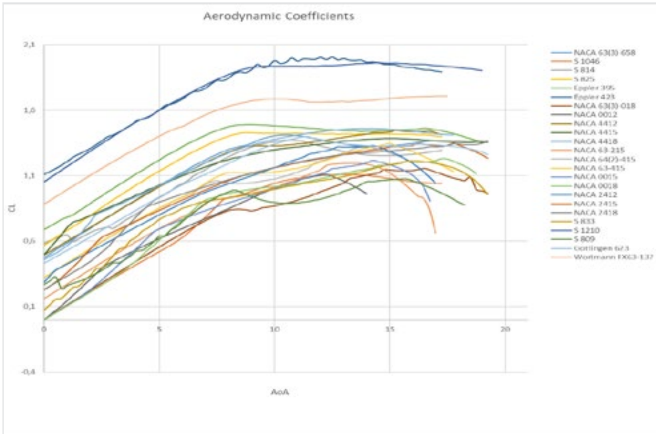

Figure 1. C_L values of the airfoils commonly used in horizontal axis Hydrokinetic Turbines.

When Figure 1 was examined, it was found that the blade profiles with the highest C_L values between 5 and 10 degrees of attack angles were Eppler 423, S1210, Wortmann FX 63 137 and Eppler 395.

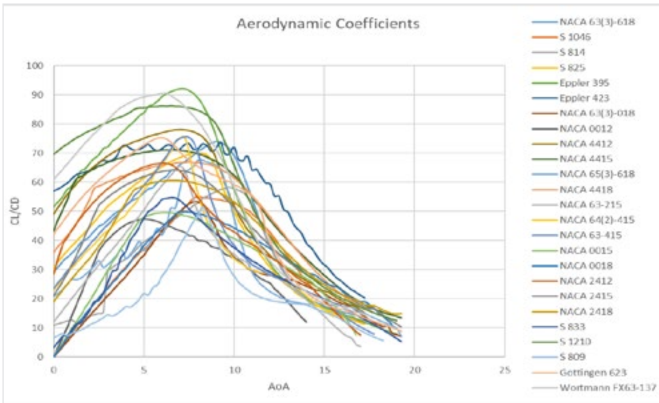

Figure 2 .C_L/C_D values of the airfoils commonly used in horizontal axis Hydrokinetic. Turbines

Figure 2 shows that the blade profiles with the highest C_L/C_D values between 5 and 10 degrees of attack angles were Wortmann FX 63-137, Eppler 395, S1210 and NACA 4412. Many researchers compared the performance parameters of these airfoils with the performance values of the newly designed airfoils using CFD and experimental methods. They modelled the horizontal axis Hydrokinetic Turbine blades using the BEM method using the blade profiles they designed.

3. Numerical Method

For the investigation of the performance parameters of the blade section profiles, two different section profiles were selected. These are the Eppler 395 and S1210 sections. The purposes of selecting these profiles are;

- The airfoil of the Eppler 395 is quite high in terms of efficiency (C_L/C_D) according to XFOIL data.
- The C_L values of the S1210 wing profile are much higher compared to other blade cross-section profiles.

Since horizontal axis Hydrokinetic Turbines operate based on lift coefficient (C_L) and since efficiency is important for all turbines, these two airfoils have been preferred within the scope of these analysis studies. The analyses were performed using the CFD method in Ansys Fluent (Academic).

In the analyses, the geometric coordinates are needed to create the selected Eppler 395 and S1210 airfoils. The 2D coordinates of the selected airfoils are taken from the Airfoil Tools [17]. The domain is formed in the same dimensions on the Eppler 395 and S1210 airfoils. The chord length (c) of the geometries used in the analyses is 0.1 m. The computational domain was modelled concerning the 2D airfoil verification studies that were previously conducted and published in the open literature [19]. The dimensions of the domain and the boundary conditions used in the analyses (Velocity input, non-slip wall and pressure output) are shown in Figure 3.

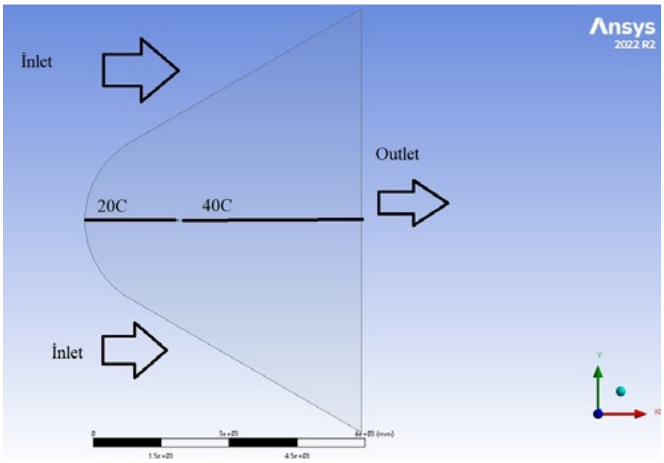

Figure 3: The domain dimensions and boundary conditions.

The mesh structure and the total number of cells were created to be the same for the Eppler 395 and S1210 airfoils. The analyses were performed in 3 different total cell counts, which were coarse, medium and fine. The total number of cells is 345K, 755K and 166K, respectively. In the Eppler 395 airfoil analyses, the medium solution network mesh was preferred by taking into account the C_L and C_D values in the analyses performed under Re=2x10^5 and angle of attack 7.25 conditions. Within the scope of the mesh independence study, The Grid Convergence Method (GCI) was preferred [20]. The results of the GCI method were found to be GCIfine21=0.0048 and Rfine=0.74 for C_L values. For C_D values, GCIfine21=0.0034 and Rfine=3.28 were found. It is understood from the results found that the analyses are convergent. A minimum thickness has been selected so that the y^+ value is below 1 on the geometries used. A layer with a growth rate of 1.2 has been formed so that the boundary layer consists of 12 layers. The mesh structure used for the boundary layer and domain on the geometry is shown in Figure 4.

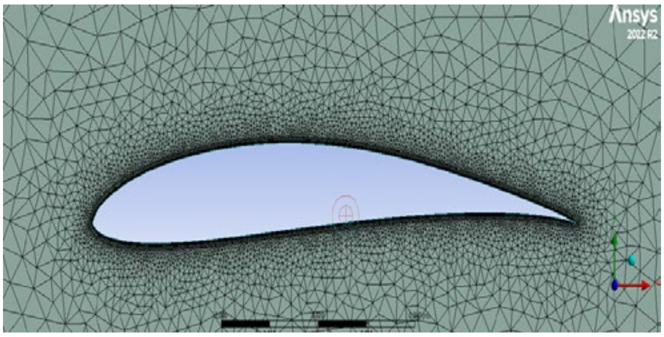

Figure 4: Mesh structure and boundary layer around foil section.

The analyses were established as pressure-based (pressure-based) and time-independent (steady). The flow area and the mesh structure were solved using the Reynolds-Averaged Navier-Stokes (RANS) method. The k-ω SST turbulence model has been preferred as the turbulence model. This model is preferred due to better prediction of the flow separations that will occur at the trailing edge part of the geometry. In the analyses performed, air was defined as the fluid that would come to the flow area. Velocity-inlet for the inlet part of the flow and pressure-outlet for the outlet patch were selected as boundary conditions. A SIMPLE algorithm for the solution algorithm and 2nd order (second order upwind) is used. C_L and C_D are defined in the reporting section so that they can be followed throughout the analysis until the convergence. The same simulation methodology was applied for both selected geometries.

4. Results

A 2D airfoil verification study was conducted to estimate the C_L and C_D values of the Eppler 395 and S1210 airfoils using the CFD approach in the analyses. The selected airfoils in this study have been preferred by many researchers in the open literature for validation and verification studies, and new airfoils have been created using experiments, design, optimization and CFD methods using these sections. The aerodynamic performance coefficients of the Eppler 395 and S1210 airfoils were predicted and compared with experimental and numerical data in the literature.

4.1 Aerodynamic Results (S1210 Airfoil)

The analyses were performed with Re=2x10^5 and Re=1x10^5 values. In these Reynolds numbers, the aerodynamic coefficients with XFOIL [17] and experimental results [21],

[22] were compared with the results of the analyses performed by the CFD approach. Figure 5 shows the C_L and C_D values at different angles of attack of the analyses performed at the value Re=2x10^5.

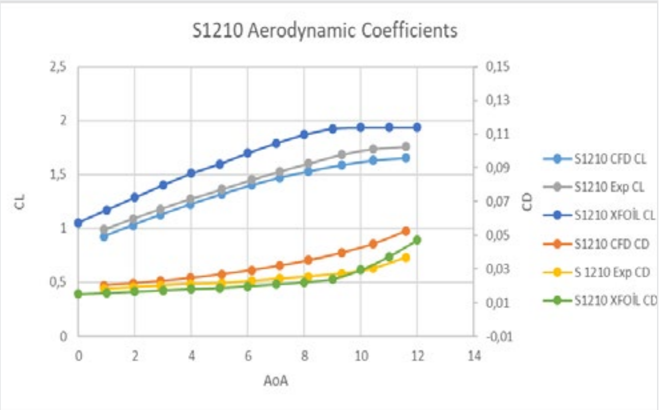

Figure 5: C_L and C_D values at different angles of attack (Re=2x10^5).

It is already seen that the C_L values remain quite far from each other when the XFOIL and experimental results are evaluated, and the CFD results can be estimated much closer to the experiments [21] (Figure 5). When this figure is examined in terms of C_D values, it is seen that the CFD results have an angle of attack between 6 and 12 degrees far from the experimental results, while the XFOIL and experimental results are much closer to each other. When the CFD results were compared with the experimental results, the error percentage for C_L at different angles of attack was found 6% (maximum). For C_D values, on the other hand, the percentage of error between 6 and 12 degrees of angle of attack is quite high. The same analyses were performed at Re=1x10^5 and compared with XFOIL and experimental results [21], [22]. Figure 6 also presents the C_L and C_D values of the analyses performed at Re=1x10^5.

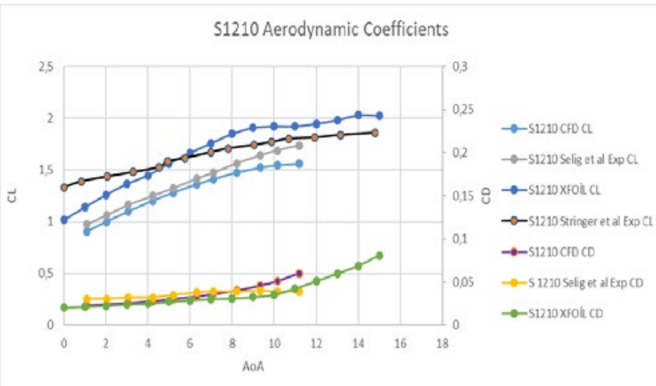

Figure 6: C_L and C_D values at different angles of attack (Re=1x10^5).

Figure 6 was examined, it is seen that XFOIL values in terms of C_L values are closer to the experimental study conducted by Stringer et al. [22] and further away from the experiments conducted by Selig et al. [21]. It is understood that the CFD results are closer to the results performed by Selig et al. for C_L values and further away from the experimental studies performed by Stringer et al. When the C_D values are investigated, CFD values were obtained closer to the results of the experimental study conducted by XFOIL and Selig et al. according to the Re=2x10^5 analysis (compared to the Re=1x10^5 results).

When the CFD results were compared with the experimental results found by Selig et al., the maximum margin of error for C_L values at different angles of attack was found to be 10%. This value has been seen at only 11.18 angle of attack. For other angle of attack values, the error rate does not exceed a maximum of 8 percent. For C_D values, on the other hand, the percentage of error between 9 and 12 degrees of angle of attack is quite high.

4.2 Aerodynamic Results (Eppler 395)

The Eppler 395 airfoil analyses were performed using the CFD method in the Ansys Fluent. The analyses were performed at Re=2x10^5 and Re=1.65x10^5 values at different angles of attack. The aerodynamic coefficient values were compared with the XFOIL [17] and CFD [23] values. There have not been any studies conducted using experimental or CFD analysis methods in the literature that can be compared under Re=2x10^5 conditions of the Eppler 395 airfoil. In some academic studies in the literature, the lack of experimental data on the Eppler 395 airfoil has been mentioned [23]. In the related study, due to the lack of experimental data, CFD analyses were performed at Re=1.65x10^5, and the aerodynamic coefficients of the airfoil were compared with the XFOIL data, but the error rates were found to be high [23]. Figure 7 and 8 show the C_L and C_D values at different angles of attack of the CFD analyses performed for the Eppler 395 (Re=2x10^5 and Re=1.65x10^5, respectively).

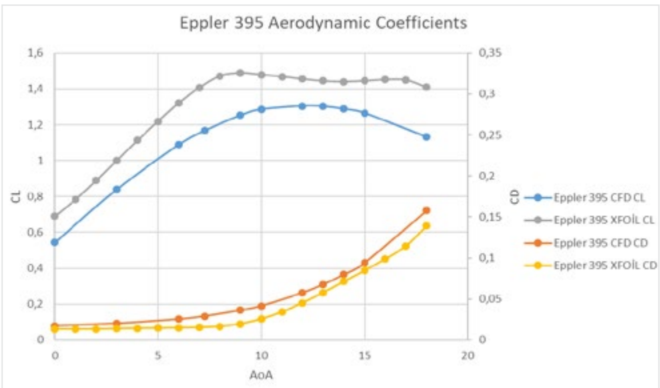

Figure 7: C_L and C_D values at different angles of attack (Re=2x10^5).

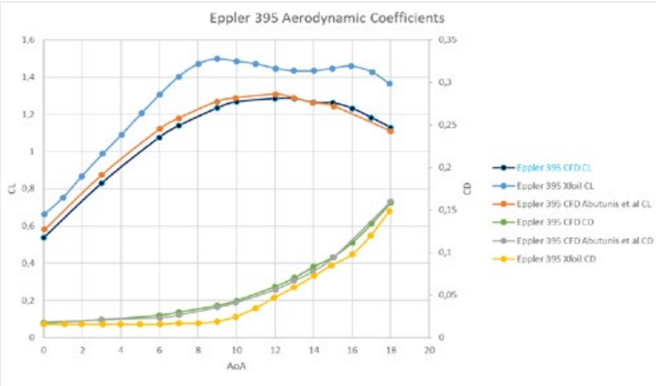

Figure 8: C_L and C_D values at different angles of attack ($Re=1.65x10^5$).

In Figure 7, inspired by the study conducted by Abutunis et al. [23], it was tried to estimate the values of C_L and C_D at different angles of attack with the value $Re=2x10^5$ and these values were compared with XFOIL. C_L values, as in other analyses, have been estimated quite far from XFOIL values and have been obtained relatively closer in terms of C_D values. When the CFD analyses performed by Abutinis et al. and the CFD results of this study were compared with each other, the C_L values could be estimated with a maximum error rate of 5% and the C_D values with a maximum error rate of 12%.

The high error rates were found when C_L values, CFD and XFOIL values were compared with each other at different angles of attack (Figure 8 was examined). When the results were compared with the CFD results performed by Abutunis et al. [23], it can be seen that the discrepancy it is quite small. C_D values, on the other hand, quite close results were obtained when comparing the CFD values calculated in this study with the CFD analysis results performed by Abutunis et al. XFOIL values and CFD values are relatively more distant from each other.

5. Conclusion and Future Work

In this study, as a result of the analyses performed, for the S1210 blade geometry;

- The C_L values of $Re=2x10^5$ and at different angles of attack were estimated quite close to the experimental values, and a maximum error of 6% was found when compared with the experiments.
- When the C_D values were compared with the experimental results, the error values were calculated high and it was found that the XFOIL source code CFD presents the same tendency as the derived C_D values.
- At different angles of attack, under the condition $Re=1x10^5$, a maximum error of 10% is observed in the analyses performed when the C_L values are compared with the experimental results.
- In the C_D values, relatively lower error rates were obtained compared to the $Re=2x10^5$ analysis and it was found that the XFOIL source code has the same tendency as the C_D values derived from it. The reason for the discrepancy in C_D values has been investigated and the following conclusion has been reached. When the experimental study was examined, C_D values were derived by momentum theory as a result of pressure values measured by 4 different points on the blade width (span) of the C_D values and their average value was calculated [21], [24]. The reason for the high error rate is thought to be due to this calculation. In addition to this, the analysed wing profiles are performed in 2D conditions.

As a result of the analyses performed in this study, for the blade geometry of the Eppler 395;

- Due to the lack of experimental results for aerodynamic coefficient values, it could not be compared with any experimental data.
- It was compared with the CFD results performed by Abutinis et al. and the lack of experimental data was mentioned in this study [23]. When the results were compared in terms of CL and CD, a maximum of 5% error was found in the CL values and a maximum of 10% error was found in the CD values.
- Inspired by the academic studies in the literature, it was tried to estimate the aerodynamic coefficient values of CL and CD at Re=2x105 at different angles of attack of the blade geometry of the Eppler 395.

In summary, when the current study is evaluated, it is seen that the results of CFD analyses of the Eppler 395 and S1210 blade geometries can be estimated using CFD approaches more accurately (with less margin of error) compared to the experimental and numerical results of the C_L values compared to the C_D values. Since it is known that the horizontal axis Hydrokinetic Turbine, which is intended to be designed and hydrodynamically estimated for performance during this study, will operate based on lifting force (C_L), the error margins for C_L estimation are acceptable. In addition, it is also predicted that the error rates in terms of C_L and C_D can be reduced by 3D analyses of the hydrokinetic turbine to be designed.

In future studies, it is aimed to perform Horizontal axis Hydrokinetic Turbine verification (CFD and Experimental data) and to design a new Horizontal axis Hydrokinetic Turbine as a result of a new blade geometry design using optimization methods. It is planned to design higher efficiency turbines by comparing the power coefficient values of the newly designed Horizontal axis Hydrokinetic Turbine at different tip speed ratios with the power coefficients of existing Horizontal axis Hydrokinetic Turbines.

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Mechanical Properties and Corrosion Behavior of the Welding Area Joined by Submerged Arc Welding and Gas Metal Arc Welding Methods

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Abstract

Ships are built by joining together plates cut and shaped in various sizes by welding. Welding, which was initially used for repair purposes, has become the main joining method used in shipyards today due to the high mechanical properties it provides in the joining area and its advantages in terms of water resistance. Although covered electrode arc welding and tungsten inert arc welding are also used in shipyards for special applications and materials, it is known that gas metal arc welding and submerged arc welding methods are mostly used in the welding of general shipbuilding steels. Determining the mechanical properties such as hardness, strength and corrosion resistance occurring in the weld area after welded joints is extremely important in order to reveal the weld quality. In this context, in this study, low-medium strength steel, which is widely used in ship construction, was joint with gas metal arc welding and submerged arc welding methods and the hardness, strength and corrosion resistance values of the welding area were examined. As a result of the examinations, it was determined that higher hardness and strength values were achieved in the welding area after submerged arc welding, depending on the welding electrode used and the welding temperatures reached. On the other hand, it was determined that the corrosion resistance increased in the welding area after both welding methods compared to the base material, and the highest corrosion resistance was achieved after welding with submerged arc welding.

Keywords: *Shipbuilding, mechanical properties, submerged arc welding, gas metal arc welding.*

1. Introduction

Ships are built by joining plates cut and formed in various sizes by welding. Welding, which was initially used for repair purposes, has become the main joining method used in shipyards today due to the high mechanical properties it provides in the joining area and its advantages in terms of water resistance. Although covered electrode arc welding and tungsten inert gas welding are also used in shipyards for special applications and materials, it is known that gas metal arc welding (GMAW) and submerged arc welding (SAW) methods are mostly used in the welding of general shipbuilding steels. While GMAW is extremely advantageous in that it has relatively portable equipment and can be applied to many types of materials, SAW offers significant advantages in terms of being a fully automatic welding process and being applicable to high-thickness plates.

The quality of the welded structures made on ships is extremely important for the ships to sail successfully. The quality of the welds made is checked with various non-destructive control methods and any errors that may have occurred on the weld surface and inside it are detected. On the other hand, determining the mechanical properties in the welding areas of the welded joints through destructive tests is extremely important to determine the weld quality. In this context, knowing the mechanical properties formed in the welding areas after the use of SAW and GMAW in shipbuilding will be extremely useful for comparing welding methods in terms of quality. Also, when the literature is examined, although many studies have been conducted examining the mechanical properties of the welding area after the application of gas metal and submerged arc welding to steels [1-12], studies examining the mechanical properties of steels used in ship construction after joining them with these welding methods are extremely limited [13-18]. In this context, in this study, low-medium strength steel, which is widely used in ship construction, was joint with GMAW and SAW methods and the hardness, strength and corrosion resistance values of the welding area were examined comparatively.

2. Experimental Procedure

Grade A low-medium strength shipbuilding steel, which is frequently used in shipbuilding, was used in the study. Hardness tests were carried out using the Vickers hardness method at room temperature and with at least 3 repetitions for each sample. During the hardness tests, 300 grams was selected as the compressive load of the penetrating tip and the penetrating tip was kept in the sample for 10 seconds during the penetrating process. Tensile tests were carried out at room temperature using an Instron 3382 brand device. Tensile tests were performed at least 3 times for each sample and average values are presented in the study. During the tests, jaw speeds were set as 5x10-4 s-1. Corrosion tests were performed at least 3 tim es for each sample in 3.5% NaCl solution with an open circuit voltage range of ± 500 mV and a scanning speed of 1 mV/sec. The corrosion behavior of the samples was evaluated according to the corrosion current density and corrosion rate.

3. Results and Discussions

The hardness values measured from the main structure, the welding area of the sample joined by GMAW and the welding area of the sample joined by SAW are given in Table 1. As can be seen, while the hardness value of the main material was 135 Hv, this value increased to 203 Hv in the welding area after GMAW and to 234 HV after SAW. This change in hardness values between welding methods is related to the electrodes used during welding and the changes in cooling rates that occur after welding.

Table 1. Hardness of base, GMAW and SAW samples.

Condition	Hardness Hv
Base	135 ± 7
GMAW	203 ± 11
SAW	234 ± 14

The strength and elongation values of small tensile samples taken from the main structure, submerged and gas submerged plates and which do not include the main structure in the gauge length region are given in Table 2. As can be seen, after GMAW and SAW, there was a significant increase in the strength values of the samples that did not include the main structure in the gauge length region. As a matter of fact, after GMAW, the yield strength increased from 239 MPa to 345 MPa, and the tensile strength increased from 431 MPa to 475 MPa. Similarly, after SAW, it was determined that the yield strength value increased to 377 MPa and the tensile strength value increased to 511 MPa. It is thought that the increase in strength values after both welding methods is caused by possible grain refining in the microstructure after welding [19]. On the other hand, the uniform elongation value in the base material after GMAW decreased from 38% to 28%, and after SAW, the uniform elongation value decreased from 38% to 30%. It is thought that this decrease in elongation values is similarly caused by the refining of the grain structure [20].

Table 2. Strength and elongation values of base, GMAW and SAW samples.

Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Uniform Elongation (%)
Base	239±7	431±10	38
GMAW	345±12	475±14	28
SAW	377±14	511±14	30

The values obtained in corrosion current density and corrosion rate values after the base material, GMAW and SAW samples are shown in Table 3. As can be seen, the current density (A/cm2) in the main structure decreased from $4.37*10^{-6}$ to $3.97*10^{-6}$ in the GMAW sample and to $3.68*10^{-6}$ in the SAW sample. Similarly, the corrosion rate (mpy) value, which indicates the depth of material removal from the surface caused by corrosion in one year, decreased significantly after the experiment, from 1.83 mpy in the base material to 1.69 mpy in the GMAW sample and 1.47 mpy in the SAW sample. It is thought that these changes in current density and corrosion rate are caused by changes in the material microstructure after welding.

Table 3. Strength and elongation values of base, GMAW and SAW samples.

Condition	Current Density (A/cm^2)	Corrosion Rate (mpy)
Base	4.37	1.83
GMAW	3.97	1.69
SAW	3.68	1.47

4. Conclusions

In this study, a steel frequently used in ship construction was joined with gas metal and submerged arc welds and the mechanical properties of the weld areas were examined comparatively. The results obtained after the study are summarized below:

1. The hardness value of the main material, which was 135 Hv, increased to 203 Hv after GMAW and 234 Hv after SAW.

2. After both weldings, the strength values of the main structure increased. The yield strength of the main material, which was 239 MPa, increased to 345 MPa after GMAW and to 377 MPa after SAW.

3. The 38% uniform elongation value of the main structure decreased to 28% after GMAW and to 30% after SAW.

4. After the GMAW, the current density decreased from 4.37 (A/cm2) in the main structure to 3.97 (A/cm2). This value was measured as 3.68 (A/cm2) after SAW.

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Using Vehicle-In-The-Loop for Free-running Ship Experiments on Ground

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Abstract

Free-running experiments play a crucial role on evaluating ship performance under realistic operation conditions. In these experiments, a scaled-down version of a ship is navigated in open water to collect data, which is then used to make estimates on the full-scale ship's behavior. While these experiments can give great insight on a ship's dynamics, they come with challenges; they are difficult to conduct, expensive, and time-consuming. Discovering errors during a free-running test can jeopardize the validity of the entire experiment. To mitigate such risks, vehicle-in-the-loop (ViL) tests are an effective intermediate step. In ViL experiments, the physical ship model navigates in a virtual maritime environment, and all the sensor measurements of the model are simulated. If the model passes the ViL tests it indicates that the model is likely to behave as expected, assuming accurate sensor data in experiments. This approach not only minimizes potential issues during free-running experiments, but also helps accelerate the development process. In this paper, we outline our approach to designing a ViL solution for the hardware and embedded code of validation of our 1/80 scale Duisburg Test Case model.

Keywords: *Ship motion control, Vehicle-in-the-loop, Course-keeping, PID controller, Duisburg Test Case (DTC)*

1. Introduction

Free-running experiments are an important part of marine engineering and naval architecture, helping the development and improvement of ships. These experiments allow researchers and engineers to analyze the performance of ship models under conditions similar to that of their future operational environments. In these experiments, a scaled-down version of the ship is navigated in open water for the collection of valuable data on it's overall behavior under various sea states. This data then is used for predicting the performance of the full-scale ship, ensuring that the ship behaves as expected, and it is efficient and safe for real-world applications.

However, despite their utility to ship design and performance optimization, free-running experiments come with their own drawbacks. They require extensive infrastructure, they are difficult to plan and conduct, and are often expensive and time-consuming to execute.

Furthermore, any potential unforeseen error can compromise the validity of the experiments, leading to costly delays and the need for additional testing. This is why Vehicle-in-the-Loop (ViL) testing is a powerful preliminary step, allowing researchers to mitigate such risks and helping them accelerate the development process.

ViL testing interfaces a physical vehicle with a simulated environment that replicates the conditions of real-life operating conditions. This hybrid approach allows for the detailed overview of a ship's behavior under a wide range of scenarios, with all the environmental interactions being simulated by a software. By conducting ViL tests prior to free-running experiments, researchers can identify and address potential errors in the hardware/software of the ship in a low-risk setting, where adjustments can be made quickly and cheaply. It provides a framework for validating a ship model, ensuring that the model is as close to its intended behavior as possible. This increases the reliability of future free-running experiments, creating a more efficient, cost-effective path from design to deployment.

In this paper, we will be documenting our approach of utilizing ViL for the validation of our model ship's hardware/software before free-running experiments.

2. Duisburg Test Case Post-Panamax Container Ship

Duisburg Test Case (DTC) Post-Panamax Container Ship is a benchmark container ship which has been designed with the purpose validating numerical methods [1]. The hydrostatic and geometric properties of the ship and the model can be seen in Table 1.

Table 1. Hydrostatic and Geometric Properties of the Ship and the Model

Model Type	L_{BP} (m)	B_{WL} (m)	T (m)	∇ (m^3)	C_B (-)	S_W (m^3)	Δ (kg)	LCG (m)	x_G/L $(-)$
Full Scale	355	51	14.5	173467	0.661	22032	1.73×10^8	174.059	-0.01
Model Scale	4.4375	0.6375	0.1813	0.3388	0.661	3.4425	337.8906	2.1757	-0.01

In this study, we use a 1/80 scale DTC model which has been built for a previous study [2]. The model can be seen in Figure 1. The hull has been equipped with a servo and DC motor that drive the rudder and propeller respectively. The model also carries the hardware/embedded software necessary for it's manual and autonomous control. During manual control, the ship can be operated with an RC remote; whereas during autonomous control, the ship uses a PID controller to correct and/or maintain it's course. The derivation of PID gains is out of the scope of this paper but might be covered in future works.

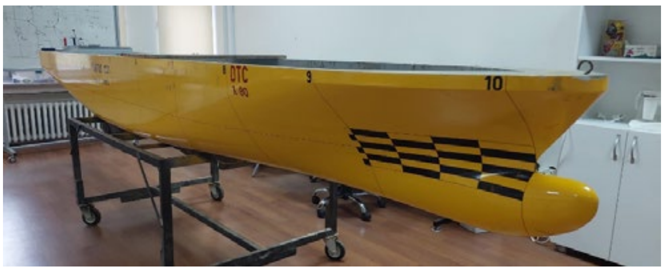

Figure 1. A View of DTC From the Bow

3. Vehicle-in-the-Loop

As mentioned before, vehicle-in-the-loop is a test framework that allows researchers and engineers to test the validity of their vehicle's hardware and software. By operating a vehicle in a simulation environment, researchers can; test new controllers, see how their vehicle behaves under extreme circumstances, see if their vehicle's hardware configuration has any issues, along many other things.

In our study, we've created a framework that consists of a simulation environment and a vehicle. When ViL tests are being performed, our DTC model sends it's rudder and propeller usage to the simulation every time step. Then, the simulation environment uses this information to calculate the state of DTC in the next time step. This state is used to generate fake sensor data right after, and sent back to DTC.

This continuous exchange between DTC and the simulation environment allows us to monitor how our model would likely behave in open-water, and allows us to detect possible issues with our hardware and embedded software. A schematic that summarizes this interaction can be seen in Figure 2.

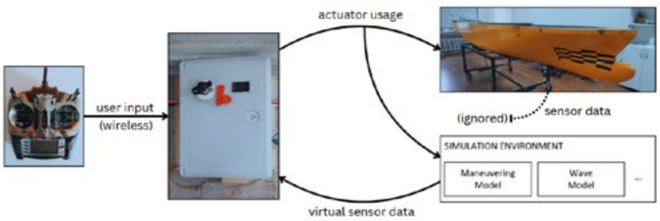

Figure 2. A schematic that summarizes ViL process

3.1. Maneuvering Model

For this study, we've utilized a section of the codebase of [3] and upgraded it for our purposes. The mentioned paper develops a maneuvering model based on the Maneuvering Modelling Group (MMG) [4]. MMG model splits the total hydrodynamic forces and moments acting on a ship into three main components; hull, rudder, and propeller. By decupling sources of forces and moments, MMG is able to simplify the mathematical model.

We use a 3-DOF model that is able to simulate a ship's motion in surge, sway, and the yaw axes. The simulation environment also incorporates the wave model of [5], which allows us to see the behavior of ships under external disturbances. The important thing that distinguishes our model from others is that it can also transmit data that replicates sensor measurements as it is running. This simulated measurement data then can be sent to our ship models under development to see if they behave as expected.

For this study, we've obtained all the necessary coefficients to model our hull, rudder, and propeller through numeric methods, and validated their accuracy through multiple open water experiments including the ones we did for the purposes of [2]. We've also validated that our mathematical model generates simulations that are consistent with these open-water experiments.

3.2. Hardware & Embedded Software

Our DTC model is equipped with a DC and servo motor which allows us actuate the propeller and rudder on the model. These motors are driven with their respective drivers. We also have all sorts of hardware such as multiple sensors, SD card modules for local logging, RC receiver that operates as an antenna which receives the signals from the RC remote; that allows us to operate the model both manually and autonomously. The processes such as reading the RC remote signals, sending the appropriate signals to the motor drivers, calculating the control output during autonomous mode, etc… are handled by a microcontroller on the ship. The so called "control box" that preserves most of this hardware can be seen in Figure 3.

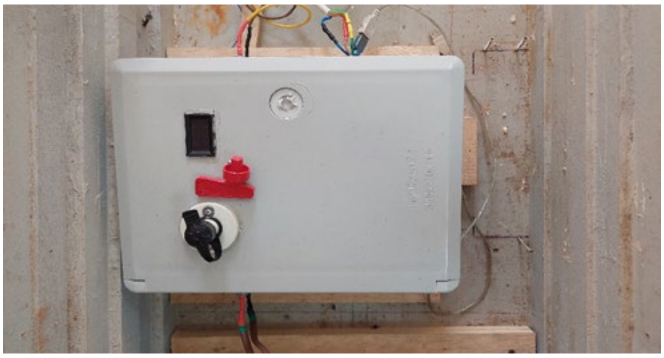

Figure 3. The "Control Box" housing the electronic hardware.

To enable the ViL experiments, we've modified the embedded code on the microcontroller so that it has two modes; operation mode and the ViL mode. In operation mode, the ship behaves as expected. However during ViL mode, it transmits it's actuator usage back to our simulation environment. This allows the simulation software to incorporate the forces and moments acting on the ship due to rudder and propeller.

4. Results

We've tested our ViL solution in two problem-cases; manual control case, and autonomous control case.

In manual control case, we are able to change the rudder angle and propeller rate manually, using an RC remote. But since we are doing ViL tests, not only do we see the physical rudder and propeller move according to our commands but we also see them change in our simulation interface. This way we are able to operate our ship in a virtual environment, and get an idea on the controls of the ship. Also this allows us to check if there is an inconsistency between what the ship thinks it is doing and what it actually is doing. For instance, looking at the simulation environment and the ship, we were able to discover an issue with our embedded software about the rudder usage.

The autonomous control mode can be enabled with a switch on the RC remote. Once enabled, the ship uses a PID controller to correct it's course. The target course can be predetermined, or can be chosen as the course when the PID controller is first enabled.

For our ViL experiments, we've predetermined an arbitrary direction as the target, manually disrupted the course, and then enabled the PID controller to see it's behavior. PID controller not only needs to correct the ship's course under the influence of virtual waves, but it also needs to maintain it afterwards which is difficult with this ship because of it's asymmetrical rudder. Using ViL tests, we were able to validate our PID implementation and see the efficiency of the PID gains we've derived. A screenshot of the simulation interface during ViL tests can be seen in Figure 4.

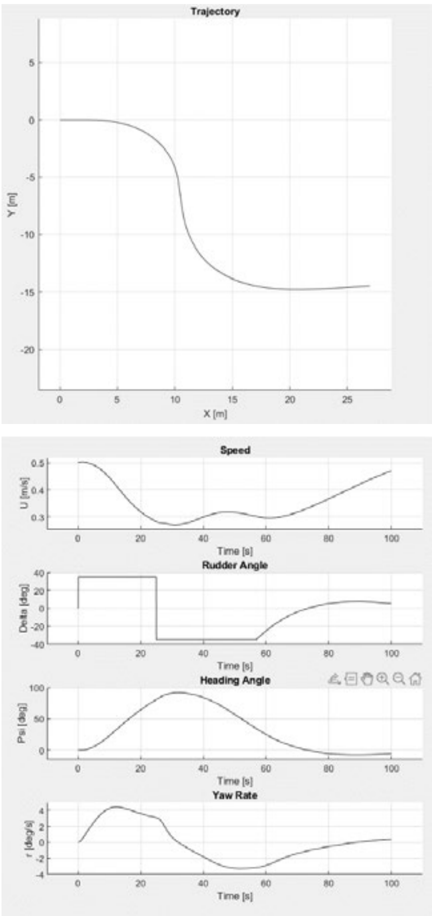

Figure 4. Course-changing & course keeping in ViL using PID. For demonstration purposes, the target heading angle has been chosen as $0°$ (corresponds to right in the figure) and $k_p = 1, k_i = 0, k_d = 0$ has been used for the controller. The heading angle has been manually disrupted with a 35° rudder angle until $t = 20s$. At $t = 20s$ the PID controller has been enabled

5. Conclusion

The development and testing of our ViL solution have allowed us to enhance the reliability and efficiency of ship performance evaluations under realistic operational conditions. By benchmarking our approach in manual and autonomous control cases, we were able to demonstrate the role of ViL tests in identifying and avoiding potential hardware and embedded software issues. The manual control tests, with the use of an RC remote for direct manipulation of rudder angle and propeller rate, have enabled the early detection of software problems concerning rudder usage. Similarly, the autonomous control mode, where a PID controller is utilized, helped us verify the our PID implementation and the appropriateness of our derived PID gains.

ViL tests serve as a helpful intermediary step that smoothens the gap between theoretical design and free-running experiments. By integrating physical vehicles with simulation environments, they allow for adjustments to be made before proceeding to more costly and time-consuming free-running tests. This approach not only helps protect the integrity of experimental process but also accelerates the development cycle by allowing early detection and correction of errors, and allowing researchers and engineers to interact with a physical vehicle earlier in the development process.

6. Future Work

Our team is working on upgrading the hardware setup, and planning on doing free-running tests to compare the our PID controller's performance on open-water with it's performance in simulation. We are using a semi-analytical method that doesn't require trial & error to derive the PID gains, which will be documented in a future publication once we gather enough data for analysis.

A future project that our team is concerned with is to design hardware similar to that of [6], but this time specialized for maritime domain. Combining this technology with ViL methodology would allow researchers to do their development on hardware, only using the MATLAB Simulink interface. Such a technology would not only provide all the benefits of ViL we've talked about, but it would also make embedded software development much more intuitive for people in maritime industry, and could hugely accelerate certification processes.

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Assessing the Appendage Effects on the Resistance Characteristics of the Joubert BB2

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Abstract

This investigation focuses on determining the appendage resistance associated with the Joubert BB2 submarine form using the steady Reynolds-Averaged Navier-Stokes (RANS) method across various modeling scenarios. The turbulent flow phenomena around the hull are modeled employing the k-ϵ turbulence model. Initially, the hydrodynamic resistance characteristics of the bare Joubert BB2 hull in submerged conditions were computed over a wide range of velocities. Subsequently, appendages consisting of sails, forward diving planes and X-type rudders were attached to the bare hull, and their effects on resistance, as well as the interaction between the appendages and the hull, were examined. The relative influence of appendage resistances on the outcomes of the fully appended Joubert configuration is elucidated. Consequently, it was determined that the forward diving fins contributes 4.58% to the overall resistance, the X-type rudders contribute 6.58% to the total resistance, and the sail contributes 8.74% to the total resistance. This research explains the findings regarding the original form, which is the initial hull condition for optimizing appendage designs in terms of resistance.

Keywords: *Joubert BB2, Submarine Resistance, Submerged Body, Appendage Resistance, RANS*

Nomenclature

∇	Displacement volume (m3)	R_S	Shear Resistance (N)
B	Breadth (m)	R_T	Total Resistance (N)
CFD	Computational Fluid Dynamics	S	Wetted surface area
C_P	Pressure Resistance Coefficient (-)	SIMPLE	Semi-Implicit Method for Pressure Linked Equations
C_S	Shear Resistance Coefficient (-)	SSK	Diesel Electric Attack Submarine
C_T	Total Resistance Coefficient (-)	SST	Shear Stress Transport
D	Depth (to deck) (m)	*Subscript -App*	*Appended Hull*
D_{MAX}	Maximum depth (to top of sail) (m)	*Subscript -B*	Bare hull
EFD	Experimental Fluid Dynamics	U_i	Mean forward speed of UV (m s^{-1})
FVM	Finite Volume Method	u_i'	Fluctuation velocity
ITTC	The International Towing Tank Conference	UV	Underwater Vehicle
LOA	Length Overall (m)	V	Velocity (m/s)
MARIN	Maritime Research Institute Netherlands	ν	Kinematic viscosity (N s m^{-2})
P	Mean pressure	x_i	Cartesian coordinate
RANS	Reynolds-Averaged Navier–Stokes	λ	Scale ratio
Rn	Reynolds Number (-)	ρ	Density of water (kg m^{-3})
R_P	Pressure Resistance (N)		

1. Introduction

The increased prevalence of underwater vehicles (UVs) for both military and research applications has highlighted the significant challenges inherent in their design. This complexity arises from the diverse operational contexts and the intricate nature of their missions. The precise determination of hydrodynamic performance metrics, particularly resistance factors is of critical importance to the design process. In order to address these challenges, researchers have employed a combination of experimental methodologies and numerical simulations to investigate submarine hydrodynamics. These investigations are centred on benchmark models, notably the Joubert BB2, which serve as vital validation tools. Despite the longstanding tradition of surface vessel hydrodynamics research, the exploration of submarine dynamics remains relatively limited yet pivotal. This underscores the necessity of comprehensive validation studies utilizing benchmark models such as the DARPA Suboff and Joubert BB2. Although the Joubert BB2, designed as a diesel electric attack submarine (SSK), offers a realistic representation of submarine dynamics, research efforts remain somewhat restrained compared to the more extensively studied DARPA Suboff model. This underscores the imperative for further scholarly inquiry into submarine hydrodynamics.

In the past, maneuvers of a Joubert BB2 Submarine model in four different appendage configurations at varying depths and near the free surface have been studied in [1]. The total resistance, wake fraction, and propulsion characteristics of the Joubert BB2 submarine in both model scale and full scale have been analyzed using numerical simulations in [2]. The added resistance of UVs near regular waves and its impact on effective power and speed loss investigated by considering various wave theories in [3]. In [4], the numerical behavior of the Joubert BB2 submarine in model scale under steady, turbulent, and incompressible flow conditions was calculated using RANS equations and appropriate turbulence models. The study [5] investigates the effect of appendages (sails and control surfaces), on the resistance characteristics of DARPA Suboff, using computational fluid dynamics (CFD). Furthermore, it identifies optimal Froude numbers for minimal total resistance near the free surface and recommends expressing appendage resistance as a percentage of the viscous resistance for better estimation. In addition to that, study [6] assessed DARPA SUBOFF resistance using computational fluid dynamics (CFD) and empirical methods across various velocities, alongside numerical analyses of the DTMB 4119 propeller in open water conditions, validated against experimental data. Findings revealed agreement between computed resistance values and experimental data, and self-propulsion characteristics for the submarine model. Focused on the development of an experimental model for a BB2 generic submarine and the acquisition of hydrodynamic coefficients from captive model tests, the research discussed in [7] aims to establish a significant reference dataset for future BB2 investigations. It delves into the submarine's maneuvering characteristics through combination tests and validates the results through simulations.The obtained coefficients serve as a crucial reference dataset for future BB2 studies. The study investigates the maneuvering characteristics of the submarine through combination tests and validates the results through simulations. Scale effects on UV maneuvering, particularly in pure pitching simulations, were observed, contributing to improved predictive capabilities for full-scale submarine performance using direct CFD simulations, as noted in [8]. Examining scale effects on submarine characteristics using CFD and the DARPA Suboff hull form, the study also evaluates the applicability of the 1978 ITTC method, with all findings presented in [9]. Results show reduced resistance coefficients with scale ratios and improved agreement with the Froude approach for full-scale submarines. In [10], a comprehensive analysis using CFD method assesses the self-propulsion performance of DARPA Suboff AFF-1 and AFF-8 forms, including open water analyses for the E1619 submarine propeller and comparisons with experimental data. Results show good agreement between numerical and experimental findings, with observed differences in propulsive efficiency and delivered power between the body force method and self-propelled cases.

In this investigation, the resistance characteristics of the Joubert BB2 attack submarine configuration will be analyzed using Computational Fluid Dynamics (CFD). Experimental trials were conducted to assess the impact of appendages on the overall resistance experienced by the submarine, comparing scenarios with both the bare hull and the complete submarine model. The resultant mathematical resistance data will be compared with experimental findings, enabling the determination of the proportional influence of individual appendages on the submarine and facilitating pertinent observations.

2. Theoretical Background

The primary equations governing the fluid dynamics involve the continuity equation and the widely recognized Reynolds-Averaged Navier-Stokes (RANS) equations, which describe the unsteady, three-dimensional, and incompressible flow conditions [11]. The continuity equation, a fundamental aspect of fluid mechanics, expresses the conservation of mass within the fluid system, it can be given as;

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

The velocity U can be separated into its components: the mean velocity and the fluctuating velocity;

$$U_i = \overline{U_i} + u_i \tag{2}$$

The expressions for the momentum equations are given as,

$$\frac{\partial U}{\partial t} + \frac{\partial (U_i U_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] - \frac{\partial u_i' u_j'}{\partial x_j} \tag{3}$$

All analyses are conducted under steady-state conditions, hence the first term in Eq. (3) is disregarded. In the momentum equations, U_i and $\overline{u_i'}$ denote the mean velocity and the fluctuation velocity components along the Cartesian coordinate i (x in this case), respectively. P, ρ, and ν represent the mean pressure, density, and kinematic viscosity coefficient, respectively.

The renowned k-ϵ turbulence model is utilized for precise simulation of turbulent flow around the submarine. This model is suitable under conditions where there are minimal pressure changes along the hull and absence of separation near the hull. It is chosen here due to the vessel being fully submerged, thus eliminating any free surface effects. Further information provided in Vilcox [12, 13].

3. Computational Method

3.1 Grid Structure and Boundary Conditions

An appropriate computational domain has been established to model the complex flow around the submarine hull. The flow region is divided into the three-dimensional unstructured subcontrol volumes. Surface remeshing, trimmed cell meshing, and prism layer meshing, which are the main grid production techniques are preferred when creating the subcontrol columes. A longitudinal half-hull was preferred in all simulations to save computational time and cell numbers. Figure 1 illustrates the computational domain, indicating assigned boundary conditions, with dimensions of $-2 \leq x/L_{OA} \leq 1.5$, $0 \leq y/L_{OA} \leq 1$, $-1 \leq z/L_{OA} \leq 1$. The incoming flow serves as the velocity inlet, the right side as the pressure outlet, and the submarine surface acts as a no-slip wall. Additionally, the side, top and bottom surfaces are designated as symmetry boundaries. Further details on boundary conditions and meshers can also be found in the user guide of the commercial CFD software [14].

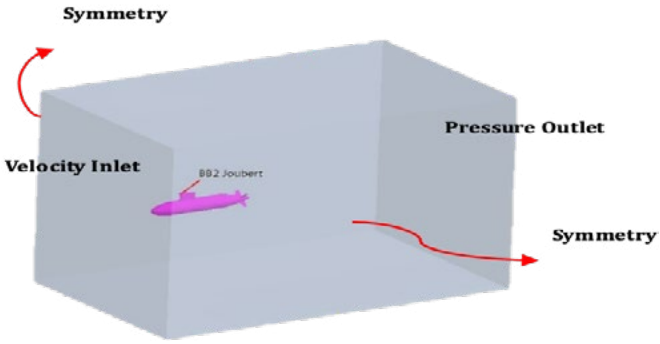

Figure 1. Computational domain with boundary conditions

The computational domain is segmented into three-dimensional finite volumes and discretized using the finite volume method (FVM). The dimensions of the computational domain are established following the ITTC guidelines to accurately analyze the steady flow [15]. Unstructured hexahedral elements are utilized throughout the domain for its construction. Mesh refinements were applied to both the full appendage configuration and the bare hull configuration. Refinements were implemented on the complete appendage structure, specifically targeting areas such as the sail and the associated wake region, as well as the stern and the wake region. Additionally, a separate volumetric control refinement was applied to cover the entire submarine geometry. This refinement approach involved consolidating the sail and its wake into one refinement area, while the stern and form wake were treated as another, enabling a thorough depiction of the flow dynamics surrounding the submarine. Regarding the bare form, the mesh refinements were designed to cover the stern, the resulting wake, and the entirety of the submarine form. The unstructured mesh representing the full appendage configuration of the computational domain is depicted in Figure 2, while the mesh for the bare hull configuration is illustrated in Figure 3. While the analyses performed for the bare hull have 4.20×10^5 number of cells, the analyses conducted for the appended hull have 1.57×10^6 number of cells.

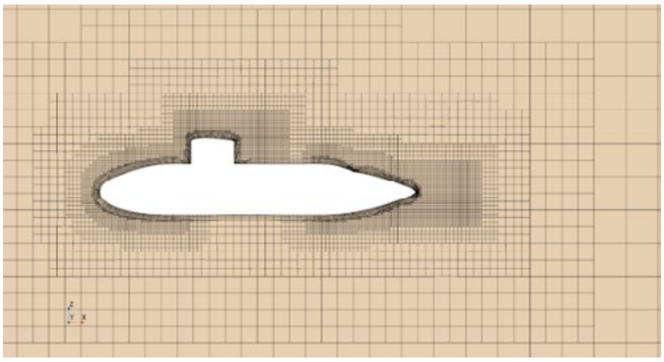

Figure 2. Unstructured surface and volume grid of the full appendage BB2 Joubert

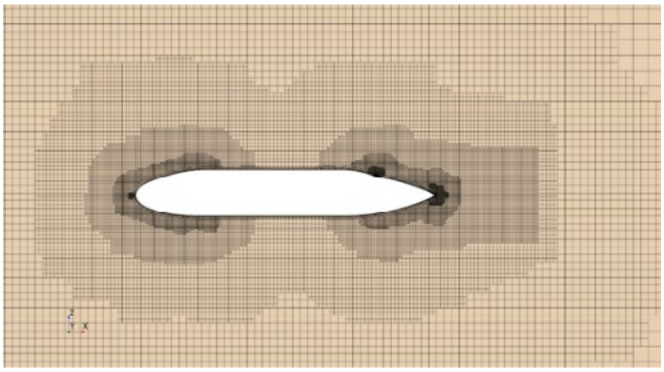

Figure 3. Unstructured surface and volume grid of the bare BB2 Joubert

3.2 Solution Strategy

The k-ε turbulence model is selected for the computational analyses due to the absence of significant high-pressure gradients along the hull. This choice is justified by the hull's slender geometry [17], which renders the effects of boundary layer separations negligible on the flow characteristics surrounding the hull. The research involves a three-dimensional flow scenario. The liquid being studied maintains a uniform density, and the flow is steady and segregated.

The pressure field is solved using the SIMPLE algorithm, a widely used method for iteratively coupling pressure and velocity fields. This algorithm, particularly effective for steady-state analyses, contributes to rapid computational time reduction. The complete SIMPLE Algorithm is given as;

$$a_e u_e^* = \sum a_{nb} u_{nb}^* + b + (\rho_P^* - \rho_E^*) A_e \tag{4}$$

$$a_n v_n^* = \sum a_{nb} v_{nb}^* + b + (\rho_P^* - \rho_N^*) A_n \tag{5}$$

$$a_t w_t^* = \sum a_{nb} w_{nb}^* + b + (\rho_P^* - \rho_T^*) A_t \tag{6}$$

By solving the momentum equations, we obtain the correct pressure field;

$$a_P \rho_P' = a_E \rho_E' + a_W \rho_W' + a_N \rho_N' + a_S \rho_S' + a_T \rho_T' + a_B \rho_B' + b \tag{7}$$

By solving the velocity corrections, we would obtain velocity corrections, further information about SIMPLE Algorithm can be found in [16].

$$u_e' = d_e(\rho_P' - \rho_E') \tag{8}$$

$$v_n' = d_n(\rho_P' - \rho_N') \tag{9}$$

$$w_t' = d_t(\rho_P' - \rho_T') \tag{10}$$

All governing equations are discretized employing a cell-based finite volume method, with advection terms discretized using a first-order upwind interpolation scheme. These computational procedures are conducted under the assumption of single-phase flow, with no consideration for free surface effects. Viscous effects near the ship are incorporated by modeling the boundary layer using an appropriate grid structure, ensuring that y+ values of the hull remain within a reasonable range of 30-300.

4. Geometry and Test Cases

The Joubert BB2 submarine model is widely recognized in naval engineering, featuring components such as a sail, an X-type rudder, and diving fins. The benchmark BB2 Submarine hull was presented in the literature as an open source by MARIN and is frequently used in the hydrodynamic investigation of submerged hulls. Table 1 presents crucial information about the model submarine. Meanwhile, Figure 4 presents a three-dimensional representation of the submarine's fully appendaged form, which serves as the case study for comparison with experimental data.

In the study, first, the resistance characteristics of the appended BB2 form were computed by CFD and compared with the available experimental results. Then, numerical analyses were re-simulated using bare and appended hull forms. While the bare hull consists only of the main body, the appended hull consists of the main body and the sail, diving fins and rudders. Analyses are performed on both the submarine's bare and appendaged forms across five varying velocity values, ranging from 1.0 m/s to 3.0 m/s, with increments of 0.5 m/s.

Table 1. Main Particulars of Joubert BB2 Submarine Model

Parameters	Symbol (Unit)	Value
Scale	λ (-)	35.1
Length Overall	L_{OA} (m)	2.000
Beam	B_O (m)	0.274
Maximum depth (to top of sail)	D_{MAX} (m)	0.462
Depth (to deck)	D (m)	0.302
Displacement volume	∇_B (m^3)	0.099
	∇_{APP} (m^3)	0.101
Wetted surface area	S_B (m^2)	1.541
	S_{APP} (m^2)	1.739

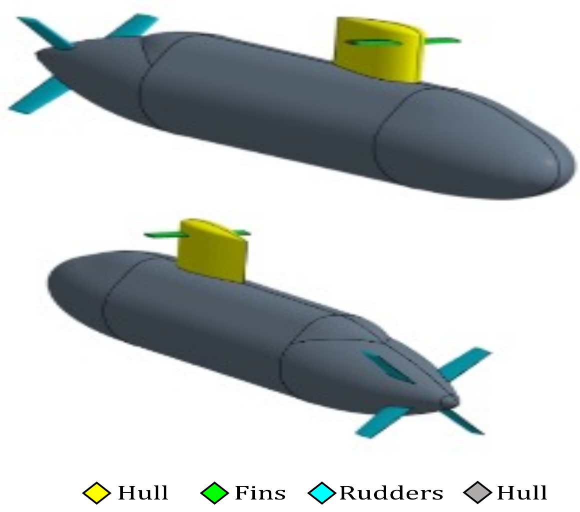

Figure 4. Fully Appended Joubert BB2 Hull.

5. Results and Discussions

This section explores the computational results obtained from the resistance analyses performed on the Joubert BB2, considering both bare and fully appended hull configurations. The results were examined in detail to what extent the bare hull and appendages contributed to the total resistance of the submarine form.

5.1 Validation Study

The compatibility of the results obtained from the established mathematical model with the available experimental results was investigated. The results, as presented in Table 2, demonstrate that the numerical method yields reasonably accurate predictions of the submarine's total resistance when compared to experimental data [7]. Figure 5 shows the comparision of EFD and CFD results.

Table 2. Comparison of the Numerical and Experimental Results

Re×10^6	V (m/s)	$R_{T\text{-}EFD}$ (N) [7]	$R_{T\text{-}CFD}$ (N)	Absolute Relative Difference (%)
1.75	1.00	5.182	5.015	3.23
2.62	1.50	10.091	10.538	4.43
3.49	2.00	17.636	17.679	0.24
4.37	2.50	26.727	26.466	0.98
5.24	3.00	38.273	37.010	3.30

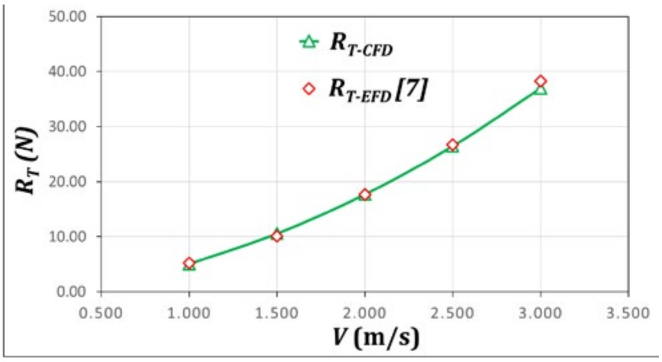

Figure 5. Comparison of CFD and EFD results for fully appended Joubert BB2.

5.2 Resistance Results

The resistances of the Joubert BB2 hull at various velocities for both bare hull and appended hull forms were numerically measured and compared in Figure 6. Table 3 gives the total resistance and total resistance coefficients of the bare ($R_{T\text{-}B}$) and appended ($R_{T\text{-}App}$) forms. Although the effect of appandeges on resistance tends to decrease slightly as velocities increase, the average increase in resistance caused by appendages is around 27.28%. When comparing total resistance coefficients (Figure 7), they show a decreasing trend as expected. The appendage resistance coefficient (C_{App}) is approximately 0.899. C_{App} is expressed as the difference between the total resistance coefficient with appended ($C_{T\text{-}App}$) and ($C_{T\text{-}B}$).

Table 3. Resistance characteristics of the bare and appended Joubert BB2.

V (m/s)	$R_{T\text{-}B}$ (N)	$R_{T\text{-}App}$ (N)	ΔR_T	Re×10^6	$C_{T\text{-}B}$ ×10^3	$C_{T\text{-}App}$ ×10^3	C_{App} ×10^3
1.000	3.642	5.015	27.37%	1.75	4.762	5.771	1.009
1.500	7.633	10.538	27.56%	2.62	4.435	5.390	0.954
2.000	12.929	17.679	26.87%	3.49	4.226	5.086	0.860
2.500	19.474	26.466	26.42%	4.37	4.074	4.873	0.800
3.000	26.577	37.010	28.19%	5.24	3.861	4.732	0.872
Mean	-	-	**27.28%**		-	-	**0.899**

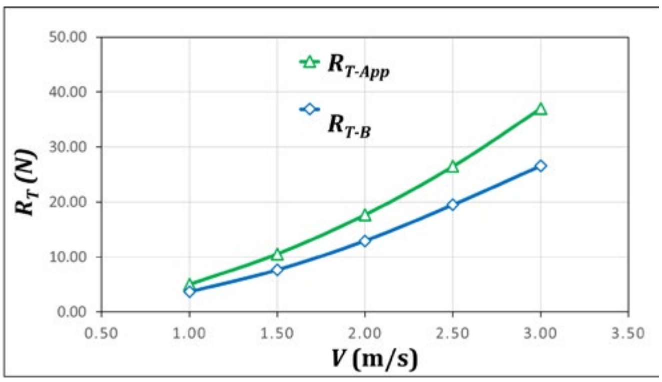

Figure 6. Comparison of bare and append resistance results.

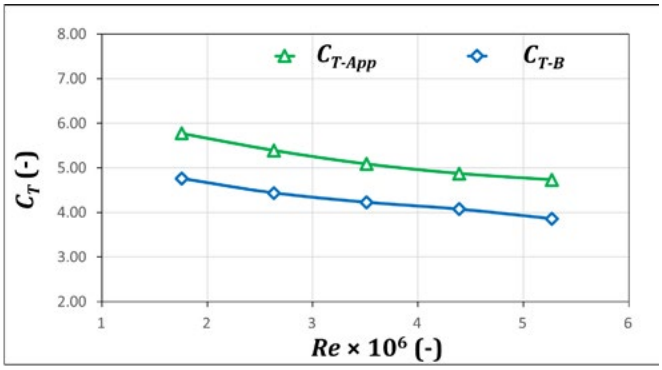

Figure 7. Comparison of bare and append resistance coefficient.

An additional objective of the investigation pertains to the assessment of appendages' influence on overall hydrodynamic resistance. Table 4 presents the proportionate contribution of each appendage component to the total resistance. Within this segment, the submarine's appendages are split into parts in CFD simulations, with subsequent reporting of their respective resistance values. This approach facilitates an examination of the appendage resistances. The findings reveal that the main hull constitutes the predominant contributor to total resistance at 80.10%, followed by the rudders at 6.58% and the fins at 4.58%. Notably, the submarine hull features four rudders and two fins. Upon disaggregating the evaluation of rudders and fins, it becomes evident that the rudders individually exhibit a lesser impact on total resistance. This observation may indicate the rudders are in a good alignment along streamline trajectories on the hull. Given the individual contributions of the hull, fins, and rudders to overall resistance, it is rational to prioritize these components respectively in appendage shape optimization endeavors. The dimensionless velocity distribution around the bare hull and appended hull are given in Figure 8 for V=2.0 m/s. The effects of the appendages on the flow characteristics around the hull are seen.

Table 4. Relative contribution of submarine appendages to total resistance

Parts / V (m/s)	Main hull ($R_{T\text{-}App}$ %)	Sail ($R_{T\text{-}App}$ %)	Rudders ($R_{T\text{-}App}$ %)	Fins ($R_{T\text{-}App}$ %)	$R_{T\text{-}App}$ (N)
1.00	78.97	9.25	8.18	3.60	5.015
1.50	79.22	8.82	7.62	4.34	10.538
2.00	80.29	8.73	7.40	3.57	17.679
2.50	80.83	8.48	7.25	3.43	26.466
3.00	81.18	8.42	7.01	3.39	37.010
Mean %	**80.10**	**8.74**	**6.58**	**4.58**	-

Figure 8. Velocity distributions around the bare hull (top) and the fully appended hull (bottom) for V=2 m/s.

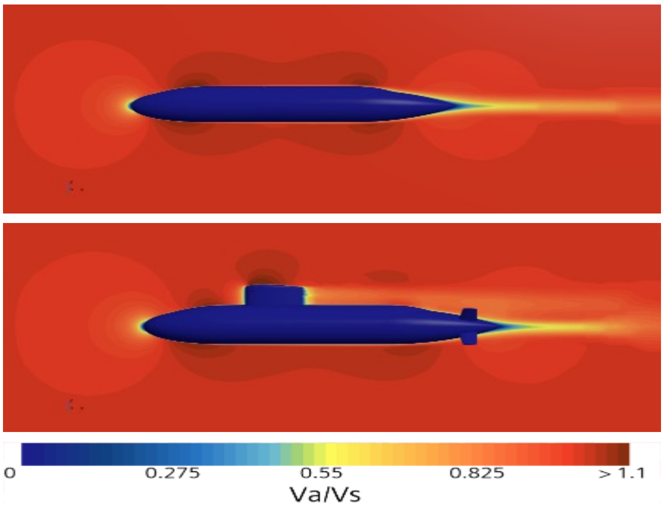

Figure 8. Velocity distributions around the bare hull (top) and the fully appended hull (bottom) for V=2 m/s.

6. Concluding Remarks

The research investigates the hydrodynamic performance of appendages attached to a submerged hull concerning resistance. The Joubert BB2 submarine hull, a commonly utilized model in academic studies, was selected as the basis hull to achieve this objective. The appendages considered in the study include the rudders, fins, and sail of the Joubert geometry. The resistance characteristics of both the bare hull and the fully appended hull were numerically analyzed separately while maintaining a fully submerged condition and varying speeds within the range of $1.0\ \text{m/s} \leq V \leq 3.0\ \text{m/s}$. The k-e turbulence model was employed to simulate the turbulent flow around the complex hull structure. The resistance findings for the fully appended Joubert BB2 configuration were corroborated with existing experimental data. Subsequently, a comparative analysis was conducted between the fully appended configuration and the bare hull form, revealing a 27.28% increase in resistance attributable to the appendages. Upon scrutinizing the contribution of each appendage to the total resistance, it was determined that the sail accounted for 8.74%, the rudders 6.58%, and the fins 4.58%. In forthcoming research, the aim is to extend the investigation into the resistance components responsible for the observed increase in resistance due to appendages and their influence on flow dynamics and wake.

7. Acknowledgement

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Effect of propulsion model on the free running simulations of a self-propelled submarine

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Abstract

Present paper covers the numerical investigation of a free-running submarine with different propulsion models. Hydrodynamic performance of DARPA suboff in surge motion is evaluated using discretized propeller (thrust generated by its actual propeller) and body force (virtual disk) methods. URANS CFD computations with overset mesh approach are performed to predict the velocity and translation of the submarine model in time domain. Furthermore, fixed and moving background modelling mythologies are applied to overset mesh setup to compare the solution performance. The results were reported in terms of computation time, velocity-position histories and details of the flow field.

Keywords: *Self-Propulsion, Free-Running, URANS CFD, Discretized Propeller, Virtual Disk*

1. Introduction

One of the primary aspects considered when accurately evaluating the hydrodynamic performance of a surface and submersible ships during the design stage is propulsion and motion characteristics. For this purpose, self-propulsion characteristics can be determined mainly using three approaches: the system-based method, model tests, and direct Computational Fluid Dynamics (CFD) simulations Compared to model tests and the system-based method, numerical computations have gained prominence for a comprehensive evaluation of hydrodynamic performance in marine vehicles. In addition to reducing computational time and costs, CFD simulations of self-propulsion provide detailed information about the ship's flow field, wave patterns, and other aspects related to the ship's hydrodynamic performance (Feng et al. [1]). Thus, CFD has become a well-established tool for estimating and evaluating self-propulsion performance.

Especially in the last decade, CFD applied to many types of self-propulsion estimations of ships. Utilizing model tests and CFD approaches, Wang et al. [2] examined propeller wake and submarine flow for the DARPA Suboff near free surface conditions. Chase and Carrica [3] investigated the wake behavior of a generic submarine propeller and its impact on the self-propulsion of the DARPA sub-off. They have studied different turbulence modeling approaches and evaluated propulsive performance at the self-propulsion point. Kinaci et al. [4] performed CFD calculations to investigate the self-propulsion performance of different ship geometries. They presented the pros and cons of different modelling techniques (virtual disc and discrete propeller) and empirical relations. Zhang and Zhang [5] investigated the self-propulsion and resistance characteristics of a submarine in both fully submerged and near-free surface conditions.

The propeller modeling is essential for analyzing interactions between the hull, propeller, and rudder (Broglia et al. [6]). In the ship hydrodynamic, two most common techniques are employed for propeller modeling: the discretized propeller model and the body force model. A discretized propeller model, which directly represents the propeller geometry, is considered the most accurate and realistic method for predicting self-propulsion characteristics. In ship self-propulsion free running computations, a discretized propeller is commonly employed as the propulsion model. Shen et al. [7] conducted self-propulsion and maneuvering computations of the KCS vessel utilizing direct discretization of the propeller via dynamic overset grids in OpenFOAM. The study included grid convergence analyses to validate the accuracy and reliability of the overset grid method implementation. Sezen et al. [8] utilized the RANS method to estimate the total resistance and self-propulsion behavior of both bare and appended DARPA Suboff forms with an E1619 propeller. For self-propulsion simulations across a wide range of forward speeds, they employed both the actuator disc (body force method) and discretized propeller approaches. The outcomes demonstrated that the self-propulsion characteristics were slightly overestimated when using the actuator disc approach in comparison to directly be employing the discretized propeller. Guo et al. [9] performed numerical simulations and analysis on the self-propulsion performance of a waterjet-propelled trimaran. They utilized the Moving Reference Frames (MRF) method to directly simulate the waterjet. By comparing the numerical results of the bare hull and self-propulsion scenarios with Experimental Fluid Dynamics (EFD) data, they confirmed the validity and accuracy of the numerical method. The body force models are commonly employed in self-propelled ship simulations due to their reliability and computational efficiency advantages. Feng et al. [1][10]; Yu et al. [11]. The body force model simplifies self-propulsion computations, enabling easier and quicker analysis, particularly in cases where detailed propeller flow is not crucial, such as studying the interaction of the propeller-hull-rudder system. Bakica et al. [12] conducted simulations of self-propulsion using CFD with the Volume of Fluid (VOF) and Ghost Fluid Method (GFM), employing an actuator disk. Both Bekhit [13] and Yuting [14] utilized a discretized propeller and the body-force method for conducting self-propulsion and dynamic maneuver simulations. The body-force method has demonstrated its validity as a suitable option for investigating propeller-hull-rudder interference, offering a balance between accuracy and rapid computational time. In a different study, Delen et al. [15] examined the interaction between the hull and propeller of the DARPA Suboff vehicle using the body force method. They estimated the hydrodynamic performance of DARPA Suboff through both numerical simulations and empirical methods.

In aim to this study, the numerical computations of a free-running DARPA-Suboff submarine model were performed using two propulsion models: the discretized propeller model and the body force method. Both fixed and moving background methodologies were employed in the free-running simulations, and their pros and cons were discussed. The differences between the propulsion models were investigated in terms of the velocity and position history in the free-running simulations, as well as the effect of the incoming flow to the propeller plane and the impact of the propeller's presence on thrust generation.

2. Definition of the problem and the geometric properties of the submarine and the propeller

This study discusses the numerical modelling of a free-running submarine's surge course considering straight-ahead motion situation. Two propulsion models of RANS tools for the ship self-propulsion free-running prediction were applied to estimate this motion: discretized propeller method and body force (virtual disk) method.

The well-known benchmark submarine model developed by the Defense Advanced Research Projects Agency (DARPA) was utilized in the virtual towing tank tests. The sail and rudder fins are part of the appended submarine geometry, often known as the AFF-8 configuration. The geometry of model is presented in Fig. 1. The main properties are also given in Table 1 in model scale of 1/24 (Groves et al. [16]).

Table 1. Main dimensions of the DARPA AFF-8 submarine form

Parameter	Dimension
Length overall, L_{OA} (m)	4.356
Length between perpendiculars, L_{BP} (m)	4.261
Maximum diameter, D_{max} (m)	0.508
Wetted surface area, S (m^2)	6.348
Displacement, ∇ (m^3)	0.706

Figure. 1. The geometry of fully appended DARPA Suboff model

The benchmark INSEAN E1619 propeller was taken into account in the computations which included open-water propeller and free-running simulations Chase and Carrica [3]. The principal particulars of the propeller and 3D geometry are presented in Table 2 and Fig. 2, respectively.

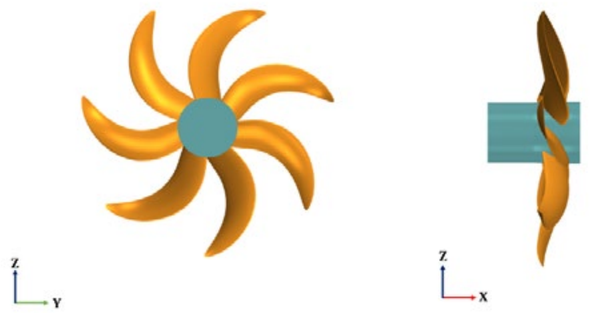

Figure. 2. 3-D view of INSEAN E1619 Propeller

Table 2. Main dimensions of the INSEAN E1619 propeller.

Parameter	Dimension
Diameter, D(m)	0,485
Number of blades, Z	7
Hub diameter ratio, D_h/D	0,226
Pitch at $r = 0.7R$	1,15
Chord at $0.75R$ (m)	0.0068
Rotation	Right Hand

3. Numerical Modelling

Free running simulations of self-propulsion of the submarine for this study were conducted by utilizing the commercial CFD software, Simcenter StarCCM+. The numerical simulation approaches employed in this study for performing direct CFD simulations were presented in this chapter.

3.1. Governing Equations

In this study the governing equations were solved by using Unsteady Reynolds-Averaged Navier-Stokes (URANS) equations. For unsteady, incompressible and turbulent flows, the continuity and momentum equations can be expressed in tensor notation and Cartesian coordinates as follows:

$$\frac{\partial U_i}{\partial x_i} = 0$$

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] - \frac{\partial \overline{u_i' u_j'}}{\partial x_j}$$

Where, U_i and u_i' depicts the mean and fluctuation velocity components in the direction of the Cartesian coordinate x_i. P represents the mean pressure, ρ the density and ν the kinematic viscosity of the fluid.

To accurately represent the turbulent flow surrounding the submarine, the k-ε turbulence model has been utilized. The Reynolds stress tensor is computed as follows during the analyses:

$$\overline{u_i' u_j'} = \nu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) + \frac{2}{3}\delta_{ij} k$$

Here, the eddy viscosity ν_t is expressed as $\nu_t = C_\mu k^2/\varepsilon$, where C_μ is an empirical constant ($C_\mu = 0.09$). k is the turbulent kinetic energy and ε is the turbulent dissipation rate. For k and ε, two transport equations are solved in addition to the continuity and momentum equations:

$$\frac{\partial k}{\partial t} + \frac{\partial (kU_j)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\nu + \frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \varepsilon$$

Further information for the k-ε turbulence model can be found in Wilcox (2006) [17].

3.2. Computational domain and boundary conditions

To start with the domain properties, two types of computational domain were created in this study: one for open-water propeller analyses and the other for resistance and free-running analyses. The solution domain sizes have been determined according to the ITTC guideline (ITTC,2011b) [18] for resistance analyses. The same procedure was employed to the free-running simulations. In addition to the resistance simulations in free-running computations, the computational domain was divided into three parts: the background region surrounding the whole fluid domain, overset region covering the submarine hull and rotating region including propeller. The propeller region subtracted from the background region, surrounded the propeller. An interface between the rotating domain and the background domain is provided by the surrounding cylindrical domain. In CFD computations, it is crucial to apply the appropriate initial and boundary conditions that obtain a good approximation of the problem's solution in order to accurately resolve flow around structures (Date and Turnock, [19]). For that purpose, the velocity inlet was defined as five sides of the background domain, while the pressure outlet was defined as one side that faces the submarine's stern. No fluid velocity was imposed from the inlets in the free-running simulations. The submarine surface was treated with no-slip boundary condition. To conduct the open-water propeller test, a rectangular-shaped domain was created around the propeller. The left side of the domain was defined as pressure outlet, whereas the opposed direction was imposed velocity inlet. The propeller blades and shaft surface are considered no-slip wall and surrounding surfaces were defined symmetry plane. The details of the solution domain and boundary conditions were illustrated in Table 3. and Figure 4. and 5., respectively.

Table 3. Details of the computational domain dimensions used in simulations

Solution domains	Directions				
	Upstream	Downstream	Up	Bottom	Transverse
Resistance	$1.5L_{BP}$	$4.5\ L_{BP}$	$2L_{BP}$	$2L_{BP}$	$2\ L_{BP}$
Open-water propeller	4.5D	11D	5D	5D	5D
Free-running	$1.5L_{BP}$	$4.5\ L_{BP}$	$2L_{BP}$	$2L_{BP}$	$2\ L_{BP}$

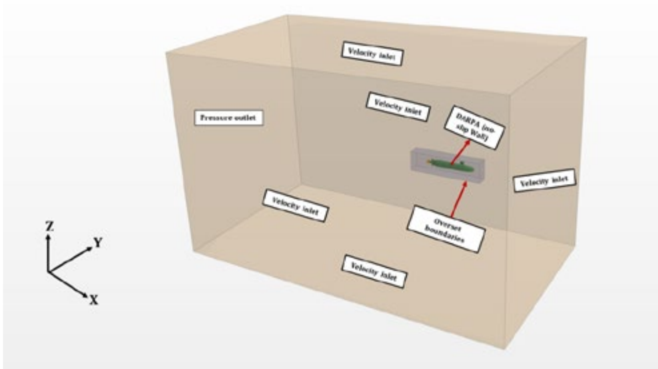

Figure 3. The solution domain and boundary conditions

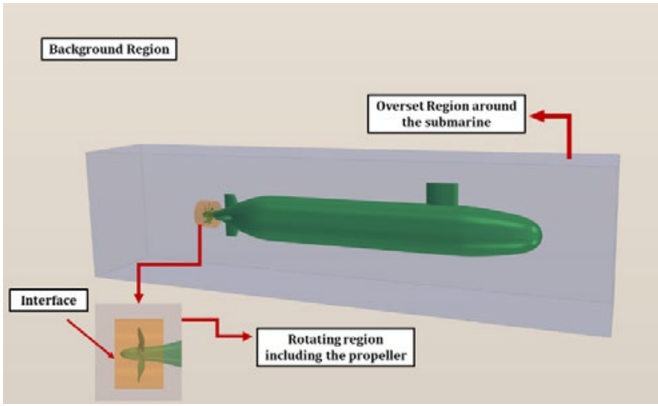

Figure 4. The details of the overset grid configuration

3.3. Grid Structure

The implementation of an appropriate grid structure can be regarded as one of the challenges in the majority of CFD hydrodynamic modeling problems. In accordance with the finite volume method, the computational domain is discretized using three-dimensional finite volumes. For the simulations of resistance, open water propellers, and free-running, the trimmer mesh with hexahedral elements was used throughout the whole computational domain. To capture possible flow separations and high-velocity gradients, additional mesh refinements were used in the submarine's wake and around its appendages. To predict accurately the swirly flow field, mesh refinement was also used in the vicinity of the propeller blades. For better representation of the boundary layer, prism layers have been created near to submarine hulls and propeller blades. The hull surface mesh size and growth rate are adjusted to keep wall y+ values within a reasonable range (30-300), viscous effects near to the submarine and propeller blades are considered. The dynamic overset grid approach was used in this study to carry out CFD simulations of a free-running submarine. The submarine's physical translation can be performed by means of an overset grid. The grid size in the overset region was 1/4 of those in the background region. Figure. 5 demonstrates the overset mesh configuration around the submarine hull and close-up view of grid structure on the propeller for the free-running simulations. The body force model (right) and the discretized propeller model (left) in stern area of the submarine are also presented in Figure 6.

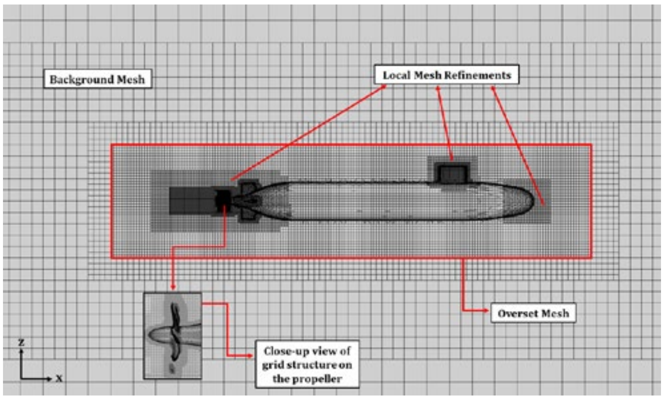

Figure 5. The overset mesh configuration in free-running simulations

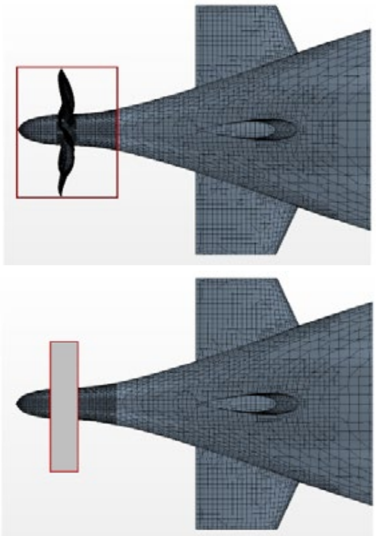

Figure 6. The gridding in stern area: the discretized propeller model (left); the body force model (right)

3.4. Solution Strategy

In this study the governing equations, URANS Eq.s, were discretized using the finite volume method with the aid of commercial CFD tool Sim-center Star CCM+. Turbulent flow around DARPA-Suboff and INSEAN E1619 propeller model have been solved using standard k-ε turbulence model with two-layer all y+ wall treatment, which has been widely used for ship hydrodynamics. A second-order scheme is applied for both spatial and temporal discretization. The SIMPLE algorithm, which is based on pressure-velocity coupling, is used to solve the pressure field. The single-phase assumption was used to conduct the analyses. Free surface effects are not considered, and the submarine was assumed fully submerged. The open water propeller simulations have been performed using the moving reference frame (MRF), while the rigid body motion and virtual disk model were adopted to the free-running simulations. In comparison to the rigid body motion (RBM) technique, the MRF approach offers steady approximation and is thought to be less computationally expensive. This method keeps the body stationary while rotating the MRF zone around it. Despite RBM computational costs, it provides more detailed flow visualization around the propeller and using this method, it can be also captured the propeller-hull interaction due to the presence of the actual propeller.

The submarine's one degree of freedom (1DOF) motion (X translation) was handled by the Dynamic Fluid Body Interaction (DFBI) model that offers to simulate interaction between the flow and the moving rigid body precisely. In order to determine the ship's new position, this approach computes the resultant force and moment acting on it as well as the governing equations of motion.

The propulsion force of the propeller was included in the calculations using body force (virtual disk) method and discretized propeller method. The body force method simplifies the hull-propeller combination model by representing the features of the propeller as a body force (Kim et al., [20]). This simplified disk model aids in reducing the numerical complexity and computational resources to perform the simulations (Feng et al. [10]). Many input factors, such as propeller dimensions, the rotational speed, and performance curve results, are necessary in order to model an actuator disk. The open water propeller experiment data were used to calculate the input variables in this study. On the other hand, the discretized propeller approach was used in the propeller is working behind the ship to generate required thrust. The DFBI Superposed rotation model was incorporated the propeller rotation by superimposing an additional fixed body rotation onto the DFBI motion, allowing the submarine propeller to be represented [21].

The free running simulations have been conducted in an unsteady manner, therefore selecting the right time step is essential for a time-effective analysis. For implicit unsteady simulations, the ITTC CFD recommendations for transient solutions were used to determine the time step. The free running computations of submarine model were performed with a time step equal to 3 degrees of propeller rotation. (ITTC,2011) [22]

Numerical simulations of the free-running were carried-out using two types of domain: moving domain and fixed domain. It should be noted that the background domain moves forward with the submarine in order to enable a synchronously static motion between the overset and background regions, it is called moving background approach. It should be kept in mind that the submarine's surge velocity was employed as the x direction velocity component of the background domain. Otherwise, to ensure that the solution domain sufficiently encompassed the distance of the ship's motion, it should be necessary to enlarge it along the expected travel path (Kim et al., [20]).

4. Results

The simulation results of the ship resistance and open-water propeller tests comparing with experimental data are first presented in this section. Subsequently, the free-running simulations of the submarine model that travels at the straight-ahead condition are demonstrated.

4.1. Resistance Tests

The DARPA AFF-8 submarine form was utilized for a number of ship resistance tests to assess the accuracy of the numerical method employed in computational fluid dynamics (CFD) computations. The simulation results, depicted in Figure 7. The total resistance results were compared with the towing tank measurements performed by (Liu and Huang [23]) in order to validate the numerical approach. For all forward velocities, the numerical results illustrated excellent concordance with experimental ones.

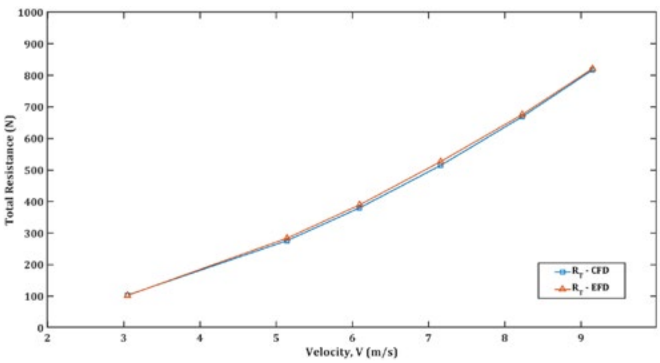

Figure 7. Validation of CFD results for submarine total resistance

4.2. Open-water propeller tests

We have carried-out open-water performance tests of E1619 propeller to compare and evaluate our numerical approach with experimental data. Figure 8 provides numerical results compared to the tests of Chase and Carrica [3]. It has been observed that the discrepancy between CFD and experimental results increase for advance coefficient in excess of 0.8 (J >0.8) for torque coefficient values. On the other hand, the open water-propeller efficiency and thrust coefficient agreement is appropriate.

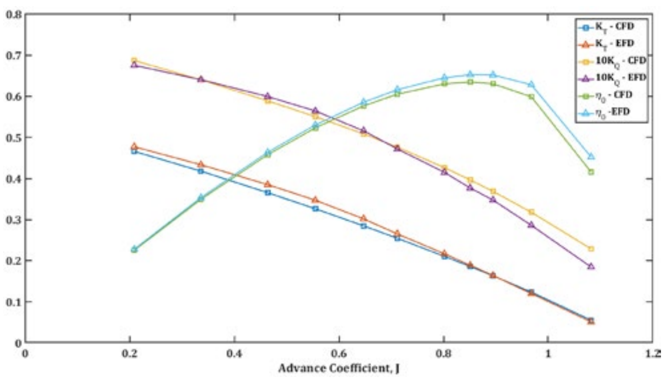

Figure 8. Validation of CFD results for open-water propeller tests

4.3. Free running tests

Results in this section are compiled in two: The first part presents the results of numerical free-running tests of the submarine model employing the body force method with fixed background and moving background. The initial submarine speed was started as zero and the propeller rotates at a rate of 20 revolutions per second (n = 20rps). As a result, the submarine accelerates with the thrust provided by the virtual disk and eventually reaches steady speed of 40 seconds. The simulation scenarios presented in Table 5 while the computation results in the time domain are illustrated in Figure 9.

Table 5. Simulation scenarios of two types of computational domain

	Unit	Fixed Background (Case 1)	Moving Background (Case2)
Initial velocity	m/s	0	0
Propeller rotation rate	rps	20	20
Ship motion type		Straight-ahead	Straight-ahead

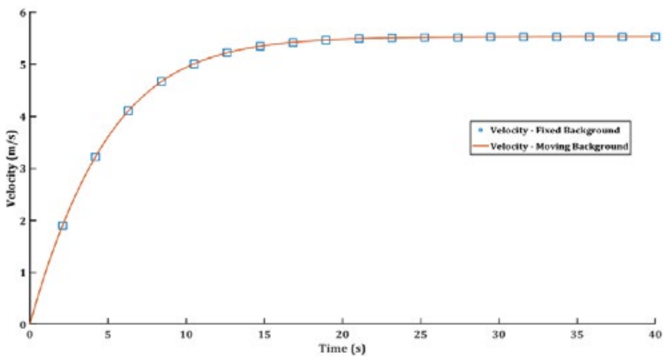

Figure 9. Comparison of the effect of the domain type on the submarine velocity

As it is clearly seen in this figure, the submarine attained velocity of around 5.53 meter per second, and it is observed that the difference in the computational domain has no effect on the result. On the other hand, fixed domain increased the computational time cost dramatically owing to the greater number of grid. Because it became necessary to expand the solution domain along the projected travel path utilizing fixed background due to the physical movement of the submarine and the size of the computational domain is strongly correlated with the grid number. Grid number and computational time also are given in Table 6.

Table 6. Computational efficiency comparison of the domain type

	Fixed Background	Moving Background
Calculation time cost (hours)	32.25	9.64
Grids Number	2348217	1048149
Processor (2.9GHZ)	18-core	18-core

Considering the computational efficiency results, fixed background requires approximately 2.5 times more computational time to obtain the same results comparing with moving background. Due to the lower time-consuming and required grid number, moving background approach have been adopted the second part of the free-running simulation of the self-propelled submarine model.

The second part of this section provides the results of the free-running computations have been conducted employing two different propulsion models including discretized propeller and body force method. The simulations were carried-out at the same initial speed and propeller rotation rate as in the first part of the section. We have also simulated the submarine trajectory in addition to velocity in the time domain. Figure 10. depicted the simulation results for two propulsion models.

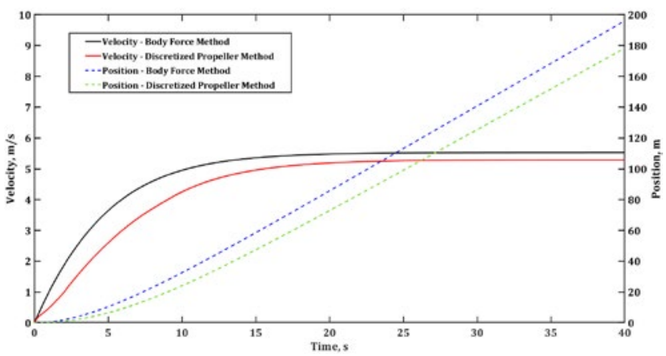

Figure 10. Comparison of the effect of the propulsion model on the submarine velocity and trajectory

It can be clearly observed in this figure, the body force method generates higher submarine velocity compared to discretized propeller method. A similar tendency was also observed in Yu et al. [24]. As an expected result of the velocity difference, the submarine moves approximately 23 meters farther in the body force method. In order to seek for the grounds of the final velocity discrepancy, the details of the flow field were investigated.

As seen in Figure 11, it is observed that the effect of the submarine hull on the flow received by the propeller are changed significantly compared to the open-water propeller condition. The presence of the submarine leads to the asymmetric flow configuration (a.k.a non-uniform flow) inside the propeller region. The incoming flow to the propeller plane becomes non-uniform and this causes to reduce thrust and affects propeller efficiency negatively, while the body force method uses the thrust values of open water curve. This reduced thrust also decreases the velocity attained the submarine in the free-running simulations.

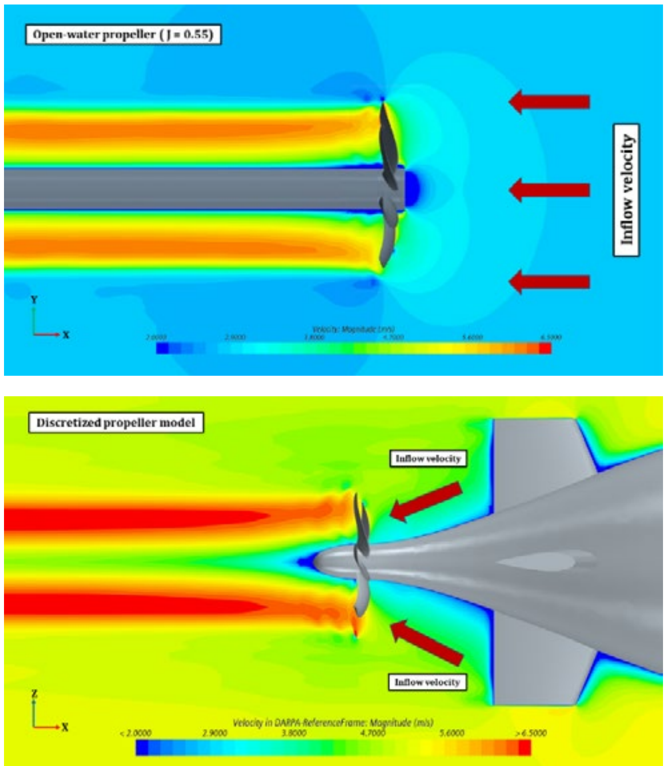

Figure 11. Comparison of the velocity distribution around the propeller: the open-water propeller case (above) and the free-running of the self-propelled submarine case (below)

5. Conclusions

In the present study, the direct URANS CFD method is adopted to assess the free-running computation of the self-propelled submarine. Two different propulsion model was selected to simulate the analysis: the discretized propeller method and the body force method. The overset grid technology was applied to the computations with fixed and moving background approach. The feasibility of these methods has been compared. Results of the resistance and open-water propeller tests were validated with experimental results and the same grid structure using these simulations was employed to the free-running simulations. The free-running computations were performed in two parts: the first part of effect of the domain types in results and the second part is that evaluated of the propulsion model. In the first part, it was observed that the domain type does not have any effect on the results. However, using fixed background requires 2.5 times more computational time than moving background. Considering the computational efficiency, the moving background approach was employed the second part of the free-running computations. In the second part, simulations were conducted using two propulsion models. The discretized propeller method was under-predicted submarine velocity and translation compared to the body force method. This is due to the presence of the propeller causes vortices around the propeller and the effect of the submarine leads to non-uniform incoming flow to propeller plane and these reasons reduce the propeller thrust compared to virtual disk model.

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Resistance Characteristics of KCS Model Advancing in a Shallow Channel

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Abstract

This paper investigates the hydrodynamics of KCS model advancing in a shallow channel via computational fluid dynamics. Determining the resistance and propulsion characteristics of a surface vessel operating in confined waterways is of practical interest, as the interaction of the vessel and the channel walls exhibits a distinctive behavior compared to open water operation. Here, we examined the resistance and flow field of the well-known KCS benchmark model subjected to the water depth effect. First, the drag of the ship model was validated with the experimental data, after, the change in resistance components with varying channel widths was studied. Furthermore, the flow field around the ship model was investigated to elucidate the flow physics of bottom-body interaction.

Keywords: *shallow water, CFD, KCS, resistance*

1. Introduction

Ships maneuvering in canals and shallow water have been a subject of interest for many years, both academically and practically, due to the complex dynamics involved. As the water depth decreases, the fluid experiences compression and accelerates as it passes through the bottom of the medium. This change in flow velocity significantly impacts the pressure distribution, particularly affecting the ship's bottom and creating a notable suction force that pulls the vessel towards the waterway bed. Additionally, variations in pressure distribution throughout the ship, such as between the bow and stern, contribute to wave-forming resistance and trim moment. When water depth decreases substantially or the ship's speed increases, inevitable speed loss occurs due to factors like wave-forming resistance, squatting, and trim, which can escalate to significant magnitudes. This situation poses a serious risk of grounding due to squatting and trim effects, necessitating consideration of the heeling effect, especially as liquid velocity may rise in shallow waters. Moreover, if the shores exhibit asymmetry, the flow velocities on the port and starboard sides may differ, leading to disparate pressure distributions that generate a suction force pulling the ship towards the shore. The resulting asymmetric pressure distribution can cause a deflection moment, potentially deviating the ship from its intended course and increasing the risk of collisions. Consequently, maneuvering surveys in shallow and narrow channels hold immense importance for safe navigation.

The objective of this research is to measure how tank wall effects affect ship model resistance estimation. By accounting for the finite width of a tank, we numerically model the flow around a ship model and estimate the associated pressure and drag. The model selected for this investigation is a medium-speed, ocean-going barge, and we evaluate the residuary resistance under various tank width conditions, defined by the non-dimensional W/B ratio. Our findings are validated by testing two geosim models under the same tank width conditions. The influences of the tank walls identified in the numerical study are effectively quantified through the experimental study, providing valuable guidelines for minimizing wall effects [1].

In Degrieck et al. research, investigated the hydrodynamic interaction between ships in shallow and narrow water, including ship-ship and ship-bank interactions. It compared CFD, EFD, and two potential flow panel method codes. The results revealed that while potential flow panel method codes were quicker than CFD and EFD, they did not achieve the same level of accuracy. Thus, further research is needed to refine the potential flow panel method [2].

Since ships will inevitably have to maneuver in channels and shallow waters, they may encounter effects such as the bank effect or squat effect. If these effects exceed a certain level, they may lead to marine accidents. Therefore, it is of great importance to investigate movements in restricted waterways. In this study, the effects of a nonlinear transient hydrodynamic model in three different restricted waterways are taken into account, and its effects on the ship are investigated through numerical modeling. As a result, it is observed that when a ship travels in a restricted waterway close to the shore at high speed, there is a deviation in its course due to the high bank effect and squat effect. Conversely, these effects are less pronounced when the ship is farther away. A ship moving in the middle of a restricted waterway at low speed will increase its maneuverability and will not be as affected by these effects. Since these results closely align with experimental findings, it is evident that the numerical modeling calculations are reliable and safe [3].

In Yasukawa's research, the effects of asymmetric forces, specifically lateral force and bending moment, were explored. This investigation led to the creation of a simulation to analyze the bank effect in a channel with changing width. The findings revealed a consistency between the effects of asymmetric forces in both the experimental and simulated scenarios. Additionally, these effects posed difficulties in maintaining course within the variable width channel, underscoring notable risks such as potential collisions or grounding incidents [4].

The experimental sets are replicated in the numerical simulations, and the CFD model is verified by contrasting the numerical output with available experimental data. This study investigates the relationship between ship speed and bank effect, looking at both propeller-free and propeller-equipped scenarios. Additionally, the propeller's advance ratio is included as a parameter in the analysis [5].

As the speed of ships maneuvering in restricted waterways changes, the negative pressure effect distributed on the bottom of the ship reveals a force that pulls and absorbs the ship towards the bottom. Additionally, as the depth decreases, wave-forming resistance, sinking, and trim values can reach large magnitudes. In this paper, ship-bank, ship-bottom, and ship-ship interactions are modeled and calculated using the potential flow program. As a result, when comparing the potential flow method with experimental studies and CFD programs, it is observed that the results exhibit better values than the predictions. However, it is noted that the potential flow method cannot predict the yaw moment due to neglecting buoyancy forces caused by unsymmetrical flow [6].

The sliding mesh technique is employed to model the motion of a rectangular floating structure resulting from fluid-structure interactions. This study investigates how different wave periods impact flow behavior, roll motion, and the forces on the structure across three distinct wave periods. The time-dependent changes in wave height and roll motion of the rectangular structure align closely with experimental results for each wave period. Additionally, the current response amplitude operator exhibits a strong correlation with experimental data based on linear potential theory. The numerical simulations effectively capture the full process of vortex generation and evolution, consistent with the experimental findings [7].

Equations of Boussinesq type and the step technique are combined to study the wave responses of a rectangular barge in varying bathymetry. We use these exact Boussinesq-type equations, which focus on velocity potential, to model the progression of waves down a sloped beach. Using the step technique, the hydrodynamic coefficients for the rectangular barge floating on the sloped bottom are found in the frequency domain. Furthermore, the barge's motions in the time domain are predicted using the impulse response function approach. There is a great deal of consistency when comparing the Boussinesq-step method results with the experimental data [8].

This paper presents and validates a novel resistance adjustment strategy at varying water depths, inspired by Raven's methodology. It contains numerical simulations of a KCS performed at various water depth to draught ratios. The results demonstrate that resistance constantly fluctuates at different water depths in full-scale and model-scale circumstances. Along with a comparison between estimates derived from the Raven approach and the CFD resistance simulation results for various water depth-to-draught ratios, the paper also includes a brief explanation of the Raven correction method. The prediction capability of the HUST-Ship solver for ship resistance is ascertained, and the practicality of the Raven approach is assessed [9].

When a ship's speed exceeds a specific threshold in shallow water, ship-bank interactions significantly affect the vessel's maneuverability, exhibiting distinct hydrodynamic characteristics, though the underlying mechanisms remain incompletely understood. This paper presents a numerical prediction of ship-bank interactions for the KCS model. The results indicate that the sway force transitions into a repulsive force relative to the bank when the water depth is $h = 1.15T$ or $Frh > 0.528$ at $h = 1.3T$, which is attributed to changes in the distribution of the sway force [10].

The propeller-free KCS model simulation was first evaluated using three distinct grid layouts. The acquired data, which included flow fields surrounding the propeller disk, resistance, and wave elevation, was carefully compared with the results of the experiments. This numerical study shows that accurately projecting propeller/hull interactions using the CFD method is becoming more feasible, underscoring the tremendous potential of CFD applications in evaluating ship hydrodynamic performance [11].

In this study, the resistance and flow field of the KCS model traveling in deep water and shallow water are investigated using CFD, and the wall-body interaction is analyzed by simulating the motion of the KCS model at different depths. These analyses are verified by comparing the results with experimental data.

2. Numerical Method

The KCS model, recognized as a benchmark model, was utilized in this study. Figure 1 illustrates the hull form of the KCS model, while Table 1 presents its main dimensions.

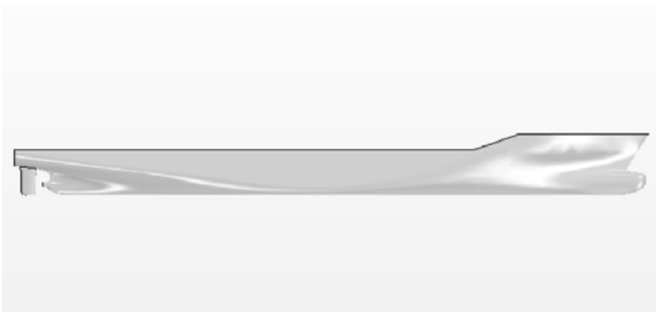


Fig. 1 The geometry of the KCS hull form

Table 1. The main dimensions of the KCS model

L_{OA} (m)	7.2785
L_{BP} (m)	7.3228
D(m)	0.6013
S (m^2)	9.5437
∇ (m^3)	1.6489

The water depth (h) is defined as the distance from the free surface to the bottom of the computational domain. Numerical calculations were performed using the commercial CFD software Siemens STAR-CCM+. The solver discretizes the governing equations using the finite volume method. To compute the velocity and pressure fields, the time-dependent Navier-Stokes equations are employed alongside the continuity equations. The governing equations are presented below:

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

$$\rho(\frac{\partial U_i}{\partial x_i} U_j) = \frac{\partial P}{\partial x_i} + \frac{\partial \tau}{\partial x_j} - \frac{\partial(\rho u_i' u_j')}{\partial x_j} \tag{2}$$

$$\tau = \tau_{ij} = \mu = (\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}) \tag{3}$$

In this context, u represents the time-averaged velocity, p denotes pressure, ρ is the density, and μ is the dynamic viscosity. The last term on the right-hand side of Equation 2 corresponds to the Reynolds stress tensor. The Realizable k-ε turbulence model, employing a wall-function approach, is utilized to model the turbulent field. Further details about the turbulence model can be found in the solver's documentation[12].

The flow around the ship model was solved using a computational domain. Numerical predictions were carried out using the flow direction from the -x axis and the Cartesian coordinate system. The inlet and outlet boundaries of the KCS model are located 2L and 4L away from the center of the KCS model, respectively, while the side walls are located 2L from the center of the KCS model. The inlet velocity varies depending on the Froude numbers obtained from the experiments Hexahedral grid elements were employed to define the solution domain. A general view of the grid structure is presented in Figure 2. During the creation of the surface grid along the KCS model body, the y+ values were maintained within the range of 30<y+<300 to ensure the accuracy of the RANS wall function approximation, where   is the friction velocity, y is the height of the first cell on the wall and   is the kinematic viscosity. Refinement zones were established in specific areas of the solution domain, with a refined computational grid created around the hull of the KCS model. Additionally, further local grid refinements were applied in the bow, stern, and free surface regions.

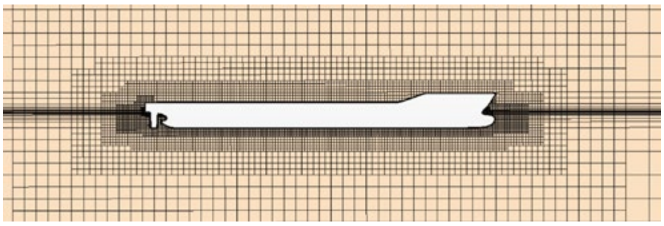


Fig. 2 The grid structure around the KCS hull

A service speed of 2.196 m/s was specified for the inlet boundary of the solution domain. In this study, the solution domain was established and analyzed with a constant velocity across different water depths. The outlet boundary of the solution domain was defined using a pressure outlet boundary condition, while the bottom surface areas were designated as no-slip walls. The remaining surfaces of the solution domain were treated as symmetric boundaries.

3. Numerical Results

In this study, the flow field around the KCS, a model-scale free-surface container ship, is simulated using the RANS solver STAR-CCM+. The validation of the numerical results is performed by comparing them with experimental data available in the literature.

The resistance coefficient and the Froude number are shown to have a dimensionless relationship in the traditional representation of the outcomes of model resistance tests. The frictional resistance coefficient and the residual resistance coefficient are the two main components that make up the overall resistance coefficient. The difference between the frictional resistance coefficient CF and the total resistance coefficient CT, abbreviated as CR, is the residual resistance coefficient. The overall resistance in this investigation is shown as follows in coefficient form:

$$C_T = \frac{R_T}{0.5\rho A_w U^2} \tag{4}$$

The y+ modifications on the ship model for Fn=0.26 are shown in Figure 3. Since the boundary layer solution directly affects the friction force, the accuracy of the y+ values on the hull is crucial. In general, the measured y+ values are within the necessary range, which is 30<y+<120.

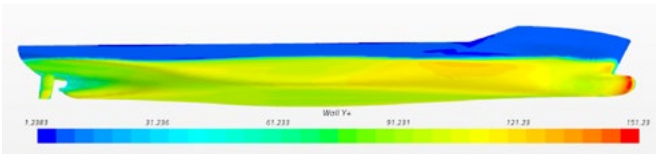


Fig. 3 Computed y+ distribution

This study implements three systematically refined grid structure, depicted in Figure 4. The grids are structured hexahedrally, and Table 2 provides the number of each grid structure.

Table 2 Number of mesh for three sets of systematically refined grids

	Coarse Mesh	Medium Mesh	Fine Mesh
Number of Grids	1,272 M	2,136 M	3,895 M

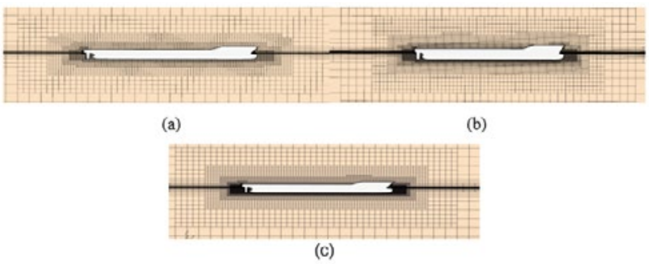


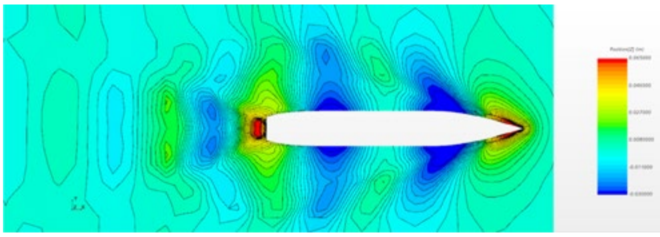
Fig. 4 Grid structure (a) coarse, (b) medium, (c) fine

The findings from this study are summarized in Table 3, along with the experimental data of Kim et al.[14], and numerical results of Zhang et al.[11], Ozdemir et al.[13] and Seo et al.[15]. It is seen that, present numerical predictions are in well agreement with the experimental data and the other numerical calculations.

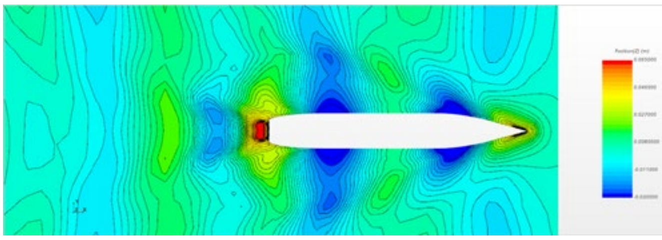
Table 3 Grid convergence study for total resistance coefficient and comparison of the total resistance coefficient

	Coarse	Medium	Fine	EFD (Kim et al.)	Zhang et al.	Seo et al.	Ozdemir et al.
$C_T(x10^3)$	3,84	3,65	3,61	3,56	3.62	3.54	3.65
Difference $\lvert(CFD-EXP)/EXP\rvert\%$	7,86	2,52	1,40	-	1,68	0,50	2,52

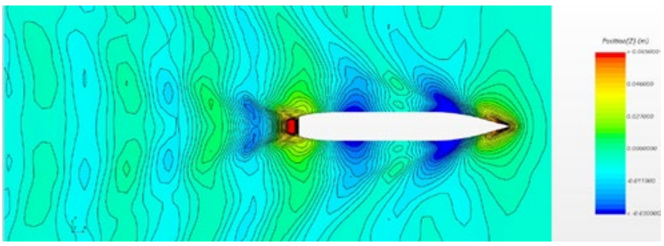
To investigate the impact of grid resolution on free surface predictions, the wave contour characteristics at a velocity of u=2.196 m/s in deep water were analyzed (Figure 5). The figure reveals a distinct Kelvin-type wave pattern across all mesh configurations. The observed wave attenuation near the outer boundaries of the computational domain indicates that the boundary dimensions are appropriate for simulating the free surface around the ship's hull. However, in the coarse mesh, free surface deformations begin to diminish over a short distance. As the mesh is refined, wave deformations become more pronounced and extend further through the ship's wake.



Coarse mesh



Medium mesh



Fine mesh

Fig. 5 Scalar of the wave elevation on the free water surface for different mesh structures

Near and far-field wave deformations can potentially introduce errors in RANS-based numerical calculations. Figure 6 illustrates a comparison of the free surface wave pattern with experimental data [14], indicating a strong correlation in both the magnitude and position of the Kelvin wave pattern between the predicted and experimental results.

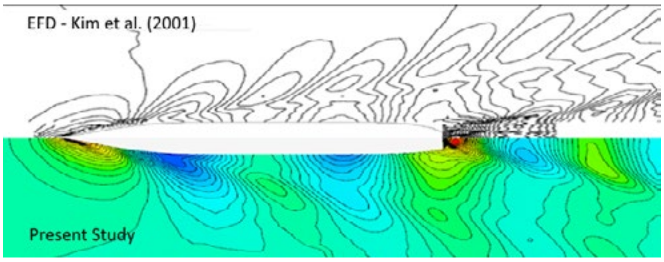


Fig. 6 Comparisons of wave pattern for EFD (top), CFD (bottom)

Table 4 presents a summary of the data, displaying the overall resistance values for the different scenarios according to the water depth. It is evident that, as would be expected, shallow water has a major negative impact on ship resistance. The ship keeps approaching the bottom while the increment trend keeps on. As several other studies have noted, the ship grounds due to a further decline in the water depth [16].

Table 4 Computed total ship resistance for different water depth.

Ship Velocity	Total Ship Resistance R_T[N]		
V[m/s]	Deep water	H=5T	H=3T
2.196	84.916	109.027	115.772

Fig.7 presents the free-surface profile for various water depths. As shown in the figure, the shallow water alters the general wiev of the wave field and the amplitudes of wave crest and though. The influence of shallow water on the wave field is relatively limited for H=5T. As the water depth decreases, the opening angle of the kelvin waves increases, and the interaction between the bottom and the wave field become more apparent in the ship's wake region.

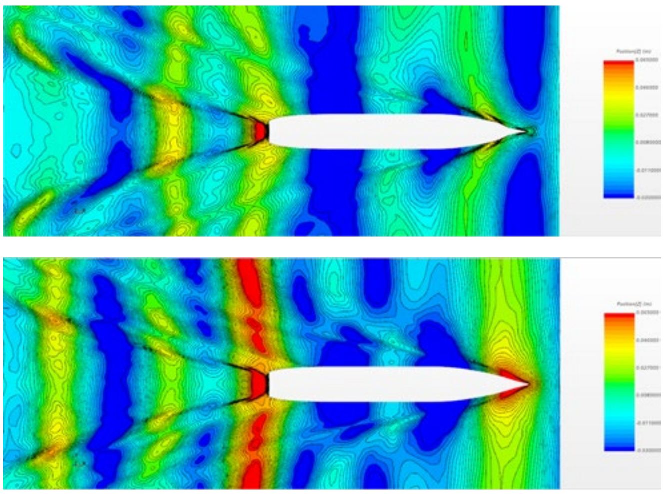


Fig. 7 Free-surface profile for (upper: H=5T, lower: H=3T)

Fig.8 shows the velocity field around the ship model for different shallow water conditions. As the water level decreases, the flow between the ship and the bottom accelerates. Furthermore, the shallow water effects the flow velocity in the bow and wake region as the free surface interacts with the bottom.

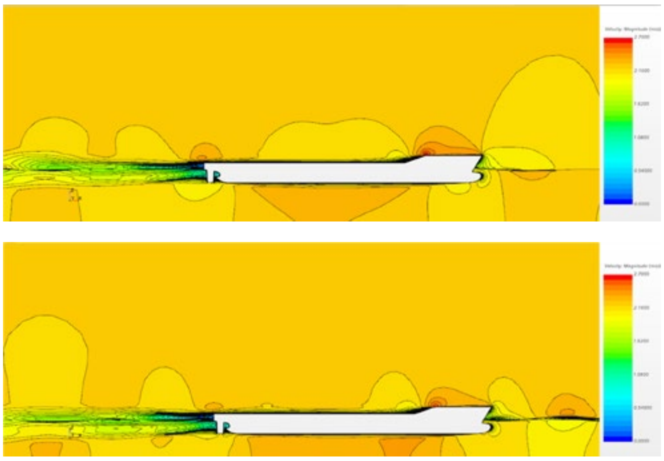


Fig. 8 Velocity profile around the ship in shallow water ((upper: H=5T, lower: H=3T)

The pressure field around the ship for different shallow water conditions are given in fig.9. As a results of the free surface-bottom interaction, higher levels of pressure are observed in the ship's bow region. Also, the pressure levels in the wake region and the flow field between the ship and the bottom are affected by the water depth. Thus, shallow water operation alters the pressure balance around the ship, and causes the changes in the resistance values.

Fig. 9 Pressure profile around the ship in shallow water ((upper: H=5T, lower: H=3T)

4. Conclusions

This study investigates the shallow water effects on the KCS benchmark ship model using a CFD viscous flow solver. Three simulation cases are analyzed, each corresponding to a different water depth while maintaining a constant ship speed. The effects of these varying conditions on the results are examined individually. To validate the numerical results, a direct comparison with EFD data is performed, revealing a strong correlation between the CFD and EFD results, with an error of less than 3%. Additionally, the wave field is compared to the measurements, showing good agreement.

The total ship resistance results for each case were compared to those in deep water, showing that the ship's total resistance increases as the water depth decreases. To better understand these resistance results, the velocity and pressure fields around the ship model were analyzed. It was observed that the flow accelerates between the ship and the bottom. Additionally, the free surface interacts with the bottom in the bow and wake regions, leading to changes in the pressure balance around the ship. This shift in pressure distribution is identified as a key factor contributing to the increase in resistance.

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Section 7
Best Practices & New Concepts in MET

Digitalization Process and Applications in Shipyards

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Abstract

Digital transformation has the applications of artificial intelligence, machine learning and Industrial Internet of Things (IIoT) which are among the high-level studies of our age, and has affected all sectors around the world. The fact that the current level of technology used both ships and in the shipbuilding process has increased significantly has made operations more complicated. Monitoring and improving operations in projects that need to be carried out within limited resources and time have also gained importance in the shipbuilding industry and hae determined the vision of shipyards on this matter. Digital transformation issues, which have become widespread in other sectors, have also begun to be used in shipyards as well. These efforts, respectively, include living-nonliving entities in metal-intensive open and closed production areas, making them suitable for internet access with sensors proper for the process, collecting the data from sensors in a data center, processing them for the control, monitoring and improvement of process and inventories, providing and presented through them in a user-friendly for the end user interface.

In this study, it is aimed to determine which process of operational and management activities carried out in shipbuilding are implemented by digitalization and how these developed applications are evaluated considering the constraints in shipyards. As a practice, the work of large shipyards that build navy and commercial ships, such as Sedef Shipyard in Turkey, which pioneers digital transformation in this regard, has been evaluated. As a result, it has been shown that when shipyards use digitalization and applications, they increase occupational safety and increase competitiveness by ensuring cost efficiency. In addition to all these, the quality of ships can be monitored with live data through inventory and process control.

Keywords: *Shipyard, Digital Transformation, Internet of Things*

1. Introduction

The shipbuilding industry, which has a global market share, increased its production by 10% to 35 million compensated gross tonnage in 2023 [1]. This global power has economic advantages as well as disadvantages such as environmental pollution, chaos and inefficiency [2]. In order for traditional shipbuilding shipyards to continue their business, they have to develop regularly and develop their production areas with alternative and creative methods, as in other industries [3]. Although these development methods are tried to be made more efficient by optimizing the design, propeller and fuel consumption etc. systems in ships, they are mostly continued with traditional systems during ship construction. This situation causes inefficiency during the construction phase of a ship. The priority of this study is to create a new working environment in the shipbuilding industry by combining physical and virtual environments and developing applications to ensure efficiency during the production phase of ships [4].

With developing technologies, products are developing and competition in the market is increasing. In order to be a player in the increasing competition in similar products, it has become necessary to use technology in production processes. The use of automation, especially in shipyards, has replaced traditional methods. For example; Navantia shipyard uses augmented reality (AI) applications, digital technologies that allow shipyard operators to gain information and interact with those around them. It can show the most suitable option and combination according to the scenario of the operation in the shipyard [5]. On the other hand, digital technologies should be used to monitor and control shipbuilding assets that have big data and also produce data [6].

Managing limited resources in limited space, lifting capacity and time is a typical challenge for shipyards. Managing the ships created by combining and equipping the blocks within these limited resources can often lead to confusion. Inventory, employee, risk, area, transportation, welding, maintenance, etc. management is one of the subsystems that make up this process. Digital systems and infrastructures should be used to manage each subsystem consisting of big data. By ensuring human-machine, machine-human, machine-machine interaction, decisions appropriate to each unique process can be made in the data-command systematic.

In this study, the application of the fourth industrial revolution to Sedef Shipyard and the digital transformation process and applications are mentioned. Digitalization is a development that will continue constantly. As technology develops and data is processed, new opportunities open to continuous development will emerge. With these applications, measurably high quality ships can be produced in a shorter time with fewer resources.

2. Methods

In this study, the steps of the digitalization process and digitalization applications in shipyards will be discussed. The data that enables digitalization in shipyards, the interpretation of the data and the areas that digital commands will affect are examined. In this section, the work of the fourth industrial revolution at Sedef Shipyard in the last ten years is explained.

2.1. Infrastructure

Shipyards are labor-intensive production areas where heavy metals are processed. These areas need to be prepared for automation and digital applications. This infrastructure consists of power distribution, electronics and communication infrastructure. Since the shipyard environment is a powerful engine and metal-dense area, especially the communication infrastructure must be suitable for the communication protocol to be implemented and must be safe against electromagnetic noise. A data center should be formed where infrastructure and application data will be collected. Wired and wireless network infrastructure has been established according to the application processes.

2.2. Software Program and Interface

Digital data is collected as raw data in data centers. Raw data needs to be categorized for the end user. A software has been developed that includes codes and libraries to filter for the needs of the end user. This developed software is combined with a visual interface before being presented to the end user. With this interface, incoming data can be monitored, decisions can be made, commands can be given and extra information can be entered. Human-machine, machine-machine, machine-human commands are carried out through this platform. The data can be monitored in real time. In this software, modules communicate with each other and provide data.

2.3. Electronic Hardware

Machines used in heavy metal processing facilities such as shipyards, designed to handle heavy metals. After the areas that are open to digital improvement and the machines in, are identified, electronic components and cards that will enable the collection of digital data should be selected in accordance with the conditions of heavy industry and in accordance with the security protocols that will overcome the working conditions. It is important not to be affected by external influences, especially in environments where there are machines that emit electromagnetic noise, such as cranes, compressors etc.. Electronic components focus primarily on collecting data to monitor and control the relevant process. For this, the most suitable components, such as sensors, are used. If action is expected to be taken directly via command, components that affect the power and motion systems are used.

2.4. Digital Applications in Production

The systematic development of technology over the centuries has enabled both ships and shipyards to systematically adapt to the digitalization process. With the increase in ship tonnage, the machinery and equipment used in shipyards have also improved within the scope of increasing shipyard capacity. Capacity increases create inefficiency and complexity in production processes. The Internet and the technologies developed with it have enabled the establishment of systems that will prevent this confusion and inefficiency. Especially in these periods when competition in the shipbuilding industry is high, digital transformation has provided great support to shipyards in time and process management. In this section, some applications developed with the Smart Shipyard concept at Sedef Shipyard along with the industry 4.0 revolution will be mentioned.

2.4.1. Energy Management

In this module, process and machine matching can be made and energy consumption analyzes can be divided into sub-breakdowns based on process and machine. This module measures energy quality and detects losses and leaks by providing detailed analysis and review. In addition, harmonic analysis of 3-phase energy is used to detect a fault that has occurred or will occur in the near future in the relevant machine. This enables machines that consume high energy to operate in the most efficient conditions.

2.4.2. Employee Management

Shipyard areas, which are quite large, are facilities where many workers work directly in the production area. These areas can sometimes be a block that forms the ship and sometimes the ship itself. Work can also be carried out in open areas and in closed narrow spaces with metal frames such as water tanks and main engine rooms. This situation has been evaluated as a opportunity open to improvement, in terms of accurate evaluation of employees' health and working hours. A module using an intuitive model has been created to check the health status of employees and examine the processes in which they work. For example, after determining the time spent by an employee carrying materials to a ship located on the seashore and the routes he preferred to travel, small warehouses were built on the shore for the most used materials.

2.4.3. Welding Operation Management

The process in which labor is most used in shipyards is the welding operation. This operation is carried out by operators applying the welding process within the value ranges determined by the engineers. In this module, all information about the welding process is sent to the software program. With the help of this command, which is sent to the welding machines that have previously been digitally converted, the process is removed from the operator's initiative and the welding machine itself directly adjusts itself for this process. In addition, welding machines are only opened by their own operators. It can be monitored how much consumables (welding wire, power, man*power etc.) the welding machines consume and how much of this consumption turns into value in production, where log information is recorded. Additionally, the locations of the welding machines can be monitored live.

2.4.4. Crane Management

One of the important energy consumption sources in shipyards is cranes. Using cranes in the most accurate and efficient way is of great importance in saving energy. In addition, a work plan must be provided for the operation of the cranes. With this module, cranes can be reserved publicly, energy consumption can be tracked on a job basis, and efficiency can be calculated. Operator log information is recorded.

2.4.5. Production Vehicle Management

Shipyards that have a limited number of vehicles such as forklifts, tractors etc. should use these vehicles with maximum efficiency in all processes. With this module, the locations of moving vehicles can be detected instantly, as with all other machines, operator information, working time and efficiency are calculated, and they can be reserved in order to avoid problems in the processes.

2.4.6. Maintenance Management

Processing big data, which is one of the biggest benefits of digitalization, provides great benefits in revealing invisible information. Instead of taking the machines into regular maintenance with the data coming from other modules, maintenance operations are planned to be carried out by emphasizing the necessity of the usage conditions.

2.4.7. Smart Strategic Planning

It is planned to achieve the goal of completing the highest quality work at the least cost in the shortest time, which is the aim of all digital work, with this module. With the creation of big data over the years, the real people, materials, inventory and energy resources used in the shipyard's processes will be identified. It is expected that the shipyard will evaluate the shipyard's own capacity and capabilities and the data of the goods to be produced with machine learning and make the most accurate and efficient production plan.

3. Conclusion

In this study, the adaptation of digital transformation, one of the trends of the period, to a shipyard and digital applications are mentioned at a micro level. Although there have been various resistance and technical difficulties to digitalization in the shipyard sector, the traceability of data has revealed the losses in the production area. Processes have become more efficient with digital monitoring. The existence of previously unknown information has enabled new developments. Digitalization and data processing are not over, they are ongoing and will provide opportunities for new developments as they continue. The Smart Shipyard application developed at Sedef Shipyard was funded by the TÜBİTAK TEYDEB 1511 program.

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Classification Analysis for Studied Fields in Maritime

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Abstract

The purpose of this study is to detect subjects related to human factors and the human factor itself which were focused on maritime studies, besides, to support for anonymous other academic studies. In this study, a classification method was actually chosen due to the fact that it has been showing up the importance of human factor, and to categorize the different studying methods about human factors that has a lot of advantages. Using this classification method provided an advantage to classify the logical and systematical features of different characteristically functions. It is taken and used from the data bases of ITU Library's network. ULAKBIM, Web of Science, Scopus, Dergipark, Science Direct, Google Scholar were used in the study. This paper was monitored over the articles belong to late 6 years between 2018 and 2023. For the searching strategy, the main titles and keywords used and a really detailed searches were carried out in order to understand the human factors In maritime. As a result of these searches, it is seen that studying areas of human factors in maritime, gained importance when compared it with last terms, besides, it took the attention of lots of searches and started to dictate and channelize their studies.

Keywords: *stress, cognitive, psychology, human factor,*

mobbing, burn-out, fatique, family

1. Introduction

After the Industrial Revolution, the amount of worldwide production has increased incomparably with the previous periods. The production of more than the needs of any country naturally required exports. Today, approximately 90% of the products produced worldwide are transported by sea. Since ancient times, the most effective type of transport has been maritime transport. With the increase in the number of ships, worldwide maritime traffic has also concentrated in certain regions. With the increase in maritime traffic and navigation hours, there has been an increase in the amount of maritime accidents. When the literature on marine accidents is examined, it is seen that the biggest cause of marine accidents is human error. Therefore, the cognitive, physical and mental state of the personnel working at sea should be good. Otherwise, marine accidents are inevitable. Marine accidents have both material and moral consequences. Marine accidents pose threats to both life, property and the environment. Therefore, it is an issue that should be carefully emphasised. When it is evaluated that the biggest cause of maritime accidents is human errors, it is concluded that studies should be carried out on the human element in maritime. The aim of this study is to collect data on the extent to which these concepts are studied worldwide through the keywords we have determined and to provide a reference for future studies.

The maritime sector, characterized by its extensive scope and a labor force surpassing one million sailors (UNCTAD, 2021), encounters distinctive obstacles including seclusion, structured hierarchical work schedules, rotation-based shifts, adverse maritime weather, demanding work tempo, and detachment from familial and social spheres [1].

Maritime Psychology arises as a crucial field within psychology, aiming to understand and tackle the complex psychological challenges experienced by seafarers [2]. In a world where the seas represent both a workplace and a living space for seafarers, Maritime Psychology delves into the complexities of their mental and emotional experiences, offering insights into how these experiences manifest and the interventions required to mitigate their adverse effects [3].

Against this background, our study originates, aiming primarily to explore how the psychological obstacles encountered by seafarers are documented and examined within the current scholarly literature in the field of maritime psychology.

During a literature review, it can be noticed that 'stress, cognitive factors, human factors, psychology, mobbing, burnout, and family' are the prominent common keywords for the studies in maritime fields [4,5,6,7].

To the best of our knowledge, while there exist two bibliometric analyses focusing on stress among seafarers [8] and the health of seafarers [9], a comprehensive bibliometric analysis concerning maritime psychology is notably absent from the literature. In a pioneering effort, our study adopts a holistic approach to address this gap, aiming to offer invaluable insights into this crucial field. Through this endeavor, we aspire to contribute to the improved well-being and mental health of seafarers, thereby positively impacting the maritime industry and its workforce.

Lim et al. (2018) conducted a risk analysis study in maritime domain. A detailed literature review of over 180 papers published between 1986 and 2017 was made. Using comparative analysis, the papers were classified according to the authors' nationality, focus, methodology, security concern type, research contribution and Denizel et al. classification [10].

Oldenburg et al. (2013) conducted a systematic review of maritime research focusing on stress and strain among seafarers. Their analysis encompassed 13 maritime studies examining stress or strain within the seafaring community. The study parameters included the research objectives, the demographics of the study population, the year of investigation, the methodologies employed to measure stress and strain among seafarers, and the outcomes of the studies [11].

Kolus et al. (2018) undertook a systematic literature review aimed at identifying peer-reviewed articles exploring the correlation between production quality and human factors in manufacturing. Their analysis involved the examination of 73 papers, during which human factors were categorized and sub-categories were delineated [12].

2. Methodology

Throughout this study, we rigorously adhered to the systematic literature review framework proposed by Kitchenham [13]. Data collection was meticulously conducted from diverse sources, strategically chosen from mainstream databases, including ULAKBIM, Web of Science, Scopus, Dergipark, Science Direct, Google Scholar all accessible through the Istanbul Technical University library network. Specifically, we focused on articles published within the preceding six years.

Our review process centered on seven predefined keywords: stress, cognitive factors, human factors, psychology, mobbing, burnout, and family dynamics within the maritime sector. Subsequently, we computed descriptive statistics for both continuous variables and categorical variables (e.g., count and percentage), encompassing metrics such as mean, standard deviation (SD), minimum, maximum, and median.

Articles were meticulously categorized based on keywords and relevant research fields. For categorical variable analysis, we employed the Fisher's Exact test, presenting outcomes as observation counts and percentages. We considered statistical significance to be present when the two-sided p-value fell below 0.05.

By meticulously adhering to these procedures, we ensured a thorough, non-derivative investigation into the maritime literature, upholding the highest standards of academic integrity and scholarly rigor.

3. Results

In this section of the study the descriptive analysis and statistical analysis of the research will be presented. In the Table 1 below the distribution of the topics were presented. The topics which were studied distributed as follows; 64 (%23,8) research in psychology, 42 (%15,6) in cognitive, 31 (%11,5) stress, 90 (%33,5) in human factor, 4 (%2,5) in mobbing, 34 (%21,1) in burnout, 4 (%2,5) in family.

Table 1. Distribution of Topics

Topics	N	%
Psychology	64	23,8
Cognitive	42	15,6
Stress	31	11,5
Human Factor	90	33,5
Mobbing	4	1,5
Burnout	34	12,6
Family	4	1,5
Total	269	100

In the Table 2 shown below, the year distribution of the research were presented. According to the results; 38 (%14,1) research were conducted in 2018, 66 (%24,5) in 2019, 34 (%12,6) in 2020, 29 (%10,8) in 2021, 43 (%16) in 2022 and lastly 59 (%21,9) research were conducted in 2023

Table 2. Distribution of the Research Year

Year	N	%
2018	38	14,1
2019	66	24,5
2020	34	12,6
2021	29	10,8
2022	43	16
2023	59	21,9
Total	269	100

Table 3 below presents the ranking of the research were collected in this paper. According to the results, 96 (%35,7) research belong the Q1, 31 (%11,5) to Q2, 49 (%18,2) to Q3, 23 (%8,6) to Q4 and lastly 70 (%26) research were belong to other ranking metrics.

Table 3. Index Distribution of the Research

Index	N	%
Q1	96	35,7
Q2	31	11,5
Q3	49	18,2
Q4	23	8,6
Others	70	26
Total	269	100

In the Table 4 presented below the frequency of the methods evaluated in this research were presented. Frequencies were listed from largest to smallest order. In general, it could be stated that the while the survey (%21,9) descriptive/informative (%17,1), and data analysis (%26) were the most common methods used the fuzzy methods (%1,5), FRAM (%1,2) and regression analysis (%0,8) were the least common methods used.

Table 4. Frequency of Methods

Index	N	%
Survey	59	21,9
Descriptive/ Informative	46	17,1
Others	30	11,2
Data Analysis	26	9,7
Interview Analysis	22	8,2
Machine Learning	21	7,8
Systematic review	21	7,8
Simulation	12	4,5
CREAM	9	3,3
HFACS	6	3,7
Bayesian	5	3,1
Data Envelopment Analysis	4	2,5
Fuzzy Methods	4	1,5
FRAM	2	1,2
Regression analysis /GLM	2	0,7
Total	269	100

The relationship between topics and years are investigated therefore univariate analysis shown in the Table 3 below states that there is statistically significant difference between topics and years (Fisher's Exact p<0,001). When the results were investigated the most studied topic in years is human factor, while the family and mobbing were the least studied.

Table 5. Topics by Years

N, %	2018		2019		2020		2021		2022		2023		p
Psychology	7	18,4	12	18,2	9	26,5	6	20,7	17	39,5	13	22	
Cognitive	4	10,5	6	9,1	14,7	9	9	31	7	16,3	11	18,6	
Stress	4	10,5	14	21,2	9	26,5	2	6,9	2	4,7	0	0	
Human Factor	21	55,3	26	39,4	11	32,4	11	37,9	8	18,6	13	22	<0,001
Mobbing	1	2,6	0	0	0	0	0	0	1	2,3	2	3,4	
Burnout	1	2,6	6	9,1	0	0	1	3,4	1	2,3	1	1,7	
Family	0	0	2	3	0	0	0	0	1	2,3	1	1,7	

Fisher's Exact test

In the Table 6 below, the relationship between topics and indices are investigated with the univariate analysis. According to the results there is a statistically significant difference between the topics and indices (Fisher's Exact p<0,05). On the other hand, when the results were examined it could be shown that the human factor is the most studied topic by indices and the mobbing and family were the least studied topics by indices.

Table 6. Topics by Indices

N, %	Q1		Q2		Q3		Q4		Others		p
Psychology	27	28,1	2	6,5	14	28,6	7	30,4	14	20	
Cognitive	12	12,5	10	32,3	11	22,4	0	0	9	12,9	
Stress	5	5,2	4	12,9	5	10,2	4	17,4	13	18,6	
Human Factor	36	37,5	8	28,5	9	18,4	8	34,8	29	41,4	.012
Mobbing	2	2,1	0	0	1	2	0	0	1	1,4	
Burnout	13	13,5	5	16,1	8	16,3	4	17,4	4	5,7	
Family	1	1	2	6,5	1	2	0	0	0	0	

Fisher's Exact test

Table 7 below shows the Ficher's Exact test results that aims to investigate the relationship between the topics and methods. According to the results there is no staticslly significant difference between the topics and methods (Fisher's Exact p<0,05). On the other hand, when the results were examined it could be shown that the human factor is the most studied topic by indices and the mobbing and family were the least studied topics by indices.

Table 7. Topics by Methods

N, %	Psychology		Cognitive		Stress		Human Factor		Mobbing		Burnout		Family		p
Descriptive/ Informative	14	21,9	6	14,3	6	19,4	15	16,7	0	0	4	11,8	1	25	
Survey	21	32,8	5	11,9	13	41,9	9	10	1	25	8	23,5	2	50	
Data Analysis	6	9,4	4	9,5	4	12,9	9	10	0	0	3	8,8	0	0	
Machine Learning	1	1,6	2	4,8	3	9,7	7	7,8	0	0	8	23,5	0	0	
Others	5	5,7	6	14,3	3	9,7	14	15,6	0	0	2	5,9	0	0	
Interview Analysis	3	4,7	7	16,7	1	3,2	8	8,9	0	0	2	5,9	1	25	
Simulation	2	3,1	3	7,1	1	3,2	5	5,6	0	0	1	9,1	0	0	
Systematic review	10	15,6	2	4,8	0	0	6	6,7	1	25	2	5,9	0	0	<0,05
HFACS	0	0	0	0	0	0	6	6,7	0	0	0	0	0	0	
Bayesian	0	0	0	0	0	0	2	2,2	1	25	2	5,9	0	0	
Data Envelopment Analysis	0	0	0	0	0	0	4	4,4	0	0	0	0	0	0	
CREAM	0	0	5	11,9	0	0	3	3,3	0	0	1	2,9	0	0	
Fuzzy Methods	0	0	2	4,8	0	0	0	0	1	25	1	2,9	0	0	
FRAM	0	0	0	0	0	0	2	2,2	0	0	0	0	0	0	
Regression analysis / GLM	2	3,1	0	0	0	0	0	0	0	0	0	0	0	0	

Fisher's Exact test

4. Conclusion

In this study, human fact which has a significant impact on the maritime sector, has been discussed. Therefore, keywords related to the human element in maritime, such as psychology, cognitive, human factor, mobbing, burn out, family and stress, have been selected. A total of 269 studies have been examined. In this research, it was aimed to identify the topics are focused on maritime studies, and then to create an idea to increase the diversity of research topics and methods. It is found that the Human Factor is studied more than any other topic. According to the journals' ranks, most of the publications were in Q1. The Survey Method was preferred more than other methods. To sum up, other topics, apart from the human factor, psychology and cognitive, can be carried out in maritime researches. The limitation of this study is due to the short period of time and having only 7 keywords. Topics can be varied and the range of years can be expanded in following studies.

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Revolutionising Maritime Education and Training through Innovative Technology Integration; Introducing Navigational Skills of Behaviour Assessments (NSBA Project)

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Abstract

Bridge simulators play a vital role in the maritime industry by simulating a wide range of situations and scenarios that seafarers may encounter in the real world. The practical experience is significantly improved through the close replication of real-life scenarios, specifically those pertaining to the safety of ship navigation and the execution of manoeuvres. While aiding in emergency scenarios, simulators provide masters and deck officers with insights into how a ship performs under various weather conditions, sea states, traffic densities, and other factors. On the other hand, compulsory Collision Regulations (COLREG) training for seafarers (including masters, watchkeeping officers, and deck cadets) primarily comprises theoretical explanations. Notwithstanding their theoretical foundations, implementing COLREG principles in practical contexts, where hierarchical complexities frequently arise, requires a specialised experiential learning framework. Compliance with and interpreting COLREG regulations necessitates a practical training system, leading to maritime accidents.

Motivated by the shortcomings of existing COLREG training approaches, our project introduces the Navigational Skills of Behaviour Assessments (NSBA) program, a cutting-edge solution with the simulation technology. NSBA is a simulation-based COLREG e-learning and assessment platform that aims to help masters, watchkeeping officers, and deck cadets improve their skills, reduce risks, and provide navigation rules with real scenarios in a cost-effective and flexible way.

This innovative approach aims to revolutionise maritime education by overcoming the existing limitations of COLREG training. The NSBA project provides a comprehensive e-learning platform that uses simulation technology to focus on realistic COLREG scenarios. Through this platform, seafarers can improve their navigation skills, reduce the potential hazards that cause accidents and access training anytime and anywhere.

Keywords: *COLREG, simulation, maritime e-learning, simulation assessment.*

1. Introduction

With the increasing world trade in recent years, the maritime sector has become important for sustainable transportation, especially during and after COVID-19. The increase in demand for world maritime has led to an increase in the number of ships and, at the same time, the number of seafarers. Moreover, seafarers' training is as necessary as international rules and procedures to ensure safety and effective maritime operations. Therefore, MET (maritime education and training) plays a key role in implementing maritime training. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) sets minimum standards for the training and certification of seafarers, emphasising the importance of competency-based training and assessment, which is based on theory and practical implementations [1]. Safety is a paramount concern for the maritime industry, and despite all technological innovations, accidents such as collisions, groundings, etc., still occur. These accidents cause loss of life and property, economic losses for companies, and even supply chain disruption due to reasons such as canal blockage and bridge collapse [2], [3]. According to the accident statistics report published annually by EMSA, the most common type of accidents occurring between 2014-2022 is determined as collision accidents[4]. COLREG rules and practices are crucial, especially in preventing collision accidents at sea. The Convention on International Regulations for Preventing Collision at Sea (COLREG) contains a set of rules that aim to prevent collisions [5]. These regulations are of great importance in ensuring the safety of navigation and preventing accidents. Masters and navigation officers are required to receive comprehensive training on COLREGs to ensure navigational safety and prevent accidents. This training covers topics such as the basic principles of COLREG, lights and shapes, navigational signs and manoeuvring requirements.

The main challenge of current COLREG training is that it is based on theoretical training today, and this rule-based training creates difficulties in applying the rules in the real world. Moreover, limitations such as high costs and limited participants in simulator training, which is one of the traditional training methods within the maritime.

In response to these challenges, the Navigational Skills of Behaviour Assessments (NSBA) project aims to offer a different approach to maritime education and training by introducing an innovative approach. The NSBA project aims to address the gaps in traditional COLREG training methods by providing a simulation-based platform. This platform covers rules-based COLREGs and includes the evaluation of seafarers' buoy and light knowledge with realistic scenarios.

NSBA project goals include:

• To improve seafarers' understanding and implementation of COLREGs in real-world situations.

• Overcoming the limitations of traditional training methods by providing a cost-effective and accessible simulation environment, especially for distance learning.

• To assess seafarers' knowledge of buoys, lights and rules to provide comprehensive training and assessments.

• To increase the effectiveness and efficiency of maritime education and training programs.

In this context, this project aims to provide valuable insights into the new approach of COLREGs training in the maritime domain. The paper is organised into four sections. This section presents the state of the art and the purpose of the NSBA projects; section 2 introduces the overview of the COLREGs training and the literature review; section 3 gives the design and the strategy of the NSBA project; and finally, section 4 provides the study's conclusions.

2. Literature Review

The International Regulations for Preventing Collisions at Sea plays a critical role in regulating maritime traffic and preventing accidents in areas of high traffic, TSS areas and emergency situations. The rules and responsibilities specified in COLREG, which must be implemented, are essential for officers of the watch and masters during their watches.

When the literature and annual reports are analysed, collision and grounding accidents occur at a relatively high rate in the maritime industry. Academic studies have identified misunderstanding or misinterpretation of COLREG rules as one of the critical causes of these accidents[6].

This project aims to overcome these challenges by developing e-learning and assessment methods that incorporate simulation-based interfaces with enhanced visual perception and interactivity.

2.1 Overview of COLREG Training Methods

COLREG training is generally evaluated through written exams, while ship manoeuvring, communication and rule applications could be assessed in bridge simulators. For this reason, it is challenging to evaluate the exact COLREG in the simulator environment to determine which rules the participants need to improve. While the evaluation of COLREG proficiency primarily focuses on testing theoretical knowledge, it is obvious that the rules in the book cannot be encountered individually in real life.

In this study, a comprehensive literature review was conducted in the Scopus database using the keywords "COLREG," "maritime," and "training." After reviewing the literature, 16 publications were found, but publications not related to training were excluded from the review. These publications were published in indexed journals and conference proceedings, and it has been determined that current literature on effective training methods is limited. In the detailed literature review of the study titled "Design and implementation of AI chatbot for COLREGs training" [7], it was stated that it emerged directly with the training needs, and an AI-chatbox designed to be used in classrooms was produced in the study. All rules are explained in the classroom using students' commands and visuals. However, a simulation-based approach is not demonstrated in this study, and a rule-based, non-interactive product has been developed. Another study, "Generalized Behavior Decision-Making Model for Ship Collision Avoidance via Reinforcement Learning Method", in parallel with other similar publications, offers a good research idea for the design of a generalised ship collision avoidance decision model suitable for COLREGs [8]. In the study "What is your intention? Tacit knowledge and community-based learning for collision avoidance in the global maritime industry", group learning and individual learning were compared, and the importance of indirect knowledge and learning by practice was emphasised on effective teaching methods [9]. "Intelligent Ship Collision Avoidance Algorithm Based on DDQN with Prioritized Experience Replay under COLREGs [10], A novel ship collision avoidance awareness approach for cooperating ships using multi-agent deep reinforcement learning [11], In the studies of Combining supervised learning and digital twin for autonomous path-planning [12], algorithms based on collision prevention rules that will pave the way for autonomous ships instead of training focus were studied. In the study titled RORSIM: A warship collision avoidance 3D simulation designed to complement existing Junior Warfare Officer training, the authors [13] conducted simulation-based COLREG studies for warships, but the approach of this study was in 2013, and it was published before it could be commercialised. It remained private for warships. The study titled Deficiencies in Learning COLREGs and New Teaching Methodology for Nautical Engineering Students and Seafarers in Lifelong Learning Programs also includes the website e.colreg, which was encountered in market research [14].

Further research has shown that the most common causes of collisions are human error and misinterpretation of the Rules. Using a survey, maritime cadets, seafarers and ship captains' understanding of the Code was tested. Results showed gaps in comprehension due to misinterpretation and application of parts of the COLREGs. Within the scope of this study and project, authors established a website called e.colreg, but this project contains videos of simulator screens and needs to provide a realistic simulation environment for hands on practices.

2.2 Limitations of Traditional COLREG Training Approaches

When the studies in the literature are examined, it has been determined that COLREG applications, one of the critical factors in ship accidents, are caused by inadequate, incorrect application or misinterpretation. The fact that these trainings are given as classroom training and that there was no sole simulator requirement in the training standards specified in the STCW code. However, in the digitalising world, there is a need to provide more interactive training and create a platform that allows one-on-one participation with scenarios. COLREG is a rule-based book. Therefore, training is provided on books and presentations, and this method could be complicated for students or participants to imagine complex scenarios and think rule-based. For this reason, the most significant contribution of the project is that this simulation would be beneficial in maritime training, allowing them to improve their skills with a more accessible, interactive simulation similar to real-world scenarios and improve their weak areas with an assessment model.

2.3 Classical Bridge Simulator for COLREG Training

In the maritime industry, bridge simulators are essential for replicating the different situations and scenarios seafarers may encounter in real life[15]. These simulators provide the closest scenario of real-life situations in seafarers' training and increase the personnel's practical experience. Bridge simulators are essential for ship navigation safety and ship manoeuvres. By simulating diverse conditions such as weather variations, sea states, and traffic densities, bridge simulators enable personnel to understand how a vessel behaves under different circumstances. Moreover, bridge simulators help gain experience in managing ships in emergencies. In the maritime industry, COLREG training is mandatory for seafarers (for masters, watchkeeping officers and deck cadets) and has a significant place. At the end of this training, seafarers receive the necessary certificates for their professional qualifications. COLREG training gives seafarers theoretical explanations of the rules. However, current training methods predominantly focus on theoretical aspects.

Bridge simulators generally aim to evaluate seafarers' knowledge and skills of ship manoeuvres and navigation operations. However, assessing COLREG competencies in these scenarios is challenging because the primary objective is often to develop and evaluate bridge team skills while assessing seafarers' maritime expertise.

However, in this approach, due to the limited designs of the simulator systems, creating the desired scenarios takes time and requires skilled simulator operators. In the round table workshop held with instructors providing maritime training within the scope of the project, the weaknesses of simulator systems in the maritime sector regarding the COLREG training were determined as follows;

• Simulator systems in maritime are expensive and can be challenging for small-scale institutions/companies.

• Simulator systems are developing rapidly technologically, and every innovation made in the systems requires costly updates.

• The manufacturer has limited ship types and sailing areas, with high purchasing costs.

• The operator needs to plan and test the scenario to be designed in simulator systems in detail before training. Creating scenarios for each rule or navigational situation takes much time.

• In classic bridge simulators, a maximum of 4-5 participants are involved, and tasks are distributed during these training sessions.

• In current simulator-based training, each participant receives the same training since the subjects the participant needs or lacks are unknown. The subjects the participant lacks cannot be determined in the current training approach because the studies are carried out as a group due to the insufficient environmental design.

3. Features and Components of the NSBA

Today, with increasing safety standards, trained and experienced masters and watchkeeping officers are necessary to maintain safe navigation, and many shipping companies aim to ensure that they have sufficient competence. The NSBA project, which is based on simulation technology, has e-learning and assessment modules that aim to introduce a more realistic and motivating approach in the maritime sector by going beyond traditional methods. In the NSBA project led by ORKA informatics, cooperation was made with ITU Maritime Faculty to assess the training models related to COLREG and conduct the gap analysis in the training system and design scenarios.

3.1Design of the COLREG E-Learning Platform

The design of the simulation is as follows;

Scenarios have been created for the questions specified within the scope of the project outputs, aiming to use the rule of the COLREG.

The scenarios in the simulation cover rules in the COLREG, are discussed in four missions, and a scenario pool has been created for each mission. Each scenario contains data on real maritime traffic and areas.Since users need to complete the scenarios determined for the platform within certain periods of time, the duration of each scenario was assigned according to the difficulty levels of the questions. Each user receives ten scenarios from each specified mission.

The questions are animated within the platform, and a design is made to attract the user's attention and increase their motivation. Users can check the correct answers to the questions they made wrong decisions during the scenario at the end of each scenario, and this process could help them learn the correct choice.

At the end of e-learning, an assessment module shows which participants need more knowledge in which specific aspect of each mission to improve their skills. The simulation consists of four critical missions, and the designed training includes not only COLREG scenarios but also missions related to buoys and lights. These missions can be summarised as follows:

Mission-1: IALA Buoyage-Daylight *This mission focuses on the IALA Buoyage system designed for daylight navigation. It is crucial for the participant to understand this rule in order to enhance their proficiency in maritime* *operations during daylight hours. The IALA Buoyage system provides a standardised set of markers and navigational aids, enabling mariners to navigate waterways and avoid potential hazards safely. Furthermore, the rule covers the lateral buoys used to indicate the sides of a channel, as well as the special-purpose buoys that denote specific areas or navigational information.*

Mission 2: IALA Buoyage-Night *This mission's main goal is to cover the use of different colours and patterns of lights displayed by buoys to indicate their position, function, and other important information.*

Mission 3: Navigation Lights *Lights are used in accordance with COLREG to ensure that maritime traffic proceeds in an orderly and safe manner during the night hours as well. These signals facilitate the identification of the vessel's status, such as power-driven vessels, towing vessels, fishing vessels, etc., reduce collision risk, and help enforce navigational rules.*

Mission 4: Navigational skills *(manoeuvring rules with complex situations): This mission involved more complex scenarios, and the participants' COLREG knowledge and decision-making abilities will be assessed.*

The simulation-based COLREG e-learning platform aims to ensure that training in the maritime sector is more effective, efficient and realistic. 3D modelling of characters, objects, and environments was developed, and every detail of the models was analysed and designed using the overall atmosphere of the simulation using Unreal Engine 5. Figure 1 depicts the ship designed within the simulation.

Figure 1. Tanker vessel in the simulation library.

Ships, buoys, and objects that should be in the environment and the bridge were modelled in the simulation. User interaction within the simulation is crucial. Figure 2 provides a view from the bridge, where navigational instruments are visually available. The primary objective of this project is to enhance the watch officer's decision-making abilities by visually identifying target vessels in accordance with COLREG rules.

Figure 2. Bridge view of the simulation.

Therefore, every aspect of the realistic environment was created, like the binoculars. Participants can walk around the bridge using keyboards. The interface and menus have been designed in detail to enhance the user experience. A user-friendly interface makes it easier for users to navigate, adjust, and interact with the simulation. Therefore, a familiarisation video for the simulation, interface, and menus was prepared for the beginning of each training session. Figure 3 depicts an example scenario from mission 3 of the NSBA project. During this scenario, participants encounter questions regarding the type of vessel and manoeuvre based on the vessel's lights in night conditions during the simulation.

Figure 3. Sample scenario of mission 3.

3.2 Assessment Methods and Performance Metrics

Within the scope of the NSBA project, each participant is evaluated using different scenarios in a simulation environment under four essential missions. Moreover, assessment is as critical as training so that participants can identify their weak areas to improve. Since users need to complete the scenario questions determined for the platform within specific periods of time, times have been assigned according to the difficulty levels of the questions. 10 scenarios from each specified mission are randomly assigned to each user.

The platform is not just a tool for evaluation but a learning environment. The scenarios, simulated and strategically designed to captivate the user's attention. Participants will have the chance to review the correct answers to questions they initially answered incorrectly, which aids in their learning and understanding of the correct choices.

At the end of the learning, an assessment system shows which mission the participants are inadequate in and which specific subject and a certificate giving statistical results is issued to the participants.

3.3 Pilot Study

Scenarios for each mission were developed together with experienced lecturers from the ITU Maritime Faculty, and these scenarios were designed from easy to more complicated. Afterwards, the scenarios were prepared together with the simulation developers in the simulation environment. An ITU-hosted workshop was held to evaluate the simulation, and maritime stakeholders, including shipping companies, training inspectors, captains, watchkeeping officers, and students, were invited to gather user feedback and facilitate familiarisation with the new user interface. Impressively, feedback from participants was positive.

4. Conclusion

Despite all technological innovations in the maritime sector, maritime accidents continue. Understanding collision avoidance rules is crucial in ship accidents, especially collisions. Previous studies show that the wrong interpretation or implementation of COLREG rules caused many accidents. The NSBA project is a simulation-based e-learning and assessment platform that aims to offer a practical and inclusive perspective to COLREG training, which is currently based on theoretical training. Through this simulation, masters, watchkeeping officers, and students would have the opportunity to receive practical training and an assessment model to identify which rules or areas need to be improved. Moreover, the importance of distance learning has become more evident after COVID-19. This simulation training also offers the opportunity for distance learning and gives flexibility to the users.

In response to challenges regarding the COLREG training, the NSBA project offers a new and revolutionary approach to the maritime industry. The extremely positive feedback received from stakeholders, including shipping companies, training inspectors, captains, officers of the watch, and students during the pilot study, underlines the project's effectiveness.

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Cross-European Collaboration in Maritime Education: Enhancing Skills Development

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Abstract

Maritime education and training are undergoing a pivotal transformation. With vessels increasingly adopting green technologies, shipping experiencing rapid digitalization, and new forms of collaboration, the sector demands a workforce equipped with suitable skills in both technological proficiency and innovative leadership. In response, educational strategies must evolve to align with these dynamic changes. The SkillSea project emerges as a response to this imperative, setting a benchmark for innovative educational practices for maritime professionals. Under this project, a consortium of 26 partners from 15 European countries worked under structural cooperation to design educational packages as a response to a number of skill gaps identified. Seven educational packages (in the area of digital skills, green skills, leadership, STEM and intrapreneurship & innovation) combined with a trainer-the-trainer package, a Toolbox for developing custom-made and further educational packages and a guide for their implementation are all designed and provided under one platform: the 'Maritime Education and Training Portal'. SkillSea's approach to educational development is characterized by extensive cross-European collaboration. This collaborative framework not only ensures a harmonized skill set across different regions but also facilitates the sharing of best practices, resources, and expertise. Using Skillsea as a case study, this study focuses on the critical role of cross-collaboration among European countries and institutions in enhancing the quality and relevance of MET programmes. In this study, the outcomes and experiences gathered from running the SkillSea project are presented and discussed for their potential impact on the maritime training and education.

The findings reveal several key outcomes of the SkillSea project's collaborative approach. Most notably, improved cooperation among MET providers has significantly enhanced knowledge sharing and trust-building. This synergy has not only strengthened the involvement and responsiveness of MET institutions to the maritime sector's needs but also inspired further educational innovations and developments. It highlights how the SkillSea consortium's collaborative model has contributed to the increased learning opportunities and mobility of current and future seafarers.

Keywords: *Maritime Education and Training (MET), Collaboration, SkillSea, Skills, Knowledge Sharing*

1. Introduction

The maritime industry is undergoing a profound transformation, driven by the rapid advancement of technologies, the pressing need for environmental sustainability, and the evolving demands of the global economy [1] [2]. It is becoming increasingly clear that the success and resilience of the sector will depend on its ability to foster a highly skilled, adaptable, and forward-thinking workforce [3]. Maritime Education and Training (MET) institutions play a pivotal role in shaping this workforce, and their ability to provide relevant, high-quality, and innovative education and training programs will be critical to the future competitiveness and sustainability of the maritime sector [4].

However, the current MET landscape in Europe is fragmented and often struggles to keep pace with the rapidly evolving needs of the industry [5]. MET institutions face numerous challenges, including the need to constantly update curricula, incorporate new technologies, and provide learners with the skills and competencies required to succeed in an increasingly complex and dynamic maritime environment [6]. To overcome these challenges and ensure the long-term relevance and effectiveness of MET, there is a growing recognition of the need for closer collaboration and cooperation among MET institutions, industry stakeholders, and policymakers [7].

This study focuses on the critical role of cross-collaboration among European countries and institutions in enhancing the quality and relevance of MET programs. Drawing on the experiences and outcomes of the SkillSea project, the study explores how collaborative approaches to curriculum development, knowledge sharing, and innovation can contribute to the creation of a more integrated, responsive, and future-proof MET ecosystem in Europe. By examining the key initiatives, achievements, and lessons learned from the SkillSea project, the study aims to provide valuable insights and recommendations for MET institutions, industry stakeholders, and policymakers seeking to promote cross-European collaboration and drive positive change in the maritime education and training sector.

2. Literature Review

2.1. Current Trends in the Maritime Industry

The maritime industry is undergoing a significant transformation driven by various technological, environmental, and social factors. One of the most prominent trends is the increasing adoption of green technologies in response to the global push for sustainability and decarbonization. The International Maritime Organization (IMO) has set ambitious targets to reduce greenhouse gas emissions from shipping by at least 70% by 2040 compared to 2008 levels [8]. This has led to a surge in research and development efforts focused on alternative fuels, such as liquefied natural gas (LNG), hydrogen, and ammonia, as well as energy-efficient technologies like wind-assisted propulsion and air lubrication systems [9] [10].

Another significant trend is the rapid digitalization of the maritime sector. The industry is increasingly embracing digital technologies, such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI), to optimize operations, enhance safety, and improve efficiency [11]. For instance, the use of digital twins, which are virtual replicas of physical assets, is gaining traction in the maritime sector. These digital twins enable real-time monitoring, predictive maintenance, and scenario testing, leading to reduced downtime and improved asset performance [12].

Moreover, new forms of collaboration are emerging in the maritime industry, driven by the need for increased efficiency, cost reduction, and knowledge sharing. Collaborative business models, such as strategic alliances and joint ventures, are becoming more common, enabling companies to pool resources, share risks, and leverage complementary expertise [13]. Furthermore, there is a growing trend towards collaboration between industry and academia, with maritime companies partnering with universities and research institutions to drive innovation and develop new technologies [7]. These trends have significant implications for the skills and competencies required of maritime professionals.

As the industry adopts new technologies and collaborative practices, there is a growing demand for a workforce with a combination of technical expertise, digital literacy, and soft skills such as communication, problem-solving, and adaptability [4]. This highlights the need for maritime education and training (MET) institutions to align their curricula and teaching methods with the evolving needs of the industry.

2.2. The Importance of Skill Development in the Maritime Sector

As the industry undergoes rapid transformation driven by technological advancements, environmental regulations, and evolving business models, the importance of skill development in the maritime sector has become increasingly evident. One of the primary drivers of the need for skill development in the maritime sector is the increasing complexity of shipboard systems and technologies. The adoption of digital technologies, such as automation, data analytics, and artificial intelligence, has revolutionized the way ships are operated and maintained [14]. These technologies require maritime professionals to possess a combination of technical expertise, digital literacy, and problem-solving skills [4]. For instance, the use of electronic charts and integrated bridge systems necessitates a high level of proficiency in digital navigation and situational awareness [15].

Another critical aspect of skill development in the maritime sector is the need to address the growing environmental challenges. The IMO's ambitious targets for reducing greenhouse gas emissions from shipping have led to an increased focus on green technologies and sustainable practices [8]. To meet these targets, maritime professionals must be equipped with the knowledge and skills necessary to operate and maintain eco-friendly technologies, such as alternative fuels, energy-efficient propulsion systems, and waste management solutions [16]. This requires a comprehensive understanding of the environmental impact of shipping activities and the ability to implement sustainable practices across the entire maritime value chain. Moreover, the changing nature of work in the maritime industry has highlighted the importance of soft skills and leadership competencies. As the industry becomes more globalized and collaborative, maritime professionals must be able to work effectively in diverse and multicultural teams, communicate clearly, and adapt to changing circumstances [17].

Despite the growing recognition of the importance of skill development in the maritime sector, there are significant challenges in ensuring that maritime education and training (MET) keeps pace with the rapidly evolving industry requirements. Traditional MET curricula often lag behind the latest technological and operational developments, leading to a skills gap between the competencies of graduates and the needs of the industry [6]. Furthermore, the lack of harmonization of MET programs across different countries and institutions can hinder the mobility and employability of maritime professionals.

To address these challenges, there is a growing emphasis on innovative and collaborative approaches to skill development in the maritime sector. The SkillSea project, with its focus on cross-European collaboration and the development of future-oriented educational packages, represents a significant step in this direction. By bringing together a diverse range of stakeholders, including MET institutions, industry partners, and regulatory bodies, the project aims to create a more responsive and adaptive MET ecosystem that can effectively meet the evolving skill requirements of the maritime sector.

2.3. Cross-European Collaboration in MET

Cross-European collaboration in maritime education and training (MET) has been gaining some momentum in recent years, as the maritime industry faces increasing challenges related to globalization, technological advancement, and environmental sustainability [18].

Table 1 provides the key cross-European collaboration projects in maritime education and training (MET).

Table 1. Selected Key cross-European collaboration projects

Project Name	Duration	Partners	Key Objectives	Type of Collaboration
SkillSea	2019-2023	26 partners from 15 European countries	Develop a comprehensive approach to maritime skills development	Curriculum Development, Knowledge Sharing and Best Practices
MATES	2018-2022	17 partners from 8 European countries	Develop a skills strategy for the marine and maritime sectors	Research and Innovation, Skills Framework Development
Skills Partnership for Shipbuilding and Maritime Technology	2020-ongoing	Key stakeholders from industry, education, and social partners	Collaborate on upskilling and reskilling the workforce in the shipbuilding and maritime technology sectors	Industry-Academia Collaboration, Policy and Strategy Development
HUMANE	2020-2023	14 partners from 6 European countries	Develop a framework for the integration of human factors into the design and operation of autonomous ships	Research and Innovation, Curriculum Development
TrainMoS II	2018-2021	27 partners from 11 European countries	Develop and implement a comprehensive training program for the Motorways of the Sea (MoS) concept	Curriculum Development, Knowledge Sharing and Best Practices
On the MoSway Network (OTMW-N)	2018-2021	22 partners from 9 European countries	Create a sustainable network of MoS stakeholders and promote the exchange of knowledge and best practices	Knowledge Sharing and Best Practices, Curriculum Development
MINE-EMI	2019-2022	14 partners from 6 European countries	Address the skills challenges in the maritime industry and promote cooperation between MET institutions and industry stakeholders	Skills Framework Development, Industry-Academia Collaboration, Curriculum Development
MET-NET	2023-ongoing	14 partners from 8 European Countries	Enhancing cooperation and mobility among maritime stakeholders to support knowledge-sharing and good practices.	Knowledge Sharing and Best Practices

The various cross-European collaboration projects in maritime education and training (MET) demonstrate a range of focus areas and objectives. One of the key areas of focus in cross-European collaboration in MET is skills framework development (e.g., MATES, SkillSea). These projects focus on developing comprehensive frameworks for maritime skills and competencies to ensure alignment with industry needs.

In addition, curriculum development appears to be the focus of several projects, including the development of new curricula, courses, and training materials to enhance the quality and relevance of MET (e.g., SkillSea, TrainMOS II, OTMW-N, MINE-EMI).

Industry-Academia Collaboration Fostering collaboration between MET institutions and industry stakeholders is another key area of focus of European cross-collaboration involving METs. A key example is the Skills Partnership for Shipbuilding and Maritime Technology, under the Pact for Skills initiative, which brings together key stakeholders from industry, education, and social partners to collaborate on upskilling and reskilling the workforce in the shipbuilding and maritime technology sectors.

Furthermore, some collaborations focus on conducting research and developing innovative solutions to address the challenges in MET (e.g., HUMANE).

Knowledge Sharing and Best Practices MET institutions and stakeholders is another crucial area of focus. These collaborations aimed to create networks of MET stakeholders, yet the sustainability of these projects was limited. The exception is two projects. First, the Mates projects built a sustainable partnership under the Pact for Skills for the maritime technology sector. Second, SkillSea launched the Maritime Education and Training Network (MET-NET) to carry on the project's legacy and create a structure cooperation among MET institutions.

Despite the progress made through these and other cross-European initiatives, there remain challenges and barriers to effective collaboration in MET. One key issue is the lack of a fully harmonized approach to MET across different European countries, with variations in curricula, training methods, and assessment practices [19]. This can hinder the mutual recognition of qualifications and the mobility of seafarers across Europe. Additionally, differences in national regulations and requirements can sometimes pose obstacles to the implementation of joint training programs and initiatives [20]. Another key challenge is the long-term sustainability of these collaboration projects, as their continued impact and implementation often depend on ongoing commitment, resources, and institutional adoption beyond the project's lifetime.

3. Presenting the SkillSea Project

The SkillSea project, funded by the Erasmus+ Programme of the European Union, is an initiative that aims to tackle the challenges faced by the European maritime industry in ensuring a highly skilled, adaptable, and future-ready workforce. The project, which run from 2019 to 2023, brings together a diverse consortium of 27 partners from 16 countries, including Maritime Education and Training (MET) institutions, industry representatives, social partners, and research organizations.

The main objective of the SkillSea project is to develop a sustainable and transferable skills strategy for the European maritime sector, with a focus on enhancing the quality and relevance of MET programs through cross-European collaboration and innovation. To achieve this goal, the project has adopted a comprehensive and multi-faceted approach that encompasses research, curriculum development, pilot testing, and dissemination activities.

One of the key pillars of the SkillSea project is the identification of current and future skills needs in the maritime industry, taking into account the rapid technological advancements, environmental challenges, and evolving regulatory landscape. Through extensive research and stakeholder consultation, the project has mapped the existing skills gaps and defined the competencies required for maritime professionals to thrive in the 21st century.

4. SkillSea's Educational Resources and Platforms

4.1. Collaborative Development of the SkillSea Toolbox for Future-Proof Skills

The SkillSea project's collaborative approach was particularly evident in the development of the SkillSea Toolbox, a comprehensive framework designed to facilitate the creation of future-proof skills training programs for the maritime industry.

One of the key outcomes of this collaborative process was the development of a standardized template for the creation of Educational Packages (EPs) within the Toolbox framework. This template, known as the "SkillSea Toolbox for Educational Packages", provided a common structure and set of guidelines for the development of training programs across different skill areas. The template was designed to ensure consistency and quality across the various EPs, while also allowing for flexibility and customization based on the specific needs and requirements of different target groups and learning contexts.

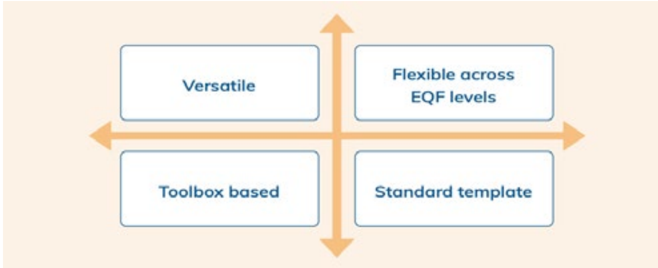

Figure 1. The SkillSea educational solution approach [21]

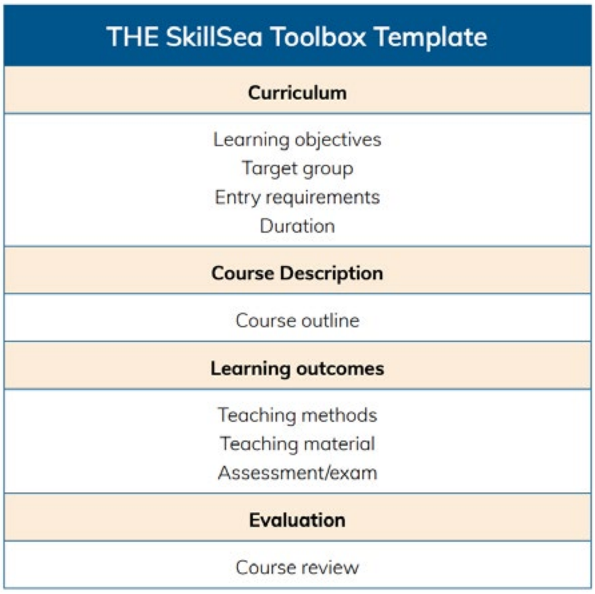

Figure 2. The SkillSea Toolbox Approach (SkillSea, 2023)

The collaborative development of the Toolbox also involved the joint efforts of partners in creating a set of seven core EPs, each focused on a critical skill area identified through the project's earlier analysis of emerging trends and skills gaps. These EPs covered topics such as green skills, digital skills, leadership, entrepreneurship and innovation, and STEM (Science, Technology, Engineering, and Mathematics). The figure below provides an overview of the EPs developed.

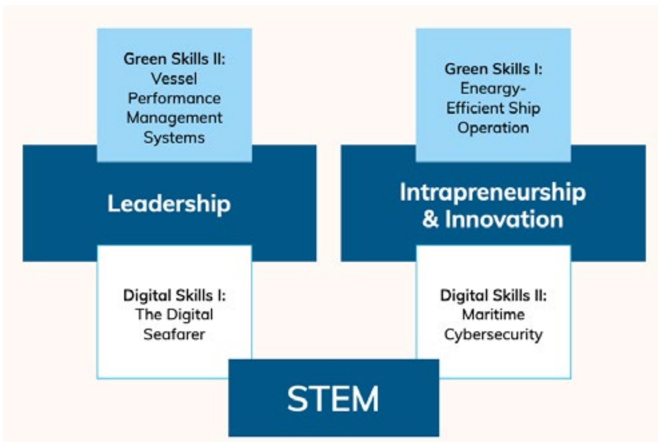

Figure 3. Overview of Educational Packages [21]

Table 2. Educational Packages content and audience [21]

	SKILLS' SET	Relevant for Roles / Occupational profiles
Digital Skills **The Digital Seafarer**	Structure, components & maintenance of shipboard network Operation and use of onboard sensors Nature and quality of shipboard generated data	All senior deck officers All senior engine officers Electrotechnical Officers Compliance Officers
Digital Skills **Maritime Cyber Security**	Maritime cybersecurity (MC) awareness and training MC Risk Management	All senior deck officers All senior engine officers Compliance Officers
Green Skills **Environmentally Friendly & Sustainable Ship Operations**	Alternative fuels and environmental impact Data collection & interpretation Energy- efficient operation, power production and consumption Energy-efficient awareness	All senior deck officers All senior engine officers (Compliance Officers)
Green Skills **Understanding and Using Performance Data**	Vessel Performance Management Systems Data collection and interpretation KPIs, calculation & documentation of emission Key elements of the green regulatory process & political structures in the maritime industry	All senior deck officers All senior engine officers Compliance Officers Vetting & Inspectors
Leadership	Cultural diversity and leadership in a multicultural industry Communication & motivation Team leadership & conflict handling	All senior deck officers All senior engine officers Compliance Officers Facilitates transition to shore-based positions
Intrapreneurship and Innovation	Innovation Creative thinking Project Management	Facilitates transition to shore-based positions
STEM	Introduction to STEM Analysis and Problem solving	Junior officers Electrotechnical Officers Electricians

The development of each EP was led by a specific partner or group of partners with expertise in the relevant skill area, but all partners contributed to the review and refinement of the packages through an iterative process of feedback and revision. For example, the EP on "Innovation and Intrapreneurship" was developed through a collaboration between the French Maritime Academy (France), as lead, and Liverpool John Moores University (UK), University of Aegean (Greece) and SIMAC (Denmark). In addition, the EP on "Green Skills" was designed by Fleetwood Nautical College (UK) in collaboration with Liverpool John Moores University (UK), forMare (Italy) and SIMAC (Denmark).

4.2. The Blueprint Maritime Shipping Portal

The Blueprint Maritime Shipping Portal, also known as the Maritime Education and Training (MET) Portal, is a key outcome of the SkillSea project. The portal serves as the main hub for hosting the toolbox and educational packages developed within the project to upskill and reskill maritime professionals in line with the future needs of the shipping industry.

The MET Portal is designed to provide easy access to the SkillSea toolbox and its associated educational packages, via Moodle, a widely-used open-source learning management system (LMS).

To ensure accessibility and usability, the MET Portal is organized into two main layers: one for teachers and one for students. This structure allows for tailored access to content and resources based on the specific needs and roles of different user groups. Teachers can access the full range of educational packages and resources, while students can engage with the learning materials and activities relevant to their particular courses.

As part of the SkillSea project's sustainability plan, the MET Portal will continue to be maintained and updated beyond the formal conclusion of the project. This ongoing support will be provided by the SkillSea partners, with a particular focus on incorporating new content and resources developed through the Maritime Education and Training Network (MET-NET), a structural cooperation initiative established within the project.

4.3. Structural Cooperation within SkillSea: Selected Examples

The SkillSea project has fostered a strong culture of collaboration and knowledge-sharing among its consortium partners, leading to the development of various structural cooperation activities.

One notable example of structural cooperation within SkillSea is the 'Good practices to enhance mobility' workshop series, organized as part of Work Package 2 (WP2). This workshop, held on 20 June 2022 and led by Liverpool John Moores University, brought together 29 participants from various organizations across Europe to share their knowledge and experiences, learn from one another, and discuss good practices to enhance mobility within the maritime sector.

Another instance of structural cooperation facilitated by SkillSea is the collaboration between the Norwegian University of Science and Technology (NTNU) and Svendborg International Maritime Academy (SIMAC) on the assessment of the BSc Nautical Science Education at NTNU. This cooperation involved establishing a review board with representation from similar study programs internationally to provide feedback on the quality and relevance of the program.

The SkillSea project has also acted as a catalyst for the formation of new consortia and project proposals, such as the COVE call under the Pact for Skills initiative. In this particular project, a consortium consisting of SEA Europe, FORO MARITIMO VASCO, South Denmark European Office, University of Southern Denmark, SIMAC, and SESG formed to develop work packages for the project application.

Staff mobility is another key area where SkillSea has made a significant impact. The Maritime Staff Mobility Programme, established by Universitat Politecnica de Catalunya, NHL Stenden University of Applied Sciences, Svendborg

International Maritime Academy, Chalmers University of Technology, and the University of Rijeka, enables each partner to send teachers, and potentially also administrative or managerial staff, to each of the partners annually. The purpose of this program is to increase knowledge, share best practices and experiences, and explore new approaches and learning methods. The staff exchanges, which started in 2022, are expected to prepare for student exchanges within the next one to two years, demonstrating the long-term impact of the cooperation and knowledge-sharing fostered by SkillSea.

Finally, the collaboration between SkillSea partners École Nationale Supérieure Maritime (ENSM) and Scheepvaart en Transport College (STC Group) serves as a significant example of the project's role in strengthening cooperation among European MET providers. The signing of a Memorandum of Understanding between these two institutions aims to advance key areas such as energy transition, ship digitalization, and skill development in collaboration and leadership. As part of the Erasmus+ program, ENSM and STC will facilitate the exchange of students and professors between France and the Netherlands, fostering knowledge and expertise sharing.

5. Key Impact of the Cross-collaboration Facilitated by SkillSea

The SkillSea project facilitated a structured cooperation among its members:

Enhanced cooperation among MET providers and industry stakeholders

The SkillSea project has significantly enhanced cooperation among MET providers and industry stakeholders, as evidenced by the establishment of the Maritime Education and Training Network (MET-NET) and the European Maritime Skills Forum (E-MSF). These platforms facilitate the exchange of knowledge, best practices, and experiences, fostering a culture of collaboration and trust-building within the maritime sector.

- Improved knowledge sharing and trust-building through collaboration

The collaborative approach adopted by SkillSea has led to improved knowledge sharing and trust-building among project partners. The development of the SkillSea Toolbox and its associated Educational Packages (EPs) has been a prime example of this, with partners contributing their expertise to create comprehensive and industry-relevant training resources. This collaborative process has strengthened the bonds between MET providers and industry stakeholders, laying the foundation for future cooperation.

- Inspiration for further educational innovations and developments through collaboration

The SkillSea project has inspired further educational innovations and developments through its collaborative approach. The partnerships and networks established within SkillSea have catalyzed new initiatives, such as the COVE call under the Pact for Skills, aimed at upskilling the maritime workforce. Moreover, the project's focus on promoting mobility and the exchange of ideas has fostered a culture of innovation and continuous improvement in maritime education and training.

- Increased learning opportunities and mobility for current and future seafarers

The collaborative efforts within the SkillSea project have led to increased learning opportunities and mobility for current and future seafarers. The development of the Blueprint Maritime Shipping Portal and the SkillSea Toolbox has provided maritime professionals with access to cutting-edge training resources that enhance their skills and employability. Furthermore, the project's emphasis on promoting mobility has contributed to creating a more interconnected and dynamic European maritime education and training landscape, ultimately benefiting seafarers by expanding their career prospects.

6. The SkillSea Legacy: Structural Cooperation and Openness

One of the key outcomes of the SkillSea project is the establishment of the Maritime Education and Training Network (MET-NET), a structural cooperation initiative that brings together 14 MET providers from 8 European countries. MET-NET is a direct result of the collaborative spirit fostered by the SkillSea project. Established in the final stages of the project, MET-NET is an independent network of European MET institutions committed to continuing the work initiated by SkillSea. The network aims to promote ongoing knowledge sharing, best practice exchange, and joint initiatives among its members, ensuring that the momentum generated by the project is maintained and built upon.

The impact of MET-NET's structural cooperation and openness extends beyond the immediate benefits for its members and their students. By setting a new standard for collaboration and innovation in MET, the network has the potential to drive systemic change in the way maritime professionals are educated and trained across Europe. As MET-NET continues to grow and evolve, its legacy will be measured by its ability to inspire and support a new generation of skilled, adaptable, and forward-thinking maritime professionals.

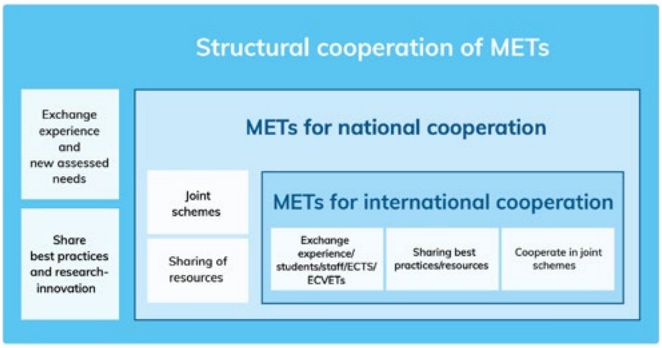

Figure 4. Structural cooperation created via MET-NET [21]

7. Lessons Learned and Implications for Future MET Collaborations

The SkillSea project has provided valuable insights into the challenges and opportunities associated with cross-European collaboration in the field of Maritime Education and Training (MET). Through the experiences gained during the project's implementation, several key lessons have emerged that can inform and guide future collaborative efforts in the MET sector.

One of the most significant lessons learned is the importance of establishing a clear and shared vision among collaborating partners. The SkillSea project brought together a diverse range of stakeholders, each with their own priorities, expectations, and institutional contexts. Aligning these diverse perspectives around a common set of goals and objectives was crucial to the project's success. Future MET collaborations should prioritize the development of a strong, collectively owned vision that reflects the needs and aspirations of all partners involved.

Another key lesson is the need for effective communication and coordination mechanisms to support collaborative work. The SkillSea project partners were geographically dispersed and had to navigate different national and institutional cultures, as well as varying levels of experience with transnational cooperation. Establishing clear channels for regular communication, such as periodic virtual meetings, workshops, and online collaboration platforms, was essential to ensure that all partners remained engaged and informed throughout the project's lifecycle. Future MET collaborations should invest in robust communication and coordination infrastructures from the outset, to facilitate smooth and efficient teamwork.

The SkillSea project also underscored the importance of embedding sustainability and long-term impact considerations into collaborative initiatives. While the project achieved significant outcomes within its funded duration, ensuring that these benefits are sustained and scaled up over time requires ongoing commitment and investment. The establishment of the Maritime Education and Training Network (MET-NET) and the proposed European Maritime Skills Forum (E-MSF) represent promising steps in this direction. Future MET collaborations should prioritize the development of durable structures and mechanisms for continued cooperation and knowledge sharing beyond the initial project period.

8. Conclusion

The SkillSea project has demonstrated the immense potential of cross-European collaboration in addressing the challenges faced by the maritime industry and in ensuring the long-term competitiveness and sustainability of the sector. By bringing together a diverse range of stakeholders, including Maritime Education and Training (MET) institutions, industry partners, social partners, and policymakers, the project has laid the foundation for a more integrated, responsive, and future-oriented approach to skills development in the maritime domain.

Through its collaborative efforts, SkillSea has made significant strides in identifying the key skills gaps and future competence needs of the maritime industry, taking into account the rapid pace of technological change, environmental imperatives, and evolving regulatory frameworks. The project's innovative outputs, such as the SkillSea Toolbox and the associated Educational Packages, provide a comprehensive and flexible framework for upskilling and reskilling maritime professionals, ensuring that they are equipped with the knowledge, skills, and competencies required to navigate the challenges and opportunities of the 21st century.

Moreover, the SkillSea project has fostered a culture of cooperation, knowledge sharing, and mutual learning among its partners, breaking down silos and promoting a more collaborative approach to skills development. The establishment of the Maritime Education and Training Network (MET-NET) and the proposed European Maritime Skills Forum (E-MSF) are testament to the project's commitment to creating sustainable structures for ongoing dialogue, coordination, and innovation in the MET sector.

The lessons learned from the SkillSea project offer valuable insights for future collaborative initiatives in the maritime domain. By prioritizing a shared vision, effective communication, flexibility, diverse expertise, sustainability, and stakeholder engagement, future projects can build on the successes of SkillSea and drive further advancements in the field. The project's emphasis on aligning MET curricula with the evolving needs of the industry, promoting student and staff mobility, and enhancing the attractiveness and inclusivity of maritime careers, sets a strong precedent for future endeavors.

As the maritime industry continues to evolve and face new challenges, the importance of cross-European collaboration in skills development cannot be overstated. The SkillSea project has shown that by working together, MET institutions, industry partners, and policymakers can create a more agile, adaptive, and future-proof skills ecosystem, capable of supporting the long-term success and sustainability of the European maritime sector.

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Automated Classification of Human Factors in Maritime Incident Reports via Natural Language Processing

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Abstract

Despite extensive efforts to increase safety at sea, maritime incidents continue to occur. These incidents often result in detrimental effects to the environment and the safety of seafarers, often causing injuries and, in the most severe cases, fatalities. Human error is known to be one of the leading causes of these incidents, necessitating comprehensive incident analysis and data processing. Traditional methods of manual analysis are both costly and time-intensive, prompting exploration of Natural Language Processing (NLP) to automate data extraction. Alternative domains such as aviation, construction and healthcare have successfully applied these techniques, although the maritime industry lags behind in these developments. This study bridges the gap by using the Safety Human Incident Error Learning Database (SHIELD) and supervised machine learning to map incident reports to the human factors taxonomy. Six of the most well-known Machine Learning (ML) algorithms were evaluated in the study, which found that Support Vector Machine (SVM) algorithm consistently yielded promising results. The results yielding average F1 scores of 0.76 shows the potential of these methods to enrich the application of human factors taxonomies within the maritime industry. Future research will expand data availability, complete taxonomy payers, and explore deep learning for enhanced performance.

Keywords: *Human factors, Natural Language Processing, Machine Learning, SHIELD, taxonomy*

1. Introduction

The maritime industry is a very safety-challenged industry due to harsh operating conditions and regulatory compliance issues due to the global nature of the industry. Although using both reactive and proactive approaches to help increase safety and drive change to culture and procedures, maritime incidents remain a persistent concern. The effects of these incidents can often be detrimental to the environment and the human element, where these incidents often cause injuries and in worst cases, fatalities.

The industry's undeniable reality is that around 80% of these incidents occur due to human error [1]. As such, the effective and efficient processing of data containing insights into human errors and the root causes of maritime incidents is of paramount importance. These incidents, though regrettable, present a unique opportunity for the industry to learn invaluable lessons by refining existing procedures and enhancing equipment designs to rectify the faults exposed by these unfortunate occurrences.

Traditionally, the extraction of information from maritime incident reports has been a labour-intensive and costly endeavour, primarily conducted by human factors experts. However, recent advances in Natural Language Processing (NLP) have led to changes, where there is now new potential to automatically extract factors and root causes from these reports. In other transport domains such as Aviation and Rail, NLP has been proven to successfully categorise causes of incidents. However, the maritime sector has lagged behind in utilising these new technological developments for this purpose.

This study looks to bridge this gap by leveraging Artificial Intelligence (AI) techniques, specifically NLP and ML, to automate the classification of human and causal factors found in incidents. The insights gained from this analysis will help guide the industry response to emerging challenges, facilitating the timely mitigation of risks and contributing to the prevention of major accidents.

2. Literature Review

In recent years, the utilisation of NLP techniques for incident analysis has gained momentum. Although usage within other industries has been growing, the application of NLP in the maritime domain is still emerging, with limited studies exploring its potential.

2.1 Maritime

Within the maritime domain, there has been a very limited body of literature exploring the application of NLP to analyse incident reports. A total of seven studies have been carried out, of which, five of these studies make reference to human factors. Those who did not were Tirunagari [2] and Liu, et al. [3]. The first looked to examine causal relations through keyword extraction of conjunctive words such as "consequently", "so", and "thus". The latter was more based on Chinese word segmentation, a technique used due to the Mandarin reports used, and so these methods were not so relevant to this study.

Two of the studies which reference human factors are by Yan, et al. [4] and Bin, et al. [5]. The latter uses an attribute reduction and rough set theory approach, reducing the dimensionality and retaining solely significant words. The method used here is no further enhanced and is now used as preprocessing steps in wider models. The other operates an unsupervised technique, topic modelling. The method generates themes based on relevant and semantically related keywords. The issue with this technique is the subjectivity and uncertainty of the method that can lead to broad themes covering many topics. Although, it requires no labelled data, and so is particularly useful in terms of resource efficiency.

Three newer and more relevant studies were conducted by Gan, et al. [6], Nurduhan and Kuleyin [7] and Ma, et al. [8].

The first by Gan et al. uses a knowledge graph construction approach. This approach aims to show a correlation among causal factors of an incident. The study primarily focused on collision incidents and found that the majority of the causal factors were human factors. The study also took into account both environmental and management factors but failed to mention organisational issues like culture. The latter by Ma et al. was similar, aiming to develop a human factors complex network. They used data which has been structured using HFACS classification and produced chi-square tests and odds-ratios to develop an understanding of the relationship between the different levels of HFACS. Lastly, Nurduhan and Kuleyin used unsupervised methods to reduce the dimensionality of the free-text incident reports and cluster the keywords. The results gave them 19 clusters which referred to different human factors, including some organisational and management factors. However, these did not include any environmental influences.

2.2. Other Transport Modes

Alternative transportation modes such as aviation, automotive and rail have a more extensive body of research in these fields. Some of these studies align with the main aim of this paper, classifying human factors. Within the Aviation domain studies conducted by Madeira, et al. [9], Tanguy, et al. [10] and Perboli, et al. [11] have all used a taxonomy-based approach for the classification of causal factors. Maderia et al. used the HFACS taxonomy and conducted competitive analysis involving random search models and Bayesian optimisation. The findings underscored the superior performance of Bayesian optimisation but also stated that SVM was more reliable for larger datasets. Tanguy et al. employed the Aviation Safety Report System (ADREP) taxonomy. This categorised incidents into four distinct classes. The study yielded the best results when using SVM. Perboli et al. used the Software, Hardware, Environment, Liveware (SHEL) approach and was able to generate high precision using only a small sample of 24 incident reports. A field test was conducted with this study which indicated that the system reduced the time required for expert taggers by approximately 30%.

The utilisation of NLP and ML techniques in the automotive and rail industries has also been increasing. However, most studies in automotive look to use unsupervised methods such as topic modelling. The same is true for the rail industry, although one study by Liu and Yang [12] looked to investigate classification factors pertinent to risk management, such as time, location, speed, causation, description, and consequence. This study used deep learning techniques, specifically Bidirectional Long Short-Term Memory alongside Random Forest and obtained high F1 scores.

3. Methods

The dataset employed in these models comprises of 125 collision incidents retrieved from the SHIELD database. These incidents span a substantial temporal range, from 1992 to 2019, encompassing various types of vessel collisions, including cargo, fishing, passenger, recreational crafts, navy vessels, and service ships. Although most incidents transpired within the UK, the dataset is globally diverse, encompassing incidents from countries such as Australia, Belgium, Canada, China, Denmark, Dominica, France, Germany, Greece, Indonesia, Japan, Korea, New Zealand, Singapore, Spain, Sweden, Tunisia, Turkey, U.A.E and the USA.

As NLP models rely on the frequency of specific or related words, word clouds were generated to provide an overview of the distinctions within the descriptions and justifications across the four layers of the taxonomy.

The current findings of this research are primarily centred on the classification of the "acts" layer. In the pursuit of deeper data analysis, the study aimed to identify factors with limited data, determining whether they should be omitted or merged. This process resulted in the creation of the new SHIELD-NLP "acts" layer, illustrated in Figure 1.

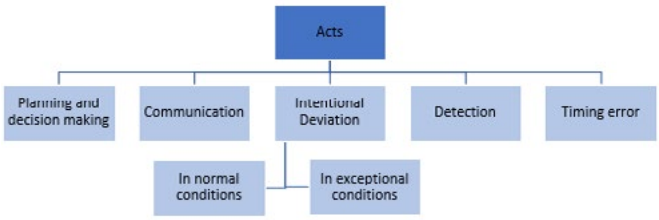

Figure 1. SHIELD-NLP acts layer

Following the initial data cleaning steps, a comprehensive data preprocessing phase was conducted. This includes the following: stop word removal, lemmatization, punctuation and white space removal, lowercasing, removal of words less than three letters long, and tokenisation. Subsequent to this, the data underwent transformation using the Term Frequency-Inverse Document Frequency (TF-IDF) technique. Downsampling was also applied for each of the six factors due to the substantial class imbalance existing between these factors, which was essential due to the binary structure of each of the models.

Six of the most commonly used machine learning algorithms were then applied to this data which were compared using standard evaluation metrics. These algorithms were support vector machine (SVM), Naïve Bayes, K-nearest neighbours, random forest, decision trees, and logistic regression. To gauge the performance of these models the F1 score was calculated. The F1 score is the harmonic mean of the precision and recall allowing for a more accurate representation of the model performance when data is imbalanced.

4. Results

The distribution of the acts layer was of the 125 incidents, there were 537 acts found across the six categories. As shown in Figure 2, most of the incidents had one or more than one issue with planning and decision-making; the same can be said for communication issues. Detection was also a major issue in these incidents. Intentional deviation, both in normal conditions and exceptional conditions, was found less in these incidents as well as timing errors, although these may be compounded within some of the other categories, i.e. late decision or plan and late detection.

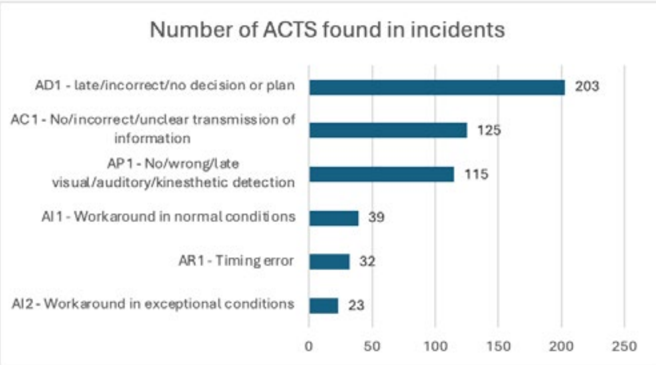

Figure 2. Bar chart of distribution of identified ACTS.

As depicted in Figure 3, the performance of the six machine learning models exhibits fluctuations, with varying F1 scores for different variables. Notably, none of the models demonstrate consistent performance across all variables. However, specific models excel in particular contexts. For variables such as “inappropriate decision or plan”, “communication”, and “detection”, all six models yield similar performance. Although, it is worth mentioning that Naïve Bayes and SVM attain the highest scores for all three variables. A stark contrast emerges with “timing error”, where both decision tree-based algorithms show considerably superior performance compared to the other models.

The variable “intentional deviation in normal conditions” ranks as one of the least effectively predicted variables, with logistic regression, random forest and decision trees yielding notably low scores. In contrast, SVM and KNN produced scores more in line with the other variables. Surprisingly, “deviation in exceptional conditions” emerges as the best-performing variable, with SVM and KNN both achieving scores of 0.94. This assessment underscores the reliability of the SVM model across the variables, consistently generating satisfactory F1 scores.

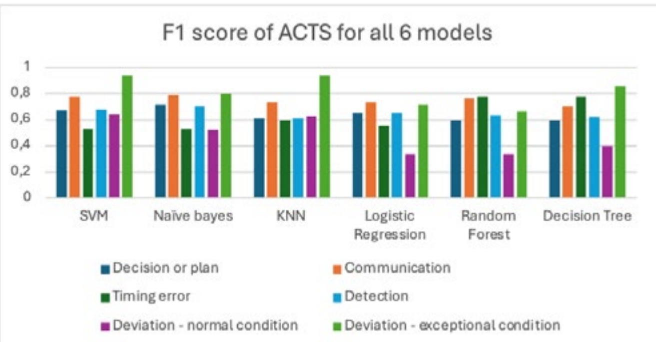

Figure 3. Bar chart of F1 scores for all six acts, with all six models, estimating the model performance.

5. Discussion

The findings from this study underscore the promising potential of these methods to elevate incident analysis and enrich the application of taxonomies within the maritime domain. The assessment of machine learning models reveals an array of performance variations across models and variables. Of particular note, the SVM model consistently delivers commendable results across most variables, underscoring its potential to enhance predictive accuracy. The overall F1 scores, spanning from 0.64 to 0.94, with an average of 0.76, distinctly illustrate the impact of variations in training data size and non-specific or contextual reasonings within the free-text data.

The primary constraint encountered in this study pertains to the quality of the available data. This limitation arises from the inherently subjective nature of human factors classification analysis, compounded by the human errors within the configuration of the data. Consequently, this subjectivity results in inaccuracies, introducing challenges to the classification models’ performance, as they are trained on erroneous data, leading to the production of imprecise models. Therefore, enhancing the data quality through further in-depth analysis is of paramount importance, as it significantly influences the effectiveness of the NLP and ML processes.

As previously mentioned, certain classifications have been amalgamated or excluded due to data limitations. For instance, very few incident reports contained causes related to memory, leading to the removal of this classification from both the taxonomy and the dataset. Typically, the taxonomy incorporated finer-grained subcategories, such as differentiating types of detection into visual, auditory, and kinaesthetic. However, due to data scarcity within some of these subcategories, they were consolidated. Utilising the complete SHIELD database alongside acquiring additional data for these underrepresented categories would be instrumental in extending the analysis.

The subsequent phases of this study will encompass the completion of classification models for the remaining taxonomy layers, which include preconditions, supervision, and organisational factors. Upon finalisation, these models will facilitate comprehensive incident analysis and are scheduled for integration into a codebase capable of processing full-text reports and assigning labels based on all the factors within the taxonomy.

Alternatively, to the methodology used, further research could also be carried out, which explores the use of large language models (LLMs) (e.g. BERT or GPT) or other deep learning approaches. Previous studies, such as the one conducted by Wong, et al. [13], have found that deep learning can outperform machine learning in classification tasks of free-text.

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AI-Based Adaptive Learning for Advanced Crew Training to Enhance Maritime Safety

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Abstract

Safety has emerged as a critical concern as larger, faster ships navigate increasingly crowded sea spaces due to globalization. Although developments in information technologies are transforming training and making it more accessible, numerous training methods fail to consider users' experience levels or learning preferences. This research aims to propose a framework that will personalize the training experience for trainees by developing an adaptive tutoring system. AI algorithms will be developed to identify gaps in seafarers' knowledge and skills, and the system will dynamically adapt to the specific needs of each trainee in the system.

Keywords: *Artificial Intelligent, Adaptive Tutoring, Safety, Human Factor*

1. Introduction

The maritime industry reports that more than eighty percent of maritime accidents reported from 2014 to 2022 have human factors as contributing factors [1]. Further analysis of the Marine Accident Investigation Branch database revealed that more than thirty percent of human-related incidents are caused by training-related factors, while 12 percent of them are caused by inadequate training programs [2].

Furthermore, with globalization and the transport of goods, vessels are getting more advanced, and they require a more skilled workforce. Currently, maritime training is transforming with the development of information technologies, which provide seafarers with different platforms to practice their skills and gain knowledge. These new learning systems provide more accessible training options for individuals in the maritime industry and address logistical constraints. Despite this shift, the current learning systems fail to consider the personal learning needs of the individual and their knowledge levels.

This research investigates the use of AI (artificial intelligence) algorithms in maritime safety training. It focuses on identifying the weaknesses of seafarers during their safety training to enhance maritime safety. Moreover, this study investigates different knowledge tracing models and assesses their performance with the interactions of seafarers on different safety training courses.

2. Literature Review

In recent years, there has been a significant shift in safety training with the development of e-learning systems. Unlike traditional classroom training, these systems enable trainees to access the training without any logistical constraints and offer a more cost-effective alternative. Additionally, Intelligent Tutoring Systems (ITS) have emerged to address the limitations of the one-size-fits-all training approach and provide a more engaging training environment. These systems use technologies such as artificial intelligence and data analytics to tailor the learning content dynamically during training based on the interactions of trainees. In this literature review, we delve into adaptive tutoring systems which are developed for safety training, and the role of artificial intelligence in user modelling.

There are only a few studies found in the literature about the application of Adaptive tutoring systems to maritime training. One of these studies proposed an adaptive learning environment design to teach higher mathematics to future seafarers [3]. The system delivers the learning content through modules and checks their knowledge with questions after every learning object. If the learner does not satisfy the requirements of the current content, they are navigated to extra learning materials and exercises. Learners could also receive an online teacher consultation when they revisit the failed modules. This study showed that knowledge-based navigation systems on e-learning platforms significantly increase learning outcomes.

While adaptive tutoring systems are not widely integrated into maritime training, the transition of safety training to online platforms such as Learning Management Systems (LMS) and Massive Open Online Courses (MOOC) provided substantial data about trainees. This data includes the interactions of trainees with materials, the time spent, the materials completed, and the frequency of engagement. Studies show that this data enables us to have a more detailed understanding of their needs and learning styles.

In one study by [4] an artificial intelligence algorithm is utilised to recommend the most suitable learning materials for primary education. To achieve a personalized learning experience, an AI algorithm is trained to recommend the most suitable learning material to learners. In the developed system, learners are requested to rate various materials in the system, and these ratings are used to predict their learning styles through collaborative filtering. The results of post-assessment tests showed that the proposed model improved learning outcomes noticeably.

In addition to education, AI-based algorithms are also integrated into training systems in various safety challenged industries such as construction [5] and aviation [6]. Duan et al. [5] presented a persona-based safety training system that identifies the learning needs of trainees and recommends the most suitable training content. The system relies on a machine learning algorithm that tags individuals based on their demographics and behavioural patterns. Based on their tags, a recommendation algorithm suggests training content to individuals. This approach significantly improves the system's effectiveness compared to traditional methods, highlighting the importance of demographic differences in training systems.

Some studies compare the performance of AI-based tutoring with that of human experts. In one of them, Peñafiel et al. [7] studied the use of AI for tutoring in medical education and training. During the study, participants were divided into two groups. While the first group received experts' comments during training, the second group received feedback about their knowledge state from an AI tutor, which participants received feedback about their strengths and weaknesses. Following a six-week training programme, AI tutoring performed significantly better than experts based on learning outcomes. This study highlights the advantages of AI-based algorithms for tutoring trainees, enhances the effectiveness and engagement of the trainees.

3. Research Methodology

This section will provide more details about the methodology implemented to investigate how artificial intelligence algorithms can identify knowledge gaps among seafarers. Our research aims to bridge the gap between conventional training approaches and the evolving demands of the maritime industry by focusing on the personalized learning needs of seafarers using advanced knowledge tracing algorithms.

The experiment was conducted with the assistance of the Intelligent Sea Group, which granted us access to their LMS and trainee reports. In this system, they provide various safety training courses that feature practical exercises and real-life examples for seafarers. At the end of each chapter, trainees are given a post-assessment test to receive feedback. To evaluate the performance of knowledge tracing algorithms in this training system, BKT (Bayesian Knowledge Tracing) [8] is selected which has proven its effectiveness across various domains including education and training [5][9].

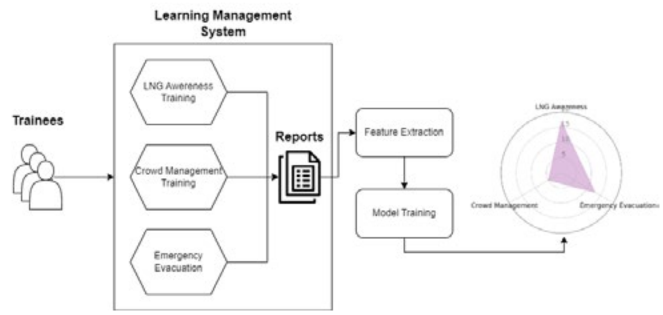

Figure 1. Research Framework

3.1. Data Collection

The training data for 286 trainees in LNG Awareness courses was collected from the SCORM reports of Talent LMS. These courses were designed and developed by Intelligent Sea Groups. In total, 5825 interactions are recorded, which include variables such as skill name, question name, time spent in exercise, date of the interaction, and correctness of the given answer. During the research, only researchers had access to the dataset, which did not contain any sensitive data to ensure data privacy.

3.2. Model Evaluation

The data is used to evaluate the performance of the BKT (Bayesian Knowledge Tracing) [8] model. The model is implemented using Python 3.9 using machine learning and data processing libraries such as PyBKT, Pandas, and NumPy. The implementation of Badrinath et al. [10] is utilized for the BKT model since it enables us to evaluate various BKT variants, such as individual item learning rate and individual student prior knowledge. To have a fair evaluation, different BKT variations are tested on the dataset, and the best-performing model is identified.

To evaluate the model, it is necessary to partition the dataset into training and testing sets based on the objective. Since our goal is to predict future trainee responses during the training, the model is trained with the first 75 percent of interactions in each sequence while the remaining data is used to evaluate the performance of the selected model in predicting the future performance of trainees. During the process of model selection, training samples are used to identify the best-performing BKT variations. After determining the best-performing model, the model is assessed on each LNG Awareness module and results are reported.

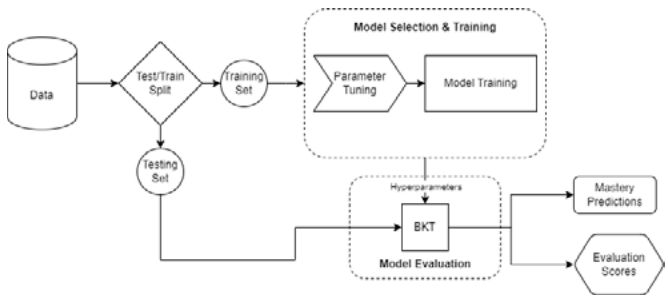

Figure 2. Model Evaluation

4. Results and Discussion

This section outlines the evaluation results acquired by utilizing the algorithm. The results are presented in Table 1 below.

Table 1. Evaluation Results

Model	Accuracy	F1 score	AUC
English LNG Awareness and Polar Familiarization	0.84	0.91	0.57
French Basic LNG Awareness and Polar Familiarization	0.84	0.92	0.61

The table displays the performance of the BKT model in tracing the knowledge states of trainees within the system, based on accuracy, F-measure, and AUC metrics. The trained model achieved excellent performance in LNG Awareness courses with an accuracy score of 0.84 and F1 scores approaching 0.91. However, the AUC scores remained around 0.60, likely due to the limited size of the dataset.

The experiment results from the maritime safety training system demonstrate the practical applications of knowledge tracing models. In addition to monitoring trainee knowledge states, the model can be used to dynamically adapt learning content, resulting in a better learning experience and increased training effectiveness.

As part of future work, we aim to increase the number of interactions in the dataset through experimentation with new trainees from various experience levels and demographics. By incorporating new interactions, a more inclusive and accurate model will be trained. Consequently, this will enable personalized learning paths for trainees. In addition to that, the effects of the knowledge-based personalized training will be assessed in the system based on knowledge gain, knowledge retention, and training time.

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CUL-MAR-Skills Project: Development of Culinary Skills in Maritime

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Abstract

It seems that nutrition, which plays a major role not only in the health and physical well-being of seafarers but also in their contentment, happiness, and motivation, has not received the attention it has deserved so far. However, proper nutrition on board not only helps seafarers perform their jobs effectively but also supports them to be healthy, happy, and successful. From this point of view, the galley, where the staff have important duties in the preparation of appropriate and delicious meals, can be defined as the place where the heart of the ship beats. This study introduces an Erasmus VET Project, "CUL-MAR-Skills Project", which aims to determine the needs of seafarers regarding food and to develop a module to train next-generation galley staff who are aware of the importance of balanced and nutritious food on board for healthy and motivated seafarers, waste management for blue seas, and sustainability for a green world. It emphasizes the importance for galley staff to consider environmental and sustainability issues while preparing healthy, balanced, and nutritious food to meet the needs of the crew. The project also aims to develop training programs for professional skills in ship logistics services and maritime food supply. All in all, the project aims to provide balanced and healthy eating habits that will appeal to all maritime sector employees, starting from ships, and to train environmentally friendly chefs who will serve to create a sustainable world. The project will also help establish a tasty bridge among neighboring countries in the region while exploring common maritime and cultural heritage.*

Keywords: *Maritime, Nutrition, Seafarers, Galley, Sustainability*

1. Introduction

Food has an important place in the lives of all living things since all of them need it to survive. However, for humans, although food is primarily a means of survival, it has meanings beyond this because a balanced diet not only satisfies their hunger but also provides them with the vitamins and minerals they need to live healthily. For this reason, they need to be more conscious about their food choices and have a diet to meet the requirements of their lifestyle, job, and age. Adequate and balanced nutrition is very important for individuals to live healthy and strong lives, increase their welfare level, and improve their quality of life (1).

It is clear how much and what kind of nutrients people should take to lead a healthy life. These amounts and characteristics, which vary according to gender and age, also vary according to the calories spent by the person during the day's work, in other words, calorie needs. The calorie needs of people are proportional to the work they do. The calories needed by someone who works in an office and sits at a desk are different from the calories needed by someone who spends physical strength and is constantly on the move. The maritime profession also differs from other professions in terms of both the work done and the working environment. This situation requires that the number of calories that seafarers need to take to maintain their lives healthily should be different from desk workers. While a sailor should take 4750 calories, (2), which can be 6000 calories depending on the place he works at, [3]a desk worker should take a maximum of 2500 calories [4].

The maritime job differs from other professions not only in terms of the severity of working conditions but also in terms of the harshness of living conditions. Seafarers must be well-fed, in high spirits, and in good health to work successfully under these harsh conditions. However, seafarers work on ships where they do not have much room for movement, they stay away from land, their families, and friends for a long time, and they cannot do their favorite activities as they wish. Another problem caused by working on board is the limited access to fresh fruit, vegetables, and food. As such, there are several obstacles to their success and happiness. Fortunately, they are not impossible to overcome and can be solved with some measures. The most important of these measures is a healthy and balanced diet, which can be seen as the key for seafarers to maintain both their success and their health.

As can be seen, a healthy and balanced diet is extremely important firstly for the happiness, productivity, and efficiency of seafarers, and secondly for an effective performance onboard. This study will introduce the CUL-MAR-Skills project, which aims to address this important issue in detail.

2. Literature Review

The importance of good nutrition for seafarers has also been recognized by international organizations and some rules and regulations have been prepared in this regard. In 2006, the International Labor Organization International Labor Organization (ILO) provided comprehensive guidance on ensuring the health and medical care of seafarers. These guidelines cover a range of topics, including preventive measures to promote the health and well-being of seafarers, standards for medical facilities and personnel onboard ships, and protocols for responding to medical emergencies at sea. Additionally, the guidelines cover the rights and responsibilities of shipowners, employers, and maritime authorities in providing adequate health protection and medical care to seafarers, per international labor standards [5]. The Maritime Labor Convention has a regulation concerning the provision of food and catering services onboard ships. This regulation outlines the requirements for shipowners to ensure that seafarers receive nutritious, well-balanced meals prepared and served in hygienic conditions, considering cultural and religious backgrounds, as well as the duration and nature of their work [6].

It is important to address nutritional concerns within the maritime industry and advocate for interventions to improve dietary provisions and health outcomes for crew members onboard merchant ships. Clark, Coggon, and Cruddas (2019) studied this and questioned whether nutritional issues are underestimated in merchant ships. The research investigated the prevalence and nature of nutritional challenges faced by crew members working on merchant vessels. It also discussed factors such as access to adequate and varied food options, the impact of long voyages on dietary habits, and the potential consequences of poor nutrition on the health and well-being of seafarers [7].

Some researchers pointed out the importance of learning about dietary patterns of seafarers. They discussed the importance of exploring factors such as dietary habits, access to fresh and nutritious food onboard ships, the prevalence of malnutrition or deficiencies, and potential health implications. They claimed that it was possible to raise awareness to improve the nutritional well-being of seafarers and contribute to the broader discourse on maritime health and welfare if dietary patterns of seafarers are known [8]. An important starting point of the research related to food onboard is to investigate the nutritional status of seafarers. A study on this issue found that eating habits and dietary intakes in maritime settings are unhealthy. Seafarers consumed high amounts of meat, processed meat and eggs, frozen and canned food, sugary drinks, alcohol, and fatty and salty foods, but low amounts of fruits, vegetables, dairy products, and cereals. aboard typical ocean-going cargo ships [9].

Some studies have focused on investigating the relationship between the nutrition of certain diseases. A study that investigated the relationship between the nutrition of seafarers and metabolic syndrome and cardiovascular diseases found that malnutrition triggers these two diseases and increases stress [10]. This study also concluded that seafarers' adoption of conscious eating habits can lead to an increase in both individual and sectoral productivity, sustainability, quality of life, and improved health and well-being. In a study conducted to determine the dietary habits of Turkish seafarers on board ship, in which 60 seafarers participated, it was found that Turkish seafarers generally eat a healthy diet and pay attention to their food and drinks. According to the findings obtained from the data, it was seen that they avoided or tried to avoid the foods and beverages that they thought could be harmful to themselves as much as possible [11].

3. Methodology

The method to be used to determine the curricula of the courses to be prepared within the scope of the project will be the application of questionnaires. The stakeholders to be consulted on the subject are divided into three groups and three separate questionnaires are prepared to be applied to these groups. The first questionnaire is aimed at students and seafarers who are or have been on board. It intends to determine their current situation, problems, and expectations. The second questionnaire is prepared to understand the perspectives of the staff working in the ship's kitchen and the third one is prepared to learn the views of the employers.

Besides the questionnaires various observations and interviews were conducted during and after the preparation of the project proposal to clarify the details of the needs and to elaborate the programs exactly in line with the needs. In view of these, it is concluded that training ship cooks requires a comprehensive approach that covers various aspects of culinary skills, safety procedures, and operational knowledge specific to maritime environments. The following can be regarded as the basic considerations for developing an education and training program for marine cookery.

1. *Basic Culinary Skills*: Starting with foundational culinary skills such as knife handling, food preparation techniques, cooking methods (e.g., grilling, baking, frying), and food presentation. Ensure that ship cooks are proficient in preparing a wide range of dishes to meet the diverse tastes and dietary needs of crew members.

2. *Food Safety and Sanitation:* Emphasizing the importance of food safety protocols, hygiene practices, and sanitation standards in accordance with maritime regulations and international guidelines (e.g., Hazard Analysis and Critical Control Points - HACCP). Train ship cooks to handle food safely, prevent cross-contamination, maintain proper storage conditions, and follow hygiene protocols in the galley also consider waste management (not only for the limited stores at sea conditions but also in view of extra expenses for delivering the waste in port or high penalties for marine environment pollution if discharged improperly overboard at sea).

3. *Menu Planning and Nutrition:* Teaching ship cooks how to plan balanced menus that provide adequate nutrition for crew members working in physically demanding conditions. Incorporate principles of nutrition, portion control, and dietary requirements into menu planning, considering factors such as cultural preferences, food allergies, and special diets.

4. *Galley Operations:* Familiarizing ship cooks with the layout and equipment of the galley, including cooking appliances, refrigeration units, storage areas, and safety features. Train them to efficiently organize workflow, manage inventory, minimize waste, and maintain cleanliness in the galley while adhering to space constraints and safety regulations.

5. *Emergency Preparedness*: Providing training on emergency procedures and crisis management specific to maritime environments, such as fire safety drills, evacuation protocols, and first aid training. Ensure that ship cooks are prepared to respond effectively to onboard emergencies and assist with emergency duties as needed.

6. Cross-Training and Multi-Skilling: Encourage cross-training and multi-skilling among ship cooks to broaden their culinary repertoire and enhance their versatility in the galley. Offer opportunities for learning new cuisines, experimenting with different cooking techniques, and developing specialized skills (e.g., pastry making, seafood preparation) to expand their culinary expertise.

7. Cultural Sensitivity and Communication: Foster a culture of respect, diversity, and inclusivity in the galley by promoting cultural sensitivity and effective communication among ship cooks from diverse backgrounds. Encourage open communication, teamwork, and collaboration to create a positive working environment and ensure smooth operations in the galley. Introducing students to diverse culinary traditions, cuisines, ingredients, and cooking styles fosters an appreciation for cultural diversity and enriches their culinary knowledge. This context encourages exploration, creativity, and respect for different culinary practices.

8. Continuous Learning and Professional Development: Support ongoing learning and professional development opportunities for ship cooks to stay updated on industry trends, culinary innovations, and best practices. Provide access to training resources, workshops, seminars, and certifications to help ship cooks advance their culinary careers and enhance their skills onboard. Equipping students with essential professional skills, such as time management, teamwork, communication, and leadership, prepares them for success in a fast-paced culinary environment. This context ensures that students are not only skilled in the kitchen but also possess the soft skills necessary to thrive in their careers.

9. Industry Standards and Trends: Understanding the current landscape of the culinary industry, including emerging trends, evolving consumer preferences, and industry standards, is crucial. This context ensures that the curriculum remains relevant and prepares students for real-world challenges.

10. Creativity and Innovation: Encouraging culinary creativity and innovation within the curriculum empowers students to experiment, develop their unique culinary style, and push the boundaries of traditional cooking techniques. This context fosters a spirit of creativity and entrepreneurship among aspiring chefs.

11. Ethical and Sustainable Practices: Incorporating lessons on ingredient sourcing, sustainability, ethical considerations, and environmental stewardship instils a sense of responsibility and awareness in students. This context emphasizes the importance of ethical and sustainable practices in the culinary industry and encourages students to make informed choices.

12. Experiential Learning: Providing hands-on learning experiences, such as cooking labs, kitchen simulations, culinary competitions, and internships, allows students to apply theoretical knowledge in practical settings. This context enhances learning outcomes, builds confidence, and prepares students for real-world culinary challenges.

4. The Aim of the Project

CUL-MAR-Skills Project aims to create a new, innovative, and joint curriculum to provide the participants with a sound education and training based on three pillars.

- The first of them is to promote healthy nutrition on board, which will give the participants an outline of the framework for proper nutrition on board and menu planning in addition to raising awareness of seafarers on proper nutrition.
- The second pillar consists of basic education for the victualling services and food logistics on board the ships, which will provide the participants with knowledge on supply chain management for the galley, how to prevent food waste on board, and how to be environmentally friendly in the galley, in addition to providing them with entrepreneurship and management skills with an emphasis in victualling services. It focuses on equipping students with the necessary tools and competencies needed to come up with creative and innovative ideas to be both entrepreneurs and intrapreneurs in the maritime sector.
- The third pillar focuses on culinary arts, which covers the activities to give students cooking skills with an emphasis on marine cuisine. To realize this, creative maritime culinary recipes reflecting the rich cultural heritage of the region will be used as a medium while teaching students the basics of culinary art. They will also research and find forgotten ship cuisine-specific recipes so that culinary practices can be based on these recipes. Despite its rich cultural background, traditional ship cuisine has been neglected.

Another aim of this project is to revitalize this cuisine and to compile a booklet of maritime cuisine recipes specific to the geographical area where the partner countries are located to preserve the cultural heritage of the maritime cuisine specific to the area. Enhancing the creativity of the participants, providing them with entrepreneurial and managerial skills, boosting friendship among nations, and sharing cultural heritage is only possible through the cooperation and interaction of the youth. Since they will work together in the galleys, there will be an emphasis on teamwork as well as cultural interaction, which naturally, increases creativity.

Over and above this, eventually, the Project will contribute to the motivation of the seafarers positively. Seafarers work under very unique conditions, that's why it is necessary to relax and boost their mood with something they like - good nutrition and delicious food is something that not only keeps them healthy and strong but also boosts their morale and makes them feel good.

CUL-MAR-Skills Project aims to achieve the following objectives and produce the following concrete results. The overall objective of the project is to provide the students/people with education and training on basic nutrition and culinary skills with an emphasis on maritime cuisine, as well as to give them basic knowledge on the logistics of supply to meet the supply-demand of the galley while gaining skills for entrepreneurship and increasing their awareness for environment protection & fighting against marine pollution. These skills are those that can help them to be employed easily and give them a chance to have a job anywhere in the maritime sector.

This objective will be realized in three steps.

The first step is to create a curriculum for a common maritime healthy nutrition course. The partner in charge of this objective will work together with the other partners to decide on the topics to take place in this course. It will be accompanied by video tutorials where necessary.

The second step will be to provide the students with education and training upon which they can build competence by taking the necessary steps to be experts in victualling, to have an entrepreneurial mindset, and to train students to be conscious about environmental protection and waste management, thus contributing to the protection of clean and blue seas. These three topics will be given in three different courses. These pieces of training given in the module are the first steps to be taken by a person who aims to work in the galley onboard a ship.

Apart from the courses, the project also aims to produce a booklet that will give a healthy compilation of the popular recipes used onboard ships throughout history; thus, helping the cultural heritage to live longer. The booklet will contain a unique combination of recipes peculiar to the maritime sector. With this feature, the project will undertake an important task for the protection of cultural heritage and help increase the creativity of the students in cooking, which is an art.

On the other hand, there is a lack of qualified employees in the maritime sector, esp. when it comes to cooks working onboard. The project will meet labor market needs and provide students with the skills to work in the ship's galley and help to close the shortage of employees in the maritime sector while reducing unemployment among young people. The project will also increase the flexibility of opportunities in vocational education and training since the participants with basic culinary education can find jobs in all sectors. All in all, the concrete results we would like to produce are 5 courses to train and educate the students and a cookbook for sustaining maritime culinary heritage while the long-term objective is to give the students another job alternative onboard and the unemployed a chance to have a job.

5. Innovative Aspects of the CUL-MAR-Skills Project

The project will combine both cooking skills with an emphasis on maritime cuisine including healthy nutrition and food supply chain management on board for proficient victualling with core entrepreneurship and management skills to be efficient staff on board. It aims to prepare a training program consisting of five courses. It will focus on a larger spectrum such as health nutrition, the logistics of supply for planning the course menus that is for the galley in general, victualling services, and culinary arts for merchant ships, the Navy, and Cruise lines. The course will be a blend of the basic courses to be a proficient cook with an emphasis on marine cuisine and the courses that are the first steps to being an employee in the maritime sector, esp. seafarers with basic knowledge on entrepreneurship, supply chain management, and management in general. It also aims to prepare a maritime cookbook to contain recipes that reflect the culture of the participating countries. In this way, it will prevent their maritime culinary culture from fading away. Beyond all this, the most powerful feature that distinguishes the project from its peers may be to provide the participants with a virtue, an entrepreneurial mindset, which is one of the indispensable features of the 21st century, perhaps the most important one.

The most innovative aspect of the project is that it provides basic knowledge in areas that have not been covered much in the maritime sector and aims to provide participants with skills in key areas such as cooking, supply chain, management, and entrepreneurship and make them sought-after employees who will work in a limited space such as a ship.

Another innovative feature of the project will be the creation of a booklet that will contain maritime cultural heritage for culinary.

The project will create synergy among different fields of education, training, and youth. Firstly, the special curricula for maritime victualling and culinary skills supported by 21st-century skills such as entrepreneurship and supply-chain or waste management will be designed to be used in the first module of the training to be given in the maritime schools in the partner countries. An important feature of this course is that it will include online materials. Therefore, anyone who wants to take the first steps to be a proficient worker in the maritime sector but cannot attend a school to realize this aim will be able to be familiar with the prerequisite of the job and can get further education and training in the related institutions easily. It can even be taken by staff working onboard.

The second step will be to design courses to give basic education in key maritime-related fields that can pave the way for the participants to get further education to work onboard ships.

The third step will be to prepare an entrepreneurship course to give the participants basic knowledge on how to prepare a business plan. A competition will be held among them to give basic concepts of commercialization of an idea, get ready to take risks, and prepare them for future challenges. The training will be transferable to other fields, so will be adaptable to other training activities a part of which requires soft skills enhancement.

Additionally, in the frame of the curriculum creation studies, the collection of recipes, especially those belonging to traditional maritime cuisine, will be compiled. This activity will also help the cultural heritage of maritime cuisine to be kept alive. In this way, skills development and competencies that reinforce creativity will be enhanced. The creative potential of the people will be triggered.

The project will also reinforce the cultural awareness of all citizens since cuisine is a part of national culture, and it will facilitate social inclusion through culinary arts, and foster intercultural dialogue.

Finally, the project will help women find a job onboard so it will contribute to the promotion of gender equality. All in all, the project aims to furnish the students with skills and competencies to find a job esp. as kitchen staff in the maritime sector, which is full of job opportunities for cooks and there is a huge need for books containing nutritious recipes for seafarers. Since the project will combine culinary and maritime education with an emphasis on entrepreneurship, it is expected to have a strong impact on maritime culinary education and training.

On the other hand, it has the potential to create synergies between different fields of education, training, and youth since it will both help raise awareness of the youth about working as a galley staff on board and collaboration of instructors in various fields to train and educate able maritime staff. The staff will plan to combine their unique efforts with the jointly chosen aim of educating and training staff, esp. for the galley but generally to work on board.

6. Added values that the project can provide

A competitive, resilient, and socially fair blue economy needs highly qualified and skilled professionals. Many blue economy sectors have difficulties finding the right people, which hampers their growth. The European Commission is supporting actions to solve this mismatch that aim to:

- reduce the skills gap between education offers and labor market needs
- improve communication and cooperation between education and industry
- improve the attractiveness and awareness of career opportunities in the blue economy
- improve the ocean literacy culture at the basis of it all.

A career development model for the blue economy, which should contribute to faster and more efficient blue growth by incorporating high professionalism, innovative skills, and capacity requires innovative approaches, cooperation in all related fields, and professional guidance, for building a model for personal development through any career in the blue sector. It is of great importance to develop a brotherhood among people, to ensure intercultural approach and cooperation, and to solve possible problems. People from different nationalities and cultures, speaking different languages and having different eating habits, need to get to know each other, to make friends, and to benefit from the world's blessings jointly. This leads to another aim of the project which is to develop international cooperation and to create common modules based on seafaring cuisine supply-chain management, procurement for victualling, and entrepreneurship. The point that should be noted here is the purpose of the project is not to teach how to cook seafood, but to create a common culinary module based on the characteristics of the maritime cuisines of different countries in addition to providing participants with 21st-century skills for better employment opportunities, especially on board. What is more, intercultural interaction will be provided with the unifying feature of food, which is the common need of every living thing.

7. Result and Discussion

Nutrition has an important role not only in protecting the health of seafarers but also in improving their performance, keeping them fit, and keeping their morale high. It is known that malnutrition can lead to fatigue, low morale, diabetes, and various diseases. When malnutrition occurs on board a ship, the harmful effects will be multiplied due to the harsh living conditions there. The fact that the nutrition of seafarers is so important has increased the importance of the ship's cooks and galley staff who will ensure proper nutrition and created the need to train and educate galley personnel who are aware of the importance of good and balanced nutrition, who know the food groups that seafarers need, how often they should be consumed, and who can cook meals that can be enjoyed by all seafarers living together from different cultures. Today, the expectations from kitchen staff are not limited to simply cooking good food. They are now expected to be aware of sustainability, pay attention to hygiene, be knowledgeable about food storage, and follow developments in nutrition and health.

The main aims of the CUL-MAR-Skills Project are to raise awareness among participants on healthy nutrition at sea, provide them with the necessary supply chain knowledge for a ship's galley, and equip them with entrepreneurship, management, and basic cooking skills, as well as provide cultural interaction and prevent the loss of cultural prosperity. The project will certainly train and educate ship cooks who can effectively speak the common language spoken by all seafarers, the language of food, and who have a green mindset that will ensure that the blue seas will remain blue forever.

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Section 8
Maritime Policy, Law & Governance, Maritime Economy

Assessment of Turkish Commercial Ports in The Context of Sea Power Strategy

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Abstract

Ports contribute significantly to economic prosperity through their cultural contributions and facilitation of trade among various nations. Türkiye's strategic location between Asia and Europe grants its ports a pivotal role in global trade. The structural features, capacities, and operational efficiencies of ports are critically important at both national and international levels for trade and strategy.

Starting from the premise that Turkish commercial ports act as critical actors in national and international trade, this study delves into the contributions of ports to sea power strategy and operational efficiencies in this context. Traditionally approached from a military perspective, sea power strategy is re-evaluated in this work through the lens of civil commercial ports. The research conducts a comprehensive literature review and analysis of existing reports on various aspects of Turkish ports, including their structural features, capacities, technological advancements, and security measures. This analysis aims to ascertain the readiness of ports to face contemporary maritime challenges. Furthermore, it assesses the economic, political, and environmental factors that could influence port operations and strategic significance. The study aims to analyze the current role of Turkish commercial ports in the sea power strategy.

Keywords: *Sea Power, Ports, Maritime Economy, Türkiye, Shipping*

1. Introduction

Seas have always been of central importance to international policy and strategy, exerting a profound influence on the socioeconomic and cultural dynamics of civilizations. Access to the seas, viewed as both an economic necessity and a strategic advantage, has historically explained how nations dominant over the seas have achieved a commanding position on the global stage. The seas offer numerous advantages including the provision of natural resources, facilitation of international trade, and cross-cultural information exchange. Within this extensive range, ports emerge as the lifeline of international trade, playing a critical role in the transfer of goods and passengers, and serving as significant indicators of economic development and national power. In the modern era, technological and logistical innovations enable ports not only to offer cargo handling and storage services but also to provide a variety of value-added services, making substantial contributions to national and regional economies.

Türkiye possesses significant potential in the maritime sector due to its strategic location and geographical features. Serving as a strategic bridge between Europe and Asia and surrounded by seas on three sides, Türkiye holds a central role in maritime transportation and port operations. This strategic position enhances Türkiye's economic and strategic importance, reinforces its position in global maritime trade, and plays a decisive role in national prosperity. Maritime power encompasses the relationships established with seas and oceans, including both military and civilian dimensions, with pillars such as maritime trade and naval forces determining a nation's international efficacy and capacity. In this context, Türkiye's strategic position and vast potential in the maritime sector are of critical importance for economic development strategies and international relations. The effective utilization of maritime power, shaped through seas and ports, serves as a fundamental element for future economic and strategic planning.

2. Seas

Seas have always been of central importance to international politics and strategy. Throughout history, the influence of maritime activities and the seas themselves have laid the foundation for the socio-economic and cultural dynamics of great nations [1]. This is corroborated by their contributions to the evolution and growth of civilizations over the ages. The seas have played a critical role in the development and expansion of civilizations throughout history [2]. Access to the seas provides not only an economic advantage but also a strategic one for nations. This advantage explains how certain states have come to dominate the global arena over historical periods. It has been observed that, historically, states with access to the seas have played a more dominant and active role compared to those confined to land. A review of traditional maritime strategies reveals that states efficiently utilizing the seas have maintained a more dominant position on the global stage [3].

As pointed out by Till [4], the seas offer numerous advantages to humanity. They are particularly important in the provision of natural resources, serving as a conduit for international trade, facilitating intercultural knowledge transfer, and defining national sovereignty areas. These characteristics not only highlight why the seas have been so valuable throughout history but also demonstrate that the seas offer more than just physical advantages; they also shape political and economic dynamics on a national and global level. For centuries, the seas have been a significant factor affecting the welfare, security perceptions, societal behaviors, and foreign policies of states. Furthermore, the maritime industry plays a key role in connecting states economically with the world. While international relations literature often focuses on the strategic aspect of sea supremacy, critical components such as maritime economy and maritime studies are frequently overlooked [4]. While seas cover a large portion of the Earth's surface, a significant portion of the world's population lives along coastlines. Moreover, a large percentage of global trade is conducted over the seas. These factors necessitate nations to prioritize their naval power and maritime security [2]. In recent times, the global economy has become more integrated, and the last four decades have seen a significant increase in sea-based trade. A substantial portion of world trade and the majority of oil transportation are conducted via sea routes [5]. It should not be forgotten that the seas are important not only for economic activities but also for strategic and power balance considerations. The seas have always retained their economic value. According to some experts, the primary objective of naval conflicts is to limit the economic advantage gained by the enemy through sea routes [6].

3. Maritime Power

Maritime power encompasses a broad concept involving the use of the sea for both civilian and military purposes; it includes military, political, and economic activities related to the utilization of the sea [7] [8]. Delving deeper into this concept, we observe that maritime power encompasses all of a nation's capacities related to the sea. The benefits derived from the seas by states are materialized through warships and merchant vessels, supported by ports, bases, the shipbuilding industry, and maritime personnel. These components collectively constitute Maritime Power [9][10]. Maritime power represents the process of evaluating and utilizing a nation's tangible and intangible resources and capabilities related to the sea and maritime activities, in alignment with national interests, and the development of this potential. This concept includes all elements of power connected to the sea and maritime activities, aiming for the management of these elements in the most beneficial way for national interests [11]. Maritime power is a system that encompasses the various concrete and abstract capabilities provided by the seas and transforms these capabilities into national power. The relationships we establish with the seas and oceans, including their military and civilian dimensions, are examined within this framework. While maritime trade and naval forces form the cornerstone of maritime power, other factors directly or indirectly related to maritime activities also play a role in this structure [12].

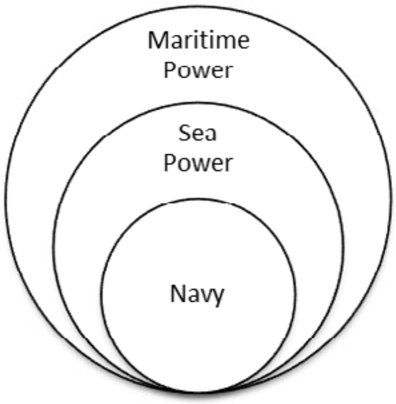


Figure 1. Maritime power scope [13]

4. Sea Power

Sea power can be considered a component of maritime power, particularly encompassing coastal structures and institutions directly associated with the sea. This conceptual framework reveals the impact of maritime activities on coastal regions and how the relationship between maritime affairs and the coast is shaped [11]. The concept of power in maritime affairs has deep historical roots, stretching back around 2500 years to the era of Ancient Greece. The historian Thucydides (460-395 BCE) asserted in his works that the protection of sea trade was critical for the security and prosperity of a state. According to him, sea power was an essential component in achieving national military and political objectives [14]. The notion of sea power emphasized by Thucydides has occupied a central place in the strategic planning of many states throughout history. Since the Ancient Greek period, this significant concept has been further explored by Western states, aiding them in establishing their maritime hegemony. For the effective realization of sea power, land-based elements that support sea power, such as ports, shipyards, shipbuilding industries, maritime companies, and educational institutions, must also be strengthened. This demonstrates that sea power is not limited to the domain of the sea alone, but is deeply interconnected with the elements situated on the coast [15].

5. Ports

In modern international commercial transportation, ports stand out as one of the most vital elements of maritime logistics. They are defined as service areas equipped with all the necessary infrastructure and facilities to safely transfer goods and passengers between ships and other transportation means, or to store cargo, thereby enabling the execution of associated economic functions [16]. Maritime transportation has a history that spans approximately five thousand years [17]. Historically, ports primarily served as facilities providing shelter to ships, but today they have transformed into members of the supply chain offering value-added services (such as packaging, storage, assembly, etc.). Within this chain, ports collaborate with a variety of actors to ensure coordinated flow of cargo and the associated information. Ports emerge as significant indicators of a country's level of economic development; the number and capacity of ports serve as crucial metrics of a nation's power and competitive ability. As a link in the transportation chain, ports have been offering logistic services in recent years, contributing substantially to the economies of their countries, aiding the growth of regional industry, and fostering the advancement of trade [18].

Various studies in the academic literature are dedicated to analyzing the contribution of ports to a country's economy. Berköz and Tekba [19] conducted a multiple regression analysis to analyze the relationships between the Gross National Product of the provinces where ports are located and variables such as port length, total cargo, exports and imports, number of ship calls, number of employees, and stock capacity. The study concluded that there is a high correlation between the total cargo, exports and imports, and the number of ship calls with the cities' Gross National Product. Ferrari et al. [20] measured the relationship between ports and employment using econometric analysis methods and identified a positive correlation with regional development. Cong et al. [21] examined the relationship between 16 port cities in China and urban economy between the years 2000-2016 using panel data analysis methods. The results of the study determined that port business volume has a significant impact on the Gross Domestic Product.

Türkiye's coastline, totaling 8,333 kilometers, is composed of 2,805 kilometers along the Aegean Sea, 1,795 kilometers by the Black Sea, 1,577 kilometers on the Mediterranean, and 927 kilometers bordering the Sea of Marmara. The latter is notably significant, hosting the bulk of the country's key commercial ports and positioned at the crossroads of major international maritime routes, especially manifest in the extensive operations of the Marmara Sea ports [22]. These ports facilitate not only domestic commerce but also serve as vital gateways for international trade, benefiting from the strategic thoroughfare provided by the Marmara region, including the critical link of the Marmaray undersea rail tunnel which enhances connectivity and trade flow between the European and Asian sides of Istanbul.

In the Mediterranean, the ports of İskenderun, Mersin, and Antalya are the main commercial hubs stretching from east to west, serving as vital arteries for regional trade. The İskenderun Port, with its wide-reaching hinterland connections and strategic position, has evolved rapidly. It serves as the gateway for exports from Southeastern and Eastern Anatolia. The Port of Mersin is one of the fastest-growing due to its geographic location, capacity, and hinterland advantages, making it not only a significant port for Türkiye but also for the Middle East and Eastern Mediterranean. Although the Antalya Port holds less significance in volume compared to Mersin and İskenderun, it plays a key role in the export of fresh fruits and vegetables and is also utilized for tourism purposes.

The Aegean Sea hosts key ports including İzmir, Aliağa, and Çanakkale. İzmir Port, with its substantial handling capacity and traffic, stands as the largest in the Aegean region and a pivotal exit point for Türkiye export products. Aliağa's ports are among the region's rapidly developing facilities, witnessing a continual increase in operational volume.

The Sea of Marmara is home to critical ports such as the Port of Istanbul, the largest in Türkiye in terms of cargo and passenger traffic and engaged in various international trade activities, and serves as a hub connecting the Black Sea to the Mediterranean. Izmit, Derince and Bandırma are also important ports on the Marmara Sea and in the country, with Izmit increasingly becoming an export and import hub due to its industrial activities and petrochemical facilities.

The Black Sea ports, with Zonguldak as the main trade port particularly for coal, and Samsun as a central hub facilitating cargo transit from Balkan and Central European countries to the Middle East and Central Asia, reflect the industrial and commercial vibrancy of the region. Trabzon Port stands apart with its strategic importance for trade transiting through Iran, further highlighted by its connectivity via the Zigana Pass.

5.1. Türkiye's Cargo Handling Volume

The handling data from 2003 to 2023, demonstrating the progression in cargo volume at Türkiye ports, is depicted in Figure 2.

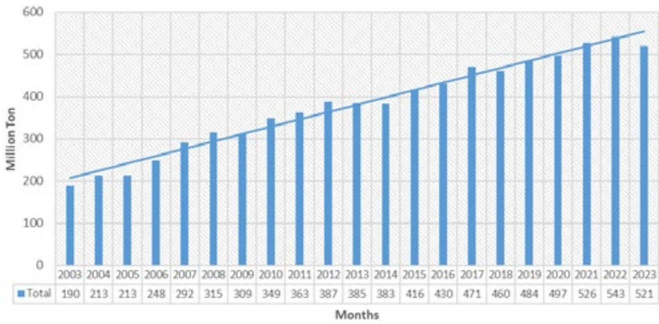


Figure 2. Handled at Türkiye Ports (according to total tons) [23], [24].

When examining the data from 2003 to 2023, a general upward trend in the volume of cargo handled at Türkiye ports is apparent. This increase correlates with the growth of Türkiye's industrial production and the expansion of its import and export capacities. Particularly after 2010, the acceleration in cargo volume can be interpreted as a result of investments in infrastructure and enhanced logistical capacity. Furthermore, the fluctuations caused by the global pandemic in 2020, and the continued trend of cargo volume increase despite this, demonstrate Türkiye's resilience and adaptability in maritime trade. From a naval power perspective, Türkiye's strategic location on major maritime trade routes is a significant factor contributing to this increase. Therefore, the volumes of cargo handled at ports are indicative not only of Türkiye's economic progress but also of its strategic maritime strength.

The data showing the volume of cargo handled according to the customs regime between 2003 and 2023 is presented in Figure 3.

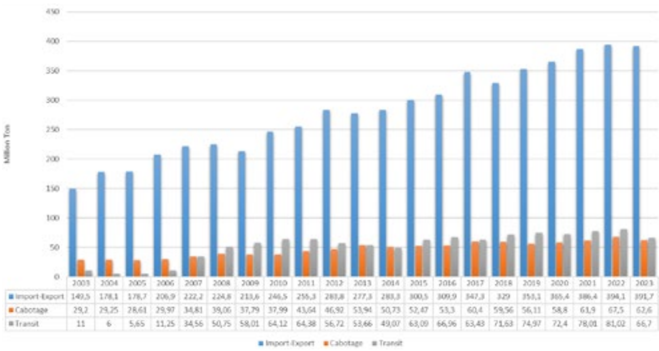


Figure 3. Cargo handled at Türkiye Ports (according to customs regime) [23],[24].

The data delineated in the chart presents a comprehensive overview of cargo traffic through Türkiye ports, categorized by import-export activities, cabotage, and transit from 2003 to 2023. A discernible increment in import-export cargo manifests the intensification of Türkiye's international trade engagements. Such an uptrend indicates a robust industrial sector that continually responds to global market demands, facilitated by the strategic expansion of port facilities and maritime infrastructure.

Cabotage operations, reflecting the national maritime traffic, exhibit fluctuations that could be attributed to internal market dynamics and possibly the regulatory framework governing coastal trade. The observed variations necessitate further scrutiny to understand the underlying factors affecting domestic maritime transport.

Transit cargo, a marker of Türkiye's intermediary role in international logistics, notably peaks and dips, suggesting variable utilization of Türkiye's transit potential. This underlines the geopolitical significance of Türkiye's maritime corridors as conduits of cross-continental trade flows.

The aggregate growth trajectory of cargo volumes handled underscores the strategic evolution of Türkiye's commercial ports within the broader ambit of maritime power. This growth is not merely indicative of increased trade volumes but also of a deliberate strategy aimed at harnessing Türkiye's unique geographic leverage. Enhancing port throughput capacities is reflective of concerted efforts to bolster Türkiye's standing in maritime logistics, which in turn contributes to its economic fortitude and geopolitical influence. These dynamics assert Türkiye's ports as critical nodes in the global maritime trade network, embodying the nation's ascent in maritime strategy development.

5.2. Cargo Handling Volume in the World and Türkiye

The graph showing the total handling in the world and the total handling in Türkiye is displayed in Figure 4.

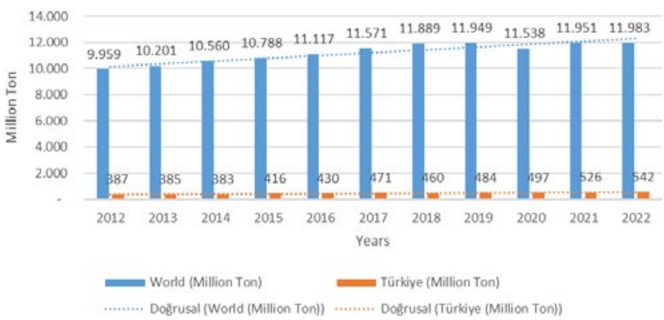
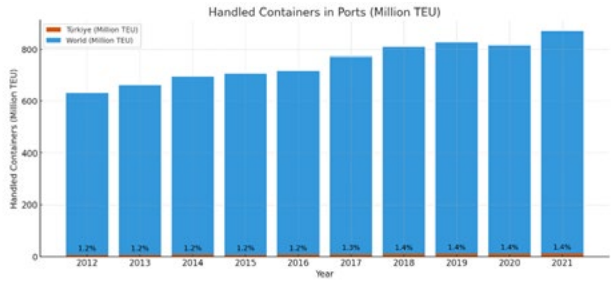


Figure 4. Graph of cargo handled in Türkiye and the World (2012 – 2022) [23], [24].

Between 2012 and 2022, the global volume of cargo handled increased from 9.959 million tons to 11.983 million tons, indicating a growth of 20.3% during this period. In Türkiye, the volume of cargo handled rose from 387 million tons to 542 million tons, showing a significant increase of 40.1%. Throughout this time, Türkiye's share of the globally handled cargo volume grew from 3.90% to 4.50%. These figures demonstrate that the increase in cargo handling capacity in Türkiye exceeds the global average and that the share of cargo handled at Türkiye's ports is progressively increasing. This analysis highlights the necessity of investments in Türkiye's port infrastructure and its strategic position to play a more pronounced role in international transportation networks.

The graph displaying total container handling data in Türkiye and the world is illustrated in Figure 5.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
World (Million TEU)	630.1	661.4	694.2	705.6	716.4	771.7	810.1	825.3	815.6	868.6
Türkiye (Million TEU)	7.3	8.0	8.4	8.2	8.9	10.2	11.1	11.6	11.7	12.5

Figure 5. Graph of the amount of containers handled at World and Türkiye ports [23], [24].

Between 2012 and 2021, the amount of containers handled in ports worldwide increased from 630.1 million TEUs to 868.6 million TEUs, marking a 37.8% rise. During the same period, the volume of containers handled in Türkiye rose from 7.3 million TEUs to 12.5 million TEUs, reflecting a 71.2% increase. Throughout this period, Türkiye's share of the global container throughput elevated from 1.2% to 1.4%. This growth, especially for Türkiye, underscores the necessity of investing in port and infrastructure improvements, as well as the need to assume a more competitive and effective role in international trade. The increase in Türkiye's container handling capacity signals its potential to become a significant hub within global trade corridors by leveraging its strategic location. Moreover, this development highlights the importance of efficiency in Türkiye's maritime power strategy and port management in strengthening its position within global logistic chains. Therefore, to achieve sustainable economic growth and increase its share in international trade, it is imperative for Türkiye to continue its investments and strategies in this area. This will contribute to facilitating trade at both national and international levels and support economic development.

The detailed monthly analysis of Türkiye for the years 2023 and 2022 following the pandemic is shown in Figure 6.

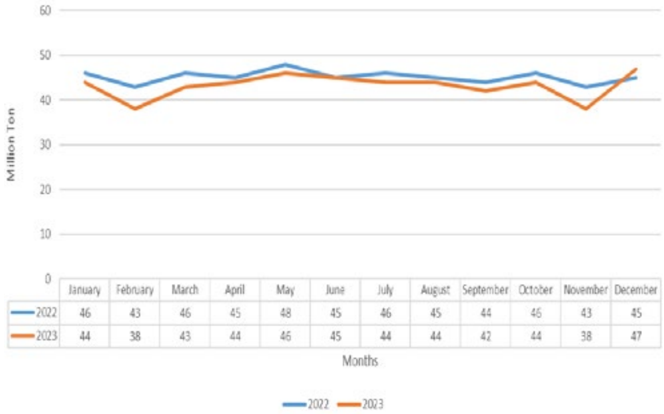


Figure 6. 2023 and 2022 Türkiye Cargo Handling Graph [23],[24].

When examining the period between 2022 and 2023 on a monthly basis, the changes observed in the monthly cargo handling statistics at our ports indicate an annual decrease of 3.4%. While the total amount of cargo handled in 2022 was 543 million tons, this figure dropped to 526 million tons in 2023. Particularly, a decrease of 11.6% was observed in both February and November, while December was an exception, showing an increase of 4.4%. During this period, February and November witnessed the most significant declines, with an average decrease of 1.5% occurring in the other months of the year.

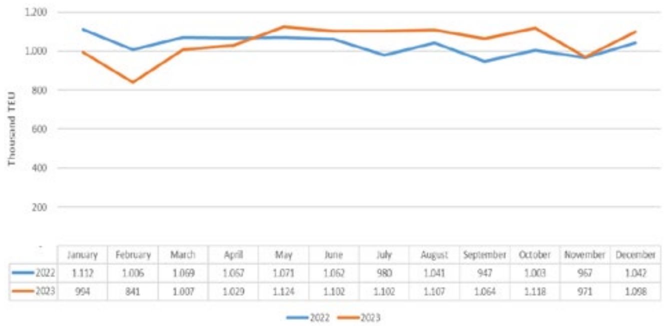


Figure 7. 2023 and 2022 Türkiye Container Handling Graph [23],[24].

In 2023, the container handling volumes at our ports displayed a variable performance when compared with the previous year, quantified in TEUs. The first quarter witnessed a 10.83% decrease to 2,842 TEUs compared to the same period of the previous year, whereas the second quarter saw a 1.72% increase to 3,255 TEUs, the third quarter a 10.28% increase to 3,273 TEUs, and the fourth quarter a 5.81% increase to 3,187 TEUs. The total throughput for 2023 showed a cumulative increase of 1.54%, handling 12,557 TEUs compared to 2022. On a monthly basis, the largest decline was recorded in February with a 16.4% decrease, while July exhibited the highest increase at 12.45%, marking a year of fluctuating trends.

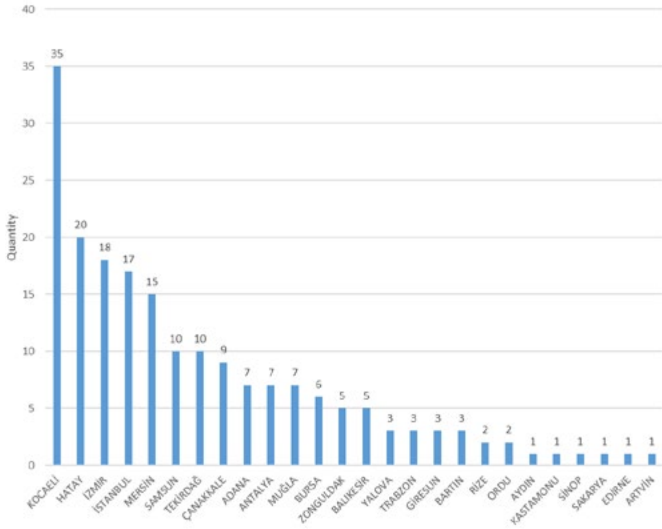


Figure 8. Number of Ports in Türkiye Cities graph [23],[24].

Port operations in Türkiye are classified into various categories, including Ferry/Passenger Services, General Cargo, Bulk Cargo, Petroleum Products, Ro-Ro, Chemical Tankers, LPG/LNG, Containers, and Others. This classification underscores the diversity of maritime activities and highlights their pivotal role in facilitating trade and transportation. Among Türkiye cities, Kocaeli stands out with a total of 35 port operations, reflecting its strategic importance as an industrial and shipping hub, likely due to its proximity to major trade routes and industrial areas. Following Kocaeli in the number of ports are Hatay with 20, İzmir with 18, İstanbul with 17, and Mersin with 15, indicating their significant contributions to maritime trade, likely influenced by their geographic positioning, economic scale, and industrial infrastructures. The presence of only one port in cities such as Aydın, Kastamonu, Sinop, Sakarya, Edirne, and Artvin suggests that maritime operations are not a primary economic focus there, potentially due to limited industrial activities, smaller-scale economies, or geographical limitations that do not support large-scale port operations. The distribution of permits among cities provides insights into the focus on maritime operations and highlights the potential for enhancing Türkiye's maritime industry and regional economies.

In Türkiye, the authorization of port operations is conducted through permits issued by the Ministry of Transport and Infrastructure and is regulated under the "Regulation on Operating Permits for Coastal Facilities and Coastal Facility Operators." The distribution of permits is underpinned by specific conditions and full regulatory compliance. Within this framework, there are 192 coastal facility operating license documents. This document ensures a standardized approach to maintaining safe, secure, and efficient maritime operations in line with Türkiye's strategic transport and economic objectives.

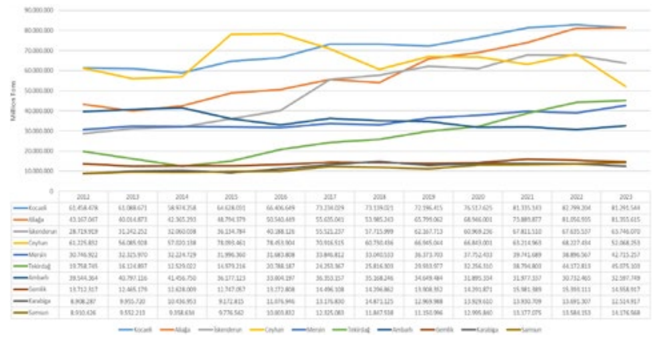


Figure 9. Port handling graph based on cities [23],[24].

Over the past decade, Türkiye's premier ports have registered impressive growth; Kocaeli and Aliağa more than doubled their throughput, mirroring the focused expansion in Türkiye's port infrastructure to meet increasing trade demands. İskenderun also showed significant growth, while Mersin and Tekirdağ substantially boosted their capacities, accentuating their roles in Türkiye's maritime trade. This robust expansion at Türkiye's leading ports underscores the nation's rising prominence as a key maritime hub in the region.

6. Conclusion

Türkiye's ports have not fully leveraged their advantageous position in the Mediterranean to become main transshipment hubs in the global container transport, a sector where a significant portion of world container traffic, approximately 25%, utilizes the Mediterranean corridor. The global long-distance container transport between Far Eastern and European countries mainly passes through the Eastern Mediterranean, Suez Canal, and the Red Sea, primarily serviced by main ports like Malta, Piraeus, Limassol, and Alexandria. Moreover, ports like Damietta and Port Said in Egypt, Haifa in Israel, Limassol and Larnaca in Cyprus, Valletta in Malta, Piraeus in Greece, and Ravenna in Italy stand out as key transshipment hubs. For Türkiye to enhance its maritime standing, there is a need for infrastructure improvement and service quality enhancement in its ports to facilitate a more significant role in global trade.

The enhancement of cabotage maritime transportation's appeal over road transportation in Türkiye is set to steer industrial firms towards shipping their products by sea, leading to an increase in handling operations at ports. This shift offers significant opportunities across various dimensions: economically, through cost advantages and the strengthening of the national economy; environmentally, by contributing to sustainability goals with lower carbon emissions; and operationally, necessitating the development of port infrastructure and operational capacities. This process not only boosts the efficiency of port operations but also strengthens Türkiye's position in global trade and marks a significant step towards sustainable development. Making short-distance sea transportation attractive is of vital importance for the strategy of maritime power, necessitating cooperation and coordination among industrial firms and all relevant stakeholders.

The development of ports resistant to earthquakes necessitates the promotion of investments with government support, the extension of operational periods for private ports, standard checks conducted by independent firms, simplified zoning permits for vulnerable structures, and backing for management and capacity enhancement initiatives. In the Marmara region, environmental regulations supportive of port projects and inter-ministerial collaboration are essential. Given Türkiye's significant earthquake risk, it is crucial to increase the resilience of coastal and port facilities through thorough evaluations and strengthening actions undertaken by independent engineering firms, reforming port insurance laws, encouraging strategic investments, and providing public support. This strategy demands a comprehensive approach supported by legal and regulatory frameworks.

In Türkiye, considering the extensive processes encompassing planning, project development, permitting, construction, and commissioning phases for accelerating and facilitating port investments, the early extension of existing port usage and operation contract durations is of significant importance. Specifically for private ports, it is understood that current short contract durations economically hinder additional investments, potentially adversely affecting the country's port capacity expansion and, consequently, its external trade competitiveness.

The increase in industrial production in Türkiye directly impacts the development of the maritime sector, necessitating the more frequent and voluminous transportation of both raw materials and manufactured goods by sea. This scenario mandates the creation of long-term state plans that encompass integrated intermodal transportation from production to port and maritime transport. Such planning should include the expansion of fleet capacity, the development of port infrastructures, the implementation of legal and financial support policies, and the identification of strategic steps to strengthen Türkiye's position in the international maritime sector.

Global Terminal Operators (GTO), with their robust financial structures and investments in innovative technologies, hold a key role in port management worldwide. These operators, through their strategic positions in international transportation networks and their ability to swiftly forecast and implement sectoral developments, continually enhance their efficiency and profitability. Particularly in countries with strategic locations like Türkiye, the impact of GTO significantly shapes the dynamics of both local and global trade. The activities of Türkiye-origin companies such as Yılport Holding, Global Ports Holding, Arkas Holding, and Ekol Logistics in the international arena not only reinforce Türkiye's position in global trade but also provide competitive advantages on a regional and global scale. In the 21st century, an era of information and innovation, the integration of these operators into the sector and their innovative strategies are of vital importance for sustainable growth and competitiveness. In this context, Türkiye's port management sector must continue to be an integral part of global trade networks, making moves to further enhance its competitiveness in international markets.

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Random Shocks and Their Effects on Black Sea Maritime Trade Between 2008 and 2023

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Abstract

Maritime transportation, which is a component of the blue economy concept, is the main contractor of the global supply chain and is the most preferred transportation mode. For this reason, the mentioned sector is very sensitive to external influences and is one of the sectors primarily affected by external factors such as war, natural disasters and economic crisis. The aim of this study is to examine the random shocks that occurred between 2008 and 2023, analyze their effects on the Black Sea maritime trade. The data set used in the study is Turkey's maritime import and export data with the Black Sea countries and was taken from the statistics published by the General Directorate of Maritime Affairs. Frequency analysis, qualitative data analysis and Census X-13 ARIMA analysis methods are used to analyze the data. Frequency and qualitative data analysis revealed that Turkey's exports to the Black Sea countries decreased after the 2008 Global Financial Crisis. When import data are analyzed, it is found that Turkey's imports with Russia and Ukraine decreased after the Covid-19 pandemic. After the Russia-Ukraine war, Turkey's foreign trade with Russia reached its peak in 2023, while its foreign trade with Ukraine reached its bottom.

Keywords: *Random Shocks, Maritime Trade, Black Sea, Maritime Transportation.*

1. Introduction

Maritime transport, which is of vital importance for the sustainability of global trade and connects global markets, is one of the main functions of the supply chain. This type of transportation contributes to economic growth and employment both at sea and on land [1]. Maritime transportation is classified and divided into subsectors in various aspects, taking into account factors such as ship type, distance, stability, cargo characteristics and geography [2]. The Black Sea region is an important area with growth potential for maritime transport. It is also located in important transport and energy centers [3]. The share of the Black Sea region in international maritime trade is 2.5% [4]. The Black Sea coast has 56 ports that contribute to the economic prosperity of this region and make the Black Sea one of the world's busiest trade routes [5]. The ports with the highest container handling capacities are Constanta, Novorossysk and Odessa. Strategic products such as coal, grain, oil, fertilizer, timber and iron ore are shipped through Black Sea ports [6].

However, maritime transportation is vulnerable to external factors and is affected by random shocks [7]. Random shocks are events that are beyond the control of the business but directly affect the business. Economic disturbances, wars, political events, pirate attacks, epidemics, strikes and revolutions are referred to as random shocks [8]. Examples of random shocks affecting maritime trade globally in recent years are 2008 - Global Economic Crisis or Great Recession, 2019 - Covid 19 Pandemic and 2022 - Russia Ukraine War in the Black Sea region. Table 1 shows the random shocks that occurred in the Black Sea region between 2008 and 2023.

Table 1. Random Shocks in the Black Sea Region

Yıl	Random Shocks	Country
2008	South Ossetia War	Russia - Georgia
2012	Syria/ Aircraft Crisis	Russia - Turkey
2014	Russia's Annexation of Crimea	Russia - Ukraine
2015	The Sukhoi Su-24 Incident	Russia - Turkey
2016	Military Coup Attempt	Turkey
2017	Russian Air Force Al-Bab Incident	Rusya - Turkey
2021	Russia - Ukraine Crisis	Russia - Ukraine
2022	Russia's Invasion of Ukraine	Russia - Ukraine

The aim of this study is to identify the effects of random shocks on the Black Sea maritime trade. In order to achieve this aim, Turkey's maritime export and import data with the Black Sea countries between 2007 and 2023 are taken from the statistics published by the General Directorate of Maritime Affairs. Frequency analysis, qualitative data analysis and Census X-13 ARIMA analysis methods are used to analyze the data.

2. Literature Review

Extensive studies in the literature and industry reports make it clear that the maritime sector is vulnerable to economic recessions [9, 10, 11]. With the global economic crisis hitting the container transportation market hard since the third quarter of 2008, the global demand for container transportation has dropped significantly [12]. This crisis has significantly affected the containership market and the shipping industry as a whole. The combination of low demand for containership services and the continuous entry of new tonnage into the shipping market has resulted in a significant overcapacity [13]. Time charters rates because of the reduced speed of vessels, and freight rates, have dropped drastically due to the poor demand of cargo [14]. The COVID-19 pandemic in 2020 and the restrictive measures taken by governments to contain it inevitably dealt a major blow to the world economy and caused widespread difficulties [15, 16] The maritime transport sector experienced increases in the number of empty or skipped sailings and idle container ship capacity in the first half of 2020. The COVID-19 pandemic has had a major impact on both the demand and supply sides of the economies of China and the Belt and Road countries, causing potential trade values to shrink between China and other Belt and Road countries [17]. The war between Russia and Ukraine had an impact on maritime trade and indirectly on many other areas. Changes in trade routes, adverse effects on supply chains, price increases in service and commodity markets are some examples of the effects of the war on markets. At the same time, international economic sanctions and trade restrictions imposed due to the war also affected global and national markets [18]. Grain prices and transportation costs, which have been on the rise since 2020, have accelerated with the conflict in Ukraine. Between February and May, prices for dry bulk transportation increased by around 60% [19].

In 2009, container handling in the Black Sea countries dropped significantly due to the impact of the global economic crisis [20]. Due to the impact of 2019 Covid 19, financing expenses in the Turkish maritime transportation sector increased by 86% in 2020 compared to the previous year. In the Black Sea region, trade volume came to a standstill, the freight market experienced major declines and almost all ships had to wait for cargo, and even shipowners went for short-term laid up solutions. However, in September 2020, trade resumed in terms of volume and transportation demand with intense demand [21]. 2022 The number of vessels passing through the Bosphorus, which was significantly affected by the Russian-Ukrainian war, decreased by 23.42% in March 2022 compared to the same month of the previous year, and the total Gross Tonnage decreased by 30.50% in April 2022 compared to February 2022 [22]. The war caused serious challenges to the global energy supply and reshaped the oil and gas trade. In addition, container transportation was also affected, with nine of the ten largest global container shipping companies suspending their operations in the Black Sea region [23].

3. Materials and Methods

Data on maritime freight transportation are taken from the statistics published by the General Directorate of Maritime Affairs. There are two data sets. The first data set consists of annual maritime import-export data between Turkey and the Black Sea littoral countries between 2007 and 2023. Qualitative data analysis and frequency analysis methods were used to analyze the first data set. The second dataset consists of monthly maritime import-export data between Turkey and the Black Sea littoral countries between 2019 and 2023. Census X-13 ARIMA analysis method is used to analyze the second data set. In Figure 1 all steps of the method are shown.

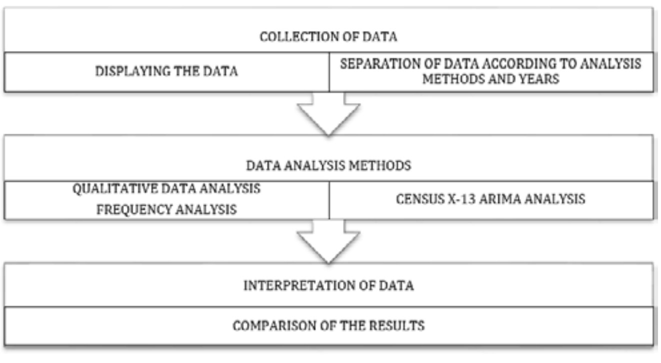

Figure 1: Steps of the Method

Frequency analysis is a descriptive statistical method that shows how many times an event occurs [24]. Frequency analysis is used to estimate how often certain values of a variable phenomenon are likely to occur and to assess the reliability of the estimate [25]. Qualitative data analysis involves the processes of defining and classifying phenomena and describing how concepts are related to each other. First of all, the phenomena under study need to be fully defined. In order for the researcher to interpret and explain the data, a conceptual framework should be developed and the data should be classified. After this stage, concepts can be formed and related to each other [26, 27]. In qualitative studies, it is desired to understand the essence of large amounts of data by reducing the volume of raw data, to identify important patterns and to create a logical chain of evidence about the phenomenon under investigation by making sense of the data [27].

The Census X-13 ARIMA model, which is a continuation of X-12-ARIMA and X-11, is a statistical method for seasonal adjustment of time series data developed by the Bureau of Census [28]. The model first decomposes the time series into three components. These components are trend, seasonal and irregular. ARIMA models are then applied to each component separately to estimate and smooth the remaining trend and irregular components. Finally, the adjusted components are combined to produce a seasonally adjusted time series [29].

4. Results

As a result of the frequency and qualitative data analysis, Turkey's maritime export data with the Black Sea Region countries between 2007 and 2023 are shown in Figure 2.

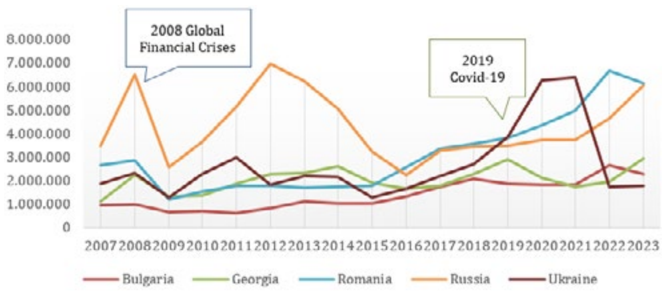

Figure 2: Turkey's Exports by Countries (Tons)

When the data are analyzed, a decline in Turkey's maritime exports to the Black Sea countries was observed in 2009 due to the impact of the 2008 Global Financial Crisis. Exports with Bulgaria fluctuated after 2011, reaching a peak in 2022 and then declining in 2023. Exports with Romania have been on the rise since 2015, increasing by around 53% from 2019 to 2022. In 2023, they decreased by about 10%. Due to the 2019 Covid 19 impact, exports with Georgia decreased by around 40% from 2019 to 2021.

Turkey's maritime export data with Russia and Ukraine between 2007 and 2023 are shown in Figure 3.

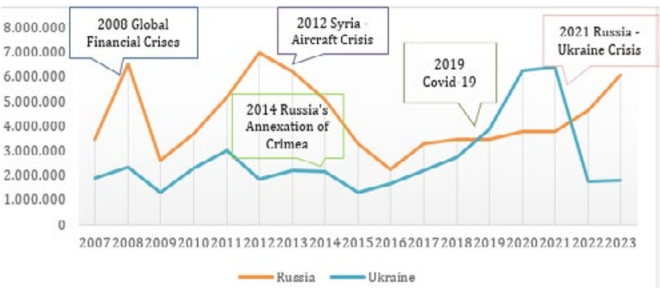

Figure 3: Turkey's Exports to Russia and Ukraine (tons)

According to these data, after the 2008 financial crisis, there was a 60% decrease in exports with Russia in 2009. After 2009, exports started to increase and reached a peak in 2012, but after the Syria/aircraft crisis between Russia and Turkey, exports started to decline again until 2016. Exports of 6,963,163 tons in 2012 dropped by 68% to 2,247,125 tons in 2016. In 2016, with the improvement in diplomatic relations between Russia and Turkey, exports started to increase again. In 2020, exports stagnated due to Covid 19 and continued to increase as of 2021. Exports with Ukraine decreased by 45% in 2009 due to the 2008 financial crisis. Since 2015, exports have been on the rise, reaching a peak in 2021 and then declining sharply by 73% in 2022. In 2023, they increased by 3%.

The maritime import data of Turkey and the Black Sea countries between 2007 and 2023 are shown in Figure 4.

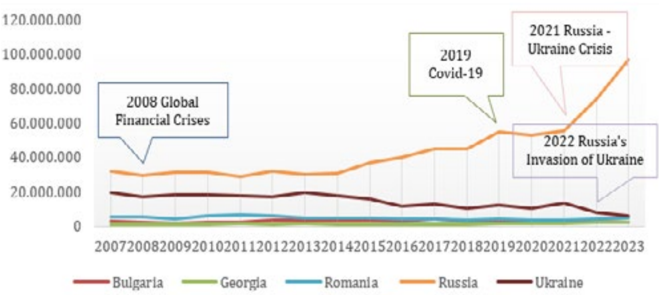

Figure 4: Turkey's Imports by Countries (Tons)

With the exception of Russia and Ukraine, imports from Turkey have been stable, import values have been lower and the impact of random shocks has not been significant.

Turkey's maritime import data with Russia and Ukraine between 2007 and 2023 are shown in Figure 5.

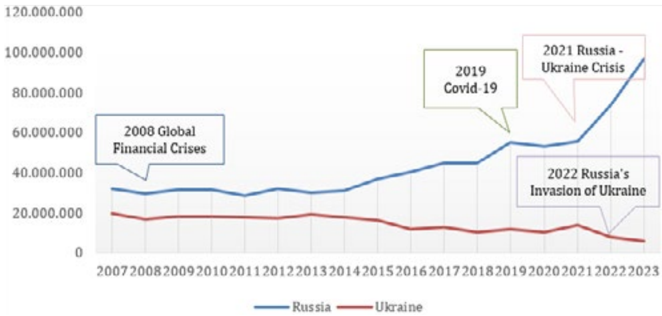

Figure 5: Turkey's Imports with Russia and Ukraine (tons)

In 2008, exports to Russia fell by 8% as a result of the financial crisis. Imports, which followed a wave-up process in subsequent years, declined by about 4 per cent in 2020. Imports, starting to rise in 2021, have reached a peak of 74 per cent in 2023. In 2008, exports to Ukraine decreased by 13% as a result of the financial crisis. There was a wave decline in subsequent years, and in 2023, as a result of the Russian-Ukrainian War, imports fell by about 57% compared to 2021, and reached a peak.

After the qualitative data analysis processes carried out above, the, in order to reveal whether sea export and import data have parallel seasonality with the given random shock periods, Census X-2019 – 2023 analysis was performed and the results are shown below. Table 2 shows the extrem values of monthly sea exports and imports between Turkey's Black Sea countries and 2019 – 2023.

Table 2: Export and Import Extreme Values

EXPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	87.5	87.0	93.8	93.5
	150.6*	110.4	101.6	109.9
	108.6	121.3	86.4	87.7
2020	84.5	121.0*	99.2	96.6
	107.4	119.1	84.8	129.1*
	109.5	124.1	95.4	80.4
2021	87.2	73.3	112.6	102.2
	97.1	113.3	98.8	96.1
	138.6*	111.0	99.3	83.4
2022	79.6	76.7	115.8	94.6
	98.2	126.9	90.6	102.2
	122.1	124.5	91.6	120.8*
2023	73.4	58.7*	106.9	95.5
	115.5	88.6*	132.1*	103.6
	89.0*	102.9	109.5	81.2

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Bulgaria

IMPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	101.6	120.8*	98.0	83.9
	112.9	113.1	92.8	90.5
	103.7	100.7	100.4	103.9
2020	103.7	88.5	75.5*	113.6*
	126.7	92.0	91.7	102.3
	78.4	109.4	108.3	93.2
2021	101.2	95.5	103.4	88.3
	128.6	99.5	98.7	112.0*
	82.4	99.0	88.8	94.9
2022	119.7	82.7	108.7	99.4
	104.7	121.4*	104.0	94.6
	111.4*	97.6	90.4	129.0*
2023	85.0*	88.2	117.6	106.2
	113.4	75.5*	103.6	78.3
	84.6	115.1	111.9	103.6

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Bulgaria

EXPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	90.4	78.5	94.0	126.8
	89.9	100.8	110.2	114.5
	97.8	98.1	87.3	83.1
2020	82.7	74.9	128.0	130.7
	89.5	107.2	92.1	101.6
	113.7	117.0	81.8	138.1*
2021	78.1	59.0	117.0	114.9
	118.0	116.2	93.0	102.3
	143.0*	102.3	81.1	85.0
2022	76.1	66.0	112.0	31.6*
	203.7*	143.8*	79.2	78.4*
	130.4	89.1	116.4*	102.0
2023	84.7	54.0	68.8*	125.6
	120.3	104.3	85.5	124.1
	94.1	99.7	91.5	96.6

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Romania

IMPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	74.3	83.0	116.1	129.3
	162.6*	121.4	74.2	58.4*
	115.0	110.1	91.1	120.0
2020	96.0	95.5	108.3	102.8
	90.3	98.1	94.7	87.0
	97.7	124.2	73.1	112.7
2021	95.8	118.1	96.9	129.8
	96.4	83.9*	77.9	187.9*
	98.5	87.2*	124.9*	108.3
2022	123.6	73.8	139.5*	78.4
	83.9	135.8	142.6*	87.4
	108.1	122.3	60.1	104.7
2023	92.4	111.8	100.6	102.6
	179.1*	126.4	98.4	77.2
	98.4	99.9	76.4	114.7

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Romania

EXPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	82.8	75.9	100.2	95.2
	96.4*	112.9	90.4	117.1
	103.6	129.9*	101.7	94.7
2020	75.8	104.0*	95.4	91.5
	123.9	106.4	96.7	118.1
	96.7	116.2	98.2	93.4
2021	84.0	76.0	104.6	85.6
	130.7	88.6*	92.5	119.9
	114.7	96.3	96.8	107.3
2022	64.3*	93.8*	86.5	96.0
	123.7	102.9	116.3*	102.2
	103.4	99.6	95.0	102.9
2023	79.0	75.6	102.5	96.0
	92.7*	109.0	107.3	104.0
	106.7	105.3	85.5	112.3

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Georgia

IMPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	196.3*	89.5	115.4	81.2
	96.9	81.5	71.3	116.8
	90.0	101.0	87.7	130.6*
2020	147.8	86.2	98.7	104.0
	75.0	79.4	108.6	100.7
	109.4	99.5	105.0	77.8
2021	105.7*	104.4	110.1	94.0
	104.1	108.8	77.2	133.8
	70.1	73.1	90.0	116.4
2022	149.2	98.7	104.6	78.2
	102.4	82.5	121.2	98.5
	95.6	142.5*	113.7	81.8
2023	85.1*	94.9	97.5	134.2*
	93.3	124.9	98.0	119.2
	92.0	69.3	65.9*	115.1*

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Georgia

EXPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	-50134.6	-63005.2	-6158.9	-11823.1
	-5472.5	-36387.5*	-4490.0	-50165.9
	-17308.7	29733.6	116122.6	66374.9*
2020	19984.6	57937.6*	-21967.7	-73206.6*
	-30924.9	26978.6	25021.3*	-75540.9
	1238.4	-7966.9	128280.2	115296.8
2021	-13368.9	-112295.1	17861.3	-6738.5
	-48394.6	19229.4	-56769.0	-13813.3
	-11263.0	-20281.9*	120297.5	103623.5
2022	-11656.5	-52174.7	-113984.5*	-54448.8
	-17661.6	24992.6	-115206.9*	-1510.7
	-18116.7	58176.4	32567.5*	103909.4
2023	10040.2	-180492.0*	-12828.1	-33579.4
	250.4	40902.7	-42765.4	-81518.2
	-105728.0*	60277.8	64397.2	139857.6

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Russia

IMPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	83.2*	85.3	111.0*	90.9
	101.3	99.6	96.7	113.0
	102.2	111.9	105.8	96.5
2020	105.8	87.5	88.4	90.3
	97.3	99.7	94.2	113.7
	116.7	97.4	111.0	102.2
2021	94.2	81.8	104.9*	99.0
	84.0*	91.6	107.4	106.6
	109.1	89.9*	105.8	107.6
2022	109.7*	74.4	78.9*	95.2
	103.3	100.5	106.7	108.1
	101.8	126.2*	110.0	101.6
2023	97.5	76.7	90.0	101.4
	104.9	98.9	107.9	99.3
	102.0	107.2	97.3	117.6

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Russia

EXPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	-61389.9	-50277.5	5216.7	-132779.9*
	10894.5	-62918.1	153.0	-2736.8
	133229.8	68955.9	19395.0	-32846.6
2020	-126717.5*	-74951.3	65603.1	212807.6*
	-121272.8*	-45582.2	-19421.6	64751.2
	109648.8	13131.6	58651.3	-72644.2
2021	-48424.1	-93193.8	-2948.4	66664.8*
	-21212.6	-98553.9*	93498.1*	10486.4
	-103959.8*	155528.0*	41795.3	-24635.8
2022	8777.2	96169.8*	-209545.5*	-141394.1*
	-64646.3	13338.3	57316.3	50070.1
	49061.7	11713.2	5939.8	14439.0
2023	-30915.8	-63906.3	-18599.0	-63789.6
	19796.3	43700.3	6821.3	15206.5
	14215.0	61670.3	12017.4	40482.3

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Ukraine

IMPORT

	Jan May Sep	Feb Jun Oct	Mar Jul Nov	Apr Aug Dec
2019	-27681.8	28445.3	21008.9	-180260.9
	14747.4	-91955.9	-176161.8	-213187.5
	-154885.2	302108.3	95879.5	303165.3
2020	140833.7	54690.8	-111936.7	-47379.5
	-173385.3	-169458.4	-18868.1	-161965.5
	-63176.2	16537.2	192206.7	347826.2
2021	151543.1	24375.5	-165884.9	80228.8*
	-62656.8	-363737.0	-461547.6*	-10070.8
	-141948.1	222938.9	36687.2	457520.9
2022	440432.8*	215700.4	-453368.8*	-572348.6*
	-183939.9	-249519.7	-113073.4	27308.4
	223013.4*	30438.4	289118.6	191651.2
2023	26405.3	75755.4	258582.4*	-2720.7
	88038.0	-223675.0	-136439.1	-243009.3
	-145668.9	155088.8	231581.9	328604.9

Key to symbols:
* : extreme value as determined by X-11 extreme value procedure

Ukraine

Figure 6 shows the seasonal relationship between Turkey and exports of other countries in the Black Sea region between 2019 and 2023 using the Census X-13 ARIMA method.

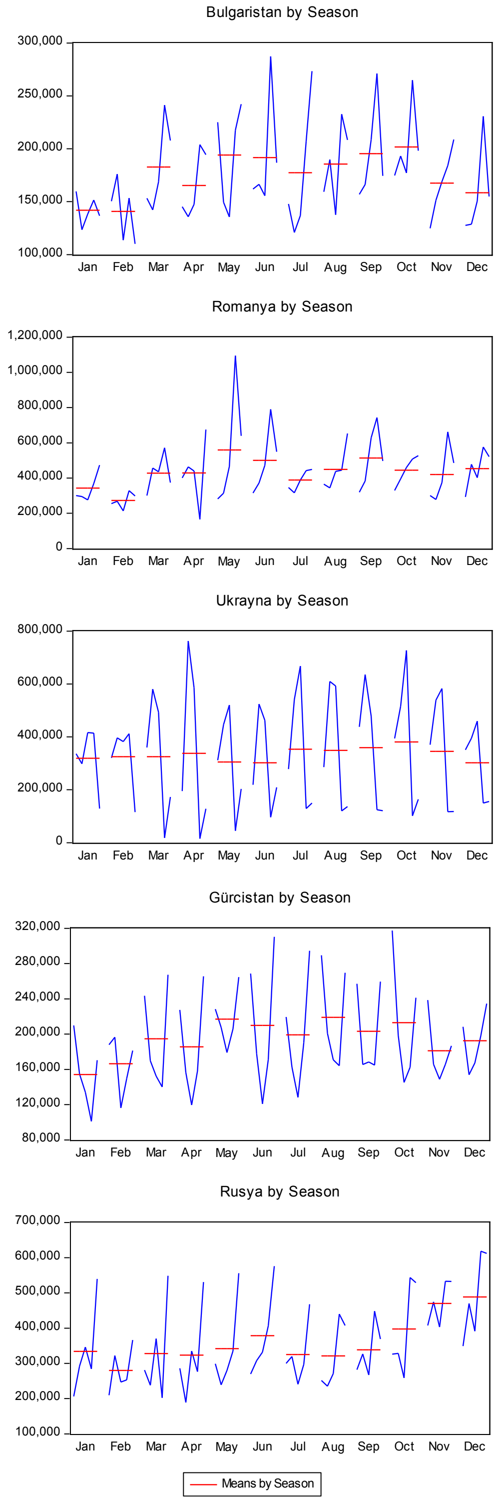

Figure 6: Seasonality of Export Data

As a result of this analysis, there is seasonality at a 99% confidence level in Turkey's exports to Bulgaria, Romania, Georgia and Russia. However, the seasonality found varies by month. The presence of seasonality in different months each year can also be seen in the chart. There is seasonality in exports to Ukraine, but months do not vary. This situation can also be seen in the graph.

Figure 7 shows the seasonality relationship between imports of Turkey and other countries in the Black Sea regions between 2019 and 2023 using the Census X-13 ARIMA center.

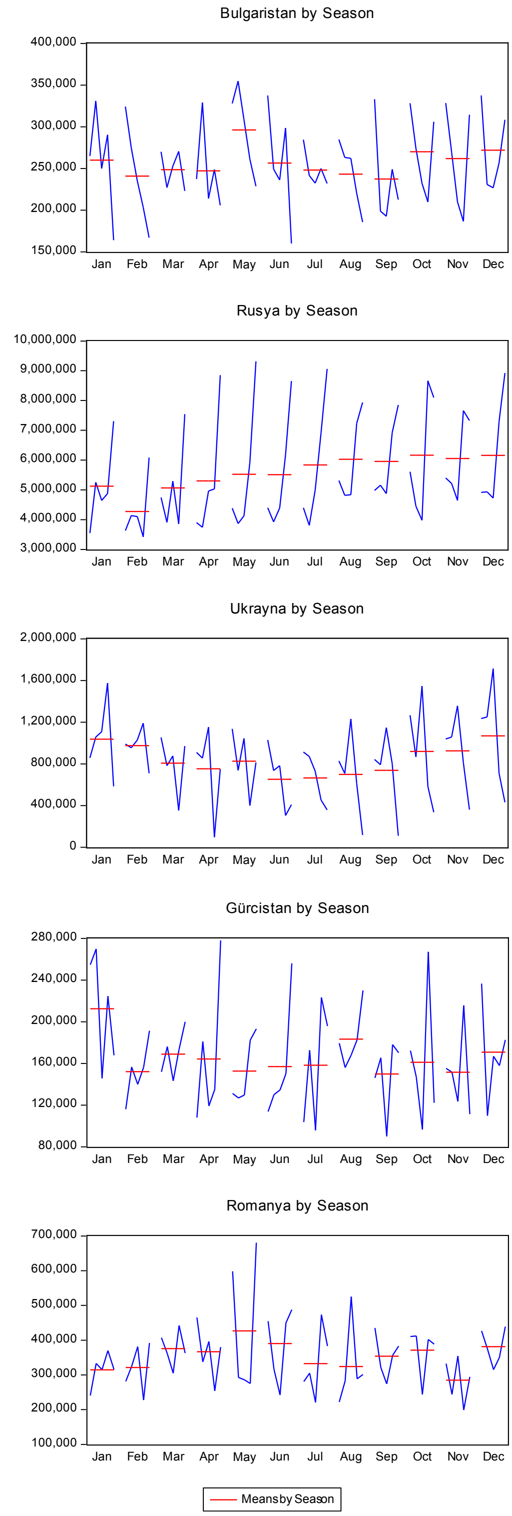

Figure 7: Seasonality of Import Data

There is no seasonality at the 1% significance level in Turkey's imports from Bulgaria, Romania and Georgia, so seasonality is out of the question. There is seasonality in imports with Russia and Ukraine at a 99% confidence level.

4. Discussion

This study was carried out to determine the effects of random shocks on Black Sea maritime trade. In this context, the effects of random shocks on the maritime trade of the Black Sea region were examined using qualitative data analysis, frequency analysis and Census X-13 ARIMA analysis methods. The findings revealed that random shocks cause significant difficulties in the maritime transportation industry. Due to the impact of the Global Financial Crisis, a decrease was observed in Turkey's maritime exports and imports with the Black Sea countries in 2009. In parallel with these findings, Şengönül & Esmer (2016) concluded in their study that container handling of the Black Sea countries decreased significantly in 2009 due to the impact of the global economic crisis, but started to recover in 2011 [30]. Koca (2018), in his study, found that Turkey's cargo handling volume on the cabotage line decreased by 14.4% in 2009, cabotage passenger transportation decreased by 3.1%, and total foreign trade handling decreased by 1.6% in 2009 due to the contraction in imports [31].

The study also found that there has been a decrease in Turkey's imports with Russia and Ukraine due to Covid-19. Taşdelen et al., (2022) their study also found that during the Covid-19 pandemic, Turkey's share in maritime transportation has gradually decreased and the value of freight has been constantly decreasing [32]. In the study conducted by Yildirim (2021), the effect of the pandemic period on Turkey's foreign trade was examined. In the study conducted, it was stated that there is a contraction in foreign trade and the contraction observed in imports is less compared to exports, and as a result, the country's current account deficit has increased [33]. One of the findings of this study is that the amount of cargo handled by Turkey with Ukraine has been decreasing since 2021 and Turkey's foreign trade with Ukraine has reached a bottoming point after the Russia – Ukraine war. In parallel with these findings, Erol & Alver (2022) examined the effects of the Russia-Ukraine war on the Port of Trabzon and found that there was an 81% decrease in the cargo of coal, which is the most important cargo item handled [34]. Cong et al., (2024) emphasized that maritime container traffic in the Black Sea basin has recently undergone significant changes due to the impact of the COVID-19 pandemic and especially the conflict in Ukraine. As a result, they found that containerized goods passing through Russian ports have decreased significantly since the outbreak of the conflict, and container traffic in Ukrainian ports is almost zero. For the Black Sea basin, they found that the port of Constanta in Romania is the main actor in the flow of containerized goods through the DP Word terminal in the Agigea region and faces problems of taking over most of the flow of containerized goods from Ukraine in 2023 [35]. According to the UNCTAD report, Ukraine experienced a sharp decline in shipping volume in the weeks following the outbreak of the Russia-Ukraine conflict. While the number of ships departing from Ukrainian ports per week decreased from about 160 to about 10, the ships departing from Russian ports in the Black Sea region decreased from about 280 to about 150 per week. The overall volume of shipping in the Black Sea region has decreased from about 1500 ships to about 1000 ships [36].

5. Conclusion

Maritime transport forms the basis of international prosperity as the most important tool of global trade. Countries that know how to use the seas efficiently make significant contributions to their economies with this sector. Statistics on world trade show that the seas are becoming increasingly important in international trade and the cargo transported by sea is constantly increasing. However, maritime transportation is affected by random shocks that directly affect demand. In this study, the relationship between Turkey's maritime exports and imports with the Black Sea countries and random shocks was examined. For this purpose, frequency analysis, qualitative data analysis and Census X-13 ARIMA analysis methods were used. As a result of frequency and qualitative data analysis, a decrease was observed in Turkey's maritime exports with the Black Sea countries in 2009 due to the impact of the 2008 Global Financial Crisis. When the export data after Covid-19 was examined, a decrease was observed in maritime exports with Georgia and an increase with Ukraine, Russia and Romania. When maritime import data between 2007 and 2023 is examined, a stable course was observed between Turkey and the importing countries, except for Russia and Ukraine, and the effects of random shocks were not seen much. As a result of the analysis, it was determined that the countries where Turkey's maritime exports and imports were most affected by random shocks were Russia and Ukraine. Turkey's imports and exports with Russia were positively affected after the 2021 Russia-Ukraine crisis, but its imports and exports with Ukraine were negatively affected. Census There is no seasonality in Turkey's imports from Bulgaria, Romania and Georgia. There is seasonality in imports from Russia and Ukraine.

At this point, the fact that maritime transportation is affected by random shocks is important in terms of determining and using alternative routes. It is of great importance to evaluate and instantly monitor the problems and solution methods that cause random shocks. Current studies need to be carried out covering issues such as how the effects of shocks change over time and how they can be balanced with new developments and measures. Governments and relevant institutions should develop rapid and effective response strategies and make emergency planning against crisis situations such as epidemics, war or natural disasters. Industry participants who face unexpected events such as financial crises, political events and epidemics should create policies that provide operational flexibility to keep up with changing environmental conditions.

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Cargo Claims in Marine Transportation and Cargo Insurance in Maritime

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Abstract

The maritime industry serves as the backbone of global trade, facilitating the movement of goods across vast oceans and connecting distant markets. However, amidst the complexity of marine transportation, the risk of cargo loss, damage, and liability looms large. This paper presents a thorough examination of cargo claims in marine transportation and the pivotal role of cargo insurance within the maritime sector[1].

Drawing upon a synthesis of scholarly literature, industry reports, and legal precedents, this study sheds light on the multifaceted nature of cargo claims, exploring the various factors contributing to their occurrence and the intricate legal frameworks governing liability. Through a comprehensive analysis, key sources of cargo loss and damage are identified, ranging from inherent risks of maritime transport to operational errors and external perils. Moreover, the paper delves into the diverse stakeholders involved in cargo claims, including shippers, carriers, insurers, and regulatory authorities, elucidating their respective roles and responsibilities in the resolution process.

Central to mitigating the financial repercussions of cargo claims is the role of cargo insurance, which serves as a vital risk management tool for stakeholders across the maritime supply chain. This paper evaluates the different types of cargo insurance available, from traditional marine cargo insurance to specialized policies tailored to specific industry sectors. Furthermore, it examines the evolving landscape of cargo insurance in response to emerging risks such as cyber threats and climate change, highlighting the need for adaptive risk mitigation strategies in an increasingly interconnected world.

By synthesizing theoretical insights with practical considerations, this paper aims to provide a comprehensive understanding of cargo claims in marine transportation and the pivotal role of cargo insurance in safeguarding the interests of stakeholders. Through nuanced analysis and empirical evidence, it offers valuable insights for industry practitioners, policymakers, and scholars seeking to navigate the complex terrain of maritime liability and risk management.

Keywords: *Cargo claims, Marine transportation, Cargo insurance, Maritime liability, Risk management*

1. Introduction

The maritime industry stands as a cornerstone of global commerce, facilitating the movement of goods across vast oceans and connecting economies around the world. Spanning from the transportation of raw materials to finished products, the maritime sector plays a pivotal role in sustaining international trade and economic growth[2]. However, within this intricate web of maritime logistics lies a complex ecosystem fraught with risks and uncertainties, chief among them being the issue of cargo claims. Cargo claims, encompassing a broad spectrum of incidents such as damage, loss, theft, spoilage, and delay, represent a significant challenge for stakeholders involved in marine transportation[6,7,8]. Despite advancements in technology, infrastructure, and risk management practices, the maritime industry continues to grapple with the financial repercussions and operational disruptions caused by cargo-related incidents. The resolution of cargo claims entails navigating through a labyrinth of legal, contractual, and regulatory frameworks, often involving multiple parties with divergent interests and obligations.

At the heart of the cargo claims dilemma lies the delicate balance between risk and responsibility. Shippers entrust their goods to carriers with the expectation of safe and timely delivery, while carriers assume liability for the cargo in their care. However, the reality of maritime transport exposes cargo to a myriad of perils, ranging from adverse weather conditions and navigational hazards to operational errors and acts of piracy. Consequently, disputes often arise regarding the allocation of responsibility for cargo loss or damage, leading to protracted legal battles and financial liabilities for all parties involved.

Amidst the complexities of cargo claims, the role of cargo insurance emerges as a critical risk management tool for stakeholders across the maritime supply chain. Cargo insurance provides financial protection against the various perils that may compromise the safety and integrity of goods in transit, offering reassurance to shippers and carriers alike[3]. From basic coverage for loss or damage to specialized policies tailored to specific industry sectors, cargo insurance serves as a safety net, mitigating the financial impact of cargo-related incidents and enabling businesses to navigate the uncertainties of global trade with confidence.

This paper seeks to delve deep into the intricate dynamics of cargo claims in marine transportation and the indispensable role of cargo insurance within the maritime sector. By synthesizing insights from scholarly literature, industry reports, and legal precedents, it aims to elucidate the multifaceted nature of cargo claims, the legal frameworks governing liability, and the evolving landscape of cargo insurance in response to emerging risks and challenges.

Furthermore, this study endeavors to offer practical recommendations for stakeholders involved in marine transportation, from shippers and carriers to insurers and policymakers. By fostering a deeper understanding of the complexities surrounding cargo claims and the mechanisms of cargo insurance, this research aspires to facilitate informed decision-making and foster collaboration among stakeholders, ultimately contributing to the resilience and sustainability of the maritime industry in an ever-changing global landscape.

2. Case Studies: Cargo Damages and Insurance Claims

The examination of case studies offers a nuanced exploration of the complexities surrounding cargo damages and the corresponding insurance claims within the maritime industry. Through a detailed analysis of these real-world scenarios, we gain valuable insights into the multifaceted nature of cargo-related incidents, the diverse range of factors influencing their occurrence, and the intricate processes involved in their resolution.

Each case study serves as a microcosm of the challenges faced by stakeholders across the maritime supply chain, providing tangible examples of the myriad risks and uncertainties inherent in the transportation of goods by sea[4,5]. From physical damage resulting from mishandling or improper stowage to theft, spoilage, contamination, and delay, these case studies offer a comprehensive view of the various perils confronting cargo in transit.

Moreover, case studies offer a window into the intricate interplay between contractual obligations, legal frameworks, and insurance coverage in the aftermath of cargo-related incidents. By examining the response of insurers, carriers, shippers, and other relevant parties to each scenario, we can discern the effectiveness of risk mitigation strategies and the adequacy of insurance protection in mitigating financial losses and preserving the integrity of the supply chain. Furthermore, case studies provide valuable insights into the evolving landscape of cargo insurance, particularly in response to emerging risks and challenges facing the maritime industry. In an era marked by technological advancements, climate change, geopolitical instability, and evolving trade patterns, cargo insurers are continually innovating to address new threats and vulnerabilities, offering specialized coverage tailored to the needs of specific industry sectors and geographic regions[9].

Through the detailed analysis of case studies, this section aims to achieve several objectives. Firstly, it seeks to illustrate the practical implications of cargo damages and insurance claims for stakeholders involved in marine transportation, from shippers and carriers to insurers and regulatory authorities[11]. By examining the real-world responses to cargo-related incidents, we can identify best practices and areas for improvement in risk management and claims resolution processes.

Secondly, this section aims to highlight the importance of proactive risk mitigation strategies and robust insurance coverage in safeguarding against potential losses and liabilities. By showcasing the role of cargo insurance in providing financial protection and promoting resilience within the maritime supply chain, we can underscore its significance as a critical component of effective risk management practices[16].

Lastly, by offering a comprehensive analysis of case studies spanning various types of cargo damages and insurance claims, this section aims to contribute to a deeper understanding of the complexities surrounding maritime liability and risk management[12]. Through empirical evidence and practical examples, we can enhance our knowledge of the challenges and opportunities inherent in managing cargo-related risks, ultimately fostering informed decision-making and collaboration among industry stakeholders.

3. Enhancing Cargo Insurance Practices: Recommendations and Strategies

In response to the ever-evolving landscape of risks and challenges within the maritime industry, it is imperative to continuously enhance cargo insurance practices to ensure the resilience and sustainability of the global supply chain[10]. Drawing upon insights garnered from empirical research and theoretical frameworks, this section proposes a comprehensive array of recommendations and strategies aimed at optimizing cargo insurance practices and mitigating the financial impacts of cargo-related incidents.

A fundamental aspect of enhancing cargo insurance practices lies in fostering collaboration and communication among stakeholders. Establishing channels for transparent dialogue between shippers, carriers, insurers, and regulatory authorities can facilitate the proactive identification and mitigation of potential risks. By sharing information on emerging threats, industry trends, and best practices, stakeholders can collectively develop more informed risk management strategies and insurance solutions tailored to the specific needs of the maritime sector. Moreover, promoting a culture of shared responsibility and accountability can foster greater trust and cooperation among stakeholders, ultimately strengthening the resilience of the entire supply chain.

Furthermore, investing in education and training programs is essential for building capacity and expertise in cargo insurance practices. Providing stakeholders with access to comprehensive training modules, workshops, and informational resources on risk assessment, insurance coverage, and claims management can empower them to make informed decisions and navigate the complexities of cargo insurance effectively. Moreover, incorporating risk management principles into maritime education curricula and professional development courses can equip future generations of industry professionals with the skills and knowledge needed to address emerging challenges and opportunities in cargo insurance practices.

Embracing technological innovations represents another critical avenue for enhancing cargo insurance practices. Leveraging advancements in blockchain technology, IoT (Internet of Things), and data analytics can revolutionize the way cargo insurance is underwritten, priced, and managed. Implementing digital platforms for real-time tracking of cargo shipments, automated claims processing, and risk assessment can enhance the efficiency, accuracy, and transparency of insurance operations, thereby reducing administrative burdens and enhancing the overall customer experience. Moreover, exploring the potential of emerging technologies such as artificial intelligence and machine learning can enable insurers to develop predictive models for assessing and mitigating risks, allowing for more proactive and data-driven decision-making in cargo insurance practices.

Additionally, incentivizing proactive risk management behaviors can play a pivotal role in enhancing cargo insurance practices. Insurers can offer incentives such as discounts, bonuses, or preferential terms to policyholders who implement robust risk mitigation measures and demonstrate a commitment to safety and sustainability. Encouraging the adoption of industry best practices, such as regular maintenance of vessels and cargo handling equipment, adherence to international safety standards, and investment in staff training and development, can lead to a reduction in the frequency and severity of cargo-related incidents, ultimately benefiting both insurers and insured parties.

Furthermore, fostering partnerships with industry associations, research institutions, and governmental agencies can facilitate the sharing of knowledge, resources, and expertise in developing innovative risk management solutions and promoting a culture of continuous improvement in cargo insurance practices.

By implementing a multifaceted approach that encompasses collaboration, education, technology, and incentivization, stakeholders can enhance the resilience, efficiency, and effectiveness of cargo insurance practices, thereby safeguarding the interests of all parties involved in marine transportation and promoting the seamless flow of global trade.

4. Conclusion

In conclusion, this paper has undertaken a comprehensive exploration of cargo claims in marine transportation and the indispensable role of cargo insurance within the maritime sector. Through an in-depth analysis of case studies, theoretical frameworks, and empirical evidence, we have elucidated the multifaceted nature of cargo-related incidents, the complexities surrounding their resolution, and the strategies for enhancing cargo insurance practices.

Cargo claims present formidable challenges for stakeholders engaged in marine transportation, spanning from physical damage and loss to theft, spoilage, contamination, and delay. These incidents not only disrupt the seamless flow of global trade but also entail significant financial liabilities for shippers, carriers, and insurers alike[13]. The resolution of cargo claims necessitates navigating through a labyrinth of legal, contractual, and regulatory frameworks, often involving intricate negotiations and disputes among multiple parties with divergent interests and obligations.

Amidst these challenges, cargo insurance emerges as a linchpin of risk management within the maritime supply chain, providing essential financial protection against the myriad perils that threaten the safety and integrity of goods in transit. By offering coverage for physical damage, theft, liability, and other risks, cargo insurance serves as a critical safeguard, mitigating the financial impact of cargo-related incidents and promoting resilience within the global supply chain[14].

However, the efficacy of cargo insurance practices hinges upon proactive measures aimed at enhancing collaboration, innovation, and risk management strategies among stakeholders. Collaboration among shippers, carriers, insurers, and regulatory authorities is essential for fostering transparency, communication, and mutual understanding, thereby facilitating more effective risk assessment and claims resolution processes. Moreover, investment in education and training programs can empower stakeholders with the knowledge and skills needed to navigate the complexities of cargo insurance effectively.

Leveraging technological innovations such as blockchain, IoT (Internet of Things), and data analytics can revolutionize cargo insurance practices, enhancing the efficiency, accuracy, and transparency of operations. By embracing digital platforms for real-time tracking of cargo shipments, automated claims processing, and risk assessment, insurers can streamline processes, reduce administrative burdens, and improve the overall customer experience. Furthermore, incentivizing proactive risk management behaviors through flexible insurance solutions and tailored coverage options can encourage stakeholders to invest in preventive measures and sustainable practices, thereby reducing the frequency and severity of cargo-related incidents.

In conclusion, while the maritime industry continues to face evolving risks and challenges, cargo insurance remains a cornerstone of risk management, ensuring the continued viability of international trade[15]. By embracing collaboration, innovation, and proactive risk management strategies, stakeholders can navigate the complexities of cargo claims and insurance, thereby fostering a more resilient and sustainable maritime sector for generations to come. It is through concerted efforts and collective action that we can safeguard the interests of all parties involved in marine transportation and uphold the integrity of the global supply chain.

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Recognition And Endorsement of Turkish Certificates of Competencies for Better Worldwide Job Opportunities

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Abstract

To be deployed on board a vessel, seafarers should have the certificate of competency (CoC) endorsed by the flag state or their CoC should be mutually recognized by the flag state of the ship they will serve. Recognition and/or endorsement of the CoCs is very important for seafarers providing them with working opportunities on board the ships registered with different flags. Working on board the developed countries' flag provides many advantages to the seafarers such as better and regular payment, insurance, social security, and better working conditions.

This study aims to investigate the problem areas for endorsement and recognition of Turkish seafarers' certificate of competencies shortly and make proposals to secure the working opportunity for them to work on board developed countries' flags which will provide better wages, working and living conditions. It is strongly believed that the result of the study is to assist the Turkish maritime authorities in producing solutions to improve the quality of seafaring officers to make them eligible to find better job opportunities.

Keywords: *Certificate of Competence (CoC), Endorsement of CoCs, Recognition of CoCs,*

Better Job Opportunities for Seafarers

1. Introduction

1.1 International Arrangements

The world relies on a safe, secure, and efficient international shipping industry and this is provided by the regulatory framework developed and maintained by the International Maritime Organization (IMO).[1] Shipping is a truly international industry, and it can only operate effectively if the regulations and standards are agreed, adopted, and implemented on an international basis. IMO is the forum at which this process takes place. IMO measures cover all aspects of international shipping including ship design, construction, equipment, manning, operation, and disposal to ensure that this vital sector remains safe, environmentally sound, energy-efficient, and secure.

The national maritime authorities are authorized for a Certificate of Competency (CoC) for seafarers following The International Convention on Standards of Training Certification and Watchkeeping for Seafarers (STCW 78, 2010). These certificates are valid onboard the ships carrying the country that submits the certificate. The seafarers need to have additional certificates submitted by the respective country if they work under other flags.

The mutual recognition of CoC for seafarers is subject to the procedures explained in Article 1/10 of STCW 78 (2010). Nations are authorized to make mutual agreements to recognize CoC as described in STCW. The STCW convention requires parties to maintain registers of certificates and endorsements for masters and officers and to make information available on the status of such certificates and endorsements to other parties and companies that request verification of the authenticity and validity of certificates produced by seafarers.

Normally seafarers are deployed on board their national flag ships. To be deployed on board, the other flagships need additional procedures. The nations are also authorized to make bilateral agreements to recognize the CoC mutually as defined in STCW. After manning of many ships with multinational crews, the bilateral agreements for mutual recognition of CoC became an important issue.

The procedure for mutual recognition starts with signing an agreement and completes with acceptance of a protocol that defines all details that explain how the system works. These agreements and protocols are to be included in the national regulations.

STCW certificates of proficiency are documents issued to the seafarer to certify that he or she has met the required standard of competence in a specific duty. These certificates include certificates for personnel serving on certain types of ships (tankers, and passenger ships) and for those assigned with safety, security, and pollution prevention duties. It certifies that the holder meets STCW standards of competence in specific functions related to the safety, and care of persons, or cargo. Certificates for masters, officers, and radio operators must be endorsed by the issuing administration and re-validated at intervals not exceeding five years.

Not only SRCW but also the Maritime Labour Convention (MLC, 2006) [2] addresses "training and qualification" in its regulations with the purpose of ensuring that "seafarers are trained or qualified to carry out their duties on board ship" and that: 1. Seafarers shall not work on a ship unless they are trained or certified as competent or otherwise qualified to perform their duties. 2. Seafarers shall not be permitted to work on a ship unless they have successfully completed training for personal safety on board a ship. 3. Training and certification in accordance with the mandatory instruments adopted by the International Maritime Organization shall be considered as meeting the requirements of paragraphs 1 and 2 of this Regulation.

1.2 The Status of Turkish Seafarers

To be deployed on board a vessel, seafarers should have the Certificate of Competency (CoC) endorsed by the flag state of this or their CoC should be mutually recognized by the flag state of the ship they will serve, and the state should submit their certificates. Recognition and/or endorsement of the CoCs is very important for seafarers providing them with working opportunities on board the ships registered with different flags. Working on board the developed countries' flag provides many advantages to the seafarers such as better and regular payment, insurance, social security, and better working conditions.

Unfortunately, CoCs of Turkish seafarers are recognized by only 9 countries which are generally not well-known maritime nations except Malta as a convenient flag. Approximately 70 percent of the Turkish-owned ships are registered under convenient flag, and it is required to have an endorsement from these countries. Nowadays Turkish-owned ships are registered on four major convenient flags which are Liberia, Malta, Marshall Island, and Panama. Panama did not endorse the Turkish CoCs since 2016. Malta being a European Union member will make an endorsement depending upon European Maritime Safety Agency (EMSA) approval shortly. There is still not a problem related to Marshall Island but the endorsement condition for Turkish CoCs is becoming rather difficult under the new policy of this flag state.

STCW Endorsement and recognition certificate is issued by an administration as an official recognition of the validity of a certificate issued by another administration. To obtain an endorsement of recognition, the seafarer needs to submit the original of their national certificate of competency to the representative of the issuing administration.

If the seafarers intend to serve on ships registered under the flag of a foreign country, then they need an endorsement of recognition issued by the administration of that country. Some administrations may also require an endorsement of recognition for specialized training certificates. In some instances, administrations from other countries will only recognize training which has been completed at specific training institutions in the country of origin.

Turkey has made agreements for mutual recognition of CoC with 35 countries by the end of 2023. However, the protocols necessary to put these agreements in force could not be completed. The protocols were mutually signed with only 18 countries by now which are Bulgaria, Italy, Romania, Malaysia, Thailand, Singapore, Malta, Ukraine, Russian Federation, Azerbaijan, Iran, Netherlands, Georgia, Qatar, Jordan, Denmark, Hong Kong, and Norway. The Turkish seafarer's CoC is now valid on board these countries. Although Turkey has signed agreements with other 17 countries; Germany, Belize, Japan, Poland, Portugal, Dominic, Marshall Islands, Bahama, Barbados Vanuatu, Cambodia, Antigua and Barbuda, Liberia, Sen Vincent and Granada, Lebanon, and Luxemburg, the protocols could not be signed and Turkish CoCs are not mutually recognized. (Turkish Transportation and Infrastructure Ministry, 5 April 2021) [3].

1.3 Relations with the European Maritime Safety Agency (EMSA)

Turkey's most important economic partner is the European Union countries. 95 percent of Turkish legislation is regulated according to EU legislation. The most important maritime organization in the EU is EMSA. training competence of the personnel working or working on board carrying the flag of the European Union (EU) member states and ensuring that they are trained by European norms. EMSA has to comply with the criteria of EMSA in the relations of EU countries with other countries, including the recognition of CoCs. All EU countries are periodically audited by EMSA. This inspection covers all maritime institutions and working conditions of the country. Turkey has voluntarily accepted the EMSA inspection. Turkey has passed the last three inspections. EMSA has given a directive to the EU countries not to accept the CoCs of the countries that do not pass this audit. In this respect, if the EMSA audit is not passed, serious problems may arise in terms of recognition with the EU countries with which we have already made agreements and protocols.

EMSA audits are based on the international conventions and codes and the relevant directives of the European Parliament, and the EU Council based on these conventions. The third countries that have been recognized under the procedure referred to in the first subparagraph of Article 19(3), including those referred to in Article 19(6), shall be reassessed by the Commission, with the assistance of the European Maritime Safety Agency, regularly and at least every five years to verify that they fulfil the relevant criteria set out in Annex II and whether the appropriate measures have been taken to prevent fraud involving certificates (EC of EU 2008/106, 2008). [4]

All components of Maritime Administration are subject to EMSA inspection The maritime education and training (MET) system has priority in the EMSA inspections. Not only the MET but also port controls, flag state applications, review and evaluation of shipping companies (ISM Audits), and classification societies, are evaluated by EMSA. Inspection of maritime institutions is made by EMSA in cooperation with national authorities. EMSA is very keen on the education and training competence of the personnel working or working on board carrying the flag of the European Union (EU) member states and ensuring that they are trained by EU norms which is beyond STCW minimum standards.

EMSA inspections continue at 5-year intervals unless otherwise directed. While audits are going on in 5-year periods, continuity is ensured with the quality standards mentioned in the directive 2008/106 / EC of the European Union Parliament and Council which are required to be provided by the member states. The quality standards referred to herein include not only training units and simulator-based training but also the qualifications and experience that the instructor and the auditors of the countries must take. Ultimately, although EMSA was originally a regional area of activity, it has taken the field of activity to the international level fact over time, many countries started to inspect their training activities to EMSA with the understanding of providing a wider field of work for seafarers.

From a European member state perspective, training aligned with STCW standards is taught across training providers and certified by national administrations.

EU's intention is to the establishment of an online tool/platform whereby all this information is included. The seafarers, training providers, and national maritime administrations will have access to such data. This could help to streamline and improve knowledge sharing in the maritime and shipping sector, and possibly lead to more collaborative endorsement or recognition of such training in Europe (Acar, 2023) [5].

1.4 General Overview of the Turkish Seafarers

Turkey is among the countries that raise seafarers in the world and will play an important role in terms of the supply of seafarers in the coming years. There are 136.103 actively working seafarers in Turkey and one of the few countries in the world that raises seafarers in terms of numbers (UDHB, 2023).

Table 1. Turkish Seafarers

Officers	30.412	**Rating**	104,297
Oceangoing Master	4,276	***Able Seaman***	*17,535*
Oceangoing Chief Engineer	1,222	***Oiler***	*13,373*
Ocean. Chief Officer	2.434		
Ocean. 2nd Engineer	866		
Oceangoing OOW	3580		
Oceangoing EOOW	1610		
TOTAL	136,103		

The deficit in the officer class has been tried to be closed with new maritime institutions opened in recent years. There are a total of 88 maritime institutions and a rapid increase has been observed in the number of maritime institutions to cover the deficit in officer class. Compared to the Turkish fleet, there is an excess supply not only on the seafarer side but also on the Turkish-flagged fleet in the oceangoing officer class.

Table 2. Authorized by the Maritime Education and Training Institutions (UAB, 2022)

Higher Education Tertiary	**Ministry of Education Secondary**	**Private Maritime Courses**	**Total**
22	34	32	88

2. Research Method

This study aims to investigate the problem areas for endorsement and recognition of Turkish seafarers' certificate of competencies shortly and make a proposal to secure the working opportunity for them to work on board developed countries' flags which will provide better wages, working and living conditions

The objectives of this study are as follows:

- To define major deficiencies concerning recognition and endorsement of the Certificate of Competency
- To create proposals to overcome deficiencies
- To understand major problems related to the recognition of CoCs in EMSA inspections

The study is mainly based on a literature study supported by a field study to realize the concept and principles of recognition and endorsement of the certificate of competency and the importance of the EMSA inspections in evaluation/assessment. Then structured research to clarify problem areas and major reasons for deficiencies to conclude.

The result of the study may be used by Turkish maritime authorities to produce solutions to improve the quality of seafaring officers to make them eligible to find better job opportunities.

3. Research

3.1 Recognition of Turkish Officer Competencies in the International Maritime Sector

Turkish MET institutions implement their education and training in compliance with IMO standards. Students are entitled to take the English Language Proficiency Exam before starting their education and the Seafarers Qualification exam at the end of their program.

Turkish ship-owned fleet is approximately 28 million DWT (Dead Weight ton) and 22 million DWT is operating under the foreign-flagged ships mostly convenient flag. The Turkish-owned ships are generally manned by Turkish seafarers either in Turkish or Foreign flags. To allow Turkish seafarers to work on board a foreign flag ship they need the endorsement of their COCs by the Maritime Administration of their respective country.

In Turkey, after receiving the officer's competency, if the flag of the ship that will be working for is different from the Turkish flag, it is an obligation to obtain endorsement from that flag state. For this purpose, normally the shipowner/operator must submit a request for endorsement of the certificate from the relevant flag state. If this approval or eligibility is not obtained, seafarers cannot be allowed to work on board the ship of the relevant flag state, regardless of the training received by seafarers according to international standards.

Today Turkey has mutual recognition agreements and protocols with 18 countries (Bulgaria, Italy, Romania, Malaysia, Thailand, Singapore, Malta, Ukraine, Russian Federation, Azerbaijan, Iran, Netherlands, Georgia, Qatar, Jordan, Denmark, Hong Kong, and Norway). However, the endorsement of CoCs is not possible with 17 other countries for which protocols could not be signed (Germany, Belize, Japan, Poland, Portugal, Dominic, Marshall Islands, Bahama, Barbados Vanuatu, Cambodia, Antigua and

Barbuda, Liberia, Sen Vincent and Granada, Lebanon, and Luxemburg). Between these countries, the Marshall Islands, Vanuatu, and Liberia are important convenient flags which has working opportunities for Turkish seafarers. Some temporary solutions have been found to the recognition problem in these countries, but it is not guaranteed to lasting of these temporary solutions. As a good example, Panama started not to endorse new Turkish CoCs starting in 2018. The countries with the highest number of flag registrations today are Panama, the Marshall Islands, and Liberia. Turkey has signed an agreement with Liberia and the Marshall Islands but has not signed a protocol. It has not signed both mutual recognition and protocol with Panama.

3.2 International Seafarers Statistics

The estimates prepared for the BIMCO/ISF Manpower Report 2015 indicate that the current global supply of seafarers is around 1,647,500 seafarers, of which approximately 774,000 are officers and 873,500 are ratings, and that the current global demand for seafarers is around 1,545,000 seafarers, with the industry requiring approximately 790,500 officers and 754,500 ratings. The current supply-demand situation is a shortage of 16,500 officers and a surplus of 119,000 ratings, with an overall surplus of 102,500 seafarers as seen in Table 3.

Table 3. Summary of the estimated global supply of seafarers 2015-2025 (BIMCO/ISF, 2015)

	ESTIMATED SUPPLY-DEMAND BALANCE FOR OFFICERS		
	2015	2020	2025
Supply	774,000	789,500	805,000
Demand	790,500	881,500	952,500
Shortage/Surplus	-16,500	-92,000	-147,500
%	2.1%	11.7%	18.3%

The top five countries indicated by companies were China, the Philippines and the Russian Federation, followed by Ukraine and then India. This closely resembles the countries estimated to supply the largest number of seafarers, except Indonesia. Due to the war between Russia and Ukraine, the seafarer supply from Russia and Ukraine, which is the leading supplier of seafarers, has suffered great losses in recent years. As Turkey, we can turn this situation into an opportunity and fill the place of Russian and Ukrainian seafarers. Turkey may be an important country providing seafarers to the World fleet in particular officers.

Table 4: Top Five Largest seafarer supply countries (BIMCO/ISF 2015)

	FOR ALL SEAFARERS	FOR OFFICERS	FOR RATINGS
1	China	China	Philippines
2	Philippines	Philippines	China
3	Indonesia	India	Indonesia
4	Russian Federation	Indonesia	Russian Federation
5	Ukraine	Russian Federation	Ukraine

3.3 Deficiencies in Education

The increasing importance of the maritime industry and maritime education in Turkey are becoming the most important and priority issues of the industry from a strategic point. Since maritime education includes many disciplines, educational institutions should be organized and operational in line with the needs of the sector from a global perspective. In 2009 almost all lines of business all over the world were in the global financial crisis the world experienced supply shortages and unemployment was seen in Turkey in shipping. This demand for personnel has been tried to be met with newly opened maritime institutions, especially after 2009, but it is stated that the quota of these training institutions has not been determined to meet the sector demand and to create maritime employment appropriately in the country. As determined numerically in the previous chapters, the quota was quite high in all departments in 2015 and no scientific, planned and sectoral studies were conducted to determine the quota numbers. Accordingly, it is predicted that there will be excess supply in the employment of graduates in the future. According to the Ministry of Transportation, Maritime Affairs and Communications 100,000 officers, 350.000 seamen and one million amateur sailors aimed to reach Turkey in 2023. It is seen that the previous maritime education planning causes employment problems today and the current education policy will cause employment problems in the future (Anadolu ajansı, 2018).[6]

To eliminate excess supply and demand, quality expectations of demand in this sector should be determined and maritime education should be renewed according to these expectations. In this context, instead of opening new maritime institutions, the quality should be improved, and the quota and qualification levels of the educational institutions should be updated and renewed according to the needs of the sector so that they do not create employment problems in the sector.

Although maritime education institutions increase the number of people who want to study in this field, they cannot meet the need because they do not have sufficient physical infrastructure. The shortage of maritime lecturers is continuing. Moreover, the qualification given by Turkey is not accepted by some countries and create obstacles on the employment abroad of Turkish seafarers. In order for graduates to be employed in international companies other than the national fleet, maritime education must be updated according to the recruitment criteria of multinational foreign companies in accordance with international standards.

3.4. Communication Deficiencies

Today, the most prominent approach in human resources is that when a person has completed his /her higher education, he /she must gain intellectual competence, high thinking, and cognitive skills in problem-solving, decision-making, and effective communication in social relations and group work (soft skills). The maritime sector also has a human-centered system needed for continuous development. Although this system is mandatory in international standards through the STCW convention and EMSA audits, maritime education institutions should offer further opportunities and contribute to the socio-cultural, intellectual, and cognitive development of students. It is especially important to continue and update the training with simulation and applied technical training. Thus, maritime education will be transformed into an education system that constantly renews itself against the changing conditions and ignores it in place.

Maritime is an international business, and the foreign language knowledge of the employees is the biggest employment element (Demirel, 2013i)[7] The problem of not speaking English in the employment of Turkish seafarers is seen as one of the biggest problems. Although countries like Georgia, Romania, India, and Ukraine are not developed countries, they stand in front of Turkey in the employment of seafarers. In higher education, foreign language education is accepted as an element of professionalization for the profession beyond the beginner level. Therefore, foreign language education should start in elementary school and vocational foreign language education should be started in maritime high schools. Foreign language preparatory Schools in secondary education institutions should be compulsory in the program. In higher education institutions, foreign language education should be intensely included in the curriculum, and Second Foreign language education should be provided. In particular, one-year preparatory classes can be added to vocational colleges and transition to vocational foreign language education can be done with 1 + 2 years education applications. In vocational institutions, it would be appropriate to provide professional foreign language and maritime English at a high level (Koca, 2016).[8]

Today, many ships are equipped with a multinational crew. To maintain a common social life on this ship and to achieve their tasks, a common language is needed, which will be English.

3.5. Accreditation System

The Total Quality Management (TQM) system is the most commonly used tool to ensure quality. TQM provides essential feedback to improve the quality of procedures and processes applied. In particular Quality Assurance provided by recognized external authorities plays an important role in defining corrective actions to reach the commonly accepted standards. External verification and continuous feedback support are required to ensure the quality of Maritime Education and Training (MET). This will provide reliable support to continue the improvement of the system (Erdogan and Demirel, 2015).[9]

Improvement accreditation is a term used to describe the process that institutions of higher education undergo to confirm they meet the strictest educational standards. Accreditation is earned through private accrediting bodies and nongovernmental organizations that have been created specifically to review higher education institutions and programs.

The purpose of accreditation is to create a set of standards for all institutions of higher education to be held to, while also encouraging schools to be the best they can be. Further, accreditation aims to ensure the accountability of maritime institutions and degree programs to boost public trust and confidence. When an institution or degree program is properly accredited, students can gauge its overall quality without conducting a detailed analysis on their own.

Accreditation is a tool that society uses to monitor, assess, and evaluate the standards and quality of the education a student receives at a college, university, or other institution of higher learning. Here are some of the main benefits enrolled students receive by attending an accredited school.

While not all careers require workers to become certified, some do. Many careers, especially those in maritime, won't allow students to sit for their certification examination unless they earned a degree from an accredited institution. When a maritime institution is accredited, students and employers can trust the quality of the education received. That's why accreditation is one of the biggest factors any student should consider when choosing a school or degree program. When an institution is properly accredited, students can rest assured that the proper vetting has already taken place. A degree from an accredited school or program enables graduates to sit for all types of certification examinations.

Although accreditation is a comprehensive process, it is not a one-shot deal. Most accrediting agencies require institutions to continually apply and improve their standards to keep their accredited status. While it can be a pain, the ongoing accreditation process ensures that institutions don't become complacent and let their standards slip. To stay accredited, institutions need to always be at their best and keep their standards high over time (What is Accreditation System, 2019).[10]

4. Discussion

4.1. Importance of Endorsement and Recognition for Working on Ships of Developed Countries

All seafarers serving on board foreign-flagged ships must have their national certificates of competency endorsed for recognition by the foreign flag administration. The foreign flag administration shall issue an endorsement attesting to the recognition of a certificate issued under the provisions of the STCW Convention. Recognition and endorsement of the CoC is very important for seafarers providing them with many advantages such as better and regular payment, insurance, social security, and better working conditions.

However, there are only 18 countries (Bulgaria, Italy, Romania, Malaysia, Thailand, Singapore, Malta, Ukraine, Russian Federation, Azerbaijan, Iran, Netherlands, Georgia, Qatar, Jordan, Denmark, Hong Kong, and Norway) that are mostly are not well-known countries except Denmark and Malta as a convenient flag. 18 other countries signed mutual recognition agreements but not signed protocols which means they do not accept mutual recognition.82 percent of Turkish- owned ships are registered foreign-flagged vessels that Turkish oceangoing officers are serving. These officers need recognition of their COCs by convenient flag countries in particular Marshall Islands, Liberia, and Panama. Panama started not to endorse the newly submitted Turkish CoCs in 2018. According to the new European Union acquis Malta will make an endorsement depending upon EMSA approval shortly. As a result, Turkish seafarer's opportunities to work on foreign-flagged ships diminishing day by day. To prevent this, the Turkish Maritime Authority should take steps to complete the signing of protocols immediately with 18 countries to achieve mutual recognition and give importance to ensuring the quality of maritime institutions.

4.2. Importance of EMSA Inspections

To be recognized of a CoCs by the EU other countries, Turkey needs to pass EMSA inspections without any major problems. To avoid any deficiencies in these inspections, maritime institutions in Turkey should provide quality assured maritime education and training. All MET institutions in Turkey should be strictly supervised by the competent authorities, and it must be ensured that education quality meets international standards. Maritime institutions that are found to be inadequate as a result of the audits and do not meet the education standards may create many problems during EMSA country audits. If adequate education and standards cannot be achieved, there will be difficulties for EU countries to recognize Turkish CoCs. For example: Malta or Italy will not give an endorsement to Turkish seafarers due to Turkey have not passed EMSA audits. Transportation and Infrastructure Ministry (2022).

When the "2053 Transportation and Logistics Main Plan (MoIT,2022a)"[11] and "Arriving and Reaching Turkey 2002-2022 (MoIT,2022b)"[12] documents reflecting the transportation policies of Turkey were examined, there was no clear goal regarding both the cooperation with the European Union- EMSA and the development of maritime education.

4.3. Importance of Accreditation of MET Institutions

Accreditation is the most important element in the mutual recognition of the quality of education in the schools of other countries. As the most common example, if a university is accredited by an accreditation body recognized by the Washington Accord, it is recognized by every country included in this agreement. Accreditation will also be the most important criterion for mutual recognition of maritime education. In this respect, it will be appropriate for all maritime education institutions to be subject to accreditation.

Although accreditation is a comprehensive process, it is not a one-shot deal. Most accrediting agencies require schools to continually apply and improve their standards to keep their accredited status. While it can be a pain, the ongoing accreditation process ensures that schools don't become complacent and let their standards slip. To stay accredited, schools need to always be at their best and keep their standards high over time.

4.4. Verbal Communication Problem

The common language of all seafarers around the world is English. All publications, are submitted in English and most of them have not been translated into either Turkish or other flag countries' languages. The common language used in the practice of the profession when working on board is English. Therefore, Turkish seafarers need to have sufficient English language suitable to international standards depending upon their rank and positions. Not only the seafaring officers but also maritime administration staff, shipping and port operation companies' managers, supervisors, experts, and technicians must know English well. However, there are only 4 tertiary maritime institutions that provide education fully in English. In particular maritime tertiary level schools are not only for education but also for research institutes. The academic staff should have sufficient English language to be able to follow developments in the maritime sector and collaborate with other MET institutions around the world. is spoken well, developments can be followed in the field of international maritime. Foreign language education starts at primary schools and continues at every stage of the profession. The English language is indispensable for maritime business.

In maritime schools, emphasis should be placed on maritime English as well as normal English. One of the most important things to do in this regard is to provide the English preparation course in maritime institutions together with maritime English. With this application, students can adapt to vocational courses more quickly and start developing themselves from the beginning.

The students cannot and must not be excused because it is difficult for them to learn a second language, in this case, English. The profession demands that the ship officers be able to communicate effectively in English. The students must be impressed upon of this very basic and essential requirement (Demirel, 2013).[13] The maritime administration should be very keen to ensure the English language level of seafaring officers for all levels by conducting gradually harder examinations. The foreign language education and examination procedures must be improved within the framework of the maritime English course.

5. Conclusion

The findings of this study are discussed, and respective results are obtained. Based on the results some applicable, suitable, and acceptable proposals are introduced.

5.1. Mutual recognition

Recognition and endorsement of Turkish Seafarers CoCs are very important for Turkish seafarers to have better working conditions, payment, and reliable insurance. The number of countries that recognize Turkish CoCs is not sufficient due to a lack of mutual protocols. To ensure that primarily Turkish Maritime Administration should realize mutual agreements and protocols with these countries according to STCW I/10. Firstly, the negotiations should be started with 18 countries which Turkey has already reached an agreement but still waiting for the sign of the protocol. Turkish Maritime Administration should work on this subject to increase the number of countries in which mutual agreements and protocols are signed in particularly developed countries and significant convenient flag countries that Turkish crew serves. Otherwise, it will be very hard for Turkish seafarers to find job opportunities on board of developed countries' flagged ships.

5.2. EMSA inspections

Recognition and endorsement of Turkish CoCs is directly proportional to how well your maritime schools perform during EMSA inspections. Thus, every sacrifice needs to be made to improve our maritime education. Turkey needs immediate action should be taken to mitigate deficiencies at the schools which create a negative effect on the quality.

5.3. Accreditation of MET Institutions

If Turkey provides external approval by internationally recognized accreditation organizations for MET institutions, it will be the most important element in the tasting of these COCs.

For an educational institution to be accredited, it is necessary to meet international standards. Nowadays, it is necessary to make a big investment to provide this with its facilities, lecturers, laboratories, and simulation facilities. In addition, the government should never give permits for the operation of MET institutions that are not capable of meeting STCW requirements.

5.4. Communication problems

Communication between ships, port authorities, and crew members is very important for the safety of the ship and the benefit of personnel as well. Misunderstanding due to verbal communication may cause many problems during ship operations even fatal results. To avoid that, all seafarers should have sufficient verbal English skills. The seafaring officers should have also written skills in English to provide perfect communication between the ship and other respective authorities.

Speaking English in the Maritime Sector is more important than learning English. Most practices in maritime operations are based on speaking. For example, fluency in radio conversations, understanding the spoken language, and understanding the commands given by the pilot captain shows how vital it is to speak and understand English. To overcome this, the emphasis should be given to speaking.

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Effects of Including Maritime Transport in EU ETS

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Abstract

The study focuses on the decarbonization efforts in the maritime sector towards the International Maritime Organization's (IMO) and the European Union's (EU) goal of achieving the zero-emission target by 2050. In particular, the role of policies and regulations developed by IMO and EU, such as the Energy Efficiency Design Index (EEDI), Energy Efficiency Existing Ship Index (EEXI), Carbon Intensity Indicator (CII), Fuel EU Maritime and Emissions Trading System (ETS) in reducing carbon emissions in maritime transport is examined. Established in 2005, the effects of the EU Emissions Trading System (ETS) on a marine vessel operating in Emission Control Areas (ECA) and non-ECA regions are analyzed through two scenarios. These scenarios provide a comparison of the effectiveness of the ETS in reducing GHG emissions and the impacts of this policy on the overall maritime sector. The results provide important implications for the maritime sector's sustainability and guidance for future policymakers and industry stakeholders. By highlighting the complexity of the decarbonization process and its multidimensional impacts on the maritime industry, this study aims to lay a foundation for future studies.

Keywords: *EU-ETS; Decarbonization; Greenhouse gas emissions; Maritime*

1. Introduction

Maritime transportation accounts for a significant part of the global transportation. Compared to other modes of transportation, maritime transportation has a dominant position, with a share of more than 80%. By 2022, the world merchant fleet will comprise 105,493 vessels over 100 GT (Gross Tonnage), with a total carrying capacity of 2.27 billion DWT (Deadweight Tonnage). Maritime transport is of great economic value, with trade volume 2022 recorded at 12,027 million tons (Review of Maritime Transport, 2023).

While maritime transportation is essential for trade sustainability, it faces global threats like climate change. According to the fourth International Maritime Organization (IMO) greenhouse gas study (GHG), in 2020, maritime transport's carbon dioxide (CO_2) emissions accounted for about 3% of the global total; sulphur oxides (SOx) emissions, about 13%; and nitrogen oxides (NOx) emissions, about 15%. The IMO has developed strategies to mitigate climate change impacts from the maritime industry, aiming to reduce GHG emissions to zero gradually. (Baroudi et al., 2021).

One of the most critical methods to reduce the impacts of maritime transportation on climate change is to reduce the use of carbon-based fuels. According to the fourth International Maritime Organization (IMO) greenhouse gas study, heavy fuel oil (HFO) had the highest share among the fuels used in maritime transport in 2018, with 79.3%. Heavy fuel oil produces CO_2, SOx and NOx emissions, which positively affect climate change (IMO, 2020). Decarbonization is one of the most essential strategies to reduce carbon emissions. Decarbonization represents one of the primary responsibilities of the maritime industry in the fight against global warming. It aims to minimize atmospheric emissions, with a particular focus on reducing emissions from the combustion of fossil fuels. Developing zero-emission fuels and innovative technologies are central to decarbonization efforts, making the maritime industry a critical component in the fight against climate change.

The Paris Agreement adopted by the United Nations (UN) on April 22, 2016, set out strategies to mitigate the impacts of climate change. This agreement set targets for limiting the rise in global temperature and defined goals and strategies to minimize the rise (United Nations, 2015). The Paris Agreement addresses global industries in general, and the International Maritime Organization (IMO) is specifically responsible for developing specific targets and strategies for the maritime sector that align with the Paris Agreement goals. The main targets set by the IMO are to reduce CO_2 emissions by 40% by 2030, greenhouse gas emissions by 30% by 2030, and 80% by 2040 compared to 2008; ultimately, the aim is to eliminate all emissions by 2050. To achieve these interim and final targets, IMO has taken design and operational measures to improve the energy efficiency of ships. On the design side, this includes measures such as the Energy Efficiency Design Index (EEDI), which applies to new buildings from January 01, 2013, and the Energy Efficiency Existing Ship Index (EEXI) for existing ships, which entered into force on January 01 2023; on the operational side, measures such as the Carbon Intensity Indicator (CII), which entered into force on January 01 2023 (IMO, 2023)—achieving decarbonization targets also impacts the commercial operation of ships, such as applying limitations on engine or shaft power where necessary according to the Energy Efficiency Existing Ship Index (EEXI).

In line with the goals and strategies set by the International Maritime Organization (IMO), the European Union (EU) has developed the "Adaptation to 55" package, which aims to achieve climate goals and create a roadmap. This comprehensive package includes measures and

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recommendations for implementation in various sectors, from construction to transportation. It also includes elements such as the Social Climate Fund and the Border Carbon Regulation Mechanism, which support climate policies and focus on providing financing (Kayali, 2023).

Founded in 2005, the European Union Emissions Trading System (EU ETS) has taken significant steps towards reducing greenhouse gas emissions. The EU ETS functions as a system for limiting the greenhouse gas emission values of the sectors within its scope, including the maritime sector. The main objective of the system is to achieve an initial net emission reduction of 55% in 2030 compared to 1990 and to reach climate neutrality by 2050 (European Commision, 2024).

The EU's regulations provide a strategic framework for reducing carbon emissions in the maritime transport sector and ultimately achieving zero-emission targets. These regulations ensure the maritime sector contributes to sustainability goals while driving emission reduction efforts. Examples include the Monitoring, Reporting and Verification (MRV) regulation, which came into force on January 01, 2018, and allows for the determination of ships' CO2 emissions; the ETS, which came into force from January 01, 2024, in addition to MRV; and the FuelEU Maritime regulations, which will come into force on January 01, 2025, and will measure GHG emissions per unit of energy (EMSA, 2023).

The scope of the EU ETS has been extended to include only CO2 emissions for cargo/passenger ships of 5000 GT and above as of January 1, 2024. CH4 and nitrous oxide emissions will be included in the scope of the EU ETS after 01 January 2026. In addition, 40% of CO2 emissions will be considered between 01 January 2023 and 01 January 2024, 70% between 01 January 2024 and 01 January 2025 and all CO2, CH4 and nitrous oxide emissions in the following years. The EU ETS will cover offshore vessels over 5000 GT to cover CO2, CH4 and nitrous oxide emissions after 01 January 2027. A decision will be made for cargo/passenger ships between 400 GT and 5000 GT on 01 January 2027. The ETS timeline is shown in Figure 1.

Figure 1: ETS timeline (DNV, 2024)

The study assessed the impacts of the ETS on shipping vessels operating within or outside ECAs using two different scenarios. The scenarios examined were designed to compare the effectiveness of the ETS in reducing GHG emissions and the overall impacts of this policy on the maritime sector. The research provides an in-depth analysis of the decarbonization process of the maritime sector. It lays a foundation for future research by detailing the far-reaching impacts in this sector.

1.1. Literature Review

The research aims to contribute to the existing literature on the decarbonization process of the maritime sector. (Christodoulou & Cullinane, 2023) The maritime sector's inclusion in the EU ETS could have positive consequences, such as increasing incentives for green technologies and reducing the carbon footprint. (Lagouvardou & Psaraftis, 2022) examined the risk of container ships operating within the European Economic Area leaving the area with the EU ETS. (Kirval & Çalişkan, 2022) The study does not address the specific impacts of the EU ETS on maritime transport. However, it raises potential vital concerns such as environmental and social responsibilities, economic implications, feasibility, and policy coherence. (Christodoulou et al., 2021) assessed the economic impacts of including maritime transport in the EU ETS, noting that Ro-Ro cargo/passenger vessels, in particular, would see disproportionate cost increases compared to other vessel types. (Cariou et al., 2021) discussed the sectoral impacts of the inclusion of maritime transport in the EU ETS and suggested that payments per tonne of carbon emissions could provide incentives for emission reduction measures, particularly wind-assisted technologies, of around USD 0.3 to 1.4 billion. (Wettestad & Gulbrandsen, 2022) study discusses the impacts and motivations of the EU ETS on the maritime sector.

The study starts with an overview of the EU ETS (Chapter 2). Then, it analyzes its impacts on shipping operating inside and outside Emission Control Areas (ECA) through two scenarios (Chapter 3). The analysis results are presented in Chapter 4, where the findings are discussed. By providing an in-depth analysis to understand the decarbonization process of the maritime sector, this study demonstrates the wide-ranging impacts on the sector and lays a foundation for future studies.

2. EU ETS in the Maritime Industry

The EU ETS promotes decarbonization and reduces greenhouse gas emissions as an essential tool in the fight against climate change. (Bayer & Aklin, 2020) states that the EU ETS helped reduce more than 1 billion tons of carbon dioxide emissions between 2008 and 2016. Besides global industry, the system impacts maritime transport, which is responsible for around 3% of greenhouse gas emissions. The EU ETS provides a framework to increase sustainability in this sector by steering maritime transport towards lower-carbon technologies and more efficient operations.

The EU ETS aims to increase the contribution of this sector to the decarbonization process by extending the scope of CO_2 emissions to maritime transport as of 01 January 2024. As of 01 January 2026, the scope of the system will be extended to include CH_4 and N_2O emissions in addition to CO_2 emissions (ICAP, 2024). With this extension, the EU ETS aims to reduce greenhouse gas emissions from maritime transport comprehensively.

Between January 01, 2024, and January 01, 2025, the responsibility for CO_2 emissions of marine vessels is set at 40% for voyages within the EU and 20% for voyages with one of the ports of departure or destination in the EU. Between 01 January 2025 and 01 January 2026, these values were increased to 70% and 35%, respectively. After 01 January 2026, the responsibility will be further expanded by covering all CH_4, N_2O and CO_2 emissions (European Commision, 2024).

3. Case Study

In this section, the impact of the EU ETS on a ship operating in the Emission Control Area (ECA) and outside the ECA regions is analyzed using two scenarios. The voyage-related fuel consumptions for the ship's main engine, auxiliary engines, and boiler for a period of one year were compiled and analyzed to calculate the total voyage-related cost of EU Allowance (EUA). For the ship to sail in the ECA, ship operators must have an EUA for its emission. In maritime transport, there is no free allocation of EUA as in other industries and one EUA is equivalent to one ton of greenhouse gases. To determine the value of the EUA cost according to the formula below, the fuel consumed during the voyage, the emission factor of the fuel, the rate of the trading area, the EUA price and the phase-in allowance must be known. The fuel consumption is the total amount of fuel consumed by the vessel during the voyage, emission factor (EF) is a coefficient for each type of fuel, e.g. for heavy fuel oil 3.114, low sulfur fuel oil 3.151 and marine gas oil 3.206, trading area rate is %100 for voyages between and within EU ports, %50 for voyages from an EU port to a non-EU port or vice versa and zero for journeys between and within non-EU ports, EUA price is the price per ton of carbon dioxide produced and phase-in allowance as %40 in 2024, %70 in 2025 and %100 in 2026 and beyond. (EU ETS, 2023)

EUA cost = Fuel consumption*EF*Trade Area Rate*EUA Price*Phase-in Allowance

The subject vessel carried out a total of 80 voyages in one year, of which 40 were in the ECA region and the remaining 40 were in the non-ECA region or only one of the ports of arrival or departure in the ECA region. Voyages in the non-ECA region are categorized under scenario 1, while voyages in the ECA region are categorized under scenario 2. The calculation of total fuel consumption of voyages listed under scenario 1 is calculated as 1127.80 MT for the main engine, 109.05 MT for the auxiliary engines and 79.360 MT for the boiler, while in scenario 2 in the same order 991.24 MT, 130.793 MT and 88.385 MT. The total fuel consumption is 1316.11 MT in scenario 1 and 1210.31 MT in scenario 2.

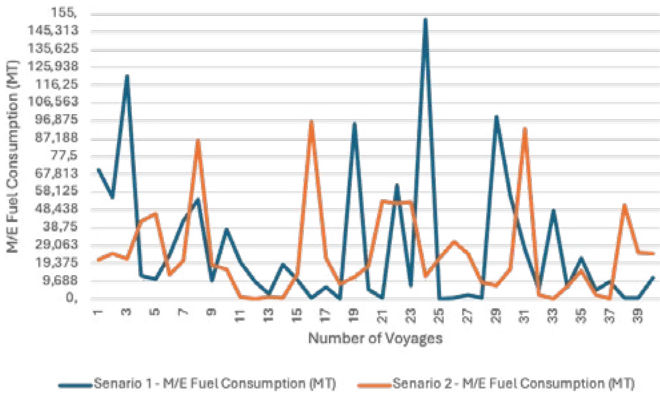

Figure 2: Main Engine Fuel Consumption per Voyages

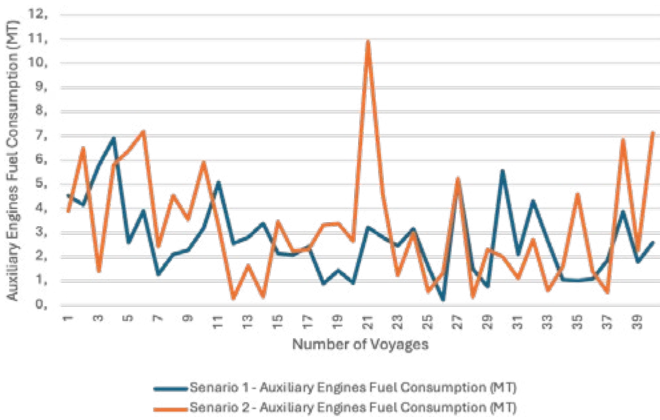

Figure 3: Auxiliary Engines Fuel Consumption per Voyages

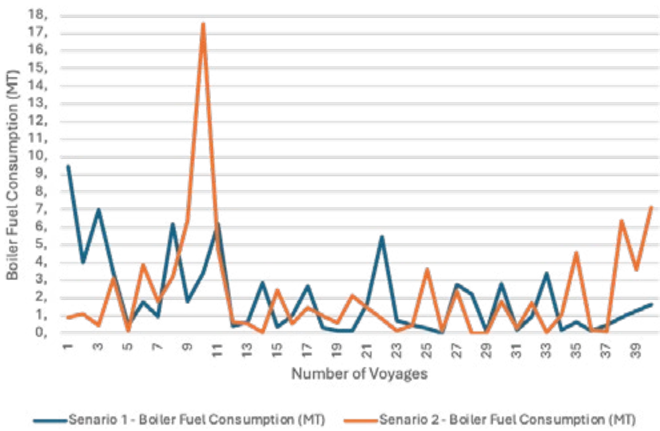

Figure 4: Boiler Fuel Consumption per Voyages

Following the calculation of fuel consumption values, the emission factor for Marine Gas Oil was determined as 3.206 and the EUA price of approximately 70 USD was taken as the basis for the calculation of EUA costs in January 2024 and presented in figures 2, 3 and 4 (Carbon Price Tracker, 2024). Based on 2024 data, the phase allowance is assumed to be 40% and the trade rate is set to 100%, 50% and zero depending on the ship's loading and unloading ports located inside or outside the ECA. The EUA cost is calculated per voyage for two different scenarios, as illustrated in Figure 5.

In the first scenario, one of the loading or unloading ports is assumed to be in the ECA for 12 voyages and non-ECA for the remaining 28 voyages, resulting in a total EUA cost of EUR 27,922.34. In the second scenario, all voyages are performed between the ports of the European Union and the total EUA cost is calculated as EUR 92,472.8.

The study results show that although the number of voyages and fuel consumption of the vessel are similar between the first and second scenarios, there is an EUA cost difference of approximately EUR 65,000 due to the cost per tonne of carbon dioxide emissions during operations inside and outside the ECA. This difference may have commercial implications and may have an impact on freight rates, especially for ships sailing in ECA regions. On the other hand, ETS can act as a steering tool for the maritime sector towards technologies such as alternative fuels and renewable energy sources in achieving its decarbonization targets.

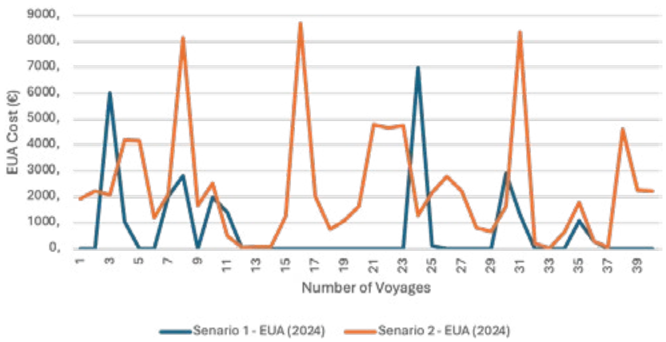

Figure 5: EUA Cost Calculation per Voyages

4. Conclusion

Decarbonization is critical in maritime transport to mitigate the impacts of climate change. IMO and the EU have set targets and strategies to reduce GHG emissions in maritime transport. Based on this study, the extension of the EU ETS to maritime transport shows the potential to promote sustainability. The analysis of ship operating scenarios within and outside the ECA highlights the significant impact of the EU ETS on the cost of emissions and the importance of such measures in promoting sustainable practices.

In this study, EUA cost analysis is performed to demonstrate the impact of operating a ship in ECA and non-ECA regions on the EU ETS. In this context, the EUA cost is calculated for the two scenarios, the relevant literature is reviewed, and the results are presented comparatively to show the difference between travel in ECA and non-ECA regions.

On January 01, 2024, because of the entry into force of the EU ETS, the maritime transport sector in the ECA region has seen an economic impact because ship operators in the ECA region are required to have an EUA for their emissions. Furthermore, the EU ETS opens the door for further research and action to accelerate the decarbonization of the maritime sector and encourages studies on alternative fuels and renewable energy to reduce emission levels. As the maritime industry continues to cope with the challenges of climate change, the insights of this study offer important implications for the sustainability of the maritime sector and provide guidance for future policymakers and industry stakeholders.

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Investigation of the Impacts of the COVID-19 Pandemic on Maritime Transportation and Proposing Strategies for the Future of the Maritime Industry

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Abstract

The COVID-19 pandemic, which emerged in China at the end of 2019, has swiftly and unpredictably impacted the entire world. The simultaneous and rapid global spread of the outbreak severely affected the global economy and trade activities worldwide. Alongside the economic and trade repercussions, measures taken to control and end the pandemic have significantly influenced maritime transportation on a global scale. The aim of this research is to examine the effects of the COVID-19 pandemic on maritime transportation, focusing on four different modes: container shipping, bulk cargo shipping, tanker shipping, and cruise shipping, as well as the impacts on ports and seafarers. The research seeks to develop measures that can enhance the sustainability of the industry in the face of potential crises in the future. The findings are derived from scientific studies and sectoral reports from national and international maritime institutions. The research results indicate that, despite the negative impact of the crisis on freight transportation in the first half of 2020, the industry returned to 2019 levels in the second half of the same year and reached record levels in 2021. However, the positive recovery observed in freight shipping did not extend to cruise shipping, which continued to be adversely affected by the pandemic for an extended period. Post-pandemic strategies for sectoral sustainability and resilience to potential future crises highlight the acceleration of technology usage and digitalization processes, along with the strengthening of international organizational structures within the maritime industry.

Keywords: *COVID-19, maritime transportation, shipping, ports, seafarers*

1. Introduction

At the end of 2019, the COVID-19 outbreak emerged in China and swiftly escalated into a pandemic, affecting 770 million people worldwide and officially causing the death of 7 million individuals according to official figures, while unofficial estimates suggest up to 20 million fatalities. The sudden onset of the pandemic and its rapid global spread severely impacted the global economy and world trade.

In addition to the supply and demand-related challenges posed by the COVID-19 outbreak in terms of production and consumption, stringent measures implemented to prevent the spread of the virus also significantly affected global trade. The crisis atmosphere created by the pandemic inevitably affected maritime transportation, which constitutes a significant portion of global trade. The impact of the pandemic on maritime transportation was not solely due to disruptions in trade but also resulted from disruptions in supply chains and port operations due to imposed restrictions and measures.

This study examines the effects of the COVID-19 pandemic on maritime transportation through various modes of transportation. Furthermore, the impacts of the pandemic on ports and seafarers are highlighted, and other factors influencing maritime transportation are observed. Considering the measures that enabled maritime transportation to remain resilient during the COVID-19 pandemic and the factors contributing to its adverse effects, measures to be taken to ensure the resilience and sustainability of maritime transportation and the maritime industry in similar crisis situations in the future are evaluated.

2. Impacts of COVID-19 on maritime transportation

Maritime transportation can be described as the transportation of all kinds of cargo and passenger activities over the sea, by maritime vessels and vehicles. A large part of the global trade around the world is carried out by maritime transportation. While 80% of the global trade in terms of volume and 70% [1] in terms of value is carried out by maritime trade, all kinds of developments such as regional and global political events, natural disasters, economic crises, epidemics etc. have direct effects on the maritime transportation industry.

The corona virus (SARS-CoV-2) outbreak spread unexpectedly and rapidly to the whole world, and was declared a pandemic by the WHO on March 11, 2020, under the name COVID-19 (Corona Virus Disease-19) [2]. Described as the largest outbreak since the Spanish flu pandemic in 1928 [3], the COVID-19 outbreak has had significantly adverse effects on global economies and international trade, including maritime transportation.

As of November 2023, the COVID-19 pandemic has spread to 203 countries around the world, infected 770 million people and caused the deaths of approximately 7 million people. Although the effects and transmission rate of the pandemic have been significantly reduced, there are still new cases and deaths in the world. As of March 15, 2024, the number of COVID-19 cases in the last 1 week was 69369 [4].

Officially, the first response and preparedness measures for the COVID-19 pandemic in Türkiye started on January 10, 2020 with the establishment of a scientific committee at the Ministry of Health [5]. The first case in Türkiye was seen on March 11, 2020, when the outbreak was declared as a pandemic [3].

On May 5, 2023, the World Health Organization (WHO), 3 years and 2 months after declaring the COVID-19 pandemic, announced that the situation no longer constituted a global emergency. The statement highlighted that, according to official figures, at least 7 million people had died due to the COVID-19 pandemic, but the actual number was stated to be more than 20 million [6].

While the process of globalization has seen disruptions in the world economy over the past 30 years, the emergence of a crisis particularly in China, a major contributor to the world's trade volume, caught global economies unawares. In other words, the crisis caused by the pandemic has been notably different from previous crises, as it originated in a region that holds a significant share in the world's trade volume. This brought about unprecedented challenges for the world economies.

The harsh measures taken by China to prevent the outbreak led to a decrease in production all over the world, and a supply-driven crisis environment was created at its onset. In March 2020, the outbreak was declared a pandemic, which meant it spread rapidly and simultaneously all over the world. Various measures taken to end the pandemic caused consumer habits to change and this translated into a demand-driven crisis environment. This in turn slowed down trade and economic activities all over the world. As a result of all these negative developments and decreased commercial activities, maritime transportation was seriously affected in the first 6 months of the pandemic. The deterioration in the supply-demand balance led to a decrease in trade, an increase in prices and a decrease in Gross Domestic Product (GDP) as a macroeconomic effect (Figure 1).

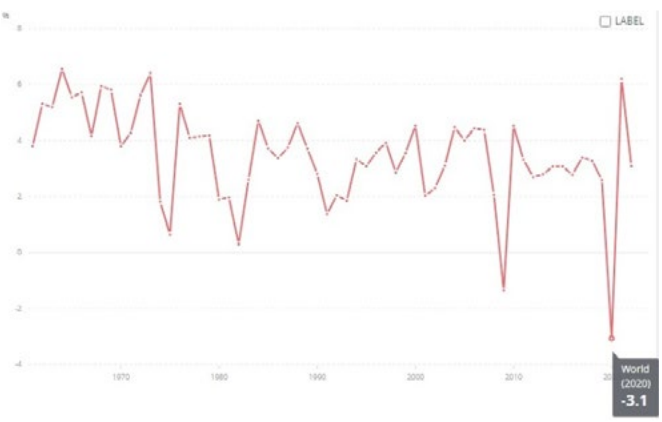

Figure 1. World GDP growth rate (1961-2021) [7].

Due to the disruptions caused by the COVID-19 pandemic, global economic and trade activities have been adversely affected, impacting maritime transportation negatively. The deteriorating transportation activities, in turn, have led to increased transportation costs and delays. Consequently, the global economy and international trade have been indirectly and once again negatively influenced by the above factors.

The decline in GDP growth figures due to global trade tensions and political uncertainties in the pre-pandemic period accelerated with the COVID-19 pandemic. Falling to 2.5% in 2019, the GDP growth rate fell 3.1% below the 2018 growth rate and 1.1% below the average growth rate of 2001-2008. With the COVID-19 pandemic, the growth rate for 2020 was reflected as -4.3% and a contraction was observed (Figure 2).

Figure 2. GDP and world maritime trade growth rates [8].

Notwithstanding the predictions for an average growth of 3.4% for 2019-2024 and 2.2% for 2020 according to the 2019 forecasts before the COVID-19 outbreak, maritime transportation declined for the first time since 2009. This was an immediate result of the measures taken to prevent the outbreak and the problems experienced in the industry due to the direct effects of the outbreak. The 2020 growth rate was 3.4% lower in tons, 500 million tons below the 2019 forecast. Nevertheless, there emerged a shift towards maritime transportation since other modes of transportation were more prone to be affected by the pandemic. Moreover, medical products needed for the pandemic were transported by sea. Thanks to these factors, maritime transportation in 2020 met 87% of the global transportation (Table 1).

Table 1. World trade and maritime transportation [9].

Global Trade and Maritime Transportation	2015	2016	2017	2018	2019	2020	2021	2022	2023 (approx.)	2024 (est.)	10 Year Trend	5 Year Trend
Maritime Trade (per Capita)												
World Maritime Trade (Billion Ton)	10.79	11.12	11.57	11.89	11.95	11.54	11.96	11.88	12.06	12.39	1.6%	0.2%
World Population (Million)	7.38	7.46	7.55	7.63	7.71	7.80	7.88	7.95	8.03	8.11	1.1%	1%
Trade Tonnage (per Capita)	1.46	1.49	1.53	1.56	1.55	1.48	1.52	1.49	1.50	1.53	0.5%	-0.8%
Bulk Shipping (per Capita)	1.04	1.06	1.06	1.09	1.08	1.02	1.05	1.04	1.04	1.06	0.1%	-1.2%
Container Shipping (per Capita)	0.22	0.22	0.23	0.24	0.24	0.24	0.24	0.23	0.22	0.23	1.2%	-0.5%
Maritime Transport Multipliers												
Global Maritime Transportation Growth Rate	2.2%	3.0%	4.1%	2.7%	0.5%	-3.4%	3.3%	-0.7%	1.5%	2.8%	1.6%	0.3%
GDP Growth Rate	3.4%	3.3%	3.8%	3.6%	2.8%	-3.1%	6.0%	3.4%	2.9%	3.1%	3.0%	2.4%
Mar. Transp./GDP Multiplier	0.63	0.93	1.09	0.77	0.18	1.1	0.55	-0.20	0.50	0.89	0.55	0.11
Global Trade (Billion Ton)												
Global Maritime Transportation	10.79	11.12	11.57	11.89	11.95	11.54	11.96	11.88	12.06	12.39	1.6%	0.2%
Global Trade (All Modes)	12.78	12.95	13.56	13.95	14.07	13.33	14.04	14.11	14.32	14.80	1.5%	0.2%
Global Transportation Maritime Rate	84%	86%	85%	85%	85%	87%	85%	84%	84%	84%	85%	85%

Despite the significant adverse effects of the COVID-19 pandemic on maritime transportation, freight rates remained at positive levels for industry stakeholders throughout the pandemic. Particularly, container carriers experienced an increase in freight rates and profits in 2020 compared to the previous year, attributed to the measures they implemented. Freight rates even reached record levels in November 2020, doubling the rates observed at the beginning of the same year. Freight rates, which were protected by the measures taken during the periods when the effects of the pandemic were felt hard on the transportation industry, increased further as port operations returned to normal and bans were relaxed and lifted. Despite this positive outlook in container freight rates, fluctuations in bulk cargo and tanker markets have led to increases and decreases in freight rates, making it difficult to keep rates constant.

At the beginning of the pandemic, there were decreases in freight rates across all maritime shipping modes. However, due to China quickly gaining control over the pandemic and the measures taken by transportation companies, significant increases in freight rates were observed from the second half of 2020. Container shipping freight rates reached record levels after the pandemic, thanks to capacity management and blank-sailing measures. Similarly, bulk cargo shipping saw freight rates that remained close to the 2020 predictions. Like container shipping, there was an increase in bulk cargo freight rates after the pandemic was brought under control. In tanker shipping, however, the freight rates experienced high volatility during the pandemic due to a decrease in energy consumption and demand for oil, combined with the use of oil tankers as floating storage facilities.

Although the negative impacts of maritime transportation varied in different regions, at different times, and for different types of transportation during the first six months, all types of maritime transportation were significantly affected by the adverse effects of the pandemic. From the second quarter of 2020 onwards, there was a substantial decrease in the number of container, passenger, and other cargo ships calling at ports, especially during the first six months of the pandemic, compared to the year 2019 (Figure 3). However, as the maritime transportation industry stakeholders took appropriate measures, the industry, except cruise shipping, showed a rapid recovery trend from the second half of 2020, reaching pre-pandemic transport and growth figures from 2021 onwards.

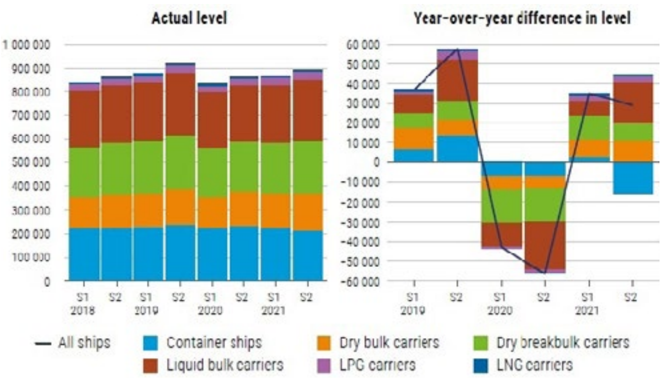

Figure 3. Number of port calls and annual change rates [10].

The volume of cargo handled during the pandemic was much less affected by the pandemic than the number of ships calling at the ports. While the number of ships visiting ports decreased due to blank sailings, the implemented capacity management strategies resulted in a much lower decrease in cargo rates. [11].

The stakeholders in the maritime transportation industry, having learned valuable lessons from the 2008 economic crisis, implemented effective measures that allowed the industry to swiftly overcome the challenges posed by the pandemic. These measures contributed to achieving record growth figures in certain transportation modes starting from 2021. As a result of the implemented regulations, the number of ships calling at ports decreased for many types of vessels. Despite significant negative impacts felt at the beginning of the pandemic, especially in container shipping, the industry successfully navigated through the challenges by adopting measures such as capacity constraints and blank sailings, leading to the achievement of record profits in container shipping.

Although container shipping has successfully withstood the pandemic, the same has not been the case for cruise shipping. Tourism activities came to a standstill as a result of measures imposed by countries, such as travel bans and border closures. In the light of these developments, cruise shipping can be listed as the most affected type of maritime transportation by the pandemic.

Since the pandemic could not be brought under control for a long time all over the world, this negative scenario continued for a long time for cruise shipping. On the other hand, in tanker and bulk cargo shipping, although the impact of the pandemic was initially strongly felt, signs of recovery began to emerge from the second half of 2020. By 2021, these shipping modes had returned to pre-pandemic levels.

The negative impacts of the COVID-19 pandemic on maritime transportation were influenced not only by disruptions in global trade and tourism activities but also by the measures implemented. Precautions taken in ports resulted in a slowdown in loading, unloading, and handling activities, leading to cargo accumulation and congestion in ports. Measures such as social distancing, a decrease in the number of port personnel, and remote work contributed to the deceleration of port operations. This, coupled with a reduced need for truck drivers in hinter transportation, led to an increase in waiting cargo at ports. The shortage of available containers due to the accumulated cargo and congestion at ports caused delays in cargo transportation activities.

As a result of the supply and demand-driven crisis environment caused by the pandemic and the measures taken by companies, supply chains all over the world have been disrupted, and raw material supplies needed for production have experienced shortages and delays. Disruptions in supply chains occur in the form of supply shocks due to shortages of raw materials, parts and labor, demand shocks due to stockpiling, declining demand and changes in consumption habits, and distribution constraints due to the measures taken, and supply and demand shocks cause greater disruptions by spreading and triggering each other within the supply chain. Supply chain disruptions due to reduced production and measures taken by maritime transportation stakeholders were followed by a panic environment due to the pandemic and a crisis in demand caused by people whose consumption habits changed as a result of the economic crisis. During the pandemic, which caused economic uncertainty, people started to save money and as a result, the trade of goods considered as luxury decreased and the demand for essential products increased.

Although the pandemic was brought under control by China in the first three months of 2020, and production returned to normal, changes in consumer demand have led to overproduction in some products while causing difficulties in meeting demand for others. Measures such as lockdowns, stay-at-home practices, remote work, and restrictions on entertainment activities have resulted in people spending more time at home. This has simultaneously increased demand for products like home and garden furniture, sports equipment, gaming consoles, printers, televisions, etc., worldwide. On the contrary, there has been a decrease in demand for non-essential products like automobiles.

During the COVID-19 outbreak, the shipbuilding industry and shipyards saw a 16,7% decrease in the tonnage of newbuilding vessels demanded in 2020 compared to 2019 with the delay of new built orders between 4-8 weeks [12]. Newbuilding demand for bulk cargo, tanker and container ships decreased by 34%, 12% and 24% in 2020 compared to the previous year in terms of DWT, respectively. The decrease in newbuilding demand led to a decline in newbuilding prices, which reached the lowest level since February 2018 [13].

As the effects of the pandemic diminished in the second half of 2020 and continued to decrease in 2021, new build demands experienced a resurgence in 2021 [14]. Particularly with the reduction of capacity limitation measures and the rising freight rates after decline in the impacts of the pandemics, new shipbuilding investments reached the highest level since 2014.

During the COVID-19 pandemic, disputes arose in maritime transportation regarding financial issues such as compensation for delays and similar matters. The question of who would bear the mentioned expenses remained uncertain. Insurance coverage and payments related to delays put companies in a difficult situation. Companies, already facing reduced revenues due to the decline in transportation activities caused by the pandemic, encountered financial difficulties, including insurance and demurrage payments [13]. UNCTAD and other organizations have called for collaboration and agreement among industry stakeholders regarding these payments to facilitate a swift recovery from the crisis caused by the pandemic in maritime transportation.

The COVID-19 pandemic has had adverse effects on economy, trade, transportation activities, and various employment industries on a global scale. Despite being considered a significant player in maritime transportation, the negative impacts of the pandemic on seafarers have unfortunately not received widespread attention worldwide. Seafarers, already regarded as one of the most challenging branch of employment, faced intensified issues during the pandemic, contributing to the psychological challenges they had been experiencing even before the outbreak.

Particularly due to travel restrictions and border closures, seafarers who couldn't join their ships or were unable to leave their vessels even after their contracts had ended were compelled to stay onboard for extended periods. Although maritime transportation industry stakeholders and national and international organizations have constantly tried to take measures to protect the health of seafarers by publishing declarations, there has been an increase in psychological disorders and suicide cases among seafarers during the pandemic.

The COVID-19 pandemic has highlighted the necessity for maritime transportation to remain resilient against crises to ensure the continuity of global trade. In situations such as pandemics, the classification of maritime transportation workers as essential personnel, similar to health and safety personnel, is crucial for the industry's resilience. This recognition is essential to enable transportation activities to continue in a healthy and sustainable manner during challenging circumstances.

2.1 Container shipping

Container shipping, constituting 60% of global maritime transportation by volume and valued at 14 trillion dollars, saw consistent growth over the last decade. However, in 2020, it faced a decline for the first time due to the COVID-19 pandemic [15]. Since 2021, it has resumed its upward trajectory with the implemented measures.

In the first months of the outbreak, the effects of the pandemic were strongly felt in container shipping, especially due to the decrease in production and trade originating from China. Disrupted container shipping led to increased freight rates, decreased number of ships calling at ports, difficulty in finding space on ships due to capacity limitations, limited customer service, low schedule reliability, and a shortage of empty containers in the market. Although the effects of the pandemic were strongly felt in container shipping, especially in the second quarter of 2020, a rapid recovery process was experienced as a result of the measures taken.

Initially, when the pandemic began, there was an assumption that the disease would remain more regional and confined to China. Consequently, container shipping experienced minimal impact in the first months of 2020, resulting in a modest 1.1% decrease in the number of ships calling at ports. However, by the second quarter of 2020, despite the containment of the pandemic in China, it had spread globally and was declared a pandemic by the WHO. This global escalation led to a more pronounced decline in the number of ships calling at container shipping ports, reaching 6.1%. Although there was a 3.6% decline in the number of port calls in the first half of the year, by the second half, the figures rebounded to 2019 levels, indicating a relative control over the pandemic (Figure 4).

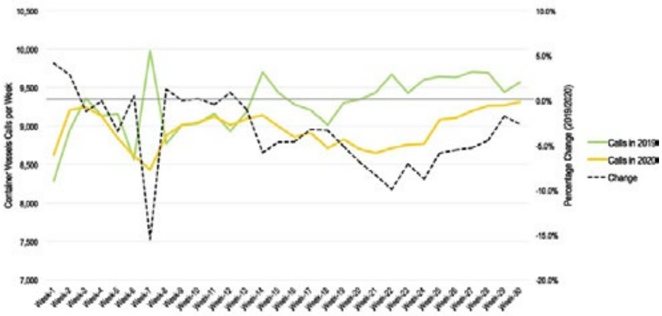

Figure 4. Container ships calling at ports and change compared to 2019 (Week 1-30) [8].

During the COVID-19 pandemic, container shipping demonstrated resilience thanks to the implementation of measures such as capacity restrictions and blank sailings, which had not been utilized during the 2008 economic crisis. This resulted in a rapid recovery [16]. With lessons taken from the 2008 crisis and changes in consumption habits brought on by the pandemic, container shipping has achieved record-breaking levels of profitability since the end of 2020. In 2021, container shipping achieved a new milestone by transporting a whopping 165 million TEUs (Twenty-foot Equivalent Units) (Figure 5).

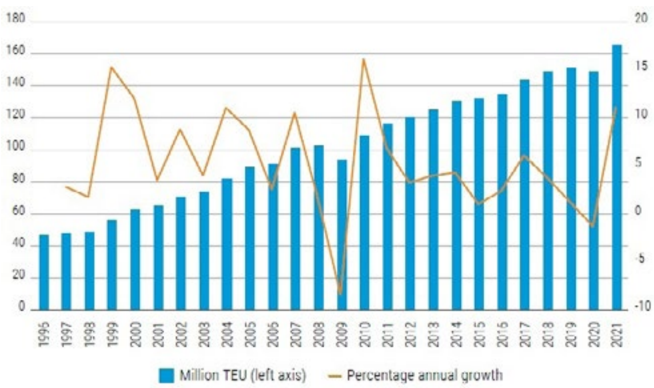

Figure 5. Container shipping in TEU and growth rate by years (1996-2021) [10].

2.2 Bulk cargo shipping

Maritime transport plays a crucial role in transporting the majority of the world's bulk raw materials, minerals, and agricultural products. Consequently, bulk shipping experienced adverse effects due to the pandemic, stemming from reduced production, diminished demand for raw materials, and a slowdown in agricultural trade activities. However, the negative impact on bulk shipping was less severe compared to other forms of maritime transportation. Despite the challenges, bulk shipping remained in proximity to the 2020 forecasts throughout the pandemic.

The pandemic, originating in China, led to a halt in production and a subsequent decrease in the demand for raw materials like iron ore and coal. Simultaneously, the restrictions on tourism and service industries resulted in a reduced need for grain products. This collective impact caused a significant contraction, up to 80%, in bulk shipping during the first quarter of 2020. The downturn was particularly noticeable in Capesize vessels, especially on routes involving China and the Far East. However, by the second half of 2020, with the containment of the pandemic in China and the resumption of production, bulk shipping rebounded, reaching 2019 levels by July 2020 [2]. As indicated by the BDI index (Baltic Exchange Dry Index), bulk shipping continued its upward trajectory into the first quarter of April 2021, reaching its peak value by surpassing 5000 points at the end of the first six months of the same year (Figure 6).

Figure 6. Dry bulk shipping according to BDI index [17].

2.3 Tanker Shipping

From the second half of 2020 onward, maritime transportation started to show signs of recovery. However, the same cannot be said for tanker shipping. Travel restrictions, production halts in service industries, and disruptions in various industries led to a drastic reduction in global oil consumption, plummeting from 100 million barrels to 30 million barrels. This decline caused Brent crude oil prices to fall from $66 to around $20. In response to the falling oil prices, oil exporting countries implemented policies to take advantage of this decline, resulting in refineries being filled and tankers being used as floating storage facilities. This led an increase in demand and freight rates for tanker shipping [18].

The fluctuation in the tanker markets, which continued in the first half of 2020, turned into a downward trend as of the second half of the same year, and there was a serious decrease in tanker market earnings. Due to decreasing global demand in the tanker market and falling freight rates, tanker market earnings reached the lowest levels of the last 10 years in July 2021 (Figure 7).

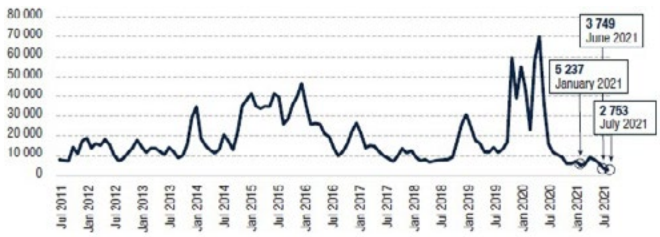

Figure 7. Tanker shipping average earnings (2011-2021) ($ per day) [14].

From 2022 onwards, tanker shipping freight rates also increased in line with the rising demand. In 2023, tanker shipping supply remained at lower levels compared to the increasing demand and freight rates remained at high levels. However, although the effects of the COVID-19 pandemic on tanker shipping ended in 2023, uncertainties about the near-term future of tanker shipping continue due to the problems experienced by OPEC countries in oil production, the ongoing Russian-Ukrainian and Israeli-Palestinian wars, and the embargoes imposed on countries such as Venezuela and Iran. Despite all these uncertainties, the demand for LNG (Liquefied Natural Gas) is expected to double in the coming period due to its lower carbon emission rate within the scope of sustainable environmental policies, and it is predicted that there will be growth in the LNG tanker market in the long term.

2.4 Cruise and Passenger Shipping

The COVID-19 pandemic, primarily transmitted in closed environments and through contact, has significantly impacted cruise and passenger shipping, making them the most affected forms of maritime transport. Due to the heightened risk of transmission and the potential for the disease to spread between countries, cruise shipping faced severe disruptions not only at the onset of the pandemic but also for an extended period. This prolonged impact resulted from stringent measures implemented by countries against cruise shipping and the closure of ports. The preventive measures and bans aimed at containing the outbreak have also led to substantial declines, particularly in urban passenger shipping.

Cruise ships are regarded as environments conducive to the easy transmission of outbreaks due to their closed nature and numerous shared areas. The average duration of a cruise trip, around 7 days, amplifies the risk, as even a single person among passengers or staff carrying the disease can potentially lead to the transmission of the illness to everyone on board. Given that a significant portion of cruise passengers is aged 65 and above, a demographic with the highest likelihood of transmission and mortality rates, stringent measures have been implemented, recognizing the potential effectiveness of cruise ships in contributing to the spread of the COVID-19 outbreak. While COVID-19 cases were seen on many cruise ships during the outbreak, 30 people died due to the outbreak on 3 large cruise ships with the highest number of cases [19].

Ito et al. (2020) examined the link between cruise ships and the COVID-19 outbreak and found that the rate of disease transmission and spread in countries that do not close their ports to cruise ships is much higher than in countries that do (Figure 8). In the same study, it was stated that the spread of the pandemic was higher in cruise ships with longer cruises and ships with larger passenger capacity [20].

Figure 8. COVID-19 transmission rate in countries with and without cruise tourism restrictions in March 2020 [20].

In another study, Mocerino and Quaranta (2023) examined the reduction in emissions from cruise ships at the port of Naples during the COVID-19 lockdowns and the subsequent period. In their study, it was revealed that the number of cruise ship arrivals at the port of Naples decreased by 77% compared to the same period in the previous year, spanning from March 12 to July 31, 2020.[21] Considering the significance of the port of Naples in Mediterranean and Italian cruise transportation, this study is significant in demonstrating the adverse effects of the pandemic on cruise transportation.

In addition to the fact that cruise and passenger ships are platforms where disease can be easily transmitted, the restriction on entertainment activities has also led to a decrease in cruise shipping. UNWTO (United Nations International Tourism Organization) announced that 83 % of tourism facilities in Europe, 80% in America, 70% in Asia and the Pacific, 62% in the Middle East and 57% in Africa have stopped their activities as a result of the measures taken regarding tourism activities that have come to a standstill all over the world [22].

Initially, the United States and European Union countries (such as Italy, France, Spain, etc.) were significantly affected by the pandemic and cruise tourism activities were canceled in Italy on March 19, in Croatia on March 20 and in Spain on March 25, 2020. In Türkiye, cruise reservations were canceled up until October 2021. These cancellations were also extended globally by the International Cruise Ship Operators as of March 23, 2020 [23].

Millefiori et al. (2021), in their study comparing the AIS data of cruise ships between 2016-2019 with the data of 2020, revealed that cruise and passenger shipping decreased between 19.57 % and 42.77% between March and June 2020. In the same study, after March 2020, the rate of decline increased, reaching a dramatic level of 45.3% in June 2020 [24].

Although cruise shipping had remained resilient to past crises and recovered quickly, the effects of the COVID-19 pandemic have been very long-lasting. However, despite it was the most affected transportation type by the COVID-19 pandemic, cruise and passenger shipping have been able to return to pre-pandemic levels by the end of 2023.

The pandemic has underscored the need for cruise companies and governments to draw valuable lessons, especially given that cruise shipping was the most severely impacted by the COVID-19 outbreak, with lingering effects over an extended period. Stakeholders in cruise shipping, including companies, port operators, and both port and flag states, should proactively implement necessary precautions for potential crises. This involves learning from the challenges faced during the COVID-19 pandemic and establishing robust measures to mitigate risks and ensure a more resilient and adaptive cruise industry in the face of unforeseen challenges.

2.5 Ports

The COVID-19 outbreak, with an incubation period of 2-14 days, prompted many countries to implement quarantine and isolation measures lasting for 14 days. This timeframe led to delays in the loading, unloading, and handling activities of ships at ports, extending their stay. Beyond cargo operations, the isolation measures also applied to port personnel, causing delays in service activities essential for ships, including fuel transfer, garbage disposal, waste disposal, and logistical supply. These delays in service activities further contributed to prolonging the ships' stays in ports.

Due to the prolonged port operations and lack of personnel, cargo over-capacity and congestion problems emerged in ports. Ships could not unload their cargo because the cargo in the ports could not be transported by highways due to the scarcity of truck drivers. As cargoes could not be transported by hinter transportation, there was a shortage of empty containers in the market, marking another crisis.

Another problem experienced in ports was concerning ship inspections. Due to the inability of port authorities and inspectors to enter the ships due to the measures taken and the problems experienced in documentation activities, ship inspections have decreased and survey and certification periods have been extended. Although the number of inspections decreased, there was a significant increase in the number of detained ships during the pandemic [25].

The effects of the pandemic were felt especially severely from the end of the first quarter of 2020, when the outbreak was declared as a pandemic. After the outbreak was partially controlled, these effects decreased in the second quarter of the same year as the measures taken were relaxed and the companies adapted to the new working norms. In the last quarter of the same year, port managements and port operations have mostly returned to the pre-pandemic period norms.

3. Discussion and Conclusions

The COVID-19 pandemic caught the whole World unawares due to its sudden emergence and rapid spread. The outbreak not only affected economic circles, but also made a huge social and cultural impact. The pandemic also introduced a new shift in terms of globalization, resulting in new norms in the fields of work and education.

While the most serious negative impact was seen on the economy and global trade, it was inevitable that maritime transportation, which transports a very large part of world trade, was also negatively affected by the pandemic.

The effects of the COVID-19 pandemic on maritime transportation have been seen both due to the disruptions in the economy and trade, and due to the effects of the pandemic on people and working patterns.

Due to the decline in the economy and trade and the deterioration in supply and demand balances, the amount of cargo transported by sea has decreased and supply chains have disrupted. In the face of declining transportation activities, maritime transportation companies have had to take measures to keep freight rates stable.

Diseases and deaths due to the pandemic, quarantine measures, and new working patterns that favored social distancing and contact caused problems especially in port activities, resulting in over-capacity and congestion in ports, and delays in loading, unloading and handling activities.

Despite facing unexpected challenges and being unprepared for a crisis of such global scale, maritime transport stakeholders swiftly navigated through the impacts of the pandemic-induced crisis. Lessons drawn from the economic crisis of 2008-2009, coupled with effective measures implemented by container shipping, played a crucial role in rapidly overcoming the challenges encountered during this period. The resilience and adaptability demonstrated by the maritime transport industry, informed by past experiences and strategic responses, contributed to a quicker recovery from the disruptions caused by the pandemic.

While container shipping overcame the pandemic period quickly and profitably, bulk shipping reached the pre-pandemic transportation rates as of the second half of 2020.

Despite the demand for tanker shipping decreased due to decreasing production and energy demand worldwide, tankers started to be used as floating warehouses due to falling oil prices. Although there were fluctuations in the tanker markets in 2020, a serious decline was observed in 2021. By 2022, the supply-demand balance in tanker shipping was established and pre-pandemic levels were reached.

The most serious effects of the pandemic were experienced in cruise shipping and these effects continued for a long time. Cruise shipping suffered serious damage as a result of border closures, travel barriers and restrictions on tourism activities. Ongoing cruise operations faced challenges as passengers were unable to disembark at ports, and ships often underwent quarantine measures, primarily due to the heightened risk of disease transmission and the occurrence of cases on board. The impacts of the outbreak felt long time for the cruise shipping as it was the most affected transportation mode. Nevertheless, cruise shipping has recovered by 2023, although not as quickly as other types of maritime transportation.

Due to the direct human impact of the pandemic and the bans and restrictions imposed, maritime transportation labor was also negatively affected by the crisis environment brought by the pandemic. The prohibitions and restrictions imposed to reduce human interaction in ports and the reduced number of personnel caused port activities to slow down.

Seafarers, often regarded as the primary contributors to the maritime industry, experienced some of the most severe consequences of the pandemic. Travel bans and isolation measures compelled seafarers to remain on board for significantly extended durations beyond their contract periods, leading to psychological challenges. Tragically, alongside psychological issues, there has been a concerning rise in suicide cases among seafarers, highlighting the profound impact of the pandemic on the mental well-being of these essential maritime professionals.

Although the effects of the COVID-19 outbreak have been overcome quickly for the maritime transportation industry, there are also many lessons to be learned from the pandemic for the sector stakeholders.

Since the problems experienced due to the pandemic are human-induced, increasing the use of technology and artificial intelligence and accelerating digitalization processes, especially in ports, will ensure that port activities are minimally affected in similar crisis situations in the future.

Although the measures taken by maritime transportation modes in general have been beneficial during the pandemic, there have also been disruptions in supply chains due to capacity constraints and blank sailings. Establishing new and alternative supply chains and routes globally, not only for maritime transportation stakeholders but also for all global economy and trade stakeholders, is important for ensuring the supply of raw materials needed in the future and the continuation of production.

Recognizing the significant challenges faced by seafarers during crises like the pandemic, it is imperative to categorize seafarers as a crucial employment branch, similar to health and safety personnel. This classification is vital not only for the continuity of maritime transportation but also for safeguarding the mental and physical well-being of individuals working on board ships. By acknowledging the pivotal role of seafarers and implementing measures to prioritize their health and safety, the maritime industry can better navigate and mitigate the impacts of future crises on this essential workforce.

Scientists believe that outbreaks such as COVID-19 are likely to occur in the future due to increasing human interactions with increasing transportation facilities, internationalization of world trade activities and globalization [2]. In order to prevent the negative effects of the outbreak in terms of maritime transportation in the future, it is crucial for sector stakeholders, companies, national and international organizations to assess possible risks comprehensively. Increasing the use of technology in the maritime transportation sector and accelerating digital transformation processes, along with ensuring that sectoral establishments and organizations possess robust structures, emerge as two crucial strategies for the sustainability and preservation of the competitive edge of the industry. Developing emergency plans is essential to ensure the continuity of industry, maintain transportation activities, and prevent disruptions in global supply chains and trade. Additionally, improvement and control of strategic plans periodically enables companies to take precautions against crisis. This preparedness will play a key role in adapting to and managing the challenges posed by future health crises.

In this study, the effects of COVID-19 on maritime transportation modes have been evaluated and the alterations were presented. Moreover, it is recommended for scientist to combine the effects of COVID-19 crisis with the maritime transportation costs for future research activities in order to show the economic impacts of pandemic on the sector and see possible opportunities or threads sourced by the pandemic.

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The Next Revolution in Global Trade? Exploring the Impact of Blockchain in Shipping

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Abstract

Using maritime shipping performance as an example, this article delves into the understudied topic of blockchain technology's effects on supply chain management. The purpose of this study is to examine blockchain technology's potential to improve shipping operations, specifically document exchange, and to provide a model to increase blockchain technology's utility in this sector. The study highlights the disparity in opportunities between larger and smaller companies in the shipping sector, which is very dispersed, and offers suggestions to encourage the adoption of blockchain technology despite the lack of a universal standard. Using qualitative method analysis and secondary academic data reviews, this research examines the preparedness of international shipping companies to adopt blockchain technology, comparing them to other sectors that have done so successfully. The research aims to identify the elements that drive shipping companies to embrace blockchain technology, proving its significant influence on improving supply chain efficiency, transparency, and security.With blockchain's secure, transparent, and real-time transaction recording capabilities, traditional shipping methods are greatly enhanced, eliminating error-prone and cumbersome paper-based processes. Blockchain technology streamlines operations, improves supply chain visibility, reduces fraud and inconsistencies, and ultimately elevates customer satisfaction by automating contract enforcement with smart contracts and enabling real-time tracking. A more effective, open, and safe supply chain ecosystem is within reach, but the article does note that scalability, regulatory compliance, and interoperability are obstacles to broad blockchain adoption. Although there are only small tangible benefits from blockchain technology now, it has the potential to revolutionize operational efficiency and service quality in the shipping and logistics sectors.

1. Introduction

1.1 An Overview of International Trade and Its Importance

According to the World Trade Organization, the value of global trade in goods and services is estimated to be $32 trillion annually. This trade is changing and developing because of various geopolitical factors and advancements in technology. Factors such as escalating tensions between the world's two largest economies, the invasion of Ukraine by Russia, Brexit, and the rapid advancement of artificial intelligence are shaping emerging trends and data in global trade. The climate crisis is exacerbating the situation, as the Rhine River is experiencing a rapid decrease in water levels, leading to issues and delays in the industrial centre of Europe, and significant trade routes such as the Panama Canal are being affected by drought [12].

1.2 A brief overview of blockchain technology and why it matters for the shipping industry

According to Serra et al. [13], the world shipping industry continues to be conservative and traditional, despite multiple technological revolutions. The marine transport sector has faced significant pressure from disruptive technologies, such as privacy and security regulations. Conversely, transportation companies have the potential to gain from these innovations by augmenting their profits. Blockchain technology is gaining increased attention from academic and professional communities due to its transformative nature, as it can permanently modify data in transit [8]. The logistics supply chain involves various components, such as logistics companies, exporters, and importers, who must maintain continuous communication to ensure optimal and precise information flow [7].

1.3 Thesis statement

The thesis of this study examines the dynamics of the shipping blockchain to determine its future potential as a crucial component of the global economy. The primary objective is to comprehend the manner in which blockchain technology can optimize the internal processes of shipping companies and subsequently influence the shipping industry, ultimately transforming global trade.

2. Background

2.1 Overview of shipping's role in international trade

The shipping industry is essential for facilitating international trade. Shipping has played a crucial role in human advancement since ancient times, by enabling access to previously unreachable territories, promoting global commerce, and improving the quality of life for ordinary people. The recent weakness of the system can be attributed to its complex operation, multiple information sources, and decentralized development and operation processes. Blockchain technology has the potential to enhance the current situation and is anticipated to introduce a new era of shipping in the future [14].

2.2 Overview of blockchain technology

2.2.1 Definition and key features

The inception and utilization of blockchain technology occurred in 2008, with the introduction of bitcoin by Nakamoto [11]. Nevertheless, the definition of blockchain is extensive, and there is evidently no universally recognized definition. In their study, Jugović et al. [1] provided a concise definition of blockchain as a distributed database that is shared and agreed upon within a peer-to-peer network. The system comprises a blockchain that is intricately connected, serving as a repository for transactions that are timestamped, cryptographically protected, and verified in real-time by the network community. Once an item is entered, it becomes unalterable, resulting in a blockchain that serves as an unchangeable record of previous actions [1]. Furthermore, blockchain can be precisely defined as an expanding digital ledger that records transactions. The transactions involve three components: the sender, the transaction data, and the final recipient. Every transaction is assigned a timestamp and distributed among all participants of the efficient peer-to-peer network. To ensure the security of the blockchain and validate the accuracy of the recorded item, various procedures are conducted, such as cryptography and user authentication. Furthermore, according to the system protocol and the rules governing the organization of the blockchain, once a certain number of transactions have been verified, a new block is appended [3].

2.2.2 Brief history and its origin in crypto currency

Data encryption is a crucial technology in the realm of digital security. Encryption is a process that involves using a mathematical algorithm to translate information from one form to another, effectively hiding the original data. This ensures that only the intended recipients can access the encrypted information [25]. However, it is important to note and distinguish between the two distinct types of encryptions to analyse them for the purposes of the thesis. Regarding the first technique, known as simple encryption, it involves a straightforward process of translating one data set into another using a one-to-one mapping. Hence, if the data is encoded using a mathematical algorithm, it can be decoded using the same algorithm. The second technique, commonly referred to as cryptographic hashing, is extensively employed in blockchain technology. When a transaction occurs within the system, the content is cryptographically hashed, meaning that the initial data is combined using an algorithm. Consequently, using this specific method, we are unable to decrypt a hash.

2.3 Current challenges in the shipping industry that blockchain aims to address

The shipping industry has maintained numerous conventional practices in its operations, distinguishing it from other industries. These practices are recognized for their time-consuming nature and strong reliance on physical paper documents. The presence of numerous parties in an extensive sequence of participants adds to the complexity of the situation [10]. The intricate interplay of these factors heightens the likelihood of mistakes, resulting in delays and extra expenses, while also creating the possibility for fraudulent behaviour. In addition, the inherent characteristics of transportation frequently necessitate superfluous manual manipulation of merchandise, involving numerous operators, especially for shorter distances of goods [1]. Tsiulin, Reinau, and Hilmola [22] contend that digitization, as a prevailing force, has had a substantial impact on, and continues to influence, the trade and transport sector. One significant challenge presented by the digitization movement in the transportation industry, as stated by them, is the requirement for all involved parties, such as regulatory bodies and businesses, to establish universally accepted shipping standards. Specifically, it is necessary to establish universal protocols and records for the worldwide shipment of merchandise, including bills of lading and other relevant transportation paperwork.

3. Impact of Blockchain on Shipping

3.1 Transparency and Traceability

The shipping industry is renowned for its protracted and costly transactions. The business sector has a strong foundation in traditional practices, including the use of paperwork and documentation. These methods entail the involvement of numerous parties across the supply chain, who handle both documents and goods, often in a redundant and unnecessary manner [2]. These transactions encompass individuals and entities such as exporters, importers, port and customs authorities, officials, financiers, inspectors, appraisers, agents, and other intermediaries. Regrettably, none of these parties possess access to a comprehensive dataset and information encompassing all facets of the supply chain. Transactions conducted using paper-based methods frequently necessitate the manual examination of physical documents, resulting in excessively high costs for shipping. Poor information management is responsible for approximately 20% of business budgets [8], and intermediaries contribute to additional cost increases [9].

The shipping industry encounters obstacles associated with transaction costs, which could be reduced by implementing electronic document exchange. According to IBM, the cost of paperwork in transporting a container of avocados from Mombasa to Rotterdam is approximately 15% or $300 of the total cost, which is $2,000. IBM estimates that shipping companies could achieve annual savings of up to $38 billion by completely digitizing the shipping process [28]. With the shipping industry experiencing higher volumes and customers demanding more efficient transactions and shipment tracking, there is a growing need for faster and simplified processes [2]. Blockchain technology provides a solution for digitizing bureaucratic processes in the shipping sector, thereby addressing security concerns associated with IoT and digitization. This allows for the monitoring of shipments from their starting point to their destination and guarantees that important information is documented in a clear, safe, and dependable format that can be accessed by all parties involved. Blockchain enhances the security of IoT technologies and serves as a storage solution for data collected by IoT applications. Blockchain technology does not directly enable the use of sensors for tracking, managing, or collecting data. Blockchain technology enables the documentation and storage of recorded data in a ledger. Additionally, it has the potential to facilitate the implementation of smart contracts for real-time device management [21]. Blockchain has the capacity to obviate the necessity for a central intermediary or governing body.

3.2 Efficiency and Cost Reduction

Security is a significant issue for routine transactions in the shipping industry, particularly regarding the transportation, tracking, and declaration of hazardous materials. Containers frequently lack clear labelling indicating their specific contents. While it is possible to scan or find a product code in certain data systems, these systems are seldom shared or compatible with systems used by other interested parties. This can pose a significant safety concern in the event of hazardous materials, which constitute approximately 5 to 10% of the cargo on a typical container vessel. Mis declaring cargo can lead to financial repercussions, vessel harm, injuries, and even fatalities. According to the Cargo Incident Notification System (CINS), approximately 25% of significant incidents occurring on container ships can be attributed to cargo misdeclaration [23]. Integrating digital tracking systems for shipments can lower costs associated with transactions, identify hazardous substances or items, minimize the risk of fraud and theft, and monitor the conditions of products sensitive to climate or temperature. Considering the shipping industry's goals of reducing environmental harm and ensuring the safety and efficiency of their operations, stakeholders may have a valid interest in improving monitoring and surveillance capabilities. One way to accomplish this is by using digital documentation and incorporating asset and shipment tracking technologies in the shipping industry.

3.3 Enhancing Security and Mitigating Fraud

The shipping industry is currently grappling with a significant problem of fraud, which has witnessed a recent surge in fraudulent techniques. Fraudulent activities in the shipping industry encompass a range of deceptive practices, including the tampering of bills of lading, which involves accusations of tax avoidance, as well as the offering of bribes and illicit payments to secure contracts, influence inspections, or expedite port operations. Furthermore, there is a widespread occurrence of deceitful tactics, such as unlawfully acquiring letters of credit, with the intention of deceiving importers or exporters. According to the World Economic Forum, these deceptive activities result in a roughly 10% rise in the total expenses of shipping operations. It is important to mention that there is a restricted level of responsibility for inefficiency, fraud, or cargo theft in this industry [30]. The adoption of the International Safety Management (ISM) code and the International Organization for Standardization (ISO) requirements pertaining to quality management has made reporting and document management in the shipping industry more complex. Aside from safety and quality criteria, documentation prerequisites for exports generally encompass documents pertaining to export, transportation, compliance, and certificates of origin, among other things. The regulatory requirements and the need for enhanced monitoring are anticipated to become more rigorous in response to the breakdown of trade agreements among major economic powers. This will further complicate transactions and necessitate additional documentation [18]. The shipping industry is becoming more alarmed by the escalating problem of cyber security, as emphasized in the research conducted by Balci and Surucu-Balci [5]. This concern arises from the potential consequences it may have on crucial aspects of cargo handling, passenger handling and management, crew welfare and management, machinery and power management and control, and access control and communication systems, among other areas. Intentional or unintentional mistakes, such as the loss or destruction of data, can result in operational or safety failures, as well as failures to safeguard the marine environment [35]. Several aspects of communications technology utilized in the maritime industry have been recognized as possible origins of substantial security concerns. For instance, empirical evidence has demonstrated that ships can be compromised and controlled from a distance by seizing control of the ship's GPS system. Signal jamming has the potential to disrupt multiple communication and navigation systems, as well as compromise port and cargo systems by erasing data records. The shipping industry is experiencing a growing number of cyber security risks, including the Not Petya ransomware attack that impacted Maersk in 2017, resulting in a financial loss of more than $200 million for the company [31].

3.4 Conformity and regulations

The utilization of Blockchain technology in the shipping sector has the capacity to fundamentally transform the method by which shipments are monitored. By utilizing a computer program, which actively involves all stakeholders in the shipping process such as exporters, importers, port authorities, financiers, inspectors, and appraisers, it becomes possible to upload documents and data onto a blockchain. This enables direct transactions between parties without the requirement of intermediaries. Upon the approval and signing of the requisite documents by all involved parties, the program will proceed to the subsequent phase of the transaction in an automated manner. In the end, the contract will be carried out by reaching an agreement among the network participants, and all pertinent information will be accessible to anyone who is interested. By securely storing all pertinent shipping data in a Blockchain-managed "block," the requirement for intermediaries to document, monitor, and authenticate information is eradicated. This not only decreases the expenses associated with transactions but also lowers the costs related to auditing and accounting [30]. The potential of blockchain goes beyond the mere tracking of ownership transfer in the shipping industry. It has the potential to completely transform the process of documenting and reporting, particularly in terms of ensuring compliance with codes and standards. By utilizing smart contracts, Blockchain technology facilitates the conversion, mechanization, and simplification of associated documents and reporting obligations, thereby diminishing the administrative load for agents in the shipping sector [18]. In addition, Blockchain guarantees that the transfer of ownership in a shipment is documented and promptly updated immediately after the sale, offering instantaneous visibility [19].

4. Research Methodology

Researchers frequently concentrate their attention on specific domains, analysing their intricacy, structure, content, and interaction with other contexts to derive objective conclusions about the issues they investigate. When the research interest is centred around a particular complex and operational situation, the methodology employed as a guiding principle is that of a case study [29]. The case study (CST) falls under the classification of qualitative research. Qualitative research is a type of investigation that is based on the belief that people create social reality through their own understandings and interpretations, and that these understandings are temporary and dependent on specific circumstances. The prevailing approach involves extracting these meanings and interpretations through thorough examination of real-life scenarios and analysing the results using analytic induction. A case study is a comprehensive examination of a specific phenomenon (referred to as a case) within its natural setting, focusing on the perspectives of the individuals involved in the operation of this phenomenon [16]. In a Case Study, it is feasible to initially employ one data collection method and subsequently modify or incorporate additional methods. Triangulation is a process in which the validity of a Case Study's findings can be enhanced by using multiple methods of data collection on a phenomenon. A Case Study can incorporate various research methods, including quantitative and qualitative approaches. These methods encompass statistical techniques, sampling, tests and self-reports, questionnaires, structured interviews, observation, and content analysis [29]. If there are challenges in collecting primary data, one can opt for a more theoretical approach to the topic. This involves analysing data from the company or market being studied and referring to various types of case studies to explain the chosen methodology for this work. By following this process, the work can reach reliable conclusions regarding the subject at hand [16]. A case study serves a distinct purpose, focusing on groups, programs, individuals, agencies, and companies. Additionally, it may pertain to specific events and processes. By examining these subjects, the study or analysis of case studies results in reliable and secure conclusions [26]. The different types of case studies include intrinsic, instrumental, collective, and multiple case studies. The indigenous case study centres on a particular individual or collective and may also concentrate on occurrences or an institution. The researcher answers the questions he has raised and draws objective conclusions by understanding the operation of the organization in question. In the instrumental case study, the researcher analyses and aims to acquire knowledge by examining the various factors that shape the case study. For instance, the researcher observes that the adoption of new technologies enhances the efficiency of an organization. Consequently, the researcher chooses to investigate this phenomenon and narrows down the focus to the entire operational scope of the organization [27]. The collective case study involves the examination of multiple cases, either in sequence or concurrently, to facilitate the researcher in obtaining a more comprehensive comprehension of a subject. For instance, the researcher can analyse the advancement of novel technologies in the company from both the managers' and employees' viewpoints. By considering multiple perspectives, the researcher can arrive at more secure conclusions [17]. Yin [15] analyses three types of case studies from his own perspective. The first type focuses on developing a theory that governs and explores relevant relationships. The second type involves analysing the present to explain a phenomenon and draw conclusions about it. The second type involves the presentation of narratives or stories that pertain to a specific field of interest, with the aim of facilitating the formulation of reliable conclusions. The exploratory case study is conducted to investigate a topic by focusing on a specific question and a particular field of interest. The present study focuses on analysing the dynamics of blockchain technology in the shipping industry and exploring its potential impact on the future of this crucial sector in the global economy. This work followed the typical research process, starting with outlining the problem and then drawing final conclusions based on that problem. The problem at hand pertains to the investigation of utilizing blockchain technology in the shipping industry. The primary focus of this study is to provide a solution to this research question. The present study combines the intrinsic and exploratory case study approaches. The researcher specifically examined notable examples within the sector, including the company Maersk and IBM's Trade Lens platform. Additionally, the application and utilization of blockchain technology by the company Cargo X were also analysed. Firstly, a comprehensive assessment was conducted to determine the extent to which current organizations have implemented blockchain technology and how they integrate it into their internal operations. Subsequently, potential challenges and benefits arising from its implementation were thoroughly analysed. In contrast, the exploratory study focused on researching the specific areas in which these companies face challenges, and examined how blockchain technology can be utilized to enhance their efficiency and competitiveness. The analysis of the case studies was conducted in conjunction with the theory that was formulated to obtain more targeted findings pertaining to the subject under investigation. This topic is innovative because the utilization of blockchain technology is currently in its infancy, and any conclusions derived from it can greatly enhance the functioning of the industry. The insights gained by companies will have widespread application across the entire market. The conclusions will address two aspects regarding the subject at hand. Firstly, the application of blockchain technology in the shipping industry, and secondly, the potential future impact of blockchain on the global economy as a crucial sector of development.

5. Case Studies

5.1 Maersk and IBM's Trade Lens platform

The Trade Lens platform underwent beta testing from August 2018 onwards. The trial lasted approximately one year. To assess the cost efficiency of the platform, MAERSK and IBM established a pilot program for the transportation of plants from Africa to European territory. Maersk initially conducted a flower analysis that involved transporting flowers from Mombasa to Europe in 2014. This transfer revealed over 200 transportation issues within a group of 30 entities, including transport companies, financial institutions, governments, and the manufacturer. According to the source [33], the various obstacles resulted in a collection of documents that measured approximately 30 centimetres in height. As a subsequent measure, Maersk and IBM utilized Blockchain technology to establish connectivity among all parties involved in this transportation process. Initially, Maersk conducted a flower analysis that involved transporting flowers from Mombasa to Europe in 2014. This transfer revealed over 200 transportation issues across 30 participating entities, including transport companies, financial institutions, governments, and the manufacturer.

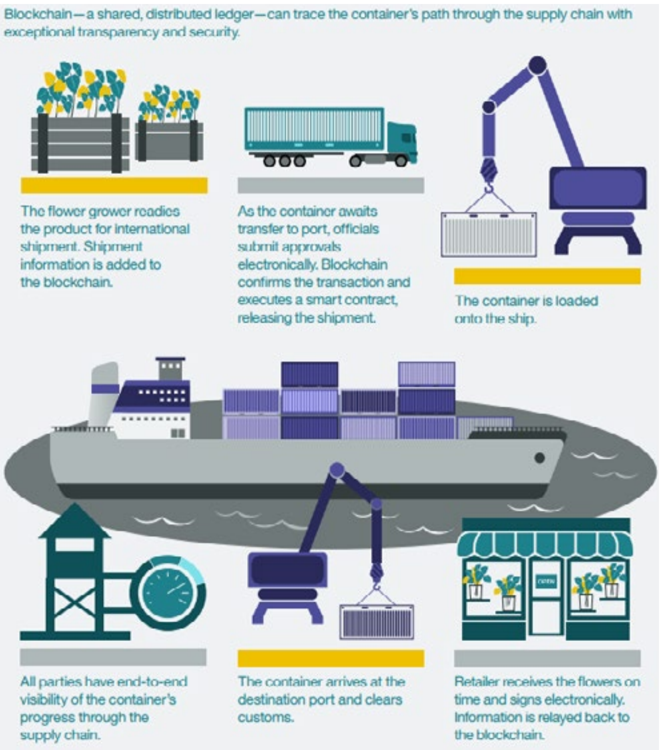

Figure 1. illustrates the process of transporting plants using the Trade Lens platform.

According to the source [33], the accumulation of obstacles resulted in a stack of documents approximately 30 centimetres in height. As a subsequent measure, Maersk and IBM established a Blockchain network to connect all parties involved in this transportation process. Following this, Maersk conducted an examination of the flowers that were shipped from Mombasa to Europe in 2014. This transfer revealed over 200 transportation issues across 30 participating entities, including transport companies, financial institutions, governments, and the manufacturer. According to the source [33], over time, these numerous obstacles resulted in a stack of documents approximately 30 centimetres in height. As a subsequent measure, Maersk and IBM established a connection between all parties involved in this transportation process using Blockchain technology.

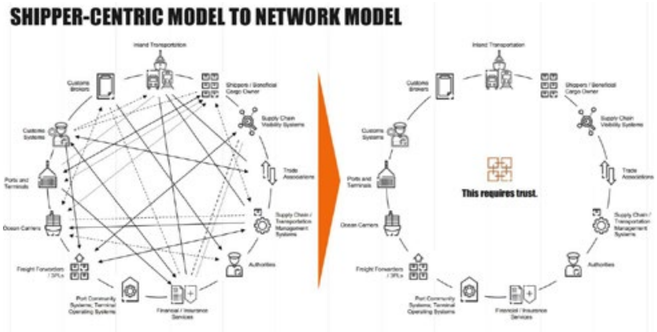

Figure 2. Traditional transportation model illustration on the left, Blockchain on the right

The test served to elaborate on the concept, yet it also imposed certain constraints: The absence of adequate protocols and effective communication among the parties involved, coupled with insufficient training of personnel in both corporate and governmental organizations, contributed to the issue. The resolution of the issues led to advancements in the transport simulations conducted through Trade Lens. The results derived from utilizing Trade Lens during the experiments were as follows: Substantial decrease in bureaucratic procedures: The Trade Lens platform significantly reduced red tape costs by approximately 80% throughout the supply chain, resulting in improved delivery times for all parties involved. The platform significantly reduced the time required for cargo transport in nearly all transfer tests conducted. This can be attributed to the escalating workload. Clearly, in complex logistics networks, the time advantage is diminished.

4.2 Additional noteworthy initiatives and their effects

It is a highly significant component of the blockchain. Cargo X, established in 2017, utilizes blockchain technology to streamline the process of providing bill of landing. This significantly reduces the time required for transporting goods from several days to approximately half a minute, effectively reducing it to almost zero [32]. Instead of using traditional methods to handle transport forms, which are typically sent with the loads and must be received in their original form by the final recipient to obtain their products, these documents are now transferred automatically and digitally. The implementation of a Blockchain-based Bill of Lading not only results in time and cost savings, but also helps to minimize the environmental impact by eliminating the need for paper transactions. Additionally, it ensures maximum security by enabling control and identification of all transactions. Cargo X also boasts high levels of security and transparency. Furthermore, it is established that this company utilizes the Ethereum platform to generate intelligent agreements pertaining to the protocols for the bill of lading. The DELIVER application is a renowned and innovative application in the logistics industry, primarily utilizing Blockchain technology. DELIVER is a consortium comprising of suppliers, logistics service users, banks, and financial institutions. They collaborate and operate through DELIVER to facilitate and enhance international business operations. The primary objective of the platform is to enable businesses to establish a single connection and interact simultaneously with multiple other businesses. This is also the primary impetus behind the network. Indeed, this is an innovative endeavour, as we are referring to a worldwide platform that actively contributes to global trading platforms. Samsung utilized the DELIVER platform to develop a well-organized logistics solution known as Cello. Subsequently, the company has successfully utilized a combination of IT science, logistics, and advanced expertise to cater to its diverse clientele and expand its presence across various industries. Its operations are present in 40 countries [34].

6. Obstacles and Constraints

The pace of technological advancement is rapid, with new applications emerging almost daily. These applications aim to improve efficiency and enhance the quality of products or services offered by businesses. The current era is characterized by the 4th Industrial Revolution, during which technological advancements have enabled artificial intelligence to simulate the functioning of the human brain. These technologies are progressively being implemented in an increasing number of production processes, resulting in a cutting-edge business environment. Facilities that are completely automated, vehicles that operate without human intervention, sensors, and robots that gather and analyse large amounts of data in real time have demonstrated the ability to decrease bureaucracy, reduce the time it takes to complete tasks, and minimize errors [24]. Simultaneously, all parties involved can utilize intelligent applications to track the location of ships and goods at any given moment, thereby achieving comprehensive surveillance and traceability of goods. The implementation of blockchain and distributed infrastructure technology has the potential to bring substantial advancements to the shipping industry. Although there are substantial potential advantages to adopting the technology, successfully implementing it poses a challenge. By thoroughly evaluating how technology can fulfil business requirements, along with considering the impact of external and internal factors, businesses can greatly enhance the probability of success for their distributed infrastructure initiatives [6]. Blockchain technology possesses immense potential to propel the forthcoming surge of innovation and can facilitate the emergence of novel business models by substantially altering current systems and processes. It is important to consider the specific contexts in which it is used when assessing the potential effects of its application. Blockchain technology is an innovative and ever-evolving technology that can be utilized in various ways and provides numerous advantages. The application of blockchain technology in global container shipping chains offers distinct advantages. These include heightened security through consensus processes and the sharing of transaction copies across all network nodes, cost reduction by eliminating intermediaries, improved traceability through transparent information, and enhanced data storage and exchange capabilities. Nevertheless, there are notable obstacles associated with blockchain technology that need to be resolved [4]. Challenges in implementing blockchain technology include its high energy consumption, the integration of this technology into companies, the complexities of gathering all stakeholders and ensuring smooth communication among them, and the inability to correct human errors during the creation of blocks due to the immutability of blockchain records. Upon examining companies that have implemented blockchain technology in container shipping, it is evident that the technology can have a positive impact on several aspects. These include facilitating information exchange among stakeholders, enabling secure and efficient payment transactions, facilitating the creation of quick and intelligent contracts, saving time, and enhancing product traceability. To summarize, blockchain is a highly promising technology that offers container shipping companies and the entire supply chain the ability to transport products securely, efficiently, and cost-effectively. For this endeavour to achieve success and operate effectively, it is imperative to establish a comprehensive legislative framework that encompasses global best practices. Additionally, it is crucial to provide the necessary information and training to users or potential users of blockchain technology.

7. Outlook for the Future

One significant discovery regarding prospects is that the existing technology will undoubtedly be utilized in every aspect of shipping. Currently, there is a widespread acceptance of the value of new technologies, particularly among executives who are open to embracing innovative and groundbreaking solutions. These advancements have the potential to revolutionize the maritime industry and prevent it from becoming stuck in outdated practices. Furthermore, it is anticipated that in the future of this application, the advantages will outweigh the disadvantages in terms of superiority. The perspective that blockchain presents numerous benefits in contrast to a limited number of drawbacks is comprehensive and ultimately what will propel its acceptance by businesses. Regarding cost effectiveness, it appears that it does not carry significant influence in the adoption of blockchain technology.

Most people consider the cost of transitioning to the new technology to be relatively inexpensive, therefore it is not seen as a hindrance. Similarly, the resulting savings are also perceived to be relatively modest, so they will not be the primary factor in the decision-making process. Conversely, the rapid transmission of information and the continuous updating of the database are regarded as the primary benefit and will serve as the primary factor in selecting the specific technology, as it aligns with the demands of contemporary business transactions. In the shipping industry, where data is subject to frequent changes, a dynamically updated system proves its ability to have a significant impact. Insufficient expertise is another factor that will influence the transition process. Based on the findings of this study, it is necessary to provide training and opportunities for employees to enhance their skills to comprehend the underlying philosophy and adopt the new approach to managing their daily tasks. Although the implementation of the transition program will require the expertise of specialized executives, it appears that there is an adequate supply of such professionals in the labour market.

8. Conclusion

Initially, we provided an overview of blockchain technology, encompassing its definition, fundamental architecture, and operational mechanisms. Next, we proceeded to explore the potential applications of this technology in the field of shipping. Immediate and remarkable benefits can be derived from implementing technologies such as smart contracts, smart bills of lading, port management, and supply chain management. Major corporations have already executed diverse initiatives and are swiftly progressing towards the advancement of blockchain technology in these domains.

Furthermore, the capability of blockchain to offer a secure and transparent documentation of the supply chain improves trust among all parties involved, such as shippers, carriers, and customers. The establishment of trust is essential when dealing with sensitive or high-value shipments, as it is of utmost importance to ensure proper documentation and authenticity. Blockchain is seen as a revolutionary solution for the shipping industry, which is grappling with issues like expensive operations, inefficiencies, and security risks. The incorporation of this technology into the management of shipping logistics not only offers the potential to make operations more efficient, but also creates the opportunity for a global trade ecosystem that is more environmentally friendly and transparent. Ultimately, adopting blockchain technology has the potential to revolutionize the shipping industry, representing a substantial advancement towards a more streamlined, secure, and open future.

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Analysing Ship Detentions: A Fault Tree Analysis of Paris MoU Database

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Abstract

Port State Control (PSC) involves the inspection of foreign-flagged ships by port states to ensure compliance with international agreements, with the aim of ensuring maritime and environmental safety. National PSCs from various regions worldwide collaborate through joint inspection agreements known as "Memoranda of Understanding" (MoUs). This study focuses on data from the Paris Memorandum of Understanding for the first half of 2023. Using the Fault Tree Analysis method, the study has identified deficiencies that resulted in the detention of ships. Initial probabilities of these deficiencies have been determined, and their impact on the top event has been calculated. The study's aim is to determine the most common deficiencies leading to ship detentions and to provide valuable insights for authorities, ship operators, and ship personnel. The study has revealed that the most prevalent deficiency leading to ship detentions is related to the International Safety Management (ISM) Code.

Keywords: *Port State Control, Ship Detention, Fault Tree Analysis, Paris MoU*

1. Introduction

Maritime transport is distinguished from other alternative modes of transport by its low cost and high carrying capacity, and it accounts for approximately 80-90% of global trade [1]. Nevertheless, maritime casualties are major events in the history of maritime transport and warrant attention and prevention as they can result in harm for the environment, human life, and property [2].

The safety and security of a ship was the sole responsibility of the flag state prior to the Amoco Cadiz disaster in 1978. However, the inadequacy of relying solely on the flag state to ensure the safety and security of ships was highlighted in the aftermath of the disaster [3]. Zhu et al. [1] state that port state controls (PSCs) are intended to prevent environmental pollution and marine casualties by inspecting ships according to the standards of relevant international conventions, national regulations, and regional arrangements. The main purpose of the PSC is to protect the seas and the environment by detecting substandard ships which fail to comply with their obligations under international conventions [4].

During a ship inspection, PSC inspectors first check the ship's and crew's certificates to assess their competence. After that, the general condition of the vessel is surveyed and then a detailed inspection is conducted and the vessel's compliance with maritime and environmental safety is determined [5].

Port States have the authority to prohibit a ship from navigating and to detain the ship until the deficiencies are rectified if the ship's company or crew do not fulfil the requirements of international maritime conventions [6]. For the flag States, the classification societies and the shipping companies, the detention of a ship results in loss of reputation and economic costs. For this reason, studies on the reasons for detention of ships are important for all concerned.

2. Methodology

Fault Tree Analysis (FTA) is a commonly used deductive and visual technique that helps identify the underlying causes of an undesired event caused by component failures within a system [7,8]. In addition, the FTA provides a visual representation of different combinations of parallel and sequential failures, demonstrating the situations that could lead to an undesirable event [9].

The first step in the construction of a fault tree is the identification of the basic events (BE) that are the source of the top event (TE). The probability of the basic events is determined by taking into account the cases that have already occurred. In the following step, the probability of TE failure is calculated using either 'AND' or 'OR' gates [13]. By the traditional theory of probability, the 'AND' gate is a logic gate that indicates that the output error will occur if all the input errors occur. However, the 'OR' gate indicates an output fault if at least one input fault occur [9]. The mathematical representation of 'AND' and 'OR' logic gates is given by equations 1 and 2.

Q(Xi) represents the probability of Xi occurring. For 'AND' and 'OR' gates, the probability of occurrence of the top event is Q(T) [9].

$$Q(T) = \prod_{i=1}^{N} Q(X_i) \quad (1)$$

$$Q(T) = 1 - \prod_{i=1}^{N} (1 - Q(X_i)) \quad (2)$$

where,

N represents the total number of basic events, while i represents the number of related basic events (i = 1, 2, ..., N).

If the probability of occurrence of each BE is less than 1 Q(Xi), then the value of Q(T) is,

$$Q(T) = \sum_{i=1}^{N_C} Q(C_i) \quad (3)$$

3. Application

This study analyses the Paris MoU database for deficiencies that have been the cause of detention of ships by the port State. The fault tree's structure has been designed to enhance comprehension of the study's findings for all parties interested in the maritime industry. Thus, the fault tree was created by referring to the list of deficiencies used by Paris

MoU port state control inspectors [10]. In this study, the stages of fault tree construction, determination of basic event probabilities, and application of quantitative and qualitative analyses were applied.

During the data collection stage, it was observed that detentions are often not due to a single cause but to the combination of multiple causes. However, in some cases ships may be detained because of a single cause. Therefore, it is necessary to apply a methodology that involved the analysis of both single cause detentions as well as multiple cause detentions. Equations 4 and 5 have therefore been used to determine the probabilities of the basic events.

In their study, Uğurlu et al. [11] applied the equation 4 approach, which states that the probability of each basic event is related to the frequency of that basic event in accidents, as it may provide more realistic results for prioritisation.

$$\begin{array}{l}\text{Probability Value}\\ \text{of Basic Event}\end{array} = \frac{\begin{array}{c}\text{The Rate of Contribution To}\\ \text{the Detention of Basic Event}\end{array}}{\begin{array}{c}\text{The Total Number of Detentions} \times\\ \text{The Total Year of Detentions}\end{array}} \tag{4}$$

It is essential to determine the top event in which each basic event is located, along with all other basic events within that top event, in order to calculate the contribution rate of each basic event to the top event. All Basic Events within each Top Event are regarded as having equal impact on the Top Event. The initial probability of the Basic Event is calculated by summing the impact values of each Basic Event causing the different Top Event, as expressed in Equation 5 [11].

$$\begin{array}{l}\text{Total Contribution To the}\\ \text{Detention of Basic Event}\end{array} = \frac{1}{Root\ Cause_1} + \frac{1}{Root\ Cause_2} + \cdots + \frac{1}{RCn} \tag{5}$$

A quantitative and qualitative analysis of the fault tree was conducted once the fault tree had been constructed and the probabilities of the basic events had been calculated. The probability of the top event occurrence is calculated for the quantitative analysis of fault tree. The probability of the top event occurrence was calculated by applying the basic event probabilities along the fault tree in an upward-flowing direction [12]. As a result, the Paris Memorandum of Understanding database was used to provide data for 306 vessels in detention from 1/1/2023 to 31/7/2023. The probability of the top event was calculated using the Isograph Reliability Workbench 14.0 software. An interpretation of the resulting data is given in the section on conclusions.

Table 1. The Abbreviation and Description of Top, Intermediate, and Basic Events

Abb.	Description
TE	Ship's Detention
IE1	Certificates & Documentation
IE2	Structural Condition
IE3	Water, Weathertight Condition
IE4	Emergency Systems
IE5	Radio Communication
IE6	Cargo Operations Including Equipment
IE7	Alarms
IE8	Life-Saving Appliances
IE9	Safety of Navigation
IE10	Fire Safety
IE11	MLC 2006, Labour Condition
IE12	Propulsion and Auxiliary Machinery
IE13	Other
IE14	Pollution Prevention
IE15	Condition of Employment
IE16	Accommodation, Recreational Facilities, Food and Catering
IE17	Health Protection, Medical Care, Social Security
IE18	Marpol Annex I
IE19	Marpol Annex Vi
BE1	Crew Certificates, Ship Certificates, Documents
BE2	Seafarers' Employment Agreement (SEA)
BE3	Manning Specified by The Minimum Safe Manning Doc
BE4	Ships Plans, Booklets, Manuals
BE5	Logbooks, Compulsory Entries, Documents
BE6	ISM
BE7	Closing Devices, Watertight Doors
BE8	Stability, Strength, Loading Information and Instruments
BE9	Steering Gear and Emergency Steering
BE10	Corrosion, Cracking, Hull Damage, Operational Damage
BE11	Ballast, Fuel, and Other Tanks
BE12	Electrical Installations in General
BE13	Water Level Indicator, Water Level Detectors
BE14	Bulkhead, Hull, Decks - Construction
BE15	Cargo Tank Vent. System
BE16	Other (Structural Conditions)
BE17	Overloading
BE18	Freeboard Marks, Load Lines
BE19	Cargo & Other Hatchways
BE20	Railing, Gangway, Walkway and Means for Safe Passage, Accommodation Ladder
BE21	Covers (Hatchway-, Portable-, Tarpaulins, Etc.)
BE22	Doors, Openings to Cargo Area, Scuttles, Windows
BE23	Ventilators, Air Pipes, Casings
BE24	Manholes, Flush Scuttles, Cargo Ports/Machinery/Space and Other Similar Openings
BE25	Scuppers, Inlets and Discharges
BE26	Public Address System
BE27	Emergency Fire Pump, Fire Pump, and Its Pipes
BE28	Emergency, Lighting, Batteries, and Switches
BE29	Drills, Communication Between Safety Centre and Other Control Stations
BE30	Emergency Source of Power - Emergency Generator
BE31	On Board Training and Crew Familiarization
BE32	Other (Emergency Systems)
BE33	MF/HF/VHF Radio Installation, INMARSAT Ship Earth Station
BE34	EPIRB, VHF EPIRB, SART
BE35	Reserve Source of Energy
BE36	Operation Of GMDSS Equipment, Operation, Maintenance
BE37	Other (Radiocommunication)
BE38	Cargo Operation
BE39	Lashing Material
BE40	Other (Cargo Operations Including Equipment)
BE41	Boiler Alarm
BE42	Machinery Controls Alarm
BE43	UMS - Alarms or Evidence
BE44	General Alarm, Fire Alarm
BE45	Other (Alarms)
BE46	Lifeboats, Equipment's, and Stowage
BE47	Rescue Boats
BE48	Inflatable Liferafts
BE49	Launching and Embarkation Arrangement Survival Craft
BE50	Pyrotechnics, Line-Throwing Appliance
BE51	Lifejackets, Lifebuoys, Immersion Suits
BE52	Radio Life-Saving Appliances, Emg. Equip. For 2-Way Comm.
BE53	Operational Readiness, Operation of Life-Saving Appliances
BE54	Maintenance of Life-Saving Appliances and Inspections
BE55	Other (Life Saving)
BE56	Pilot Ladders and Hoist, Pilot Transfer Arrangements
BE57	Radar
BE58	Magnetic Compass, Gyro Compass
BE59	Lights, Shapes, Sound-Signals, Signalling Lamp
BE60	VDR, S-VDR
BE61	Echo Sounder
BE62	Speed and Distance Indicator, Rudder Angle Indicator
BE63	Bridge Navigation Watch Alarm System (BNWAS)
BE64	Charts, Electronic Charts (ECDIS)
BE65	Nautical Publications
BE66	Voyage or Passage Plan and Monitoring
BE67	Other (Navigation)
BE68	Fire Prevention Structural Integrity
BE69	Inert Gas System
BE70	Fire Doors, Divisions
BE71	Fire Detection and Alarm System
BE72	Fixed Fire Extinguishing Installation
BE73	Fire Fighting Equipment and Appliances
BE74	Remote Means of Control (Opening, Pumps, Ventilation, Etc.)
BE75	Fire-Dampers
BE76	Ventilation
BE77	Jacketed High-Pressure Lines and Oil Leakage Alarm
BE78	Means of Escape
BE79	Fire Protection Systems
BE80	Retention of Oil on Board, Oil Accumulation in Engine Room
BE81	Other (Fire Safety)
BE82	Medical Fitness
BE83	Work, Rest Hours, and Records
BE84	Wrong Scale, Non-Payment of Wages
BE85	Other (Conditions of Employment)
BE86	Cleanliness
BE87	Provisions Quantity, Quality
BE88	Sanitary Facilities
BE89	Gas And Atmosphere Test Instruments
BE90	Electrical
BE91	Access, Structural Features (Ship)
BE92	Heating, Air Conditioning and Ventilation
BE93	Lighting
BE94	Other (Health Protection, Medical Care, Social Security)
BE95	Propulsion Main Engine
BE96	Auxiliary Engine
BE97	Bilge Pumping Arrangements
BE98	Other (Machinery)
BE99	Other (SOLAS Operational)
BE100	Other Safety in General
BE101	Dangerous Goods
BE102	Oil Disch. Monitoring and Control System, and 15ppm Alarm
BE103	Oil Filtering Equipment
BE104	Oil And Oily Mixtures from Machinery Spaces
BE105	Suspected Of Discharge Violation
BE106	Other (MARPOL Annex I)
BE107	Marpol Annex II
BE108	Marpol Annex IV
BE109	Marpol Annex V
BE110	Incinerator Inc. Operations and Operating Manual
BE111	Sulphur Content of Fuel Used
BE112	Other (Marpol Annex VI)
BE113	Ballast Water Management

Figure 1. Ship Detention Fault Tree (Continued)

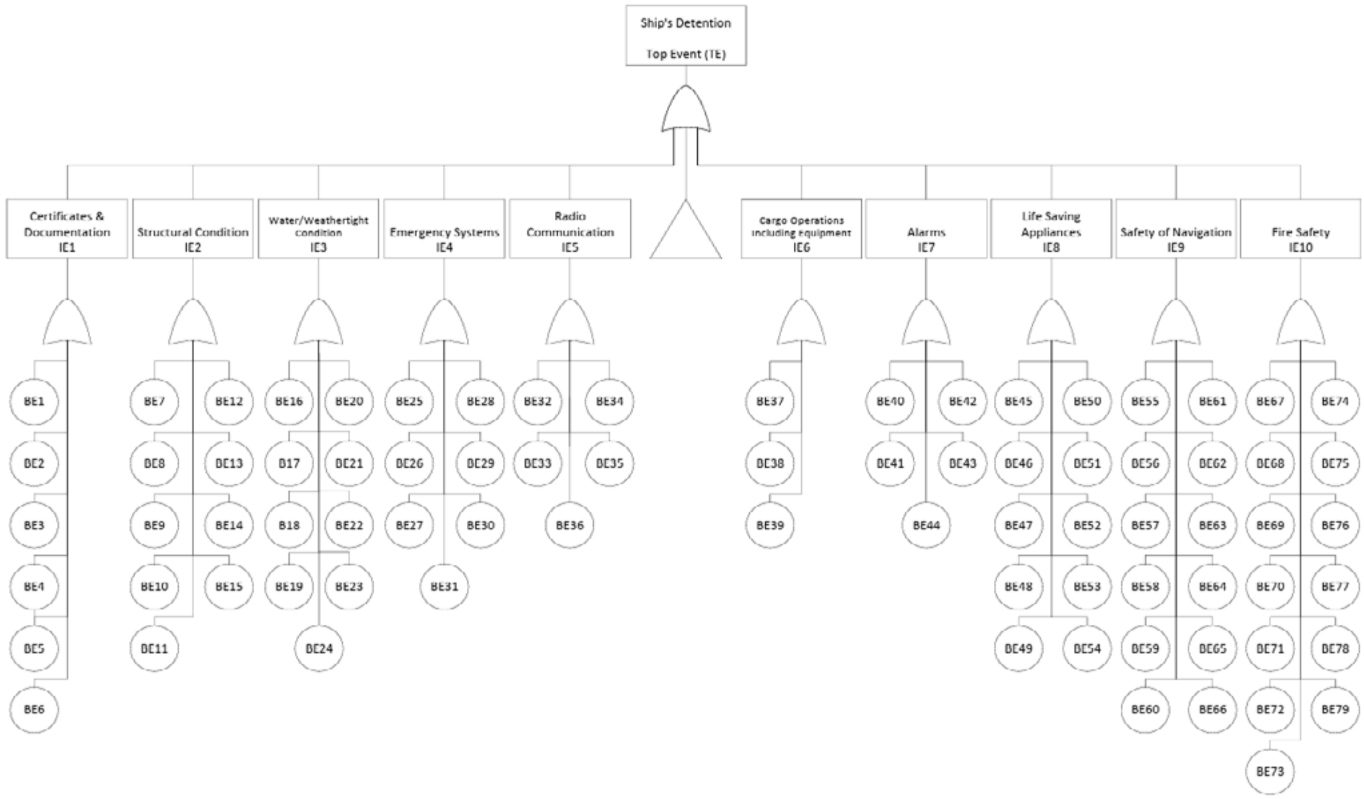

Figure 2. Ship detention fault tree

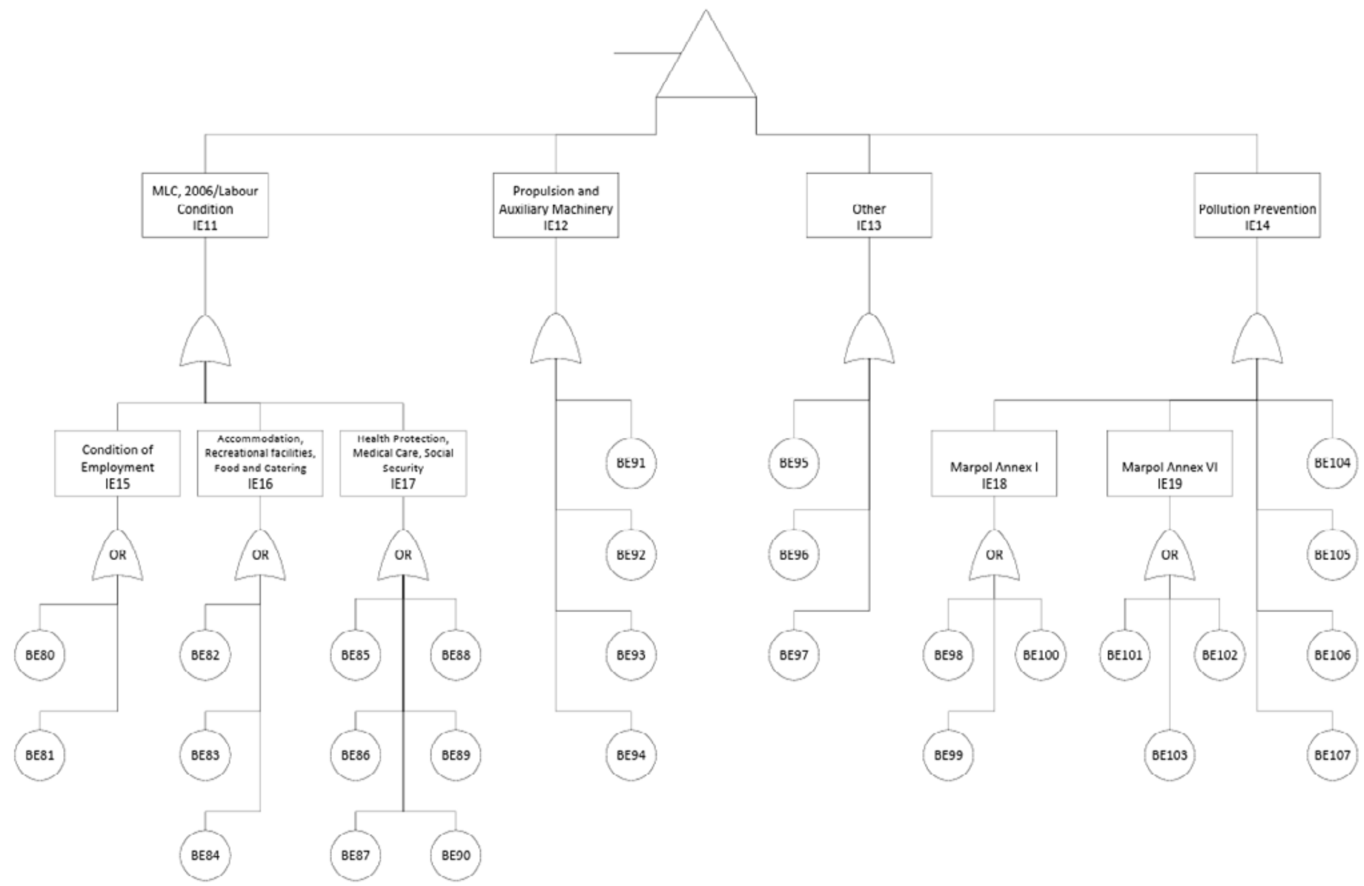

Table 2. Possibilities, Frequencies of Events

Events	Q	w
TE	1.67E-01	-
IE1	4,76E-02	370
EI4	2,48E-02	259
IE10	2,19E-02	287
IE8	1,34E-02	151
IE9	1,30E-02	189
IE11	1,15E-02	150
IE2	8,36E-03	102
IE3	7,45E-03	100
IE12	6,93E-03	88
IE14	6,76E-03	84
IE5	1,96E-03	31
IE7	1,91E-03	23
IE13	9,08E-04	7
IE6	2,18E-04	4
BE6	2,57E-02	204
BE1	1,38E-02	83
BE28	1,07E-02	110
BE46	5,04E-03	48
BE29	4,94E-03	33
BE26	4,83E-03	50
BE68	3,86E-03	54
BE72	3,42E-03	36
BE82	3,20E-03	38
BE10	3,11E-03	22
BE91	3,08E-03	35
BE73	2,89E-03	37
BE63	2,84E-03	38
BE71	2,77E-03	41
BE2	2,72E-03	22
BE70	2,54E-03	30
BE64	2,32E-03	32
BE92	2,20E-03	30
BE22	2,20E-03	29
BE69	2,11E-03	32
BE4	2,01E-03	27
BE45	1,95E-03	23
BE47	1,83E-03	21
BE81	1,77E-03	11
BE5	1,72E-03	18
BE3	1,69E-03	16
BE30	1,64E-03	25
BE99	1,54E-03	19
BE59	1,54E-03	17
BE27	1,52E-03	21
BE90	1,51E-03	25
BE58	1,45E-03	22
BE102	1,44E-03	17
BE48	1,34E-03	15
BE57	1,29E-03	19
BE84	1,28E-03	20
BE76	1,27E-03	18
BE50	1,23E-03	18
BE42	1,20E-03	8
BE98	1,17E-03	12
BE94	1,11E-03	14
BE80	1,07E-03	13
BE16	1,05E-03	6
BE11	1,04E-03	14
BE20	1,02E-03	18
BE65	1,01E-03	15
BE9	9,53E-04	16
BE88	9,15E-04	13
BE12	8,99E-04	16
BE21	8,54E-04	12
BE31	7,50E-04	14
BE106	7,45E-04	5
BE66	7,19E-04	15
BE51	6,86E-04	11
BE7	6,79E-04	10
BE79	6,75E-04	10
BE83	6,59E-04	8
BE18	6,55E-04	8
BE15	6,41E-04	8
BE103	6,36E-04	14
BE35	6,16E-04	7
BE53	5,92E-04	7
BE78	5,86E-04	6
BE60	5,85E-04	9
BE67	5,82E-04	5
BE100	5,78E-04	6
BE19	5,67E-04	10
BE75	5,51E-04	7
BE93	5,43E-04	9
BE61	5,10E-04	7
BE95	4,81E-04	4
BE8	4,60E-04	10
BE23	4,28E-04	7
BE107	4,16E-04	7
BE24	4,13E-04	6
BE36	4,02E-04	7
BE49	3,99E-04	3
BE25	3,91E-04	6
BE14	3,63E-04	3
BE32	3,52E-04	8
BE33	3,35E-04	5
BE74	3,22E-04	6
BE77	3,22E-04	5
BE96	3,18E-04	2
BE41	3,14E-04	8
BE89	3,09E-04	7
BE52	3,08E-04	4
BE85	3,08E-04	6
BE62	2,79E-04	6
BE17	2,67E-04	4
BE87	2,59E-04	5
BE34	2,52E-04	4
BE86	2,42E-04	4
BE13	2,18E-04	3
BE56	2,07E-04	4
BE55	2,01E-04	5
BE44	1,70E-04	3
BE40	1,45E-04	2
BE104	1,15E-04	2
BE39	1,14E-04	2
BE97	1,09E-04	1
BE43	7,55E-05	2
BE38	6,81E-05	1
BE101	6,05E-05	1
BE105	5,45E-05	1
BE37	3,63E-05	1
BE54	2,87E-05	1

4. Conclusion

The FTA method was used in the study to identify deficiencies that were the cause of detention of ships during PSC inspections. A total of 306 ships were examined which were in detention under the Paris Memorandum of Understanding between January 2023 and July 2023. The fault tree structure and basic events were inspired by the list of deficiencies used by the Paris MoU inspectors. The probability of the top event was calculated from the probability of each basic event using the FTA method. As a consequence of the study, 'Certificates & Documentation' was determined to have the most significant impact on the detention of ships, while 'Cargo Operations Including Equipment' was determined to have the least significant impact. In 204 out of 306 detentions, 'ISM' was observed, and 'ISM' is most important deficiency in ship detentions with a probability of 0.0257. The study, conducted with data from 2023, revealed some interesting findings in light of the developments affecting today's safety management. It is noteworthy that despite advancements in safety management and attention to documentation by companies, 'ISM' is still the most common reason for detention of ships. Despite these factors, the importance of 'ISM' in ship detentions in the study points to the impact of the human factor. The study analysed 306 ships detained under the Paris MOU over a 6-month period. Future studies may include not only the Paris MOU databases but also other available MoUs. The consideration of more than one MoU will widen the coverage of the study and provide worldwide data for the determination of deficiencies that are effective in the detention of ships. Furthermore, the 6-month period to be covered by the study can be extended, allowing the number of data to be increased. By increasing the number of data and varying the MoUs, the reasons for detention of ships can be widened and the possibilities of deficiencies leading to detention can be analysed worldwide.

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Reference Systems Used in Maritime Border Delimitation Agreements

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Abstract

There are many factors taken into account in maritime border delimitation agreements. In these agreements, the agreed upon borders are determined in terms of latitude and longitude, and how they will be combined is specified. Geodetic data of coordinate systems specify how a coordinate system is connected to the Earth.

Accordingly, it consists of parameters that explain how to define the origin of the coordinate axis, how to orient the axis and how to define the scale. The fact that different datums were used in the agreements and the need to improve the datums over time points to the hidden problems in these agreements. Since very different datum systems are used in maritime boundary determination agreements, it is obvious that there will be serious differences in interpretation even if an agreement is reached.

In this article, considering the fact that different features of datums are the subject of a separate examination, the rates of data systems stated to be used in a total of 87 international maritime boundary agreements examined are examined numerically and regionally.

Such large-scale research conducted for the first time can serve as an example for resolving various maritime disputes and preparing new agreements. It will not only trigger thinking about possible problem points in the future, but also serve as a source for research in various fields.

Keywords: *delimitation of maritime borders, datum, maritime agreements*

1. Introduction

A treaty is a formally accepted, legally binding written text, usually made between two or more sovereign countries. Treaties may also be called international agreements, protocols, conventions, pacts or other names. In international law, only documents that are legally binding on the parties are considered treaties.

The first known border agreement was between the Egyptians and the Hittites in B.C. It is the Treaty of Kadesh, thought to have been made in 1259. Over time, the number of agreements made has increased incredibly and their content has also expanded considerably. With the development of diplomacy, the provisions in the agreements began to diversify.

When the Vienna Convention on the Law of Treaties was accepted in 1969; Guidelines and rules have been put forward to resolve disputes or violations that arise regarding the creation, amendment, interpretation and termination of treaties [1].

Agreements can be about a wide variety of issues; They can vary significantly in form, content, specific circumstances and complexity. In traditional law and the Law of Treaties, international agreements are not required to conform to any standard form. All valid agreements must comply with the parties' commitment to perform their duties in good faith and to comply with the agreements, expressed in Latin as *"pacta sunt servanda"*.

Any treaty can be voided if it violates a overriding norm (jus cogens), such as allowing aggression or crimes against humanity, and the like [2].

Agreements differ on the basis of the extent to which states are bound by the rules (obligations), the extent to which the rules are clear (certainty), and the extent to which third parties have the authority to interpret, apply, and make the rules (delegation) [3].

The obligations of the parties on the agreement articles, their acceptance of the relevant articles and the transfer of authority sometimes arise as disagreements in agreements.

Since ancient times, peaceful resolution of disputes has been the preferred method. For example, mediation was one of the most common methods in the Islamic world and ancient India. Arbitration was used in Ancient Greece, China, among Arab tribes, in maritime customary law in Medieval Europe, and in Papal practices [4]. However, these principles have not always been consistent or successful.

After the establishment of the United Nations on October 24, 1945, data systems began to be used in international border agreements concluded between States.

2. Obtaining Data

According to the UN Charter, unless agreements and treaties are registered with the United Nations, the parties cannot claim any rights regarding the content of the agreements. For this reason, every country must register international agreements with the United Nations; The UN must also register these agreements and announce them by publishing them. This is why the UN has a very important archive in terms of maritime border delimitation agreements. Thanks to this archive, it is possible to understand and evaluate the legislation adopted by coastal states and others regarding their maritime zones before and after the 1982 Convention. While the States Parties to the Convention try to implement its provisions by adopting legislation compatible with the Convention, it is particularly interesting that the states that are not parties to the Convention harmonize their legislation with the United Nations Convention on the Law of the Sea, adopted in 1982. Today, the existence of States that are not party to the UN Convention on the Law of the Sea is also valuable in terms of understanding the level of acceptance of customary international law rules.

In bilateral or multilateral maritime boundary delimitation agreements, as maritime areas subject to maritime boundary delimitation; territorial waters, contiguous zone, exclusive economic zone and continental shelf and many agreements have been made regarding them. These can be divided into two: agreements made between coastal states with neighboring or opposite shores.

According to the 1982 Convention, the boundaries of territorial waters can extend up to 12 nautical miles, the contiguous zone up to 24 nautical miles and the exclusive economic zone up to 200 nautical miles. The continental shelf extends to the outer edge of the continental margin or up to a distance of 200 nautical miles, but the outer edge of the continental margin does not extend to this distance. If the limit exceeds 200 nautical miles, the outer limits of the continental shelf are determined by a complex formula contained in Article 76 of the 1982 Convention. According to international law, a coastal state's rights over the continental shelf are not subject to actual or conceptual occupation or any express declaration. Accordingly, coastal states have sovereign rights to explore and exploit all resources of the sea bed, subsoil and water column up to a distance of 200 nautical miles from the baselines where territorial waters are measured.

3. Methodology

The official texts of maritime delimitation agreements and subsequent acts are available in the archives of the United Nations, in their original language(s) and, as appropriate, in English and French translations. This archive or series contains agreements that have entered into force in accordance with Article 102 of the United Nations Charter and are registered with the United Nations Secretariat [5]. In the first step of our research, the 10 oldest and newest agreements were determined after examining the maritime border delimitation agreements registered in the UN one by one. Then, 67 randomly selected agreements, evenly distributed across regions, were examined (Figure 1).

In our research, maritime border delimitation agreements were examined in terms of whether the agreements include the ways and methods that can be applied in case of disagreement, the registration of the agreements, the date of entry into force, the annexes of the agreements and the geodetic reference systems used. This article focuses on the geodetic reference systems used and the problems that may arise when different systems are used.

4. Findings

The oldest maritime rules available in the United Nations archives are the Norwegian Royal Decree dated 22 February 1812 [6] and the Territorial Waters Jurisdiction Act enacted by the United Kingdom of Great Britain and Northern Ireland in 1878 [7].

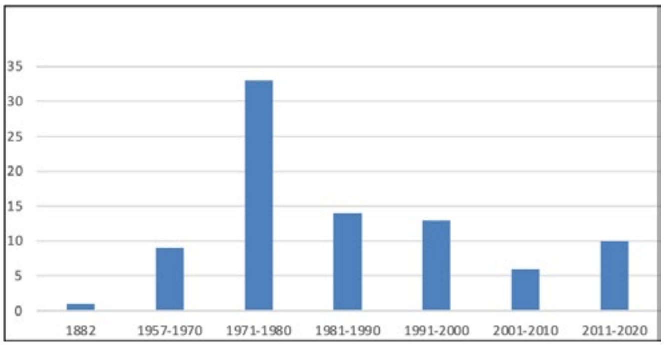

Figure 1. Distribution of approval dates of the examined agreements over the years

In mid-February 2024, the newest agreement in the UN archives was the exchange of letters in the form of a maritime agreement between Israel and Lebanon, which was accepted on October 27, 2022 [10]. As of February 20, 2024, a total of 315 agreements were registered in the UN archive. Six of these agreements were trilateral and the others were bilateral. Although the "agreement determining the exclusive economic zone border and certain seabed boundaries between Australia and Indonesia" was signed on 14 March 1997, it had not yet entered into force [11].

Seven maritime agreements of African countries such as Equatorial Guinea, Sao Tome and Principe, Senegal and South Africa have not yet been ratified.

5. Geodetic Reference Systems

Any work that must use geolocation information requires a precise reference definition. For this purpose, Geodetic Datum is used as a reference system in establishing geographical coordinates and maps that define the size and shape of the earth.

The datum, which serves to provide the orientation of the coordinate systems used in mapping the world, is the reference surface taken as the starting point to define the horizontal and vertical position of any point. When determining the datum, the ellipsoid and coordinate system on which the point will be based are also defined. This information is included in the description section at the bottom of the sheets of the maps used and is divided into two: horizontal and vertical. While horizontal datums are the starting reference surface for coordinates, vertical datums are the starting reference surface for elevation. Turkey Geoid 2020 (TG20) was produced and put into use in Turkey in 2020.

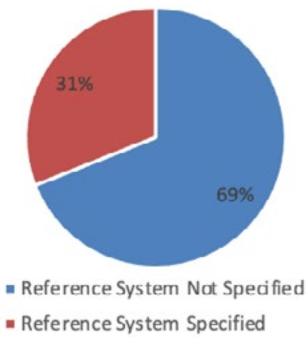

Figure 2. Maritime boundary agreements with and without specifying a geodetic reference system

Various countries use very different datums. In addition to local datums such as the North American Datum 1927 (NAD27), which are fitted to a specific region of the earth, there are also global datums, such as the World Geodetic System (WGS 84), which are fitted to the entire earth to provide consistent accuracy for long-distance, global-scale measurements. Since geographical coordinates are determined based on datum, when the datum is changed, the positions of the points may change by a few hundred meters.

In maritime border delimitation agreements, coordinates determined in terms of latitude and longitude are given in an order and it is stated that these points will be connected by straight lines, great circles, geodesic lines or other shapes. Sea borders are created by combining these points with various methods.

High-precision mapping of the regions covered by the agreement contributes to resolving differences of interpretation and disputes. To achieve this, it is important for the parties to share the hydrographic and geodetic information they have obtained and cooperate to improve it. Pointing out this fact, the only maritime agreement that has a clause on cooperation to share and develop hydrographic and geodetic information is the Agreement between Denmark and Canada on the Delimitation of the Continental Shelf between Greenland and Canada, dated 17 December 1973 [12].

In the Agreement, there is a provision that will inspire other agreements: "The Parties undertake to cooperate and share all relevant data and measurements for the purpose of obtaining and developing the hydrographic and geodetic information necessary for more precise mapping and mapping of the region covered by this Agreement" [13].

It is known that different results may occur on maps that use different reference systems when talking about any point. Even calculation methods can give different results. For example, with the "agreement on the delimitation of territorial waters" signed between France and Belgium on October 8, 1990, the points that will determine the territorial water boundaries were determined by taking into account the low tide levels in the approaches to the French and Belgian coasts. The coordinates of the points are defined by the 1950 European Datum.

However, since France and Belgium used different methods in height calculation, two different results emerged. For this reason, an agreement was reached by dividing the areas resulting from the two calculations into two equal parts [14].

5.1. Agreements that do not specify a geodetic reference system

Datum information is not provided in some maritime agreements. The reference system was specified in 60 of the 87 maritime boundary agreements examined, and was not specified in 27 (Annex 1). Accordingly, datum information was given in 68,97% of the maritime border agreements and not in 31,03% (Figure 2). Some of these agreements are extremely superficial, while others are extremely detailed. For example, although it was an extremely detailed agreement, datum information was not included in the Treaty Concerning the Rio de la Plata and Related Maritime Boundary between Uruguay and Argentina on 19 November 1973.

Among the agreements we examined, the oldest agreement that does not provide datum information is the Soviet-Polish agreement signed in 1957 regarding the drawing of the current Soviet-Polish State border in the sector adjacent to the Baltic Sea [15]. Despite the rapid development in geodetic reference systems, the agreement on the delimitation of the exclusive economic zone between Greece and Egypt, signed on August 6, 2020, does not contain datum information [16].

5.2. Agreements specifying the geodetic reference system

The reference system used in 62 of the 87 maritime boundary agreements examined, that is, 71.3%, is specified. It has been determined that many geodetic reference systems such as Pulkova System, North American Datum 1927 and 1973, European Datum 1950, Soviet Reference System, Qornoq Datum, South American Datum 1969, Brazilian, Norwegian, Swedish and Indian Datums and Astronomical Datum were used in these agreements.

The most used of these was WGS 84, which was designed to be located at the center of the Earth's mass and the error was believed to be less than 2 cm.

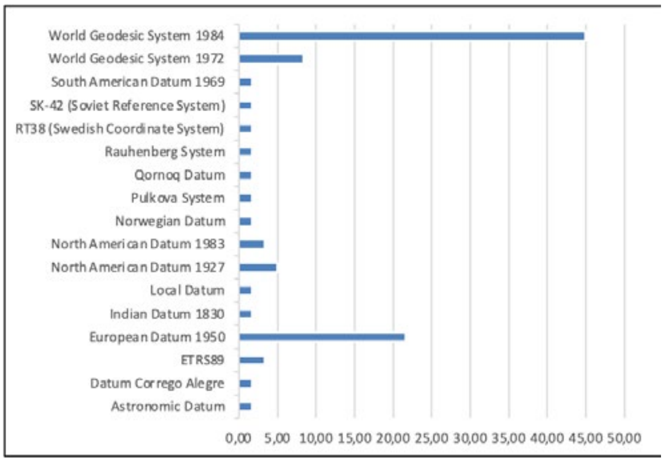

Figure 3. Reference systems and their shares used in the 87 agreements we examined

Indian Datum, Astronomical datum, Brazilian datum, Soviet reference System, Rauhenberg, Kornoq system, Pulkova system, local system, Norwegian and Swedish coordinate systems were used only once in the examined agreements and the usage rate of each was 1.59%. Systems such as ETRS 89 and North American Datum 1983 (NAD83) were preferred by

3.17%, North American Datum 1927 (NAD 27) by 4.76%, and World Geodesic System (WGS72) by 8.06%. European Datum 1950 (ED50) has a share of 20.63% and World Geodesic System 1984 (WGS 1984) has a share of 42.86% (Figure 3).

The oldest agreement providing reference information is the agreement between Norway and the USSR on the maritime border in Varangerfjord, signed on 29 November 1957, and the Pulkova system was used in this agreement [17]. It is interesting that in the agreement between Thailand and Vietnam on the delimitation of maritime borders between the two countries in the Gulf of Thailand, signed as recently as August 9, 1997, the Indian Data dated 1830 was used to calculate the coordinates of the agreed points.

Table 1. Areas where geodetic reference systems are used

Datum	*Fields used*
Astronomic Datum	Indian Ocean
Datum Corrego Alegre	South America
ETRS89	Europa
European Datum 1950	Europa
Indian Datum 1830	Asia
Local Datum	Central America
North American Datum 1927	North America
North American Datum 1983	North America
Norwegian Datum	Europa
Pulkova System	Europa
Qornoq Datum	North America
Rauhenberg System	Europa
RT38 (Swedish Coordinate System)	Europa
SK-42 (Soviet Reference System)	Europa
South American Datum 1969	South America
World Geodesic System 1972	Pasific Ocean
World Geodesic System 1984	All Areas

5.3. Agreements that do not specify a geodetic reference system

5.3.1. 1932 Pulkova System

The only agreement in which the Pulkova system is used is the defining protocol of 29 November 1957 for the maritime border drawn between Norway and the Union of Soviet Socialist Republics in Varangerfjord in 1947 [18]. It is emphasized that all geographical and rectangular coordinates referred to in the Pulkova system will be "different" if they are converted to other systems.

5.3.2. SK-42 Reference System

SK-42 Reference System is a system that was first used in the agreement between Lithuania and the Russian Federation on the delimitation of the Exclusive Economic Zone and Continental Shelf in the Baltic Sea on October 24, 1997[19]. This system was also used to determine some coordinates in the Joint Delimitation of Maritime Borders in the Baltic Sea agreement signed between Poland and the USSR on June 30, 1989 [20].

5.3.3. 1927 North American Datum

The North American Datum (NAD), based on the 1866 Clarke Ellipsoid, was calculated in 1901 and defined as the North American Datum in 1913, when Canada and Mexico adopted it. Its inconsistencies have been reviewed many times, most recently in 2022.

Although more accurate data systems have emerged, the North American data system (NAD27) was used in the Maritime Borders agreement signed between the USA and Cuba on December 16, 1977

5.3.4. European Datum 1950

Before the Second World War, Europe was divided into independent national and sub-national geodetic data. Almost every country and province had its own triangulation networks and ellipsoids that were only sometimes interconnected. The 1950 European data (ED50) is the first common data system developed for the European continent. ED50 remains the de facto data used in offshore operations in the North Sea and has legal status in determining some international borders in this sea. This data system was used for some lines in the maritime border agreement between Denmark and Germany, but the correspondence of Danish geographical coordinates to German geographical coordinates was specifically stated in the agreement [21].

5.3.5. World Geodetic System 1972 (WGS72)

Since large geodetic systems such as European Datum 1950 (ED50), North American Datum (NAD) and Tokyo Datum (TD) cannot provide a worldwide geographical data basis, the World Geodetic System 1972 (World Geodetic System) System (WGS72)) was produced. Among the agreements we examined, the first agreement using the WGS72 system was signed between the USA and the Cook Islands on 11 June 1980 [22], and the last agreement was signed between the France and Fiji on 8 November 1990 [23]. The usage rate among the 87 agreements examined is 7.92% (Figure 3).

5.3.6. North American Datum 1983 (NAD 83)

North American Datum 1983 (NAD 83), which provides horizontal data for the USA, Canada, Mexico and Central America, was preferred in only two of the 87 agreements examined and its usage rate is 3.17% (Figure 3).

5.3.7. World Geodetic System 1984 (WGS 84)

World Geodetic System 1984 (WGS 84) is the most preferred data system in maritime boundary agreements. This system was used in 27 of the 63 agreements specifying a data system; The usage rate was 42.86% [Figure 3]. WGS 84, the reference system used by the global positioning system, is considered to be globally consistent within 1 m.

This system was used in more detail in the form of WGS84 (G1150, 2001.0) in the Treaty on Cooperation and Limitation of Maritime Powers in the Barents Sea and the Arctic Ocean, signed between Norway and the Russian Federation on 15 September 2010 [24].

5.3.8. ETRS89 (European Terrestrial Reference System 1989)

The European Terrestrial Reference System was also used in delimiting maritime borders. For example, in the agreement dated 19 November 2018 between Poland and Denmark, which delimited the maritime zones in the Baltic Sea, the coordinates of the agreed border points were defined in accordance with the European Terrestrial Reference System 1989 (ETRS89) [25].

In the maritime delimitation agreement signed between Denmark and the United Kingdom on 18 May 1999 regarding the region between the Faroe Islands and the United Kingdom, although the border points were determined by the European Terrestrial Reference System 1989, the geographical coordinates were also given by ED50 [26].

5.3.9. Rauenberg system

The only agreement in which coordinates were determined with the Rauenberg data system used from 1853 until 1991 was the Treaty on the Delimitation of Maritime Areas signed between East Germany and Poland on 22 May 1989[27].

5.3.10. RT38 (Swedish Coordinate System)

Coordinates in the RT 38 reference system were first calculated in 1841 in a preliminary system called RT P (or RT F38) over southern Sweden on the Bessel ellipsoid. This system, called RT 38 by Sweden in 1938, was replaced with SWEREF 99 in 1999. The only agreement in which the RT38 reference system is used is the "Common Demarcation Point of Maritime Borders in the Baltic Sea agreement" signed between Sweden and Poland on 30 June 1989.

Although this agreement contains the provision "The geographical coordinates given for the common delimitation point are based on the World Geodetic System 1972", some coordinates were calculated according to the Swedish Coordinate system and added to the agreement [28].

5.3.11. Datum Corrego Alegre

Datum Corrego Alegre is the geodetic reference system used in Brazil. Major corrections were made to the Córrego Alegre System twice, in 1969 and in 2010. It is stated that the coordinates specified in the Maritime Delimitation Agreement between Brazil and France, signed on January 30, 1981, were calculated with the Brazilian geodetic reference system Corrego Alegre [29].

5.3.12. Qornoq Datum

Qornoq 1927, a geodetic data system suitable for use on land on the west coast of Greenland, first described in 1927, refers to the International 1924 ellipsoid and the Greenwich prime meridian.

Denmark and Canada used the Qornoq Datum in the agreement regarding the delimitation of the continental shelf between Greenland and Canada. The Parties have agreed that when information that will enable data differentiation between the 1927 North American Datum and the Qornoq Datum is obtained, the geographical coordinates of the agreed points will be adjusted and relisted according to the 1927 North American Datum and the Qornoq Datum [30].

5.3.13. Norwegian Datum

After the agreement regarding the delimitation of the continental shelf was made between Denmark and Norway on 8 December 1965, this agreement was amended by an exchange of notes on 24 April 1968. With this exchange text, Norway, Denmark and Sweden agreed on the coordinates of the intersection point of the borders of the three countries.

Although these coordinates are calculated with European Datum, Norwegian Datum equivalents are also given. This agreement was amended again by the exchange of notes on 4 June 1974, this time the coordinates were based solely on the European Data (first revision, 1950) in terms of latitude and longitude values [31].

5.3.14. Astronomical (Natural) Coordinates

A natural coordinate system is a local coordinate system that allows any point inside the element to be determined by a set of dimensionless numbers with magnitudes between 0 and 1. This system was used only when the "convention on the delimitation of economic zones" was signed between France and Mauritius on April 2, 1980 [32].

5.3.15. Local Datum

The only agreement using local datum in maritime boundary agreements was signed between the USA and the Cook Islands on June 11, 1980. Although the WGS72 reference system was used in this agreement, local datum was used to define some islands and atolls [33].

5.4. Agreements Referring to More than One Reference System

5.4.1. Borders Drawn with Binary Datum

The "Border Delimitation Agreement" signed between Venezuela and the Netherlands on March 31, 1978 is a good example of an agreement using dual datum. In the agreement, some sectors were defined by the Provisional South American Datum [Datum de Sur América (Ajuste Provisional 1956)] dated 1956, and some sectors were defined by latitude and longitude in accordance with the North American Datum 1927.

In some agreements, the Norwegian datum equivalents of the reference points calculated with the European Datum have been added to the agreement.

The agreement between Lithuania and the Russian Federation on delimitation of the Exclusive Economic Zone and Continental Shelf in the Baltic Sea on 24 October 1997 is an example of a maritime boundary agreement that uses a dual reference system: SK-42 Reference System and WGS 84 [34].

5.4.2. Agreements referencing three different coordinate systems

Although extremely rare, there are also agreements that emphasize three different coordinate systems. It is possible to see an example of this agreement in the text of the Agreement on the Joint

Demarcation Point of Maritime Borders in the Baltic Sea between Sweden, Poland and the USSR, signed on 30 June 1989 [35].

The geographical coordinates of some points in the agreement are given according to the Soviet coordinate system, and at others according to the Swedish coordinate system. The geographical coordinates accepted for the common demarcation point were calculated with the World Geodetic System 1972 [36].

It was also emphasized that if the Pulkova System is transformed into other systems, the agreed upon coordinates will be different. In this agreement, it was specifically stated that the border line in some regions was "calculated with a margin of error of ten metres" [37].

6. Conclusion

A geodetic reference system was specified in 68.9% of the 87 maritime boundary agreements examined. In agreements where the reference system is specified, it is observed that there is a 95.6% compatibility rate between the systems and the regions where they are used [Table 1]. Agreements using astronomical datum and local datum and the suitability of these systems for the region are open to discussion. The sum of these rates is 4.6%.

Although the physical surface of the Earth is precisely defined, it is extremely difficult to describe it in mathematical terms. Because of this dilemma, a wide variety of map projections have been developed over the centuries, based on mathematical relationships between locations on the Earth's surface and points on the map. Each projection serves a particular application well, but none can represent the Earth without distortion.

Although deviations and distortions resulting from the geodetic system do not pose a problem in the publication of topographic maps of 1:25,000 and larger, they pose an obstacle to the international use of nautical charts and the development of GIS data based on precise location information.

WGS 84 and its updates have started to be preferred in recent years to create a more stable reference data to obtain accurate geographical information on sea and coastal maps. The coordinates of the end points of territorial water boundaries listed in maritime boundary delimitation agreements may differ slightly due to differences in the starting points chosen, the maps used, and the mathematical model (shape) assumed for the earth's surface. Since distance measurements are calculated along geodesic line segments, different lengths may occur when different techniques are used [38]. It is noteworthy that especially before the use of WGS84, the coordinate system type was not specified as well as the projection and ellipsoid type used in calculating the sea boundaries. Since the geodetic system is not specified in the maps annexed to the agreements, there is uncertainty at the delimitation points.

In case of a data shift regarding the coordinates determined in the signed agreements, the geographical coordinates of the agreed points will need to be readjusted and listed. This aspect was taken into account in only one agreement. It is highly likely that agreements without a reference system will be discussed in the future.

With appropriate and consistent data collection and spatial referencing procedures, the correlation and integration of various spatial data sets has become a relatively easy task that can be performed on personal computers [39].

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Annex 1. Maritime border delimitation agreements examined in the article

1	1947	Exchange of notes constituting an agreement between the United States of America and the United Kingdom of Great Britain and Northern Ireland relating to the delimitation of the area within territorial waters adjacent to the leased naval base at Argentia, Newfoundland (with annex), 13 August and 23 October 1947	
2	1957	Descriptive Protocol relating to the sea frontier between Norway and the Union of Soviet Socialist Republics in the Varangerfjord, demarcated in 1957, 29 November 1957	Pulkova
3	1957	Treaty (with annexed maps) concerning the demarcation of the existing Soviet-Polish State frontier in the sector adjoining the Baltic Sea, 5 March 1957	
4	1957	Agreement between the Royal Norwegian Government and the Government of the Union of Soviet Socialist Republics concerning the sea frontier between Norway and the USSR in the Varangerfjord, 15 February 1957	
5	1961	Exchange of notes between Mexico and Guatemala constituting an agreement on the establishment of an international boundary and water commission, 9 November and 21 December 1961	
6	1963	Exchange of letters on settlement of problems concerning the delimitation of Monegasque territorial waters constituting an agreement relating to article 4 of the Treaty of 17 July 1918 establishing the relations of France with the Principality of Monaco, 18 May 1963	
7	1965	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965.	
8	1965	Agreement between the Kingdom of Denmark and the Federal Republic of Germany concerning the delimitation, in the coastal regions, of the continental shelf of the North Sea, 9 June 1965	
9	1965	Agreement between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway relating to the delimitation of the continental shelf between the two countries, 10 March 1965	ED50
10	1965	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965	
11	1966	Treaty between the Kingdom of the Netherlands and the Kingdom of Belgium on the Delimitation of the Continental Shelf, 18 December 1996	ED50
12	1967	Agreement concerning the delimitation of the fishery areas of Norway and Sweden in the North-Eastern Skagerrak (with declaration and maps), 5 April 1967	ED50
13	1968	Treaty between the Polish People's Republic and the German Democratic Republic concerning the delimitation of the continental shelf in the Baltic Sea, 29 October 1968	
14	1968	Agreement between Sweden and Norway concerning the delimitation of the continental shelf, 24 July 1968	ED50
15	1968	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965 - Exchange of notes constituting an agreement amending the above-mentioned Agreement. Copenhagen, 24 April 1968	Norvegian Datum
16	1972	Agreement between the Government of Canada and the Government of the French Republic on Their Mutual Fishing Relations, 27 March 1972	
17	1973	Agreement between the Government of the Kingdom of Denmark and the Government of Canada relating to the delimitation of the continental shelf between Greenland and Canada (with annexes) 17 December 1973	NAD27, Kornoq
18	1973	Treaty between Uruguay and Argentina concerning the Rio de la Plata and the corresponding maritime boundary, 19 November 1973	
19	1974	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965 - Exchange of notes constituting an agreement amending the above-mentioned Agreement, 4 June 1974	ED50, SK-42
20	1974	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965 - Exchange of notes constituting an agreement amending the above-mentioned Agreement, 4 June 1974	
21	1974	Convention between Spain and Italy on the delimitation of the continental shelf between the two States (with chart), 19 February 1974	
22	1974	Convention between the Government of the French Republic and the Government of the Spanish State on the delimitation of the continental shelves of the two States in the Bay of Biscay (Golfe de Gascogne/Golfo de Vizcaya) (with annex, exchange of letters and map), 29 January 1974	
23	1974	Convention between France and Spain on the delimitation of the territorial sea and the contiguous zone in the Bay of Biscay (Golfe de Gascogne/Golfo de Vizcaya) (with map), 29 January 1974	
24	1974	Agreement concerning Delimitation of the Continental Shelf between Iran and Oman, 25 July 1974	
25	1974	Convention between the Government of the French Republic and the Government of the Spanish State on the delimitation of the continental shelves of the two States in the Bay of Biscay (Golfe de Gascogne/Golfo de Vizcaya) (with annex, exchange of letters and map), 29 January 1974	
26	1975	Treaty fixing the maritime boundaries between the Republic of the Gambia and the Republic of Senegal, 4 June 1975	
27	1975	Agreement concerning delimitation of marine and submarine areas and maritime co-operation between the Republics of Colombia and Ecuador, 23 August 1975	
28	1977	Maritime Boundary Agreement Between the United States of America and the Republic of Cuba, 16 December 1977	NAD27
29	1977	Agreement between the Hellenic Republic and the Italian Republic on the delimitation of the respective continental shelf areas of the two States, 24 May 1977	
30	1977	Treaty on Delimitation of Marine and Submarine Areas and Maritime Cooperation between the Republic of Colombia and the Republic of Costa Rica (17 March 1977).	

31	1977	Agreement between the Hellenic Republic and the Italian Republic on the delimitation of the respective continental shelf areas of the two States, 24 May 1977	
32	1978	Maritime boundary Treaty between the United States of America and the Republic of Venezuela (with map), 28 March 1978	NAD83
33	1978	Treaty on maritime boundaries between the United States of America and the United Mexican States (Caribbean Sea and Pacific Ocean), 4 May 1978	NAD27
34	1978	Protocol supplementary to the Agreement of 10 March 1965 between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway relating to the delimitation of the continental shelf between the two countries, 22 December 1978	ED50
35	1978	Boundary delimitation Treaty between the Republic of Venezuela and the Kingdom of the Netherlands (with map), 31 March 1978	
36	1978	Agreement between the Government of the Republic of Turkey and the Government of the Union of Soviet Socialist Republics concerning the delimitation of the continental shelf between the Republic of Turkey and the Union of Soviet Socialist Republics in the Black Sea (with maps), 23 June 1978	
37	1978	Agreement between the Government of the Kingdom of Thailand, the Government of the Republic of India and the Government of the Republic of Indonesia concerning the determination of the trijunction point and the delimitation of the related boundaries of the three countries in the Andaman Sea, 22 June 1978	
38	1978	Agreement between the Government of the Kingdom of Thailand and the Government of the Republic of India on the delimitation of sea-bed boundary between the two countries in the Andaman Sea (with chart and exchange of notes), 22 June 1978	
39	1978	Agreement on delimitation of the maritime boundaries between the Republic of Colombia and the Republic of Haiti, 17 February 1978	
40	1979	Agreement between the Government of the Kingdom of Denmark and the Government of the Kingdom of Norway concerning the delimitation of the continental shelf in the area between the Faroe Islands and Norway and concerning the boundary between the fishery zone near the Faroe Islands and the Norwegian economic zone, 15 June 1979	ED50
41	1979	Agreement between the Government of the Kingdom of Denmark and the Government of the Kingdom of Norway concerning the delimitation of the continental shelf in the area between the Faroe Islands and Norway and concerning the boundary between the fishery zone near the Faroe Islands and the Norwegian economic zone, 15 June 1979	ED50
42	1979	Act of Montevideo by which Chile and Argentina request the Holy See to act as a mediator with regard to their dispute over the Southern region and undertake not to resort to force in their mutual relations (with supplementary declaration), 8 January 1979	
43	1979	Exchange of notes constituting an agreement between Denmark and Sweden concerning the delimitation of the territorial waters between Denmark and Sweden, 25 June 1979	
44	1979	Treaty between the Kingdom of Thailand and Malaysia relating to the delimitation of the territorial seas of the two countries, 24 October 1979	
45	1979	Treaty to submit to binding dispute settlement the delimitation of the maritime boundary in the Gulf of Maine area, 29 March 1979	
46	1980	Treaty between the United States of America and the Cook Islands on friendship and delimitation of the maritime boundary between the United States of America and the Cook Islands, 11 June 1980	WGS72, Natural
47	1980	Convention between the Government of the French Republic and the Government of Mauritius on the delimitation of the French and Mauritian economic zones between the islands of Reunion and Mauritius, with annexes, 2 April 1980	Astronom-ical
48	1980	Convention between the Government of the French Republic (Wallis and Futuna) and the Government of the Kingdom of Tonga on the delimitation of economic zones, 11 January 1980	
49	1980	Agreement between Iceland and Norway Concerning Fishery and Continental Shelf Questions, 28 May 1980	
50	1980	Delimitation Treaty between the Government of the French Republic (Martinique and Guadeloupe) and the Government of the Republic of Venezuela (with map) 17 July 1980	
51	1980	Treaty concerning delimitation of marine areas and maritime co-operation between the Republic of Costa Rica and the Republic of Panama, 2 February 1980	
52	1981	Maritime delimitation Treaty between the Federative Republic of Brazil and the French Republic (French Guyana), 30 January 1981	Corrego Alegre
53	1981	Agreement between Norway and Iceland on the continental shelf between Iceland and Jan Mayen, 22 October 1981	
54	1983	Agreement between the Government of the Republic of France and the Government of Fiji relating to the delimitation of their economic zone (with annex and maps), 19 January 1983	WGS72
55	1984	Agreement between Sweden and Denmark on the delimitation of the continental shelf and fishing zones (with map, exchanges of notes and Protocol), 9 November 1984	ED50
56	1986	Agreement between the Government of the French Republic and the Government of the Italian Republic on the Delimitation of maritime frontiers in the area of the straights of Bonifacio, 28 November 1986	ED50
57	1986	Exchange of notes constituting an agreement concerning the delimitation of areas of responsibility in connection with the Convention of 22 March 1974 on the protection of the Marine Environment of the Baltic Sea, 21 November 1986	
58	1986	Maritime Delimitation Treaty between Colombia and Honduras, 2 August 1986	
59	1988	Agreement between the Government of the French Republic and the Government of the United Kingdom of Great Britain and Northern Ireland relating to the delimitation of the territorial sea in the Straits of Dover, 2 November 1988	ED50

60	1989	Agreement between the Government of the Kingdom of Sweden, the Government of the Polish People's Republic and the Government of the USSR concerning the Common Delimitation Point of their Maritime Boundaries in the Baltic Sea, 30 June 1989	WGS72
61	1989	Agreement between the Government of the Kingdom of Sweden, the Government of the Polish People's Republic and the Government of the USSR concerning the Common Delimitation Point of their Maritime Boundaries in the Baltic Sea, 30 June 1989.	RT38
62	1989	Agreement concerning the delimitation of the continental shelf and fishing zones between the Kingdom of Sweden and the Polish People's Republic. (with nautical chart), 10 February 1989	WGS72
63	1989	Treaty between the German Democratic Republic and the Polish People's Republic on the Delimitation of the Sea Areas in the Oder Bay, 22 May 1989	Rauhenberg
64	1990	Agreement between the Government of the French Republic and the Government of the Kingdom of Belgium on the delimitation of the territorial sea, 8 October 1990	ED50
65	1990	Codicil modifying the Agreement of 19 January 1983 between the Government of the French Republic and the Government of Fiji relating to the delimitation of their economic zone, 8 November 1990	WGS72
66	1990	Agreement on Maritime Delimitation between the Government of the Cook Islands and the Government of the French Republic (with map), 3 August 1990	WGS 84
67	1990	Agreement between the United States of America and the Union of Soviet Socialist Republics on the maritime boundary, 1 June 1990	WGS 84
68	1992	Agreement between Albania and Italy for the determination of the continental shelf of each of the two countries, 18 December 1992.	ED50
69	1993	Treaty on the delimitation in the Caribbean of a maritime boundary relating to Puerto Rico/U.S. Virgin Islands and the British Virgin Islands, 5 November 1993	NAD83
70	1993	Maritime delimitation treaty between Jamaica and the Republic of Colombia (with chart). Kingston, 12 November 1993	WGS 84
71	1995	Agreement between the Kingdom of Denmark and the Kingdom of Norway concerning the delimitation of the continental shelf in the area between Jan Mayen and Greenland and concerning the boundary between the fishery zones in the area 18 December 1995	WGS 84
72	1995	Agreement between the Republic of Finland and the Republic of Estonia on the Boundary of the Maritime Zones in the Gulf of Finland and on the Northern Baltic Sea, 18 October 1996	WGS 84
73	1996	Treaty between the Kingdom of the Netherlands and the Kingdom of Belgium on the Delimitation of the Territorial Sea, 18 December 1996	
74	1996	Agreement on maritime delimitation between the Government of the French Republic and the Government of the United Kingdom of Great Britain and Northern Ireland concerning Saint Martin and Saint Barthelemy on one hand, and Anguilla on the other, 27 June 1996	WGS 84
75	1997	Treaty between the Government of the United States of America and the Government of Niue on the delimitation of a maritime boundary, 13 May 1997	
76	1997	Additional Protocol to the Agreement of 18 December 1995 between the Kingdom of Norway and the Kingdom of Denmark concerning the Delimitation of the Continental Shelf in the Area between Jan Mayen and Greenland and the Boundary between the Fishery Zones in the Area, 11 November 1997	WGS 84
77	1997	Agreement between the Republic of Turkey and the Republic of Bulgaria on the determination of the boundary in the mouth of the Rezovska/Mutludere River and delimitation of the maritime areas between the two states in the Black Sea, 4 December 1997	WGS 84
78	1997	Agreement between the Government of the Kingdom of Thailand and the Government of the Socialist Republic of Viet Nam on the delimitation of the maritime boundary between the two countries in the Gulf of Thailand, 9 August 1997	Indian Datum-1830
79	1998	Agreement Between the Government of the Kingdom of Sweden and the Government of the Republic of Estonia on the Delimitation of the Maritime Zones in the Baltic Sea, 2 November 1998	WGS 84
80	1999	Agreement between the Government of the Kingdom of Denmark together with the Home Government of the Faroe Islands, on the one hand, and the Government of the United Kingdom of Great Britain and Northern Ireland, on the other hand, relating to Maritime Delimitation in the Area between the Faroe Islands and the United Kingdom, 18 May 1999	ED50
81	1999	Treaty on the State Border between the Republic of Croatia and Bosnia and Herzegovina, 30 July 1999	
82	2000	Muscat Agreement on the Delimitation of the Maritime Boundary between the Sultanate of Oman and the Islamic Republic of Pakistan, 12 June 2000	WGS 84
83	2001	Agreement between the Government of the French Republic and the Government of the Republic of Seychelles concerning Delimitation of the Maritime Boundary of the Exclusive Economic Zone and the Continental Shelf of France and of Seychelles, 17 February 2001	WGS 84
84	2002	Agreement between the Government of the French Republic and the Government of the Republic of Kiribati concerning the delimitation of a boundary line between the exclusive economic zone around French Polynesia and the exclusive economic zone of the Republic of Kiribati, 18 December 2002	WGS 84
85	2005	Agreement between the Government of France and the Government of the Republic of Madagascar on the Delimitation of Maritime Areas situated between La Réunion and Madagascar, 14 April 2005	WGS 84
86	2010	Treaty between the Russian Federation and the Kingdom of Norway concerning maritime delimitation and cooperation in the Barents Sea and the Arctic Ocean, 15 September 2010	WGS 84
87	2018	Agreement between the Republic of Poland and the Kingdom of Denmark concerning the delimitation of maritime zones in the Baltic Sea, 19 November 2018.	ETRS89

Maps and Their Features in the Annex to the Maritime Border Delimitation Agreements

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Abstract

Most maritime border delimitation agreements are completed with maps added to the appendix. Unfortunately, the additional maps and their features added to the maritime border delimitation agreements have not been examined before this article.

These maps are extremely important in clarifying the agreed upon coordinates of latitude and longitude and understanding how these coordinates in turn connect to others. Additional maps can serve purposes such as explanation, sampling and demonstration. While there are additional maps that do not specify why they were added to the annex of the agreement, there are also agreements stating that the maps are an integral part of the agreements.

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Failure to achieve standards regarding the reference systems, projection types and scale features of the maps additionally used in the agreements may lead to a situation where the coordinates given in the agreements do not match the lines shown on the maps. In such a case, which data will be considered valid is a separate and very important issue.

Sensitivity to the language and concepts used in international maritime agreements has improved, as has scientific and technological developments. Accordingly, it can be thought that older agreements may be weak in terms of conceptual sensitivity.

In this article, the additional maps in the 87 maritime border determination agreements in the United Nations archive are examined with all their features. This study will shed light on the possible debates and differences of interpretation regarding the maps annexed to the agreements made in the past. It will also contribute to the more precise definition of additional maps in future agreements and will open a new horizon for everyone working in this field.

Keywords: *maritime border delimitation agreement, additional maps, map features*

1. Introduction

It is claimed that the history of maps dates back 5 thousand years. B.C. The map dated to 25,000 years ago and found in Pavlov in the Czech Republic and engraved on a mammoth tusk is considered the oldest map [1]. A tablet in the collection of the British Museum and dated to around 600 BC is an excellent example of Babylonian clay tablet maps. This map shows Babylon at the center with the Euphrates River, mountains, and the ocean surrounding it. This map proves that ancient scholars succeeded in depicting the earth's surface on a flat surface.

Even though the maps of the ancient period looked rough, they could show the features that the cartographer wanted to show. The relationship between features on the map and reality on Earth was often inaccurate. Despite this, it is known that the Egyptians had extensive map work to document and record property boundaries.

Ptolemy, a geographer, mathematician and astronomer living in Roman Egypt, published his famous treatise titled Geographia around 150 AD. This work contained thousands of references and maps of various parts of the world along with lines of latitude and longitude. This system revolutionized European geographical thought by applying mathematical rules to the formation of maps. Ptolemy's maps continued to be of great importance to European and Islamic scholars until the Renaissance, which began in the 1500s. Meanwhile, King of Sicily II. Al-Idrisi, an Arab scholar who worked at Roger's court, drew a series of extraordinary world maps and wrote geography books in the period around 1154. Until the 12th century, Mecca was considered the center of the world in the Islamic cartography tradition.[2] Many Western cartographers accepted the Canary Islands, which Ptolemy called the Lucky Islands, as the prime meridian. [3] Idrisi, triangular hills colored in gold to represent mountain ranges, brown and gray tones to represent rivers and lakes; He used black script to identify cities, towns and settlements.

Gerardus Mercator revolutionized the world map with the mathematical projection he designed in 1569. The Mercator projection preserved the shapes of small regions at the cost of global distortion.

Today, approximately 50% of the world's borders were drawn as a result of British and French imperialism. As a result of the Treaties of Paris, the British and French victoriously drew the modern borders of the Middle East, the borders of Africa, the borders in Asia after the independence of British India and French Indochina, and the borders of Europe after the First World War [4].

Today, map making relies heavily on computer software. In this way, personal location and distance calculation has advanced considerably. Computer-based software is dominated by large companies. Governments and scientists are working to create a high-resolution global map of the seafloor. In many countries, full mapping of the exclusive economic zone or the water area around the coastline is planned.

2. Use of sea charts in agreements

Throughout the 15th century, explorers and traders from Castile and Portugal moved deeper and deeper into the Atlantic Ocean. The kings of Portugal and Spain began to collect taxes on goods brought from overseas. Thereupon, disagreements arose as to which ruler would receive taxes from goods coming from which region. One of the most important disputes was control of the Guinea and Mina region, rich in gold and slaves. The other point of contention was over who had the right to conquer the Canary Islands. With the Treaty of Alçaçovas, accepted on September 4, 1479, the Canary Islands were given to Castile. In return, the right to occupy Morocco and all other lands seized in Africa and the Indies in the east were given to Portugal. Pope Sixtus IV confirmed this agreement by publishing his bulletin "Aeterni regis" in 1481. On June 7, 1494, in order to prevent a conflict of interest between the Kingdom of Portugal and the Kingdom of Castile and Aragon, he redivided the navigation and conquest areas of the Atlantic Ocean and the New World (America) by creating a line 370 leagues west of the Cape Verde islands.

In 1494, Castile and Portugal signed the Treaty of Tordesillas, which divided the world into two exploration and colonial zones. This route created a meridian in the Atlantic Ocean, a line specific to Spain and a line to Portugal.

The remaining part of the world was also divided by the Treaty of Zaragoza, signed on April 22, 1529, which determined the antimeridian according to the border line specified in the Treaty of Tordesillas. The Protestant maritime powers, especially England and the Netherlands, and other third parties such as Catholic France did not accept the division of the world between only two Catholic nations, mediated by the Pope [5]. Despite this disagreement, the sharing of the lands that Portugal claimed to have discovered, although they were actually inhabited, continued until the Treaty of Madrid in 1750. With all these agreements, the Pope gave Spain in the west and Portugal in the east the right to conquer the new lands they discovered. When the surviving ships of Magellan's fleet reached the Moluccas in 1521, Spain claimed that these islands were in its western hemisphere.

According to the Treaty of Tordesillas, although the world was divided between the two powers, it divided the world into unequal hemispheres. Accordingly, Portugal's share was approximately 191° and Spain's share was approximately 169° [6].

3. Use of sea charts in agreements

The United Nations Convention on the Law of the Sea was adopted on 10 December 1982 and entered into force on 16 November 1994. This Convention has had a significant impact on the practices of the states that signed, ratified or even did not sign the convention.

The UN publishes all kinds of agreements, laws, international conventions and other materials regarding the seas concluded by the states of Africa, Asia and the South Pacific, Europe and North America, Latin America and the Caribbean through its internet publication. Thanks to these materials, information can be obtained about the national legislation of coastal states and other countries, their own baselines and the legislation they have adopted regarding their maritime zones.

In order to evaluate the extent to which the rules contained in the UN Convention on the Law of the Sea are accepted by the international community, the legislation of states that are not parties to the Convention is equally important. In this way, it can be evaluated whether state practices are consistent or not.

Under the 1982 Convention, coastal states have the right to establish various maritime zones such as territorial sea, contiguous zone, exclusive economic zone and continental shelf, and can establish straight baselines between them. In the case of archipelagic States, they have archipelagic baselines against which the width of their maritime zones is measured, or they are allowed to establish various maritime zones. In this way, coastal states can exercise sovereignty, sovereign rights and jurisdiction over a significant part of the seas.

According to the 1982 Convention, the borders of territorial waters are determined as 12 nautical miles, the border of the contiguous zone is 24 nautical miles and the limit of the exclusive economic zone is 200 nautical miles. Although it is claimed that the concept of exclusive economic zone emerged with the 1982 Convention, the "Declaration on maritime zones" declared by Chile with Peru and Ecuador on 18 August 1952 is the predecessor of this concept [7].

Chile, Ecuador and Peru have declared that they have exclusive sovereignty and jurisdiction over the sea along the coasts of their countries, up to a distance of at least 200 nautical miles from these coasts. Moreover, it is stated in this declaration that "exclusive jurisdiction and sovereignty over the specified maritime zone shall also include exclusive sovereignty and jurisdiction over the seabed and its subsoil" [8]. Furthermore, in the case of Island territory, these powers will apply to the entire coast of the island or group of islands within a 200 nautical mile zone [9]. All these decisions prove that the concept of the Exclusive Economic Zone was inspired by the declaration published by Chile, Peru and Ecuador in 1952.

According to the United Nations Convention on the Law of the Sea, coastal states have sovereign rights to explore and exploit all resources of the seabed, subsoil and water column up to a distance of 200 nautical miles from the baselines from which territorial waters are measured.

It has been accepted that the continental shelf can extend to the outer edge of the continental margin or up to a distance of 200 nautical miles, but the outer edge of the continental margin cannot extend to this distance. Article 76 of the 1982 Convention explains how the outer limits of the continental shelf can be calculated if the limit exceeds 200 nautical miles. This seemingly extremely complex calculation makes it necessary to add maritime border maps to agreements.

Statistical analysis has rarely been used to explain general trends in maritime boundary agreements. To understand the current situation and historical context, this study focuses on the quantitative analysis of global maritime boundary determination in the context of treaty annexes.

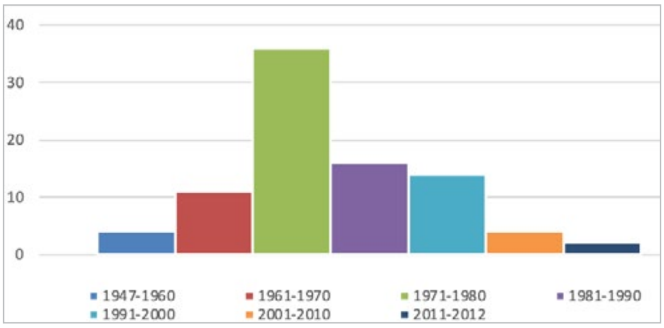

Figure 1. Distribution of approval dates of the examined agreements over the years

It is not easy to measure the subtle factors that may influence states' intentions or attitudes. Habits inherited from colonial times may reveal some hidden tendencies regarding datum selection in delimitation methods.

Since the main goal of the research is to contribute to the maritime border delimitation database as part of the information infrastructure, the analysis of map supplements aims to pave the way for further quantitative approaches. A research table covering the agreements in which all map annexes are evaluated is included in the Annex 1.

Each Member State is required to register the international agreements it has signed and ratified with the UN under Article 102 of the United Nations Charter. Because if an agreement is not registered in the UN, an international agreement cannot be accepted.

To date, no study has been carried out on the annexes of international maritime border delimitation agreements. 87 maritime border agreements, selected in a balanced manner from different continents and regions, were examined in detail in our study (Appendix 1).

In this study, annexes of limitation agreements are classified under six categories: Annex, map, protocol, exchange letter, declaration, additional declaration. It should be noted that in some agreements one or more of these annexes are added together.

To evaluate the maps included in the annexes of the agreements, the research questions were determined as follows: "What are the annexes of international maritime boundary agreements?", "What are the functions of the maps included in the annexes of international maritime boundary agreements?" and "Are there particular preferences regarding the maps used to draw borders in different types of settlements, such as bilateral negotiations and international litigation?"

To answer this question, the current research examines 87 delimitation cases that occurred in different regions from 1945 to 2023; It quantitatively visualizes the annexes of the agreements and focuses specifically on the annex maps.

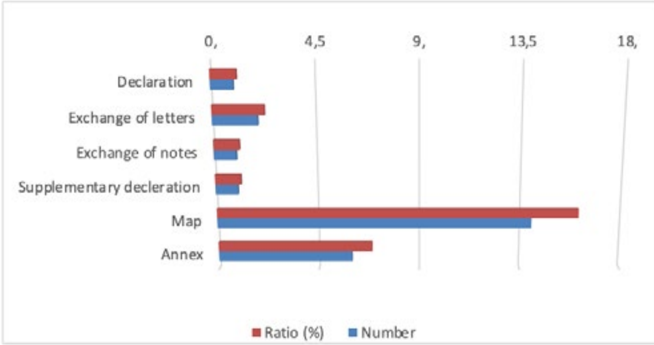

Figure 2. Elements included in the Annex to maritime border delimitation agreements

4. Use of sea charts in agreements

According to a study published in International Maritime Boundaries, the online journal of the American Society of International Law, 291 maritime boundary delimitation agreements were signed from 1942 to 2014. While some of these addressed only three points or a common development area between three countries, 256 agreements were classified as "delimitation of international maritime boundaries" agreements [10].

A number of political geographers and practitioners, including international lawyers, have adopted quantitative approaches to reveal the historical trend of agreements as well as relevant factors in the delimitation of seas and oceans. For example, Blake estimated that by 1985 there were 353 potential maritime boundaries in the world and 115 boundaries had already been determined [11]. Considering the historical developments after the LOSC was put into practice in 1994, it is observed that the agreements have become more detailed and richer in terms of annexes.

In maritime border agreements, the important role of socio-economic factors as well as coastal geography, agreement types, delimitation methods and their chronological changes should be kept in mind. As Kwiatkowska [12] argues, states implicitly consider economic and environmental situations as relevant conditions in negotiations. The importance of natural resources and the environmental factor has been consistently observed throughout the 2000s, both as a direct factor for actual borders and as a background condition intertwined with the border agreement [13].

After the establishment of the United Nations on October 24, 1945, the first maritime agreement registered by the UN was made between the USA and the United Kingdom. This agreement is about the delimitation of the area within the territorial waters adjacent to the naval base leased in Newfoundland and is an exchange of notes dated 13 August and 23 October 1947[14]. This agreement is also important as it is the first agreement to include an annex.

The "Maritime Territory Declaration" [15], declared by Chile, Peru and Ecuador on 18 August 1952, is not only the first registered declaration, but also the first maritime declaration jointly declared by three countries.

The maritime border delimitation agreements signed from 1947 to 2022 were examined and it was stated that there were 26 annexes in the title of all of them. Although some maps contain annexes, the existence of annexes is not mentioned in the titles of the agreements. The first maritime border agreement with a map attached was the agreement on drawing the current Soviet-Polish State border in the sector adjacent to the Baltic Sea on March 5, 1957[16].

5. Annexes to agreements

In maritime border delimitation agreements, agreed upon border points defined as latitude and longitude are drawn on maps. These maps are added as Annexes to the agreements by giving the country where the map was produced, its scale, map number, printing date, number of editions, and the number of corrections, if any. The first agreement containing an additional map in the UN archives was the agreement between the USSR and Poland on March 5, 1957, regarding the drawing of the current Soviet-Polish State border in the sector adjacent to the Baltic Sea [17]. This agreement is shown on Soviet-Polish maps with a scale of 1:1,000,000.

Although it is a correct method to add additional maps to agreements in order to avoid disputes due to differences in interpretation and application, it seems that this practice has not become standard.

A single map is usually added to the agreements. Sometimes it may be necessary to use more than one map due to the characteristics of the border line or area that needs to be shown. In addition, in some agreements, both Parties draw the agreed borders on their own maps and add these maps to the agreements. For example, the "Agreement on the Continental Shelf" [18] signed between Greece and Italy has two Annex maps, one Greek map and the other Italian map. As in the Agreement on Delimitation of Sea and Submarine Areas and Maritime Cooperation signed between Colombia and Dominica on January 13, 1978, the Parties draw the maritime borders on a map prepared by a third country and add them to the agreement [19]. In addition, maps "for explanatory purposes", "for visualization purposes" and "for illustration purposes" are also added to maritime boundary agreements.

The addition of scale, printing date and number of maps in the "limitation agreement" between France and Venezuela signed on July 17, 1980 can be considered a good example [20]. Maps added to maritime border delimitation agreements can be evaluated under five main headings.

1. Maps showing the agreed border line

In some maritime boundary agreements, an agreement was reached on the points where the boundary lines would pass, and these boundaries were drawn on a map and added as an Annex to the agreement. The most important feature of these maps is that the purpose for which they were added to the agreements is not clearly stated.

For example, in the agreement between Thailand and Malaysia on 24 October 1979 regarding the delimitation of the territorial waters of the two countries, there is the following statement: "The geographical coordinates obtained from the British Naval Maps and the boundary lines connecting them are specified in the maps annexed to the agreement." [21].

As in the agreement between Spain and France [22], in some agreements border lines can be drawn on maps produced by one of the parties. The provision in the additional protocol of the agreement on delimitation of the continental shelf between Great Britain and Norway that "the dividing line is drawn on the map annexed to this Protocol" [23] can be cited as another example.

Regarding the map added to the maritime border agreement signed between Gambia and Senegal on June 4, 1975, although an extended summary of the map number, publisher of the map, scale and delimitation is given, the function of the map is not specified. [24]

The "signing of fully authorized representatives" [25] of maps added to agreements without fully explaining the relevance of the maps to the agreements was encountered only in three maritime boundary agreements.

The same method was repeated in the Agreement on Delimitation of Maritime and Submarine Areas and Maritime Cooperation signed between Colombia and Dominica on January 13, 1978, [26] and in the Agreement on the Delimitation of Maritime Borders between Colombia and Haiti signed on February 17, 1978 [27].

It is noteworthy that these signed maps are at a scale of 1:1,800,000, far from showing the border lines with precision. The number of agreements showing the agreed border lines but not specifying the purposes for which the maps were added to the agreements is 5.

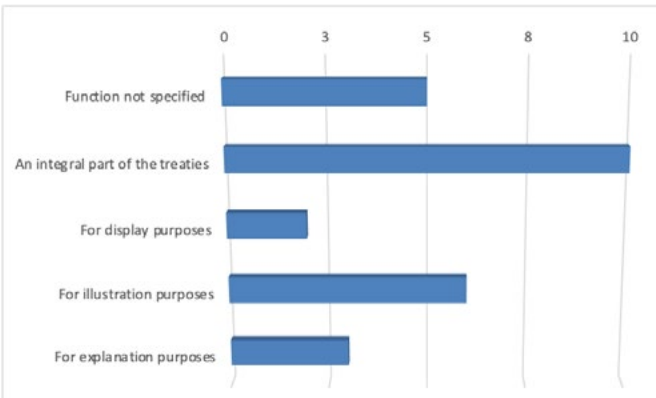

Figure 3. Functions of maps added to international maritime boundary agreements

2. Maps for explanatory purposes

There are also maps where the delimitation lines and points listed in maritime border delimitation agreements are shown for explanation purposes. For example, the border lines on the map attached to the agreement signed between Jamaica and Colombia for the "delimitation of maritime jurisdiction areas" were drawn "for explanation purposes" [28].

A map was added to the annex of the France (Reunion) - Mauritius maritime boundary agreement "for clarification purposes"; The official map was added to the agreement as a second annex [29]. In our review, it was determined that only 3 maps were added for explanation purposes.

3. Maps for sampling purposes

The maps added to some maritime area delimitation agreements are for "illustrative purposes only". For example, in the Agreement between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the United States of America Relating to the Caribbean Delimitation of the Maritime Frontier between Puerto Rico/U.S. Virgin Islands and the British Virgin Islands, dated 5 November 1993, it is stated that the boundary line drawn on the map annexed to the agreement is a "illustrative It was stated that it was drawn for the purpose of "[30].

In 6 of the 87 agreements we examined, border lines were drawn on the maps attached to the agreements "for example purposes".

4. Maps for demonstration purposes

It can be thought that showing the border points agreed upon in the agreements on maps with their manufacturer, number and scale will have a reducing effect on future disputes. Despite this, it has been stated that the Additional maps added to the two maritime border agreements are for "illustrative purposes".

5. Maps stated to be an integral part of the agreements

In some maritime border delimitation agreements, after an agreement was reached on the geodetic system and coordinates, the points of these coordinates were drawn on the map in the Annex and it was stated that these maps were "an integral part of the agreements". Thus, in addition to the coordinates specified in the agreements, the borders drawn on the maps were also made more precise. In the Agreement on Limitation of the Continental Shelf in the Black Sea signed between the Union of Soviet Socialist Republics and Turkey on June 23, 1978, [31] it was stated that the coordinates were marked on the map annexed to the agreement and that "this map constitutes an integral part of the agreement" [32]. This provision was further strengthened in the agreement made between Pakistan and Oman with the statement "It has the same legal validity as the Convention" [33].

Among the 87 maritime boundary agreements we examined, there are 10 agreements that provide for the maps in the Annex to be "an integral part of the agreement".

6. Conclusions

The location of the coordinates agreed upon in maritime border agreements on the ground and their drawing on the map may differ. This situation may lead to discussions on the lines and coordinates drawn on the maps added to the agreements.

For example, it was thought that there might be such a contradiction in the maritime jurisdiction delimitation agreement signed between Jamaica and Colombia on 12 November 1993. For this reason, the provision "In case of a conflict between the coordinates and the Table, the coordinates will prevail" was added to the agreement [34].

In the agreement between Norway and the Russian Federation on the delimitation of maritime powers and cooperation in the Barents Sea and the Arctic Ocean, an agreement was reached on this issue as follows:

"In case there is a difference between the line definition in the agreement and the lines shown on the map, the line definition in the agreement will prevail [35]".

There are also agreements, such as the tripartite agreement signed between Thailand, India and Indonesia [36], in which the coordinates of the maritime borders are determined, but the actual locations of these coordinates in the sea are not marked. However, how the actual locations of these coordinates in the sea will be determined and what the method will be are not specified in the agreement.

In the agreement on delimitation of the continental shelf signed between Denmark and Canada [37] on 17 December 1973, it was reminded that existing hydrographic maps were insufficient in certain areas. In this agreement, it was stated that the boundary line may change in the future "due to the fact that the low water line cannot be determined precisely in all sectors of some coastal areas."

Considering this situation, the following provision was made in the maritime boundaries agreement signed between Fiji and the Solomon Islands on July 11, 2022:

Charts and maps resulting from new research may show that changes in baseline coordinates are significant enough to warrant adjustments to the maritime boundary. In such a case, the Parties will realign the maritime borders on the basis of the principles used in the agreement [38].

Developments in science and technology may make the maps accepted for delimiting maritime borders insufficient. In such a situation, new disputes are likely to arise. The purpose of the annexes added to the maps should be clearly stated. It is likely that at least some of the additional maps whose purpose is not specified will pose problems in the future.

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[22] Convention between France and Spain on the delimitation of the territorial sea and the contiguous zone in the Bay of Biscay (Golfe de Gascogne/Golfo de Vizcaya) (with map), 29 January 1974. Article 2. 2. 2.The boundary established in accordance with the above-mentioned criteria and data is shown on French sea-chart No. 174, updated in 1973, which is annexed hereto. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/FRA-ESP1974VZ.PDF Accessed 03.02.2024.

[23] Protocol supplementary to the Agreement of 10 March 1965 between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway relating to the delimitation of the continental shelf between the two countries, 22 December 1978. Article 1.3. 3.The dividing line as defined in this Protocol has been drawn on the chart annexed to this Protocol. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/GBR-NOR1978CS.PDF Accessed 30.01.2024

[24] Treaty fixing the maritime boundaries between the Republic of the Gambia and the Republic of Senegal, 4 June 1975 https://www.state.gov/wp-content/uploads/2019/11/LIS-85.pdf Accessed 07.02.2024.

[25] Agreement on delimitation of the maritime boundaries between the Republic of Colombia and the Republic of Haiti, 17 February 1978. Article 2. This chart has been signed by the Plenipotentiaries and appears in the annex to this Agreement, together with the course of the baselines of each Party and of the dividing line. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/COL-HTI1978MB.PDF Accessed 01.02.2024

[26] Agreement on delimitation of marine and submarine areas and maritime co-operation between the Republic of Colombia and the Dominican Republic (with map), 13 January 1978. Article 2. The line and points agreed upon are shown on nautical chart No. 25,000, of the Defense Mapping Agency of the United States of America, which, having been signed by the Plenipotentiaries, is appended to this Agreement. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/COL-DOM1978MC.PDF Accessed 11.02.2024

[27] Agreement on delimitation of the maritime boundaries between the Republic of Colombia and the Republic of Haiti, 17 February 1978 Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/STATEFILES/HTI.htm Accessed 30.01.2024

[28] Maritime delimitation treaty between Jamaica and the Republic of Colombia, 12 November 1993. Article 6. For illustrative purposes only, the delimitation line and the Joint Regime Area are shown on a United States Defence Mapping Agency Chart 402, which is attached. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/JAM-COL1993MD.PDFn Accessed 30.01.2024 Accessed 01.02.2024

[29] Convention between the Government of the French Republic and the Government of Mauritius on the delimitation of the French and Mauritian economic zones between the islands of Reunion and Mauritius, with annexes, 2 April 1980

[30] Treaty on the delimitation in the Caribbean of a maritime boundary relating to Puerto Rico/U.S. Virgin Islands and the British Virgin Islands, 5 November 1993. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/GBR-USA1993MB.PDF Accessed 03.02.2024

[31] Agreement between the Government of the Republic of Turkey and the Government of the Union of Soviet Socialist Republics concerning the delimitation of the continental shelf between the Republic of Turkey and the Union of Soviet Socialist Republics in the Black Sea (with maps), 23 June 1978. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/TUR-RUS1978CS.PDF Accessed 01.02.2024

[32] Ibid.

[33] Muscat Agreement on the Delimitation of the Maritime Boundary between the Sultanate of Oman and the Islamic Republic of Pakistan, 12 June 2000. Article 7. These charts form an integral part of the Agreement, and have the same legal validity as the Agreement. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/OMN-PAK2000MB.PDF Accessed 03.02.2024

[34] Maritime delimitation treaty between Jamaica and the Republic of Colombia, 12 November 1993. Article 6. In the event of conflict between the coordinates and the Chart, the coordinates will prevail. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/JAM-COL1993MD.PDF Accessed 01.02.2024

[35] Treaty between the Kingdom of Norway and the Russian Federation concerning Maritime Delimitation and Cooperation in the Barents Sea and the Arctic Ocean, 15 September 2010. Article 1.3. 3.By way of illustration, the delimitation line and the points listed in paragraph 1 of this Article have been drawn on the schematic chart annexed to the present Treaty. In case of difference between the description of the line as provided for in this Article and the drawing of the line on the schematic chart, the description of the line in this Article shall prevail. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/NOR-RUS2010.PDF Accessed 01.02.2024

[36] Agreement between the Government of the Kingdom of Thailand, the Government of the Republic of India and the Government of the Republic of Indonesia concerning the determination of the trijunction point and the delimitation of the related boundaries of the three countries in the Andaman Sea, 22 June 1978. Article 1.6.The actual location of the points at sea shall be determined by a method to be mutually agreed upon by the competent authorities of the three respective Governments concerned. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/THA-IND-IDN1978TP.PDF Accessed 03.02.2024

[37] Agreement between the Government of the Kingdom of Denmark and the Government of Canada relating to the delimitation of the continental shelf between Greenland and Canada (with annexes) 17 December 1973. Article 3. In view of the inadequacies of existing hydrographic charts for certain areas and failing a precise determination of the low-water line in all sectors along the coast of Greenland and the eastern coasts of the Canadian Arctic Islands. Available at: www.un.org/depts/los/LEGISLATIONANDTREATIES/STATEFILES/CAN.htm Accessed 01.02.2024

[38] Agreement between the Republic of Fiji and Solomon Islands concerning their maritime boundary, 11 July 2022 Available at: https://www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/TREATIES/FijiSolomonIslandsTreatyEng.pdf Accessed 01.02.2024

Appendix 1.

Agreements in which the elements included in the Annex section of maritime border delimitation agreements are examined

Number	*Year*	*Parties of the Agreement, Its Content and Signed Date*	*Annex*
1	1947	Exchange of notes constituting an agreement between the United States of America and the United Kingdom of Great Britain and Northern Ireland relating to the delimitation of the area within territorial waters adjacent to the leased naval base at Argentia, Newfoundland (with annex), 13 August and 23 October 1947	With annex
2	1957	Descriptive Protocol relating to the sea frontier between Norway and the Union of Soviet Socialist Republics in the Varangerfjord, demarcated in 1957, 29 November 1957	
3	1957	Treaty (with annexed maps) concerning the demarcation of the existing Soviet-Polish State frontier in the sector adjoining the Baltic Sea, 5 March 1957	With annexed maps
4	1957	Agreement between the Royal Norwegian Government and the Government of the Union of Soviet Socialist Republics concerning the sea frontier between Norway and the USSR in the Varangerfjord, 15 February 1957	
5	1961	Exchange of notes between Mexico and Guatemala constituting an agreement on the establishment of an international boundary and water commission, 9 November and 21 December 1961	
6	1963	Exchange of letters on settlement of problems concerning the delimitation of Monegasque territorial waters constituting an agreement relating to article 4 of the Treaty of 17 July 1918 establishing the relations of France with the Principality of Monaco, 18 May 1963	
7	1965	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965.	
8	1965	Agreement between the Kingdom of Denmark and the Federal Republic of Germany concerning the delimitation, in the coastal regions, of the continental shelf of the North Sea, 9 June 1965	
9	1965	Agreement between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway relating to the delimitation of the continental shelf between the two countries, 10 March 1965	
10	1965	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965	
11	1966	Treaty between the Kingdom of the Netherlands and the Kingdom of Belgium on the Delimitation of the Continental Shelf, 18 December 1996	
12	1967	Agreement concerning the delimitation of the fishery areas of Norway and Sweden in the North-Eastern Skagerrak (with declaration and maps), 5 April 1967	With declaration and maps

13	1968	Treaty between the Polish People's Republic and the German Democratic Republic concerning the delimitation of the continental shelf in the Baltic Sea, 29 October 1968	
14	1968	Agreement between Sweden and Norway concerning the delimitation of the continental shelf, 24 July 1968	
15	1968	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965 - Exchange of notes constituting an agreement amending the above-mentioned Agreement. Copenhagen, 24 April 1968	
16	1972	Agreement between the Government of Canada and the Government of the French Republic on Their Mutual Fishing Relations, 27 March 1972	
17	1973	Agreement between the Government of the Kingdom of Denmark and the Government of Canada relating to the delimitation of the continental shelf between Greenland and Canada (with annexes) 17 December 1973	With annexes
18	1973	Treaty between Uruguay and Argentina concerning the Rio de la Plata and the corresponding maritime boundary, 19 November 1973	
19	1974	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965 - Exchange of notes constituting an agreement amending the above-mentioned Agreement, 4 June 1974	
20	1974	Agreement between Denmark and Norway relating to the delimitation of the continental shelf, 8 December 1965 - Exchange of notes constituting an agreement amending the above-mentioned Agreement, 4 June 1974	
21	1974	Convention between Spain and Italy on the delimitation of the continental shelf between the two States (with chart), 19 February 1974	With chart
22	1974	Convention between the Government of the French Republic and the Government of the Spanish State on the delimitation of the continental shelves of the two States in the Bay of Biscay (Golfe de Gascogne/Golfo de Vizcaya) (with annex, exchange of letters and map), 29 January 1974	With annex, exchange of letters and map
23	1974	Convention between France and Spain on the delimitation of the territorial sea and the contiguous zone in the Bay of Biscay (Golfe de Gascogne/ Golfo de Vizcaya) (with map), 29 January 1974	With map
24	1974	Agreement concerning Delimitation of the Continental Shelf between Iran and Oman, 25 July 1974	
25	1974	Convention between the Government of the French Republic and the Government of the Spanish State on the delimitation of the continental shelves of the two States in the Bay of Biscay (Golfe de Gascogne/Golfo de Vizcaya) (with annex, exchange of letters and map), 29 January 1974	With annex, exchange of letters and map
26	1975	Treaty fixing the maritime boundaries between the Republic of the Gambia and the Republic of Senegal, 4 June 1975	

27	1975	Agreement concerning delimitation of marine and submarine areas and maritime co-operation between the Republics of Colombia and Ecuador, 23 August 1975	
28	1977	Maritime Boundary Agreement Between the United States of America and the Republic of Cuba, 16 December 1977	
29	1977	Agreement between the Hellenic Republic and the Italian Republic on the delimitation of the respective continental shelf areas of the two States, 24 May 1977	
30	1977	Treaty on Delimitation of Marine and Submarine Areas and Maritime Cooperation between the Republic of Colombia and the Republic of Costa Rica (17 March 1977).	
31	1977	Agreement between the Hellenic Republic and the Italian Republic on the delimitation of the respective continental shelf areas of the two States, 24 May 1977	
32	1978	Maritime boundary Treaty between the United States of America and the Republic of Venezuela (with map), 28 March 1978	With map
33	1978	Treaty on maritime boundaries between the United States of America and the United Mexican States (Caribbean Sea and Pacific Ocean), 4 May 1978	
34	1978	Protocol supplementary to the Agreement of 10 March 1965 between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway relating to the delimitation of the continental shelf between the two countries, 22 December 1978	With map
35	1978	Boundary delimitation Treaty between the Republic of Venezuela and the Kingdom of the Netherlands (with map), 31 March 1978	
36	1978	Agreement between the Government of the Republic of Turkey and the Government of the Union of Soviet Socialist Republics concerning the delimitation of the continental shelf between the Republic of Turkey and the Union of Soviet Socialist Republics in the Black Sea (with maps), 23 June 1978	With maps
37	1978	Agreement between the Government of the Kingdom of Thailand, the Government of the Republic of India and the Government of the Republic of Indonesia concerning the determination of the trijunction point and the delimitation of the related boundaries of the three countries in the Andaman Sea, 22 June 1978	
38	1978	Agreement between the Government of the Kingdom of Thailand and the Government of the Republic of India on the delimitation of sea-bed boundary between the two countries in the Andaman Sea (with chart and exchange of notes), 22 June 1978	With chart and exchange of notes
39	1978	Agreement on delimitation of the maritime boundaries between the Republic of Colombia and the Republic of Haiti, 17 February 1978	

40	1979	Agreement between the Government of the Kingdom of Denmark and the Government of the Kingdom of Norway concerning the delimitation of the continental shelf in the area between the Faroe Islands and Norway and concerning the boundary between the fishery zone near the Faroe Islands and the Norwegian economic zone, 15 June 1979	
41	1979	Agreement between the Government of the Kingdom of Denmark and the Government of the Kingdom of Norway concerning the delimitation of the continental shelf in the area between the Faroe Islands and Norway and concerning the boundary between the fishery zone near the Faroe Islands and the Norwegian economic zone, 15 June 1979	
42	1979	Act of Montevideo by which Chile and Argentina request the Holy See to act as a mediator with regard to their dispute over the Southern region and undertake not to resort to force in their mutual relations (with supplementary declaration), 8 January 1979	With supplementary declaration
43	1979	Exchange of notes constituting an agreement between Denmark and Sweden concerning the delimitation of the territorial waters between Denmark and Sweden, 25 June 1979	
44	1979	Treaty between the Kingdom of Thailand and Malaysia relating to the delimitation of the territorial seas of the two countries, 24 October 1979	
45	1979	Treaty to submit to binding dispute settlement the delimitation of the maritime boundary in the Gulf of Maine area, 29 March 1979	
46	1980	Treaty between the United States of America and the Cook Islands on friendship and delimitation of the maritime boundary between the United States of America and the Cook Islands, 11 June 1980	
47	1980	Convention between the Government of the French Republic and the Government of Mauritius on the delimitation of the French and Mauritian economic zones between the islands of Reunion and Mauritius, with annexes, 2 April 1980	With annexes
48	1980	Convention between the Government of the French Republic (Wallis and Futuna) and the Government of the Kingdom of Tonga on the delimitation of economic zones, 11 January 1980	
49	1980	Agreement between Iceland and Norway Concerning Fishery and Continental Shelf Questions, 28 May 1980	
50	1980	Delimitation Treaty between the Government of the French Republic (Martinique and Guadeloupe) and the Government of the Republic of Venezuela (with map) 17 July 1980	with map
51	1980	Treaty concerning delimitation of marine areas and maritime co-operation between the Republic of Costa Rica and the Republic of Panama, 2 February 1980	
52	1981	Maritime delimitation Treaty between the Federative Republic of Brazil and the French Republic (French Guyana), 30 January 1981	
53	1981	Agreement between Norway and Iceland on the continental shelf between Iceland and Jan Mayen, 22 October 1981	
54	1983	Agreement between the Government of the Republic of France and the Government of Fiji relating to the delimitation of their economic zone (with annex and maps), 19 January 1983	with annex and maps
55	1984	Agreement between Sweden and Denmark on the delimitation of the continental shelf and fishing zones (with map, exchanges of notes and Protocol), 9 November 1984	With map, exchanges of notes and Protocol
56	1986	Agreement between the Government of the French Republic and the Government of the Italian Republic on the Delimitation of maritime frontiers in the area of the straights of Bonifacio, 28 November 1986	
57	1986	Exchange of notes constituting an agreement concerning the delimitation of areas of responsibility in connection with the Convention of 22 March 1974 on the protection of the Marine Environment of the Baltic Sea, 21 November 1986	
58	1986	Maritime Delimitation Treaty between Colombia and Honduras, 2 August 1986	
59	1988	Agreement between the Government of the French Republic and the Government of the United Kingdom of Great Britain and Northern Ireland relating to the delimitation of the territorial sea in the Straits of Dover, 2 November 1988	
60	1989	Agreement between the Government of the Kingdom of Sweden, the Government of the Polish People's Republic and the Government of the USSR concerning the Common Delimitation Point of their Maritime Boundaries in the Baltic Sea, 30 June 1989	
61	1989	Agreement between the Government of the Kingdom of Sweden, the Government of the Polish People's Republic and the Government of the USSR concerning the Common Delimitation Point of their Maritime Boundaries in the Baltic Sea, 30 June 1989.	
62	1989	Agreement concerning the delimitation of the continental shelf and fishing zones between the Kingdom of Sweden and the Polish People's Republic. (with nautical chart), 10 February 1989	With nautical chart
63	1989	Treaty between the German Democratic Republic and the Polish People's Republic on the Delimitation of the Sea Areas in the Oder Bay, 22 May 1989	
64	1990	Agreement between the Government of the French Republic and the Government of the Kingdom of Belgium on the delimitation of the territorial sea, 8 October 1990	
65	1990	Codicil modifying the Agreement of 19 January 1983 between the Government of the French Republic and the Government of Fiji relating to the delimitation of their economic zone, 8 November 1990	
66	1990	Agreement on Maritime Delimitation between the Government of the Cook Islands and the Government of the French Republic (with map), 3 August 1990	With map

67	1990	Agreement between the United States of America and the Union of Soviet Socialist Republics on the maritime boundary, 1 June 1990	
68	1992	Agreement between Albania and Italy for the determination of the continental shelf of each of the two countries, 18 December 1992.	
69	1993	Treaty on the delimitation in the Caribbean of a maritime boundary relating to Puerto Rico/U.S. Virgin Islands and the British Virgin Islands, 5 November 1993	
70	1993	Maritime delimitation treaty between Jamaica and the Republic of Colombia (with chart). Kingston, 12 November 1993	With chart
71	1995	Agreement between the Kingdom of Denmark and the Kingdom of Norway concerning the delimitation of the continental shelf in the area between Jan Mayen and Greenland and concerning the boundary between the fishery zones in the area 18 December 1995	
72	1995	Agreement between the Republic of Finland and the Republic of Estonia on the Boundary of the Maritime Zones in the Gulf of Finland and on the Northern Baltic Sea, 18 October 1996	
73	1996	Treaty between the Kingdom of the Netherlands and the Kingdom of Belgium on the Delimitation of the Territorial Sea, 18 December 1996	
74	1996	Agreement on maritime delimitation between the Government of the French Republic and the Government of the United Kingdom of Great Britain and Northern Ireland concerning Saint Martin and Saint Barthelemy on one hand, and Anguilla on the other, 27 June 1996	
75	1997	Additional Protocol to the Agreement of 18 December 1995 between the Kingdom of Norway and the Kingdom of Denmark concerning the Delimitation of the Continental Shelf in the Area between Jan Mayen and Greenland and the Boundary between the Fishery Zones in the Area, 11 November 1997	
76	1997	Agreement between the Republic of Turkey and the Republic of Bulgaria on the determination of the boundary in the mouth of the Rezovska/ Mutludere River and delimitation of the maritime areas between the two states in the Black Sea, 4 December 1997	
77	1997	Agreement between the Government of the Kingdom of Thailand and the Government of the Socialist Republic of Viet Nam on the delimitation of the maritime boundary between the two countries in the Gulf of Thailand, 9 August 1997	
78	1998	Agreement Between the Government of the Kingdom of Sweden and the Government of the Republic of Estonia on the Delimitation of the Maritime Zones in the Baltic Sea, 2 November 1998	
79	1999	Agreement between the Government of the Kingdom of Denmark together with the Home Government of the Faroe Islands, on the one hand, and the Government of the United Kingdom of Great Britain and Northern Ireland, on the other hand, relating to Maritime Delimitation in the Area between the Faroe Islands and the United Kingdom, 18 May 1999	
80	1999	Treaty on the State Border between the Republic of Croatia and Bosnia and Herzegovina, 30 July 1999	
81	2000	Muscat Agreement on the Delimitation of the Maritime Boundary between the Sultanate of Oman and the Islamic Republic of Pakistan, 12 June 2000	
82	2001	Agreement between the Government of the French Republic and the Government of the Republic of Seychelles concerning Delimitation of the Maritime Boundary of the Exclusive Economic Zone and the Continental Shelf of France and of Seychelles, 17 February 2001	
83	2002	Agreement between the Government of the French Republic and the Government of the Republic of Kiribati concerning the delimitation of a boundary line between the exclusive economic zone around French Polynesia and the exclusive economic zone of the Republic of Kiribati, 18 December 2002	
84	2005	Agreement between the Government of France and the Government of the Republic of Madagascar on the Delimitation of Maritime Areas situated between La Réunion and Madagascar, 14 April 2005	
85	2010	Treaty between the Russian Federation and the Kingdom of Norway concerning maritime delimitation and cooperation in the Barents Sea and the Arctic Ocean, 15 September 2010	
86	2018	Agreement between the Republic of Poland and the Kingdom of Denmark concerning the delimitation of maritime zones in the Baltic Sea, 19 November 2018.	
87	2022	Agreement between the Republic of Fiji and Solomon Islands concerning their maritime boundary, 11 July 2022	

Section 9
Cyber Security at Sea

GMC'24 Global Maritime Congress
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Currents of Innovation: A Bibliometric Perspective of Blockchain Approach in Maritime Studies

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Abstract

Blockchain technologies, heralded as a transformative force reshaping numerous industries, have recently garnered significant attention within the maritime sector. This study conducts a thorough bibliometric review of 107 scholarly papers authored by 310 scholars, exploring the convergence of blockchain and maritime across 74 reputable scientific journals sourced from the Web of Science databases. Utilizing the powerful R software and Bibliometrix tool, a comprehensive analysis of bibliographical data is undertaken to extract insightful findings. Traversing the scholarly landscape, this research elucidates the multifaceted perspectives and discoveries emerging within the maritime blockchain domain. Through the application of bibliometric techniques, the aim is to uncover prevalent patterns, trends, and crucial themes, thereby offering a comprehensive overview of the academic discourse. In addition to mapping out key contributors and influential journals, this study delves into the interdisciplinary nature of blockchain applications in maritime contexts, showcasing collaborative efforts among scholars from diverse backgrounds. The temporal evolution of scholarly contributions is meticulously examined, providing nuanced insights into the dynamic nature of the field and identifying periods of heightened activity. This research not only serves as a valuable resource for maritime and blockchain scholars but also lays the groundwork for future research endeavors. By integrating bibliometric rigor, diverse scholarly perspectives, and advanced analytical tools, a holistic understanding of the current state and future trajectories of blockchain technology in the maritime industry is facilitated.

Keywords: *Blockchain, maritime, shipping, technology adoption, digitalization*

1. Introduction

In an epoch characterized by incessant technological progress, blockchain technology has swiftly emerged as a revolutionary force [1], [2], [3], extending its impact far beyond its initial use in cryptocurrency [4]. Blockchain, a decentralized and incorruptible ledger system, is at the forefront of transformative changes in the maritime sector [5], [6]. This technology has garnered significant attention and adoption within the maritime industry, signifying not just a surface-level modification but a fundamental restructuring of operational frameworks [7]. Its potential to revolutionize maritime practices lies in its ability to address inherent challenges like documentation discrepancies, fraud, and inefficiencies pervasive in the global supply chain [8], [9]. The essence of blockchain in this context lies in its capacity to offer a transparent and secure foundation, promising to redefine traditional maritime operations [10].

The maritime sector, serving as the lifeblood of global trade [11] and commerce, is undergoing a metamorphosis catalyzed by blockchain integration. This transformation is crucial, addressing immediate operational challenges while paving the way for sustainable and resilient maritime ecosystems [12]. As vessels traverse oceans laden with goods and commodities, the transparency and immutability offered by blockchain promise to eliminate inefficiencies, streamline processes, and fortify the industry against fraud and malpractices.

This paper presents a comprehensive bibliometric analysis focusing on the intersection of blockchain technology and maritime studies. By meticulously examining 107 scholarly papers authored by 310 scholars, it offers a panoramic understanding of the synergies between blockchain and the maritime domain. Serving as a beacon, the paper elucidates blockchain's transformative impact on the maritime sector, providing practical insights for industry stakeholders alongside academia. Its dual purpose is to explore the evolving role of blockchain in maritime operations and provide actionable recommendations for its integration.

The first aim is to dissect how blockchain is reshaping various aspects of maritime operations, from vessel management to supply chain logistics. By doing so, a comprehensive understanding of its impact is sought. Concurrently, bridging the gap between theory and practice is intended by offering practical insights and recommendations for leveraging blockchain's potential.

The goal is not only to contribute to scholarly discourse but also to provide a practical roadmap for stakeholders navigating this evolving landscape. This study is envisioned as a dynamic repository, continuously updated to reflect technological advancements and scholarly contributions in this field. Ultimately, stakeholders are empowered to embrace blockchain's transformative potential in the maritime sector confidently.

The study utilizes a large-scale bibliometric analysis conducted with precision using a robust combination of R software and the Bibliometrix tool, to provide a comprehensive overview of research related to blockchain applications in the maritime sector. More precisely, this study has established three overarching research questions (RQs) in line with conventional bibliometric approaches [13], [14], [15], [16], to steer the investigation within this domain:

RQ1-What is the current numerical landscape and trajectory of research concerning blockchain applications within the maritime industry? Understanding the quantitative aspects and growth patterns is essential for gaining insights into the ongoing development and evolution of this specialized field.

RQ2-What distinguishes the publication trends in research on blockchain applications within the maritime sector? Exploring the distribution of literature across journals and countries provides valuable insights for researchers, aiding them in making well-informed decisions such as choosing appropriate journals for reading and submission.

RQ3-What directions hold promise for future research on blockchain applications in the maritime sector? This question aims to pinpoint specific areas of promise for forthcoming academic investigations focused on the utilization of blockchain technology within the maritime sector. Investigating these promising directions will contribute to advancing the theoretical foundations of research on blockchain applications in the maritime sector.

2. Methodology

Bibliometric analysis is a systematic and quantitative research method used to comprehensively examine academic studies within a specific field. This involves analyzing bibliographic data, including descriptive statistical information about relevant publications. The primary aim is to reveal patterns, trends, and relationships within scholarly literature.

In bibliometric analysis, researchers explore occurrences and connections among elements such as authors, journals, universities, and keywords. By scrutinizing these elements, valuable insights into the structure and dynamics of a particular academic domain can be gained. The information derived allows for a deeper understanding of the scholarly landscape and forms a basis for evaluating the impact and influence of academic contributions. This method provides a quantitative perspective on the scholarly output of a discipline. Researchers utilize metrics like h-index, impact factor, and citation counts to assess the significance and reach of individual publications, authors, or journals. In summary, bibliometric analysis is a valuable tool for researchers, policymakers, and academic institutions to assess the state of knowledge in a field and make informed decisions based on empirical evidence.

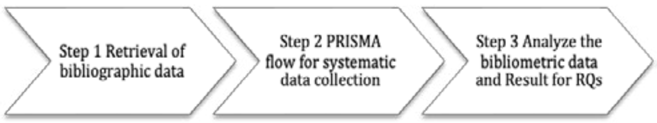

Figure 1. Research methodology steps

This research, a structured methodology consisting of three primary steps (Figure 1) is typically adhere to. The first step entails commencing the process by retrieving bibliographic data through an exhaustive review of pertinent literature. This step involves diligently searching for and identifying relevant studies within the existing scholarly body of work. Subsequently, in the second step, systematic data collection is initiated, employing a methodology known as the PRISMA flow diagram to effectively delineate the research scope and streamline the data gathering process. Finally, in the third step, the collected data undergoes bibliometric analysis to derive insights that address the research questions (RQs) posed.

2.1. Retrieval of Bibliographic Data (Step 1)

The research rigorously explores the application of the Blockchain Approach within Maritime Studies research by amalgamating bibliometric analysis and systematic content analysis conducted using Bibliometrix tool and Excel. Emphasis is placed on utilizing the Web of Science (WoS), an extensive database [17], as the primary source of bibliographic data. The study exclusively draws upon WoS, leveraging its "Topic" field to explore literature encompassing title, abstract, author keywords, and keywords plus fields.The investigation specifically targets English language content within WoS, emphasizing document types such as "Article," "Proceedings Paper," "Review Article," "Early Access," "Editorial Material," "Book Chapters," "Book Review," and "Book." Publications from the year 2024 are excluded from the analysis.

To collect relevant bibliography data, a keyword search was performed in January 2024. The search process involved the use of Boolean functions. The detailed steps and their corresponding keywords, along with the number of papers retrieved from the Web of Science (WoS), are as follows in the Table 1. Each step involved refining the search criteria to capture papers relevant to the study's focus.

Table 1. Keyword search in WoS

Steps	Keyword	Number of Papers (WoS)
	((‘transportation’ OR ‘industry’ OR ‘sector’) AND (‘blockchain’ OR ‘smart AND contract’))	6901
	((‘maritime*’ OR ‘ship’ OR ‘sea*’ OR ‘vessel’ OR ‘sailor’ OR ‘crew’) AND (‘blockchain’ OR ‘smart AND contract’)	1759
	((‘maritime’ OR ‘maritime AND transportation’ OR ‘maritime AND industry’ OR ‘ship’ OR ‘sea’ OR ‘vessel’ OR ‘seaman’ OR ‘sailor’ OR ‘crew’) AND (‘blockchain’ OR ‘smart AND contract’))	287
	((‘maritime’ OR ‘ship’ OR ‘vessel’) AND (‘blockchain’ OR ‘smart AND contract’))	243
	((‘maritime’) AND (‘blockchain’ OR ‘smart AND contract’))	117

2.2. PRISMA Flow for Systematic Data Collection (Step 2)

PRISMA, introduced as a guideline for systematic reviews and meta-analyses, endeavors to standardize the reporting practices of such studies within academic literature [18]. It advocates for clearer, more comprehensive, and transparent documentation of systematic reviews and meta-analyses. These prescribed standards play a pivotal role in enhancing the quality of research within the literature, ensuring the comparability of findings, and facilitating evidence-based decision-making processes. The framework comprises four primary stages: Identification, Screening, Eligibility, and Inclusion. Research endeavors adhere to the procedural flow delineated in Figure 2.

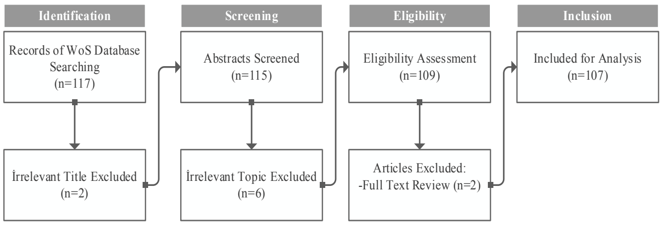

Figure 2. PRISMA flow chart

After conducting a keyword search in Step 1, 117 papers were identified using the PRISMA approach. During the identification phase, upon reviewing the titles, it was observed that 2 were not relevant to the topic and were subsequently excluded. Moving to the screening stage, abstracts of the remaining 115 papers were examined, leading to the exclusion of 6 more for lack of relevance. Subsequently, the full texts of the remaining 109 papers were thoroughly reviewed for eligibility assessment, resulting in the exclusion of 2 more irrelevant papers. Ultimately, 107 papers were deemed eligible for inclusion in the study.

2.3. Analyze the Bibliometric Data and Result for RQs (Step 3)

RQ1-What is the current numerical landscape and trajectory of research concerning blockchain applications within the maritime industry?

The academic landscape concerning blockchain applications within the maritime industry has undergone a notable evolution in recent years, as evidenced by the increasing number of scholarly publications. This trend (Figure 3) reflects a growing scholarly interest and investment in exploring the potential of blockchain technology within maritime contexts. In this analysis, a significant rise in peer-reviewed publications related to blockchain applications in the maritime sector was observed. Notably, our investigation revealed that prior to 2018, no publications were identified on this topic. However, from 2018 onwards, there has been a clear upward trajectory in scholarly output. In 2018, there were three publications on this topic, which more than doubled to nine in 2019. The momentum continued to accelerate, with 17 publications in 2020, 21 in 2021, 25 in 2022 and reaching 32 publications in 2023.

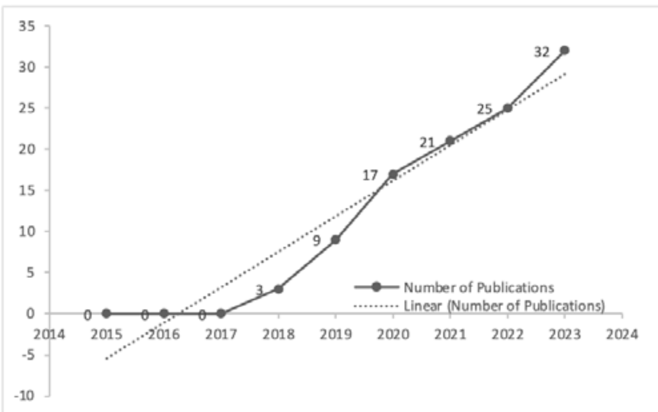

Figure 3. Publication' yearly trend.

This increasing trend underscores the expanding interest and recognition of the potential benefits that blockchain technology can offer to the maritime industry. The researchers examine a variety of topics including supply chain management, logistics, security and transparency. The growing body of literature provides insights into the challenges, opportunities, and implications of implementing blockchain solutions in maritime operations.

RQ2-What distinguishes the publication trends in research on blockchain applications within the maritime sector?

The distribution of literature (Figure 4) across journals and countries in research on blockchain applications within the maritime sector offers valuable insights into publication trends. This analysis aids researchers in making well-informed decisions, particularly in selecting appropriate journals for reading and submission. Upon examination, it becomes apparent that IEEE Transactions on Intelligent Transportation Systems, Maritime Policy & Management, and Transportation Research Part E-Logistics and Transportation Review stand out as the top journals contributing to this field. This prominence suggests a significant focus on the integration of blockchain technology into intelligent transportation systems, maritime policies, and logistics within the maritime sector.

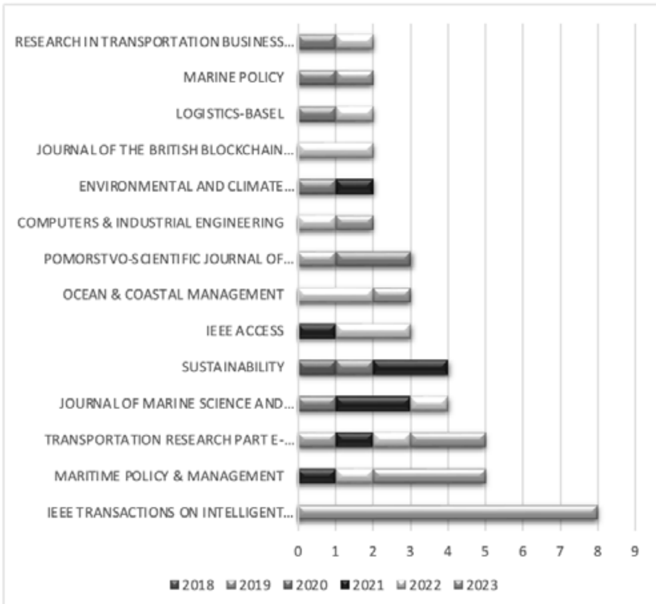

Figure 4. Source dynamics

Furthermore, the presence of journals like Journal of Marine Science and Engineering, Sustainability, and Marine Policy underscores the interdisciplinary nature of blockchain research within the maritime domain. These journals likely accommodate studies exploring the environmental, economic, and policy implications of blockchain applications in maritime operations. The relatively lower representation of conferences compared to journals suggests that blockchain research in the maritime sector tends to favor peer-reviewed publication avenues over conference proceedings. However, notable conferences such as the 16th Annual International conference on distributed computing in sensor systems and the

2020 IEEE International conference on industrial engineering and engineering management indicate emerging interest in presenting blockchain-related findings within academic conferences.

Geographically, the distribution of literature across countries reflects a global interest in blockchain applications within the maritime sector. While specific countries may exhibit higher publication outputs, the international collaboration evident in this distribution underscores the interconnectedness of research efforts in addressing challenges and exploring opportunities in blockchain technology for maritime applications.

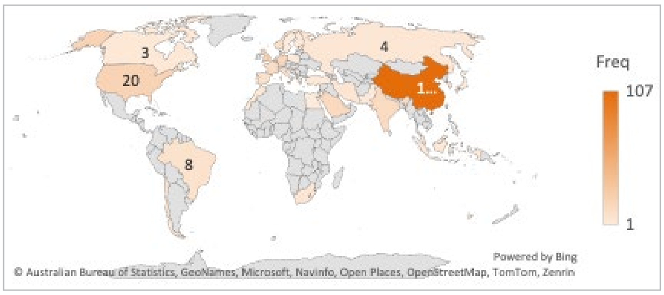

Figure 5. Geographic distribution of publications

The examination of literature distribution across journals and countries within the maritime sector's research on blockchain applications yields valuable insights for researchers, facilitating informed decisions regarding journal selection for both consumption and submission purposes. The Figure 5 provides a frequency distribution depicting the regions contributing to research on blockchain applications within the maritime sector. Notably, China emerges as the predominant contributor, with a significant frequency of 107 occurrences, highlighting its substantial research presence in this domain. Following China, the United Kingdom and the United States emerge as prominent contributors, with 24 and 20 occurrences, respectively. Moreover, Singapore, Croatia, and Germany demonstrate noteworthy frequencies of 18, 17, and 17 occurrences, respectively, underscoring their contributions to this burgeoning field.

Table 2. Globally most cited publications

Author(s)	DOI	TC	TC per Year
Yang, 2019 [19]	10.1016/j.tre.2019.09.020	157	26.17
Akhtar et al., 2020[20]	10.1186/s13673-020-00258-2	84	16.80
Zarzuelo, 2020[21]	10.1016/j.jii.2020.100173	77	15.40
Pedersen et al., 2019[22]	10.17705/2msqe.00010	71	11.83
Gausdal et al., 2018[23]	10.3390/su10061985	64	9.14
Zhou et al., 2020[24]	10.1016/j.marpol.2020.104265	55	11.00
Liu et al., 2023[25]	10.1080/00207543.2021.1930239	52	26.00
Tijan et al., 2021[26]	10.1016/j.techfore.2021.120879	50	12.50
Pu & Lam, 2021[27]	10.1080/03088839.2020.1825855	42	10.50
Bavassano et al., 2020[28]	10.1016/j.rtbm.2020.100428	38	7.60

*TC: Total Citations

Transitioning from the geographical distribution to specific research endeavors within this realm, one study stands out prominently: Yang's [19] seminal study in 2019. Yang's research not only garners the highest total citation count among the top 10 authors and works listed in Table 2 but also sustains a remarkable yearly citation rate since its publication.

RQ3-What directions hold promise for future research on blockchain applications in the maritime sector?

Based on the findings of bibliometric research, as evidenced by the resulting word cloud (Figure 6), it is discernible that the exploration of blockchain technology's prospective applications in the maritime sector encompasses several critical dimensions. Primarily, there exists a necessity to examine how blockchain technology can adeptly manage the significant volume of maritime transactions and data management tasks while upholding scalability and operational efficiency. Secondly, an in-depth comprehension of the security and privacy considerations inherent in the integration of blockchain systems within maritime operations is essential for establishing trust and dependability in the technology. Furthermore, an examination of the regulatory frameworks and legal implications associated with the adoption of blockchain in the maritime industry is imperative to foster widespread acceptance. Lastly, investigating the potential economic and environmental impacts of blockchain applications on maritime logistics and sustainability will yield valuable insights for industry stakeholders.

Figure 6. Bibliometric word cloud.

In the realm of supply chain management and logistics [29], one particularly promising avenue for future research lies in leveraging blockchain to enhance processes within the maritime sector. Studies in this area can delve into how blockchain facilitates real-time tracking of shipments, streamlines documentation procedures, and verifies the authenticity of product origins. Additionally, research efforts could explore the synergies between blockchain and emerging technologies such as Internet of Things (IoT) devices to bolster visibility and operational efficiency in supply chain activities [30], [31].

Another compelling area of interest is the exploration of smart contracts [32] and automated transactions [33] in maritime activities. Future research endeavors might focus on developing smart contract frameworks tailored to the specific requirements of vessel chartering, freight forwarding, and port services [34], [35]. Furthermore, it is essential to conduct studies examining the legal and regulatory implications surrounding the integration of smart contracts into maritime transactions, thereby paving the way for their widespread adoption. Blockchain technology holds significant promise in enhancing maritime safety and security by ensuring tamper-proof record-keeping of vital information such as vessel maintenance records, inspection reports, and crew certifications [36], [37]. Research efforts in this domain could explore how blockchain can be integrated with complementary technologies like artificial intelligence [38] to enable predictive maintenance and risk assessment [39]. Additionally, investigating decentralized identity management systems [40] on the blockchain could fortify security measures for port access and crew authentication.

Addressing environmental concerns and ensuring regulatory compliance are paramount in the maritime sector. Future research endeavors could focus on leveraging blockchain to track carbon emissions, monitor fuel consumption, and adhere to international environmental regulations such as the International Maritime Organization's (IMO) sulfur cap. Furthermore, exploring blockchain-based mechanisms for incentivizing sustainable practices, such as emissions trading schemes, warrants further investigation to promote environmental stewardship within the maritime industry [41], [42], [43].

3. Discussions

The outcomes of this research align with and enhance the current corpus of knowledge concerning blockchain applications in the maritime domain. Upon juxtaposition with earlier studies, our findings not only confirm established patterns but also introduce fresh perspectives, highlighting the dynamic evolution of academic dialogue in this sphere.

Firstly, the observation of a significant increase in scholarly publications on blockchain applications in the maritime industry aligns with the broader trend of growing interest in blockchain technology across various sectors [43], [45]. Previous studies have also documented a rising trajectory in research output concerning blockchain in maritime contexts, albeit with variations in the scope and focus of investigations. This study extends this understanding by providing a nuanced analysis of publication trends, highlighting specific topics, such as supply chain management and logistics, that have garnered substantial scholarly attention in recent years [36]. Furthermore, the identification of key journals and countries contributing to blockchain research in the maritime sector corroborates existing literature on publication patterns and geographical distribution [36]. Similarly, countries like China, the United Kingdom, and the United States maintain their prominence as leading contributors to maritime blockchain research, reflecting a global interest and collaboration in advancing knowledge in this field [44].

However, this study also unveils novel insights and nuances that enrich the existing literature. For instance, a detailed examination of publication trends across journals reveals the interdisciplinary nature of blockchain research within the maritime domain, with journals like the Journal of Marine Science and Engineering and Sustainability accommodating studies that explore environmental, economic, and policy implications of blockchain applications. Moreover, the analysis of future research directions underscores emerging areas of inquiry, such as the integration of blockchain with IoT devices and the exploration of smart contracts in maritime activities, which have received limited attention in prior literature.

4. Conclusions

The findings of this study shed light on the evolving landscape of blockchain applications within the maritime industry, providing valuable insights into the current state and trajectory of research in this domain. Through a meticulous bibliometric analysis, this research has unveiled a discernible upward trend in scholarly publications pertaining to blockchain technology in maritime contexts. Such a trend underscores a burgeoning interest and recognition of the potential benefits that blockchain can offer to maritime operations. The increasing scholarly output reflects a growing investment in exploring the application of blockchain across various facets of the maritime sector, including supply chain management, logistics, security, and transparency. Consequently, the findings contribute to a deeper understanding of the challenges, opportunities, and implications associated with the integration of blockchain solutions in maritime practices.

Despite the thorough nature of this study, there are several limitations that merit discussion. Primarily, the analysis was restricted to publications cataloged in the Web of Science database, potentially constraining the breadth of the findings. Furthermore, the reliance on English language in the review process may have excluded research conducted in other languages. Future research endeavors should consider incorporating a wider array of databases and languages to ensure a more exhaustive examination of the scholarly landscape. Additionally, the omission of publications from the year 2024 may have overlooked recent advancements in the field. Hence, researchers should approach the interpretation of the findings with caution, acknowledging the temporal constraints inherent in bibliometric analyses. Moreover, while the PRISMA framework facilitated systematic data collection, the subjective nature of eligibility assessment during the screening phase could introduce bias. Subsequent studies could explore alternative methodologies to bolster the rigor and objectivity of the review process.

Building upon the insights gleaned from this study, several avenues emerge for future research endeavors in the realm of blockchain applications within the maritime sector.

Firstly, there is a pressing need to delve deeper into the operational challenges and scalability issues associated with implementing blockchain technology in maritime transactions and data management tasks. Additionally, research efforts should prioritize investigating the security, privacy, and regulatory considerations inherent in blockchain adoption to foster trust and regulatory compliance within the industry. Moreover, exploring the synergies between blockchain and emerging technologies such as IoT devices presents promising avenues for enhancing supply chain visibility and operational efficiency. Future studies could also focus on the development of smart contract frameworks tailored to maritime transactions and the integration of blockchain with complementary technologies like AI to bolster safety, security, and environmental sustainability in maritime operations.

In summary, this study offers a comprehensive analysis of the scholarly landscape surrounding blockchain applications within the maritime industry, highlighting notable trends, publication patterns, and future research directions. By synthesizing bibliometric data and systematic content analysis, the research provides valuable insights for academics, policymakers, and industry stakeholders seeking to navigate the evolving intersection of blockchain technology and maritime operations. Despite the identified limitations, the study contributes to the existing body of knowledge by illuminating key research gaps and opportunities for advancing the theoretical understanding and practical applications of blockchain in the maritime domain.

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A Suggested Model to Evaluate Cyber Resilience Level for Vessels

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Abstract

Increasing network connections and data flows on information and operational technologies cause the cyber-attack surface to expand, which may affect institutions in the maritime sector. This can leave organizations vulnerable to potential compromise. Implementing effective cyber security countermeasures is of critical importance for the maritime industry, as threats that may arise by exploiting security vulnerabilities can pose risks to disrupt important operations such as maritime traffic and management, maritime safety and security, port security, logistics and maritime trade.

The fact that ships communicate via satellite mostly, the communication infrastructure don't have internet connection, and the use of closed network systems cause lack of necessary investment in cyber security. Institutions should be aware of their existing cybersecurity levels with the current security measures. To minimize the effects of a cybersecurity attack on institutions, they should increase their cyber resilience.

In this paper, UR E26 "Cyber Resilience of Ships", UR E27, "Cyber Resilience of On-Board Systems and Equipment" published by IACS, and OT frameworks are reviewed, and a Cyber Resilience Level Determination Methodology (CRLDM) is proposed to guide institutions in the maritime sector to determine and prepare a plan to develop their cyber resilience levels.

Keywords: *Maritime, Cyber Security, Cyber Attacks, Cyber Resilience*

1. Introduction

The growing integration of digitalized systems into maritime operations has brought unprecedented efficiency and connectivity. This integration has moreover exposed the maritime industry to a bunch of cyber threats, extending from information breaches to operational hitch. In this advanced age, where maritime systems are getting to be more interconnected through modern onboard and shore-based systems, maritime cyber resilience has gotten to be a paramount concern for the industry.

Maritime cyber threats cause one-of-a-kind challenges due to the distant and energetic nature of maritime operations, coupled with the various stakeholders included shipowners, operators, harbor specialists, and regularity bodies. Cyber-attacks within the maritime cyber space can have far-reaching results, affecting not as it were the operational productivity of vessels but moreover posturing noteworthy threats to maritime security, environmental security, and indeed national security like critical infrastructure attacks.

To effectively mitigate the risks and safeguard maritime assets against cyber threats, it is imperative for the industry to adopt a proactive approach towards cybersecurity. The nerve center of this approach is cyber maturity level determination process, which entails the ability of organizations to monitor, manage, and continuously improve their cybersecurity posture. While significant efforts have been made to enhance cybersecurity awareness and resilience within the maritime sector, there remains a critical need for well-organized methodologies to assess the cyber maturity levels of vessels comprehensively.

This study aims to address this gap by proposing a framework for evaluating the cyber maturity levels of ships. By leveraging existing cybersecurity frameworks and best practices, combined with requirements from IACS E26, this study seeks to develop a holistic assessment methodology tailored to the unique operational environment of ships. Through the application of this framework, shipowners and operators will be able to gain valuable insights into their current cybersecurity posture, compliance statements, and prioritize investments in terms of cyber security.

In essence, this research endeavors to contribute to the ongoing efforts towards enhancing maritime cyber resilience by providing a systematic approach to assess and improve the cyber maturity levels of vessels. By fostering a culture of cybersecurity awareness and readiness within the maritime industry, we can collectively mitigate the evolving cyber threats and ensure the safety, security, and sustainability of maritime operations in the digital age.

2. Literature review

Cybersecurity in the maritime industry has become a critical issue in recent years. The increasing use of digital technologies in vessel operations and the growing interconnectedness of maritime systems have made the industry more vulnerable to cyberattacks. These attacks can have significant consequences, including financial losses, environmental damage, and even loss of life.

Maritime systems widely consist of IT and OT systems at the same time. Hence, previous studies on IT and OT security are useful for maritime systems. However, having domain or mission specific systems, operational variations in the known systems and staff who are not yet aware of cyber security can change the game in cyber domain. That is why the interaction between cyber security and maritime is a recently rising research study for both maritime and cyber security researchers.

A few studies have been conducted on maritime cybersecurity in the literature. These studies have identified a range of threats and vulnerabilities that the industry faces [1], [2]. Some of the most common threats include:

Cyberattacks on shipboard systems: These attacks can target a variety of systems, including navigation, propulsion, and communication systems. They can disrupt operations, cause damage, and even lead to accidents [3], [4].

Data breaches: These breaches can expose sensitive information, such as crew personal data, cargo manifests, and financial records [5]. This information can be used for criminal purposes, such as identity theft and fraud.

Malware infections: Malware can infect shipboard systems and cause a variety of problems, including data loss, system outages, and even denial-of-service attacks. Due to the lack of research on maritime specific software and systems in terms of reverse engineering or vulnerability assessment, malware infection could be much more effective on maritime domain [6], [7].

Social engineering attacks: These attacks are designed to trick users into revealing sensitive information or taking actions that compromise security. They can be used to gain access to shipboard systems or to steal data. Although maritime systems are usually based on closed-loop networks, Vessel Tracking Systems or GNSS and GPS infrastructures are highly interactive within public networks. Hence, social engineering attacks can be harmful for such critical systems in maritime domain [8], [9].

In addition to these threats, there are a number of vulnerabilities that make the maritime industry susceptible to cyberattacks. These vulnerabilities include:

The use of legacy systems: Many ships still use legacy systems that are not designed with security in mind [10]. These systems can be vulnerable to known vulnerabilities and may be difficult to patch or update.

The lack of cybersecurity awareness: Many seafarers are not aware of the cyber threats that they face. This lack of awareness can make them more susceptible to social engineering attacks and other forms of cybercrime [11].

The lack of cybersecurity training: Many seafarers have not received training in cybersecurity. This lack of training can make it difficult for them to identify and respond to cyber threats [12].

The lack of international regulations: There are currently just rising international regulations that specifically address maritime cybersecurity. This lack of regulation makes it difficult to enforce cybersecurity standards and to hold organizations accountable for cyberattacks [13].

3. Cyber resilience level determination method

The increasing connectivity of IT and OT systems to each other, land and the internet allows vessels to become technologically more advanced. However, it also leads to an increase in cyber-attack surfaces. A cyber-attack that can be carried out by taking advantage of increasing attack surfaces can spread rapidly among vessel systems and cause disruptions in maritime operations. Such attacks can endanger the safety and security of the vessel, its crew, and the environment. To minimize the impact of potential cyber-attacks, it is necessary to enhance the cyber resilience of the vessels.

The ISM Code, supported by IMO's resolution MSC.428(98), requires the assessment of cybersecurity risks and the implementation of relevant measures within the ship's safety management system. Thus, cyber security has become a legally binding issue for the maritime sector.

The study proposes a Cyber Resilience Level Determination Methodology (CRLDM) for assessing the current security measures of vessels, identifying deficiencies and weaknesses within the cybersecurity framework, and continuously improving the structure.

The assessment conducted using the CRLDM will provide the following benefits:

- Ensuring the correct allocation of resources for required cybersecurity solutions,
- Conducting risk assessment studies,
- Measuring the effectiveness if a prior study has been conducted,
- Securing the configuration of bridge systems such as OT systems, ECDIS, AIS, VDR,
- Ensuring compliance with information security regulations applied in the maritime sector (such as IACS UR E26, E27, etc.) [14].

The CRLDM consists of the following 4 stages:

1. Preparation
2. Application
3. Reporting and Improvement
4. Verification

3.1 Stage 1 - Preparation

The main purpose of the "Preparation" stage is to create a checklist specific to the organization or vessel. Considering that the CRLDM is based on a risk-based approach, it is essential to identify the assets, processes involving these assets, and the risks affecting them for the vessel for which resilience level will be determined. In this phase, during the checklist creation part, more focus can be directed towards the identified high-risk areas.

Another important point of the preparation stage is identifying the regulations that organizations are subject to. In the maritime sector, IMO's Resolution MSC.428 (98) requires cyber security risk assessment to be included in ISM documents. Therefore, controls related to cybersecurity risk assessments should be added to the checklist. However, including only the aspects specified within regulations and laws in the Cyber Resilience Level Control List will not be sufficient to determine the maturity level.

In general, regulations and laws establish the baseline for the security levels of information security structures within organizations. To define effective security measures above this baseline, best-known frameworks/controls such as NIST SP 800-53, CIS V8, COBIT, ITIL, Presidency of The Republic of Türkiye Digital Transformation Office Information and Communication Security Guide, and ISACA Audit Programs are utilized. These frameworks assist in utilizing appropriate cyber security technologies, enhancing stuff capabilities, and ensuring data security. At the same time, guide documents issued by organizations specific to the maritime sector such as IACS, ICS, IUMI, BIMCO, IAPH, OCIMF, INTERTANKO, INTERCARGO, InterManager, WSC, and SYBAss are also considered.

In this phase, a calculation method is proposed for the cyber resilience level to be determined using the checklist. This calculation method is determined in accordance with the organizational structure and strategy of the institution/organization. The calculation method is defined specific to the institutions needs in this study. For the further implementations or researches, it will be useful to utilize the best-known practices in the creation of the calculation method.

Each control in the checklist may have different coefficients. For the implementation status of these controls to produce more accurate results in the maturity level determination process, the coefficients of each control on the processes are determined and included in the cyber maturity level calculation method.

Following the calculation method, a maturity scale is created and mapped to the total achievable point for rating cyber security resilience levels. Once the scope is defined by addressing the identified high-risk areas and processes specific to the organization, the implementation phase begins for conducting the cyber resilience level determination exercise.

Table 1. Cyber resilience level scale

Cyber Resilience Level	Cyber Resilience Level Scale	Definition
0	0.00 - 0.50	Deficient
1	0.51 - 1.50	Initial
2	1.51 - 2.50	Managed
3	2.51 - 3.50	Defined
4	3.51 - 4.50	Quantitatively Managed
5	4.51- 5.00	Optimizing

3.2. Stage 2- Application

In "Application phase", our research team visited an actively running ship to implement the assessment created in the previous phase. In the case study conducted onboard a ship, firstly the ship assets were grouped in the following categories:

- IT Network and Systems
- OT Network and Systems
- Portable Devices and Environments
- IoT Devices
- Applications
- Stuff
- Physical Locations

Next, the processes that may affect each asset group have been identified as given in ***Table 2***.

A ship-specific checklist has been prepared using the best-known frameworks for processes affecting assets, as well as the requirements of IACS UR E26 "Cyber Resilience of Ships". The number of controls for each process in the prepared checklist is as given in ***Table 3***. The control numbers for processes have been determined by removing controls that are not applicable to the ship from the control pool in the CRLDM.

Table 2. Asset Categories and Affected Processes

Asset Category	Affected Process
IT Network and Systems OT Network and Systems	Asset and Risk Management
	Access Management
	Data Security Management
	Communication Security Management
	Network and System Security Management
	Cryptography
	Malware Protection Management
	Technical Vulnerability and Security Controls Management
	Logging and Incident Management
	Business Continuity
Portable Devices and Environments	Asset and Risk Management
	Data Security Management
	Portable Device and Environment Management
IoT Devices	Security of Internet of Things (IoT) Devices
Applications	Asset and Risk Management
	Application and Software Development Security Management
Physical Locations	Asset and Risk Management
	Physical Security Management
	Infrastructure Security
Stuff	Asset and Risk Management
	Information Security Organizational Structure and Governance
	Human Resources Security

The prepared checklist was analyzed through stuff interviews, security audits, and field inspections. The implementation status of the controls related to the conducted analyses was determined. Using the calculation method determined during the preparation stage, the scoring process for the controls was carried out.

When the scoring of the controls of each process was completed, the maturity levels of the processes were calculated. The maturity level of the ship was determined as shown in Figure 1 by calculating the maturity scores of the processes belonging to the asset categories and the maturity levels of the asset categories. As seen in Figure 1, the overall resilience level has not reached the targeted level. There are missing controls that need to be improved in each process.

Matching the calculated process resilience levels with the resilience scale will determine for which processes improvement activities should be carried out. The actions and action plans to be taken for the relevant processes that need to be improved are determined at this stage.

Table 3. Control Numbers

Asset Category	Affected Process	Number of Controls
IT Network and Systems OT Network and Systems	Asset and Risk Management	21
	Access Management	IT-30, OT-18
	Data Security Management	IT-23, OT-20
	Communication Security Management	IT-6, OT-2
	Network and System Security Management	IT-21, OT-15
	Cryptography	1
	Malware Protection Management	IT- 6, OT- 3
	Technical Vulnerability and Security Controls Management	IT-22, OT-18
	Logging and Incident Management	IT-21, OT-16
	Business Continuity	28
Portable Devices and Environments	Asset and Risk Management	21
	Data Security Management	3
	Portable Device and Environment Management	8
IoT Devices	Security of Internet of Things (IoT) Devices	Not Applicable
Applications	Asset and Risk Management	21
	Application and Software Development Security Management	8
Physical Locations	Asset and Risk Management	17
	Physical Security Management	18
	Infrastructure Security	5
Stuff	Asset and Risk Management	17
	Information Security Organizational Structure and Governance	11
	Human Resources Security	20

When the ship processes are examined according to the requirements of IACS UR E26 and the referenced IACS UR E27 requirements, the ship's compliance maturity with IACS UR E26 is as shown in Figure 2. It is seen that there are deficiencies in compliance with IACS UR E26 requirements. Compliance with the requirements of IACS UR E26 will be mandatory for ships built on or after July 1, 2024. Ships built before this date can also increase their security levels by complying with the requirements of IACS UR E26.

As seen in ***Table 3***, IoT Devices heading is not applicable for this implementation of the proposed methodology. Because the ship our research team worked on was not equipped with IoT devices. In a familiar study, "IoT Devices" heading can be considered in detail due to the complex and relatively novel structure of the topic.

The methodology can be cumulatively improved by adding new controls from recently published standards, or sector, government, and technology specific control bullets from current standards and regulations.

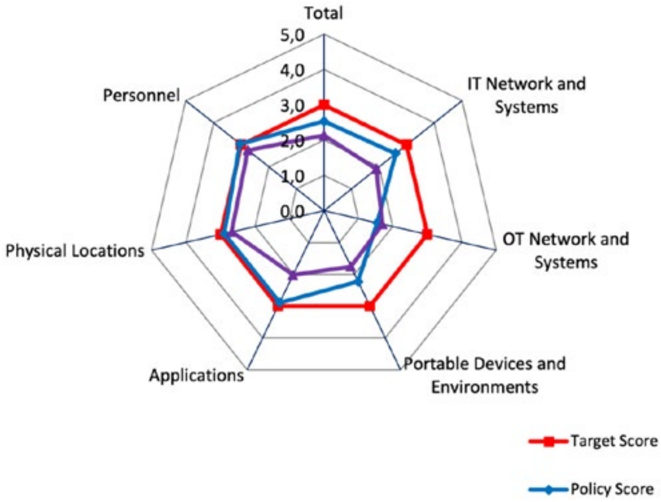

Figure 1. Cyber Resilience Level

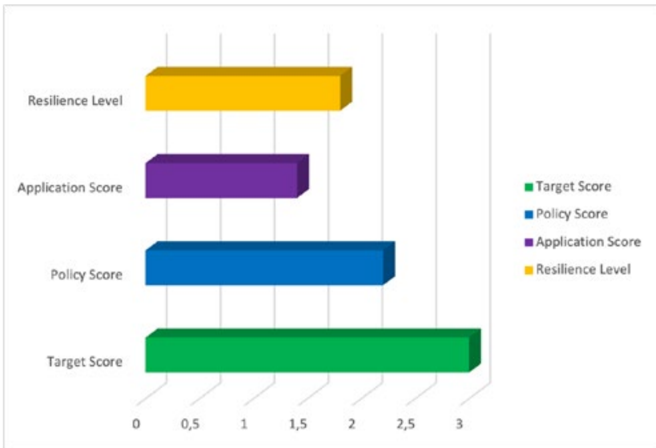

Figure 2. IACS UR E26 Compliance Maturity Level

3.3. Stage 3 - Reporting and Improvement

As a result of the application of the CRLDM, an explanatory report is prepared indicating the status of the implementation of the controls. This report includes at least the following information about the findings identified during the examination of the control items.

- Control item and information on the related regulation/law/standard,
- Information on the process/asset where the findings were identified,
- Recommended corrective actions to address the findings.

Thus, a report is created to raise awareness within the organization about the existing security measures. It is beneficial to list the controls implemented and/or not implemented by the organization under separate headings in the report to facilitate improvement efforts. Additionally, findings should be supported with objective evidence (such as screenshots, documents, emails, etc.). Considering that the report will contain confidential information about the organization, it is recommended to assign an appropriate information classification level to the report and share it encrypted only with relevant individuals during distribution.

Informing the senior management about the findings and corrective actions mentioned in the report can facilitate the provision of necessary resources to mitigate existing risks.

In the maritime sector, considering that maritime safety and security can directly impact human lives, a realistic plan should be developed for the actions to be taken. When creating this plan, the maturity levels of the processes affecting human life should be considered, prioritized, and ensured that actions are carried out as planned.

3.4. Stage 4- Verification

Following the completion and evaluation of the planned action activities, the organization needs to observe changes in the ship's resilience level. To observe this change, it is necessary to recalculate the cyber resilience scores using the initially defined calculation method. The differences in the organization's cyber resilience levels will reveal the effectiveness of the actions taken and highlight the control points that have not been improved.

4. Conclusion

The maritime sector is undergoing a rapid digital transformation, from increasing network connectivity of ships to autonomous vessels. However, the focus should not solely be on digital transformation. Along with digitalization, it is extremely important to take cyber security measures. Every year the number of attacks increases and the types of attacks become more complex.

The maritime sector is one of the industries where cyber-attacks can potentially impact human lives. Therefore, it is crucial to enhance resilience levels against possible cyber-attacks. One of the most important steps in increasing resilience is the ability to measure current cybersecurity levels.

The CRLDM is one of the methods that can measure, increase, and verify the level of security. By applying the CRLDM, it will be ensured that the existing cyber security measures will be considered as a whole, thus creating a broader perspective for root cause analysis of the identified deficiencies. With this perspective, conducting root cause analysis will enable the creation of a more effective roadmap for improvement works. Establishing an effective roadmap will ensure the identification, prioritization, and proper allocation of resources for areas requiring improvement. As a result of these improvement works, the organization's/institution's or the ship's cyber resilience level will be increased.

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Cyber Security Hygiene Assessment in Maritime Industry by Applying Multi-Criteria Decision-Making Process

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Abstract

Cyber hygiene is a modern concept based on the notion that businesses and stakeholders can enhance their cybersecurity resilience and overall strength by adopting and adhering to effective security practices. Cyber hygiene has emerged as a critical concern for ships, with the increasing reliance on interconnected systems on information and operational technologies. To enhance the robustness of ships against many common, foreseeable, as well as rare, unforeseen, and unpredictable hazards, and ensure the safety of all entities involved, it is important to understand and implement the most critical cyber strategies on the related systems. By prioritizing these strategies and integrating them into the operational framework of ships and maritime organizations, it is possible to enhance the cyber resilience and safety of maritime operations against a wide range of hazards, both expected and unexpected. In this context, this study proposes an effective approach to assess ship cyber hygiene factors, developed within the triad of human, process, and technical dimensions, utilizing the Bayesian Best and Worst Method (BBWM). In this way, the best factors for adopting a cyber security tool in terms of cyber hygiene functions on the ships are evaluated. The findings of this research contribute to the advancement of ship cybersecurity practices, offering insights into key areas of focus for enhancing cyber resilience and mitigating potential threats.

Keywords: *Maritime Cyber Hygiene, Cyber Security at Sea, Multi-Criteria Decision Making, Smart Marine Vehicles*

1. Introduction

The European Union Agency for Cybersecurity (ENISA) asserts that maintaining good cyber hygiene is crucial for safeguarding enterprises within the European Union (EU) [1]. Cyber hygiene safeguards infrastructure and customer data by increasing the methods firms use to protect them from cyber threats. Once effectively incorporated into an organization, it entails regular daily practices, positive behaviors, and periodic assessments to ensure the organization's cyber well-being is at its best. Cyber hygiene refers to the implementation of basic and regular actions to reduce the vulnerabilities and potential harm caused by cyber threats [2].

Cyber hygiene is critical for all sectors to protect against cyber threats, safeguard sensitive data, ensure operational continuity, and maintain public trust. However, finance [3], healthcare [4], critical infrastructure [5], defense and military [6], e-commerce [7], and manufacturing [8] sectors are more sensitive in terms of cyber hygiene. Each sector may face unique challenges and risks, but prioritizing cyber hygiene is essential for resilience and security in today's digital world.

Good cyber hygiene for ships, as one of the most critical infrastructure, is essential for protecting against cyber threats, ensuring safety, preserving data integrity, complying with regulations, maintaining business continuity, and safeguarding the global supply chain [9]. Ships rely heavily on interconnected systems for navigation, communication, and operation [10]. Ensuring good cyber hygiene helps protect these systems from cyber threats such as hacking, malware, and unauthorized access. A breach in ship systems could lead to dire consequences including loss of control, navigation errors, or even piracy. Cybersecurity breaches can compromise the safety of the ship and its crew. For example, a hacker gaining access to navigation systems could alter course leading to collisions or groundings. Ensuring cyber hygiene helps mitigate these risks and ensures the safety of the crew, passengers, and cargo. Ships often handle sensitive information including cargo manifests, crew details, and operational data. Maintaining good cyber hygiene helps protect this data from theft or unauthorized access, safeguarding the ship's operations and business interests [11]. Many maritime regulations now include cybersecurity requirements for ships [12, 13, 14]. Compliance with these regulations not only ensures legal adherence but also helps in maintaining the reputation and trust of customers and stakeholders.

Besides, the shipping industry is slower to adapt to cyber risk than some other areas of commerce. This may in part be due to a perception that cyber risk principally concerned issues of data management and data loss. It may also have been a result of the perception that ships trading at sea are relatively isolated and therefore immune from the broader world of interconnected cyber networks [15]. The reality of cybercrime and the threat of maritime transport confirm the need to develop a special international treaty and legal mechanisms to prevent crimes and cyber-attacks on maritime transport and ensure the cybersecurity of maritime transport [16]. Secondly, the development of an effective cyber safety culture will reduce the risk that the human element poses to safety and allow employees to "become robust human firewalls" against cyber incidents, as stated by [17].

In this context, this study aims to propose an effective approach to assess ship cyber hygiene factors, which are developed within the triad of human, process, and technical dimensions, via the Bayesian Best and Worst Method (BBWM). In this way, the best factors for adopting a cyber security tool in terms of cyber hygiene functions on the ships are evaluated. By applying the BBWM approach, this study aims to enhance decision-making processes related to ship cybersecurity by prioritizing areas for improvement and resource allocation. The incorporation of human, process, and technical dimensions ensures a holistic evaluation, taking into account the interdependencies and interactions among various factors within the ship cyber ecosystem. The findings of this research contribute to the advancement of ship cybersecurity practices, offering insights into key areas of focus for enhancing cyber resilience and mitigating potential threats. Furthermore, the BBWM framework provides a flexible and adaptive methodology that can be tailored to specific organizational contexts, facilitating continuous improvement in maritime cyber hygiene practices.

2. Literature Review

In this study, cyber hygiene design for ships, as well as smart sea vehicles are focused on. In the literature, there are limited studies, that directly consider ship cyber hygiene. One of them is about presenting cyber hygiene factors for shipboard RADAR by performing a cyber risk assessment on case-based RADAR cyber scenarios [18]. In another study, it is aimed to investigate cybersecurity in critical infrastructure, focusing on human aspects and cyber hygiene in Cyber-Physical Systems (CPS) and Industrial Control Systems (ICS) [19]. Through a qualitative literature review, the study aimed to enhance understanding of operational technology in critical infrastructure and address cyberattack prevention and mitigation. The findings emphasized the importance of human factors and cyber hygiene in risk reduction, offering valuable insights into safeguarding CPSs. In the framework of "Cyber Hygiene Issues in the Naval Security Environment", the authors focused on analyzing and illustrating basic personal, institutional, and software issues related to cyber hygiene in the context of vulnerability to cyber-attacks, cyber threats, software tools for ensuring cyber hygiene, institutional information security controls, and malware infections. Their aim was to provide insights into the importance of cyber hygiene practices in maintaining a secure naval security environment [20]. Mednikarov [21] examined the influence of maritime safety culture and cyber-security aspects on ship safety. It is quantified by assessing the resilience capabilities, decision-making performance, and collaborative performance of maritime professionals.

In the literature, the studies on the ship cyber security focused on more cyber security risk assessment and the importance of cyber security onboard ships. For instance, Svilicic et al.[22] focused on conducting a comprehensive cyber risk assessment of a ship using an experimental process that included assessment preparation activities, assessment conduct, and results communication. They aimed to evaluate the cyber security level of Kobe University's training ship named as "Fukae-maru", by incorporating computational vulnerability scanning of the ship's ECDIS (The Electronic Chart Display and Information System is a specialized digital navigation computer) system and conducting a quantitative cyber risk analysis. The findings of the assessment process provided insights into the cyber risks present on the ship and offered guidelines for mitigating these risks and improving the cyber security level of ship critical systems and assets. Park et al. [23] performed a comprehensive evaluation of the potential risks associated with cybersecurity in the maritime industry. The identification and analysis of cyber threats and their corresponding categories were conducted and a hybrid approach integrating Failure Mode and Effects Analysis (FMEA) with Reliability Block Diagram (RBN) was utilized to analyze the criticality of cyber threats and their categories, as well as to evaluate the dangers to maritime cybersecurity. Longo et al. [24] introduced MaCySTe, an open-source initiative that offered a platform for replicating the network architecture and essential elements of the onboard cyber-physical systems by the creation and evaluation of countermeasures specifically designed for shipboard infrastructures for mitigating cyber threats. Rajaram et al. [25] developed guidelines for cyber risk management in shipboard Operational Technology (OT) systems, aiming to address the growing cyber threat landscape and the potential vulnerabilities in maritime operations. Their study emphasized the importance of implementing cybersecurity measures to protect critical OT systems on ships and ensure the safety of vessels and crew members. Progoulakis et al. [26] conducted a literature review on cyber physical security for maritime assets, focusing on industry and governmental policies. They highlighted the importance of risk assessment methods like API STD 780 SRA and Bow Tie Analysis for evaluating cyber security risks. Key findings stressed the need for adequate funding, stakeholder involvement, and strong management processes to effectively manage cyber security risks in maritime operations.

The main contributions of the published studies are to identify a list of maritime cyber threats, to propose various model or approaches for maritime cybersecurity risk analysis, and to assess the criticality of the proposed cyber threats. Through the results of these studies, maritime managers are aware of which cyber threats and categories are relatively security critical and thus where they should focus their efforts especially given restricted budgets. In addition to the publishes literature, the contribution of this study is to understand and prioritize the effective strategies for adopting and improving cyber hygiene onboard ships. Additionally, the demonstration of an effective Multi Criteria Decision Making (MCDM) technique (BBWM) is performed for making the best decision on the ship cyber hygiene.

3. Methodology

The aim of this study is to evaluate the importance weights of the criteria that ensure the cyber hygiene of ship systems, using the Bayesian Best-Worst method, and to propose solutions in this direction.

3.1. Bayesian Best-Worst Method

The Bayesian Best-Worst Method (BBWM) is a type of preference analysis method used in decision-making processes. It allows participants to identify the best and worst options among a set of alternatives. BBWM combines the traditional Best-Worst Method (BWM) with Bayesian approaches. This method has been applied in various sectors such as market research, consumer preferences, product development, marketing strategies, and business decisions [27].

BWM is a multi-criteria decision-making method which finds the optimal weights of a set of criteria based on the preferences of only one decision-maker (DM) (or evaluator). Bayesian BWM is introduced to find the aggregated final weights of criteria for a group of DMs at once. To this end, the BWM framework is meaningfully viewed from a probabilistic angle, and a Bayesian hierarchical model is tailored to compute the weights in the presence of a group of DMs [27]. In this study, the BBWM framework enables the integration of subjective judgments from experts while considering both positive (best) and negative (worst) aspects of each factor. Through this method, the inherent uncertainties and complexities associated with ship cyber hygiene can be effectively addressed, providing a more comprehensive and nuanced understanding of the assessment process.

Statistical results show that BWM performs significantly better than AHP with respect to the consistency ratio, and the other evaluation criteria: minimum violation, total deviation, and conformity [28]. The BBWM method introduces a novel approach to establishing the ranking of index credibility, hence enhancing the dependability of the indicators' weights for group decision-making [29].

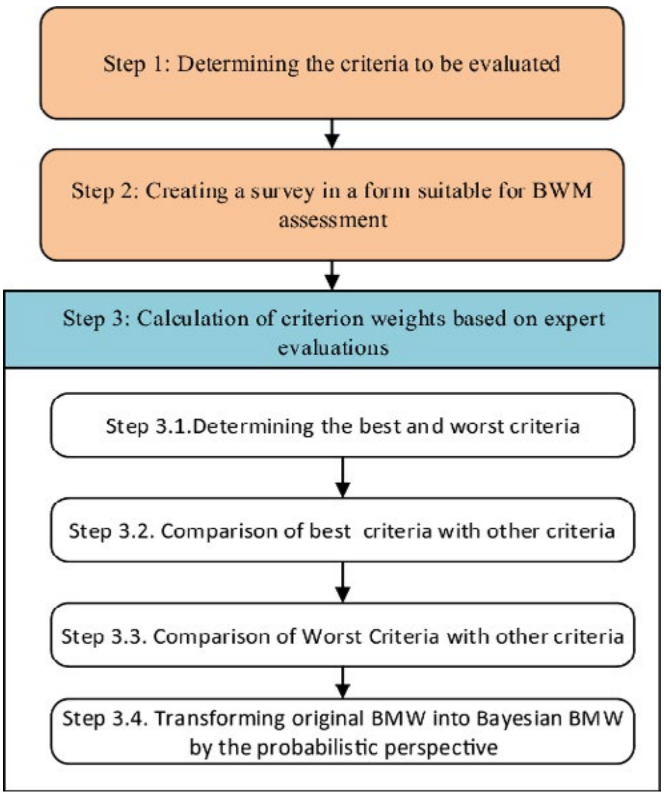

Figure 1. Implementation Steps in BMWM [30]

BBWM consists of three steps. In the first step, the criteria were determined. In the second step, a survey was prepared in accordance with the original BWM evaluation. In the third step, the problem was made applicable to BBWM with a probabilistic perspective after evaluating according to the original BWM proposed by [20]. The implementation steps are presented in the following with an acceptable level of detail and presented in Fig. 1 [30].

3.2. Analysis

3.2.1. Problem Identification

This study aims to address the following issues regarding cybersecurity onboard ships:

(i) Creating awareness about the security, safety, and commercial risks arising from the lack of cybersecurity measures.

(ii) Safeguarding the information and operational technology infrastructure and connected equipment onboard ships.

(iii) Ensuring that the cyber hygiene factors recommended by the guidelines can be provided most effectively by cyber security tools on ships.

(iv) Recognizing the prioritization of cyber hygiene factors onboard ships.

Ship systems carry cyber risks due to the factors that mentioned in the introduction section, which can lead to severe consequences such as loss of life, injuries, operational disruptions of vessels, and compromise of system integrity. Hence, ensuring cybersecurity hygiene in ships is crucial. While various standards and guidelines exist in the literature to guide cybersecurity practices in maritime settings, the issue of prioritizing control measures within a limited budget for shipping companies remains unresolved. Therefore, this study defines the problem to be addressed as determining which cybersecurity control measures should be prioritized by shipping companies with limited resources to enhance its cybersecurity effectively.

3.2.2. Data Collection

In this study, expert opinions are utilized due to the limited availability of comprehensive and reliable datasets on cybersecurity issues within the maritime industry. The expertise and experience of professionals in the field are deemed essential to ensure the accuracy and validity of the research.

Our panel of experts consists of six individuals specialized in cybersecurity within the maritime domain:

- Academician on Maritime Cyber Security: Conducts academic research on cybersecurity issues specific to the maritime sector, possessing expertise in this area.
- Cyber Security Analyst: A seasoned analyst with

experience in monitoring and analyzing cybersecurity threats within the maritime industry.

- Academician on Maritime Security and Cyber Security: Specializes in both maritime security and cybersecurity, actively contributing to research and knowledge dissemination in these fields.
- Academician on Maritime Security and Cyber Security: Another academic expert specializing in cybersecurity within the maritime context, involved in research and educational activities.
- Computer Science and Pentester on Maritime Cyber Security: A Pentester (Penetration Tester) with a background in computer science, focusing on conducting cybersecurity tests and assessments within the maritime sector.
- Computer Science and Pentester: Another Pentester (Penetration Tester) with expertise in computer science, specializing in cybersecurity testing within the maritime industry.

These experts bring in-depth knowledge and experience in cybersecurity issues relevant to the maritime sector, offering diverse perspectives. Their contributions are integral to ensuring the comprehensiveness, reliability, and applicability of the study's findings. Also, all experts' information is shortlisted in Table 1.

Table 1. Demographic Information of Experts

Experts	Education	Occupation	Experience
EXP 1	PhD	Academician on Maritime Cyber Security	8 years
EXP 2	BsC	Cyber Security Analyst	3 years
EXP 3	PhD	Academician on Maritime Security and Cyber Security	13 years
EXP 4	MsC	Academician on Maritime Security and Cyber Security	2 years
EXP 5	PhD	Computer Science and Pentester on Maritime Cyber Security	4 years
EXP 6	PhD	Computer Science and Pentester	8 years

3.2.3. Criteria Identification

For the best selection of criteria as described on Figure 1 first step, we used DNV (Det Norske Veritas) suggest three categories for cyber security management plan. These are process, people, technology [31]. Then for the step 2, a survey formed for BWM assessment. As determining of sub-criteria, the study of [32] are in referenced to develop the framework of the hierarchy as listed in Table 2.

Table 2. Hierarchical Framework for Ship Cyber Hygiene

Criteria Number	Criteria
C1	**Technical**
C1.1	Security Effectiveness
C1.2	Scalability
C1.3	Integration and Compatibility
C1.4	Network Security
C1.5	Resilience and Redundancy
C1.6	Future Readiness
C1.7	Threat Intelligence
C1.8	Data Protection
C2	**Process**
C2.1	Performance Impact
C2.2	Cost-Effectiveness:
C2.3	Compliance and Regulatory Requirements
C2.4	Manageability and Usability
C2.5	Patch Management
C3	**Human**
C3.1	Vendor and Supply Chain Security
C3.2	Vendor Support and Collaboration
C3.3	Ship Crew's Knowledge
C3.4	Ship Crew's Drill Application
C3.5	Incident Response
C3.6	Port State Inspections for Ship Cyber Security

3.3. Application

In the first phase of the calculation on step 3.1 given in Figure 1, each expert selected the best and worst main criteria listed in Table 2 as Technical, Process and Human. They used the same method for each main criterion for their sub criteria in that criterion. During these decisions, they used the scalability for the amount of how many sub criteria exist in that main criterion. When decision-maker enter the preferences in step 3.2, they compared the best criteria with other criteria as Best to Others with numbering scale given them. And then in step 3.3, they used the same technic vice versa from Others to Worst by selecting the Worst criteria to compare it with other criterions.

3.4. Findings

For step 3.4, BBMW used as the transformation of original BMW into BBMW by the probabilistic perspective. All results after calculations are given in Table 3, Table 4 and Table 5.

Table 3. Technical Criteria Comparison in BBWM

Main Criteria	Weights	Sub Factors	Relative	Global
Technical	0.3948	Security Effectiveness	0.1506	0.0595
		Scalability	0.0603	0.0238
		Integration and Compatibility	0.1191	0.0470
		Network Security	0.1913	0.0755
		Resilience and Redundancy	0.1545	0.0610
		Future Readiness	0.0801	0.0316
		Threat Intelligence	0.0864	0.0341
		Data Protection	0.1577	0.0623

Table 4. Process Criteria Comparison in BBWM

Main Criteria	Weights	Sub Factors	Relative	Global
Process	0.2534	Performance Impact	0.1948	0.0494
		Cost-Effectiveness	0.1243	0.0315
		Compliance and Regulatory Requirements	0.2860	0.0725
		Manageability and Usability	0.1980	0.0502
		Patch Management	0.1969	0.0499

Table 5. Human Criteria Comparison in BBWM

Main Criteria	Weights	Sub Factors	Relative	Global
Human	0.3518	Vendor and Supply Chain Security	0.1737	0.0611
		Vendor Support and Collaboration	0.1493	0.0525
		Ship Crew's Knowledge	0.2263	0.0796
		Ship Crew's Drill Application	0.1545	0.0543
		Incident Response	0.1885	0.0663
		Port State Inspections for Ship Cyber Security	0.1077	0.0379

As result of the main criteria comparison, when we compare the weights of main criteria, Technical is the best selection for this study mentioned on Figure2.

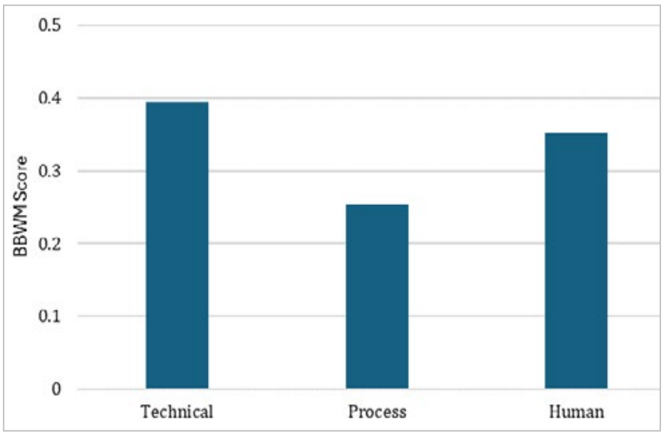

Figure 2. Main Criteria Comparisons in BBWM

All expert preferences are calculated in BBWM as Relative factor scores. In this section, we will compare decision-makers' opinions to the global sub factor scores in Figure 3.

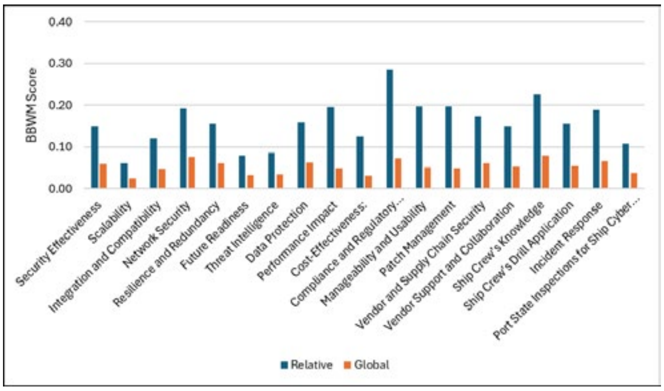

Figure 3. Sub Criteria Comparison Results in BBWM

4. Discussion

In this context, ~~in~~ according to the main criteria comparison, the "Technical" criteria is selected as the best one, when we search for the sub-criteria we can get higher relative scores on "Process". We all can say that, "Process" is directly related to "Technical" characteristic features, and at first sight, they cannot be recognized.

For experienced experts, "Network Security" emerges as the top priority in technical relative comparison, while "Scalability" ranks lowest across all categories. This emphasis on "Network Security" stems from the inherent understanding among decision makers that security serves as the foundational pillar for any project. Consequently, when assessing various criteria for project development, the primary concern revolves around ensuring robust network security measures are in place. This acknowledgment underscores the critical role of security in mitigating risks and safeguarding the integrity of projects within the technological landscape.

In discussing the importance of network security for vessels within the maritime industry, it becomes evident that robust cybersecurity measures are essential for safeguarding onboard systems and networks against evolving cyber threats. Naval Dome's [33] specialized cybersecurity platform offers a tailored solution addressing this critical need. With features including real-time monitoring, secure communication, risk assessment, and threat intelligence capabilities, Naval Dome enables maritime organizations to fortify their vessels against cyber-attacks effectively. By integrating Naval Dome's platform, maritime stakeholders can enhance their resilience to cyber threats while aligning with the unique challenges and requirements of the maritime industry, thus ensuring the safety, integrity, and reliability of maritime operations in an increasingly digitized environment.

For "Process" relative comparison, "Compliance and Regulatory Requirements" is the best one for this category and in all categories also, and "Cost-Effectiveness" is the worst one for decision makers.

The discussion highlights the significance of optimizing processes onboard vessels for ensuring operational efficiency and regulatory compliance in the maritime industry. Wärtsilä's Fleet Operations Solution (FOS) [34] emerges as a notable contributor to this endeavor. While not exclusively focused on process-related challenges, FOS offers a suite of services and functionalities that streamline compliance management, risk assessment, incident response, crew training support, and system integration. Through automated compliance checks, risk assessment tools, incident management features, and integration capabilities, FOS enhances operational efficiency and safety onboard vessels. While acknowledging its broader focus, this discussion underscores FOS's role in optimizing processes and promoting regulatory adherence in maritime operations.

In the realm of human relative comparison, "Ship Crew's Knowledge" emerges as the most valued aspect, while "Port State Inspections for Ship Cyber Security" ranks as the least favorable among experienced experts. The emphasis on "Ship Crew's Knowledge" reflects the understanding that well-informed and trained crew members play a pivotal role in maintaining cybersecurity onboard vessels. Their awareness and adherence to cybersecurity protocols are crucial for mitigating risks and responding effectively to potential threats. Conversely, the unfavorable ranking of "Port State Inspections for Ship Cyber Security" suggests skepticism among experts regarding the efficacy or thoroughness of such inspections in adequately addressing cybersecurity concerns. This perspective underscores the need for more robust and comprehensive approaches to ensuring cybersecurity in maritime operations.

Maritime cybersecurity training platforms, such as CyberOwl's CyberWISER Essential [35], provide comprehensive training modules tailored specifically for ship crew members. These platforms offer interactive learning experiences, covering topics such as cybersecurity best practices, threat detection, incident response procedures, and regulatory compliance requirements. By engaging crew members in hands-on training sessions and simulations, these platforms effectively equip them with the knowledge and skills necessary to identify and address cybersecurity threats onboard.

In the area of process relative comparison, "Compliance and Regulatory Requirements" stands out as the top priority, while "Cost Effectiveness" ranks lowest of all categories for experienced professionals. The emphasis on compliance and regulatory requirements underlines the paramount importance of adhering to established standards and guidelines within the maritime industry. Compliance not only ensures that legal and regulatory obligations are met, but also serves as a fundamental safeguard against potential cybersecurity risks. Conversely, the relegation of cost-effectiveness to the lowest rank reflects the understanding among experts that prioritizing cost savings over cybersecurity measures can lead to significant vulnerabilities and potential consequences. This perspective underscores the recognition that investing in robust cybersecurity protocols is essential to securing maritime operations and effectively minimizing risk.

5. Conclusion

In this study, the Bayesian Best-Worst Method (BBWM) is employed to evaluate the importance of the criteria ensuring the cyber hygiene of vessel systems. The BBWM offers a robust framework for decision-making by allowing experts to systematically compare and prioritize criteria based on their perceived importance. By leveraging BBWM, this study aims to provide insights into the relative importance of different criteria in enhancing cyber hygiene within the maritime industry. Through the application of BBWM, the study seeks to offer valuable recommendations and solutions for maritime organizations to effectively manage cybersecurity risks and improve their cyber hygiene practices.

The critical importance of cybersecurity within the maritime industry, as evidenced by the prioritization of Network Security as the top priority in technical relative comparison by experienced experts. This emphasis reflects a shared understanding among decision makers that security serves as the foundational pillar for any project, highlighting the necessity of robust network security measures to mitigate risks and safeguard project integrity. Additionally, the recognition of Compliance and Regulatory Requirements as the top priority in the process relative comparison further emphasizes the paramount importance of adhering to established standards and guidelines within the maritime industry. Conversely, the relegation of Scalability and Cost-Effectiveness to the lowest ranks underscores the potential risks associated with overlooking these factors in favor of security and compliance. Furthermore, the emphasis on Ship Crew's Knowledge in human relative comparison highlights the indispensable role of well-informed and trained crew members in maintaining cybersecurity onboard vessels, while the skepticism towards Port State Inspections for Ship Cyber Security underscores the need for more comprehensive approaches to ensuring cybersecurity in maritime operations. Overall, this conclusion underscores the necessity for maritime organizations to prioritize cybersecurity measures and invest in robust cyber hygiene practices to effectively mitigate risks and ensure the resilience of maritime operations in the digital era.

This study provides valuable guidance for decision-makers in the maritime industry by focusing on cybersecurity issues. The findings, particularly from the perspectives of experienced experts, contribute significantly to shaping cybersecurity strategies within the maritime sector. Emphasizing critical factors such as Compliance and Regulatory Requirements, the study also plays a crucial role in defining cybersecurity standards in the maritime industry. However, there are limitations to consider, including the potential lack of generalizability due to the focus on expert experiences and opinions. Additionally, the study's data collection methods and analysis techniques may impose constraints and could yield different results with alternative approaches. To enhance this research, future studies could involve a broader range of experts to increase generalizability and utilize more comprehensive datasets for detailed guidance to decision-makers. Furthermore, considering emerging cybersecurity developments and technological advancements, future research could focus on refining cybersecurity strategies within the maritime industry. Finally, exploring alternative methodologies could overcome limitations and provide a deeper understanding of cybersecurity issues in the maritime sector.

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Assessing the Significance of IACS UR E26 and E27 Standards with Multi Criteria Decision-Making Model

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Abstract

With the advancement of technology in the maritime industry, cybersecurity has gained increasing importance. Ships and maritime vessels are designed with complex and integrated automation systems, posing an escalating threat from cyber-attacks. Ensuring the cybersecurity of ships is crucial for personnel safety, data integrity, human welfare, and environmental protection. In this context, the Unified Requirements (UR) E26 and E27 developed by the International Association of Classification Societies (IACS) play a critical role in enhancing ships' cyber resilience. However, it is imperative to determine and compare the importance weights of these requirements. The aim of this study is to determine the importance weights of IACS UR E26 and E27 requirements by utilizing an appropriate multi criteria decision-making (MCDM) method, thereby identifying which requirements are prioritized in terms of enhancing ships' cybersecurity. This evaluation supports a strategic approach to ships' cybersecurity and contributes to the improvement of industry standards.

Keywords: *IACS UR E26 and E27, ships' cybersecurity, multi criteria decision-making model (MCDM)*

1. Introduction

The International Association of Classification Societies (IACS) plays a crucial role in advancing maritime safety. Its members include of renowned classification societies such as Lloyds Register, American Bureau of Shipping, and Bureau Veritas [1]. These organizations have a vital function in establishing and implementing regulations for the management and supervision of ship control and monitoring systems [2]. With the developments in technology, the importance of security of information systems has been understood by organizations such as IACS. Thus, in April 2022, in the Unified Requirement (UR) category, the E26 Cyber resilience of ships and E27 Cyber resilience of on-board system and equipment standards were accepted by IACS and entered as requirements for improving and increasing the cyber security resilience of ships in the maritime industry.

When we look globally, 17 million cyber-attacks occur every week and the cost of cybercrimes in 2018 is approximately 600 billion [3]. The maritime industry is also affected by cybercrimes, which have been increasing in recent years. Singaporean shipbuilder Sembcorp Marine, unauthorized access to IT systems through third-party software, attack on the IT of another Singapore-based company Voyager Worldwide in 2022, cyber-attack on the website of the Port of Lisbon or ransomware-type cyber-attacks that affected approximately 15% of DNV-GL's fleet [4]. Although ships are not much affected by cyber-attacks, IACS UR E26 and E27 standards consist of requirements that will prevent ships from being affected by such cyber-attacks.

The purpose of the IACS UR E26 is to establish minimal criteria for ship cyber resilience, giving stakeholders with technological tools to achieve this. The research problem is that although IACS E26 and E27 have benefits to maritime sector with their strength side and opportunities derived from strengths, they embody unrecognized weaknesses and threats. Therefore, it is important to define and understand these factors by using Strength Weaknesses Opportunity Threat (SWOT) Analysis. Then, their importance weights are prioritized via Analytic Hierarchical Process (AHP) Analysis. By recognizing these factors, shipping companies can develop strategies to maximize the benefits of complying with E26 and E27 requirements while mitigating potential challenges and threats.

2. Literature Review

Standards are crucial in the development of global cyber defense and security. The proliferation of standards gives rise to issues stemming from possible disparities and absence of uniformity. The increasing sophistication of cyber-attacks and our growing dependence on digital technologies have necessitated major revisions to cybersecurity standards over the past decade. Cybersecurity standards have been extensively studied and developed to provide frameworks and concepts aimed at protecting information systems and networks from potential vulnerabilities and attacks.

A number of studies, including Scarfone [5], Purser [6], and Collier [7], have brought attention to the significance of standards in the realm of cybersecurity. These studies shed light on the significance of standards in the areas of risk management, defense development, and resilience building through their findings. It is essential to have these standards in place in order to guarantee interoperability and consistency, as stated by Purser [6]. This is particularly true in circumstances that include several communities and require travelling across international borders. Furthermore, as stated by Guarino [8], they play a significant part in the preservation of significant assets that are a component of the infrastructure. Despite this, there are substantial problems that have arisen as a consequence of the growing number of standards and the difficulties that are linked with the standardization by Purser [6]. The importance of adopting a more complete strategy that takes into account the role of security standards is emphasized by Mehan [9] in relation to the topic of cybersecurity. In addition, the influence that government rules have on cybersecurity, particularly with regard to the adoption of standards, has been examined by Srinivas [10]. For the purpose of enhancing the safety of operating systems, it was found that there was an immediate requirement for a complete collection of fundamental preconditions, as stated by Hamdani [11]. These standards were designed for cybersecurity operations, and they serve as the basis for these criteria. This evolution is illustrated in the most recent study by Lanovska and Lebedeva [12], which details the development of a program to improve the implementation of cybersecurity standards.

Essentially, the establishment and implementation of cybersecurity standards by classification societies has become essential to protect the maritime industry from cyber threats. International organizations, classification societies and national regulators are working together to improve the ability of maritime activities to withstand cyber-attacks and thus protect the safety and security of global maritime activities in an increasingly digitalized world.

Utilizing the latest technologies for communication, operation and navigation, the maritime sector is a vital component of world trade. However, the integration of technology increases vulnerability to cyber-attacks. In response, the International Association of Classification Societies (IACS) has introduced EU 26 and EU 27 standards to improve maritime cybersecurity [13] [14]. The digitalization of the maritime sector has led to increased operational efficiency but has also brought security vulnerabilities. The occurrence of significant cyber-attacks against maritime companies has underscored the urgent need for strong and effective cybersecurity frameworks. IACS has formulated the EU 26 and EU 27 recommendations as a systematic framework for enhancing cyber resilience. These standards cover cybersecurity governance, identification of threats, implementation of response mechanisms and establishment of recovery procedures specifically designed for the maritime sector.

Leading maritime companies and ports have taken the initiative to incorporate these ideas into their cybersecurity policies. Challenges to adoption include differences in digital competence across the industry, costs associated with implementation and the need for staff training. Despite these obstacles, the commitment to implementing the IACS guidelines demonstrates a wider recognition in the business community of the vital importance of cybersecurity.

The implementation of the IACS EU 26 and EU 27 standards has faced several challenges. The maritime sector faces different cybersecurity barriers due to its worldwide scope, the wide range of technologies used and the need to comply with international legislation. The complexity of the sector's supply chain increases compliance challenges and emphasizes the importance of a comprehensive and collaborative approach to cybersecurity. The adoption of EU 26 and EU 27 standards has increased the recognition of cybersecurity vulnerabilities in the maritime sector. Initial results include expanded risk management techniques, improved incident response capabilities and strengthened resilience to cyber-attacks. The standards have also facilitated increased collaboration among maritime stakeholders, such as classification societies, ship owners and ports, in sharing best practices and information on potential risks.

To keep pace with evolving cyber threats, the IACS EU26 and EU27 standards need to be continuously assessed and improved. Further research priorities should include examining the enduring effectiveness of these standards, formulating sector-specific cybersecurity training initiatives, and incorporating new technologies into existing cybersecurity frameworks. Furthermore, examining mechanisms for international cooperation in the implementation and review of these rules would provide useful insights for enhancing global maritime cybersecurity resilience.

In conclusion, the maritime sector's adoption and implementation of the IACS EU 26 and EU 27 standards represents a notable progress in safeguarding the integration of new technologies into cybersecurity frameworks. Moreover, examining mechanisms for international cooperation in the implementation and review of these standards will offer useful perspectives towards improving global maritime cybersecurity resilience. Accordingly, the maritime sector's adoption and implementation of the IACS EU 26 and EU 27 standards represents significant progress in ensuring the protection of this sector.

3. Materials and Techniques

3.1 IACS UR E26 and E27 Standards

IACS UR E26 and E27 standards with revisions, which are made by IACS to increase and improve the cyber resilience of ships during the construction stages of ships after 1 July 2024, are mandatory for passenger ships that will make international voyages, cargo ships and high-speed craft that will make international voyages over 500 GT, mobile offshore drilling units over 500 GT and self-propelled mobile offshore units under construction.

Regarding the E26 standards, it has been established to prevent cyber-attacks against operational systems of ships such as propulsion, anchoring and mooring, electrical power generation and distribution, fire detection and extinguishing systems, navigational systems, ballast and ballast systems etc. Five phase elements have been established to build ships that are resistant and safe against cyber risks. These elements are Identify, Protect, Detect, Respond and Recover.

These five basic phases included in E26 are aimed to create a holistic and inclusive standard in ensuring the cyber resilience of ships. Firstly, Identify phase, ships' asset inventories are created to cover both software and hardware equipment, as well as defining roles and responsibilities and ensuring that their management and administration are controlled and monitored. The inventory list of software installed in computer-based ship systems and operational technologies is effective in ensuring effective cyber resilience. The second phase is the Protection. The necessity to use systems such as firewall, IPS/IDS, antivirus, antimalware, antispam products and network separation to ensure the security of these hardware and software products and network security has been established. In the Determination phase, it was determined that alarm and surveillance systems should be present on the network and these networks should be recorded and the relevant personnel should have training and competence on this subject. In the Respond phase, the main focus was on how to intervene when a cyberattack occurs. An Incident Response Plan is created for these situations and the management of combating cyberattacks is directed. Finally, in the Recover phase, it appears as a standard on the methods and procedures for improving the infected ship systems and data after the cyberattack occurs.

The E26 standard establishes a general approach to cyber resilience within the framework of the vessel. The E27 standard focuses on equipment for cyber resilience. These equipment are; network devices, security devices, computers, automation devices etc. may consist of equipment such as. Protection against access to these equipment by unauthenticated persons, measures against misuse of systems, prevention of manipulations by maintaining integrity, prevention of disclosure of information by eavesdropping, monitoring of operations and intervention in incidents, and security measures to be taken in matters related to the reliable operation of control systems under normal production conditions. The main scope of IACS E26 and E27 and linkage of them are shown in Figure 1.

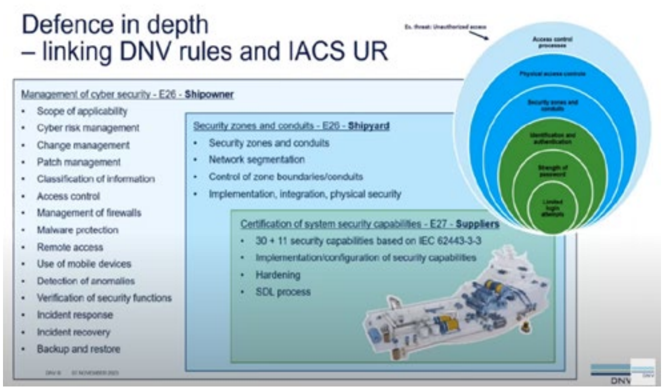

Figure 1. The scope of the IACS E26 and E27 and Their Linkage [15]

Figure 2 shows the responsibilities of the stakeholders such as yards, manufacturers, shipowners, and classification societies and the information sharing process between them. The processes of obtaining the E26 cyber resistance certificate are categorized as ship design, system design, testing and management. The shipyard has duties and responsibilities such as creating an inventory list, cyber security design descriptions. Product manufacturers with E27 type approval certificate have duties regarding the configuration of the systems to be integrated into the ship during the system design phase. In the testing phase, both the testing of the products by the manufacturer and the testing of the integration to the ship by the shipyard and the healthy operation of the systems are aimed. In the management system, it is a step created among the duties of the ship owner by creating inclusiveness in the provision and management of cyber security of ships. In all these processes, Classification Societies play an important role in the acquisition of the ship cyber resistance certificate by taking part in the examination and approval.

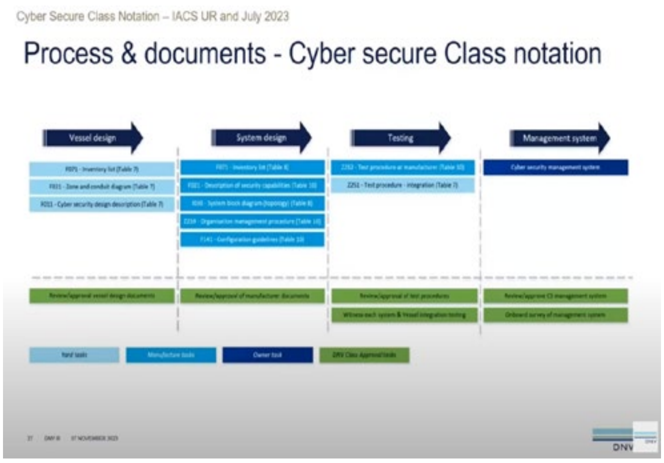

Figure 2. Stakeholders and Interaction between Them Under IACS E26 and E27 [15]

Both IACS UR E26 standards and E27 standards increase the resilience of ships against cyber-attacks and prevent them from being a threat to business, personnel data, human safety, the safety of the ship and the marine environment.

3.2 SWOT-AHP Analysis

The main challenge of strategic planning is to make well-informed decisions that will have a lasting impact on the organization. Integrating the Analytic Hierarchy Process (AHP) with standard SWOT analysis improves the effectiveness of strategic planning by providing a systematic approach to decision making. This chapter examines the SWOT-AHP methodology and highlights its utility in prioritizing strategic initiatives using measurable metrics.

Begin by providing a comprehensive explanation of SWOT analysis and emphasize its importance in identifying both internal and external factors that have the potential to affect a business's performance. Emphasize the role of SWOT analysis in providing a comprehensive assessment of internal strengths, weaknesses, external opportunities, and threats, thus providing a basis for making strategic decisions.

Strengths: Recognize internal assets and qualities that contribute to achieving company goals.

Weaknesses: Recognizing any internal constraints or shortcomings that may hinder the achievement of objectives.

Opportunities: Analyze and take advantage of external elements from which the organization can benefit.

Threats: Identify potential external problems that the organization may face.

The Analytic Hierarchy Process (AHP) is a decision-making methodology that makes complex decisions more manageable by reducing them to a hierarchical structure. This methodology involves a systematic and methodological approach to decision making. AHP uses pairwise comparisons to assess the relative importance of different elements and enables the creation of quantifiable decision criteria. The flow diagram for steps of AHP methodology is as in Figure 3 [16]. The score for the data is given by referencing the score table in Table 1 [17]. Table 2 has the constant values for RI value in the AHP analysis.

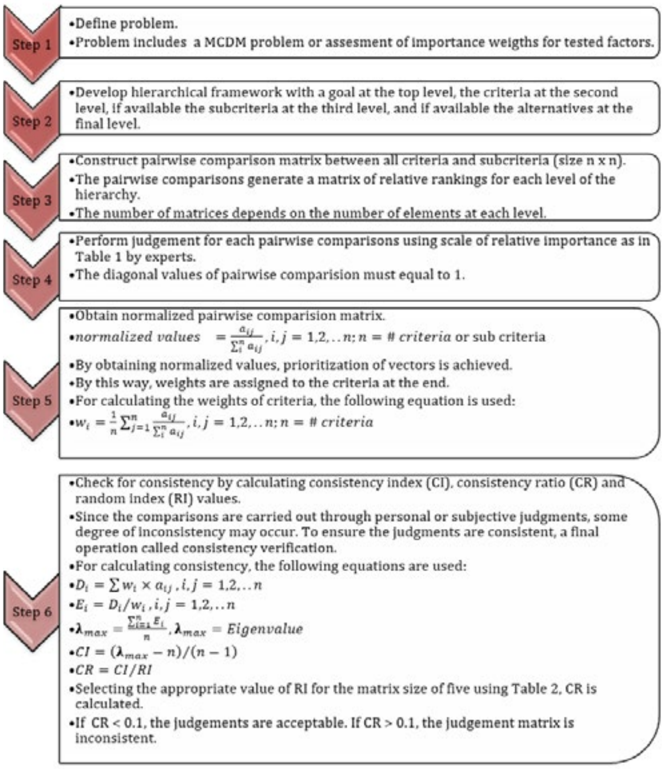

Figure 3. Flow Diagram for AHP [16]

Table 1. Saaty's Scale for Pairwise Comparisons [17]

Relative Intensity	Definition	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored, and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
1/3, 1/5, 1/7, 1/9	Reciprocals	Reciprocals for inverse comparison

Table 2. Random Index for AHP

Size of matrix (n)	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

To summary steps of SWOT-AHP analysis integrated with Figure 3:

- **Goal Formulation:** Set precise and well-defined strategic objectives.
- **SWOT Analysis:** List internal strengths and weaknesses as well as external opportunities and threats related to the strategic objective.
- **Hierarchical Structuring:** Organize the SWOT components in a hierarchical manner according to their relationship to the strategic objectives.
- **Comparisons made between each pair of elements:** Make pairwise comparisons of SWOT criteria using the Analytic Hierarchy Process (AHP) to assess their relative importance.
- **Prioritization:** Determine the relative importance of SWOT components by assigning priority weights to discover the most critical elements that have a significant impact on strategic decision making.
- **Using SWOT-AHP in the strategic planning process:** Examine the practical use of the SWOT-AHP technique in real life situations to guide strategic decision making. Please include case studies or examples that demonstrate how this integrated strategy has resulted in better decision-making clarity and strategic success.

4. Methodology

The purpose of this study is to specify the qualifications of the IACS E26 and E27 in terms of their strengths, opportunities, weaknesses, and threats using a SWOT analysis. Then, using AHP technique to prioritize the weights of these criteria, it seeks to propose effective methods for maximizing the benefits of meeting E26 and E27 requirements while limiting potential problems and dangers.

4.1 Process of the Methodology

The implementation steps of the methodology are shown in Figure 4. Accordingly, the specifications of the IACS E26 and E27 standard are examined by utilizing literature and standard documents. SWOT framework is set for understanding the effectiveness of IACS E26 and E27 on the shipping companies by defining strength, opportunities, weakness, and threats. Then, the designed SWOT framework is checked by experts on maritime cyber security. After ensuring well-designed SWOT framework, the step of data collection is carried out through the same experts to prioritize the weights of the factors in the SWOT model via AHP technique. Finally, according to the AHP results, effective strategies are developed for shipping companies to maximize the benefits of complying with E26 and E27 requirements while mitigating potential challenges and threats. These strategies are presented as the matrix on strength – opportunity (SO), strength – threat (ST), weakness – opportunity (WO), and weakness-threat (WT).

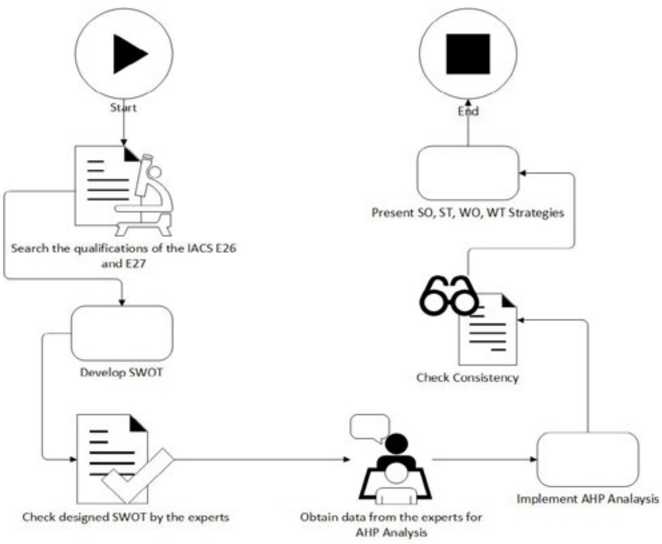

Figure 4. Flowchart of the Study

4.2 Data Collection

In this study, five experts check the designed SWOT framework and provide data for weighting and rating the factors for AHP analysis. Two experts are members of a research team on maritime cyber security at an international university and all of them have PhD education level. Three experts are cyber security specialists on several systems, including maritime systems. One of them has PhD education level, two of them have BSc education level. The average experience period of the experts is five years.

4.3 Results

4.3.1 SWOT Framework for Effect of IACS E26 and E27 on the Shipping Companies

In order to determine the criteria for the function of IACS E26 and E27, literature review is made with the key word “advantages and disadvantages of ISO standards”. There are not many studies focusing on the IACS E26 and E27 standards in the literature. IACS E27 provides 31 functional requirements and additional requirements aligned with ISO-IEC 62443 standard. IACS E26 provides 17 requirements organized in alignment with the NIST. Accordingly, IACS E26 and E27 are derived from a kind of ISO standards. In literature, there are many studies, which focus on the function of the several ISO standards. In this context, the criteria related to the strengths, weaknesses, opportunities, and threats of IACS E26 and E27 aspect from shipping companies are obtained from several studies in the literature as in Table 3 and then, they are checked by the experts on maritime cyber security [18]-[23].

Table 3. SWOT Framework for Effect of IACS E26 and E27 on the Shipping Companies

Strengths (ST)			**Weaknesses (WK)**		
ST1	Comprehensive Standards:	Providing a detailed framework as a comprehensive standard for enhancing cyber security in the maritime industry	**WK1**	Complexity:	Having complex and technical requirements
ST2	International Recognition:	Being recognized and accepted globally, ensuring uniformity and consistency in cyber security practices across the maritime sector	**WK2**	Resource Intensive:	Requiring substantial investments in terms of time, money, and personnel to develop and maintain robust cyber security measures and processes
ST3	Risk Mitigation:	Providing function for risk mitigation to shipping companies for enhancing the resilience of their operations against cyber threats	**WK3**	Training Needs:	Requiring ongoing training and awareness programs
ST4	Best Practices:	Providing best practices and guidelines for cyber security to shipping companies with a roadmap	**WK4**	Integration Challenges:	Having integration challenges to ships systems
ST5	Continuous Improvement:	Being have updated to address emerging cyber threats and technological advancements	**WK5**	Dependency on External Factors:	Relying on third-party vendors and partners by shipping companies to implement certain aspects of the requirements
Opportunities (OP)			**Threats (TH)**		
OP1	Competitive Advantage:	Creating competitive advantages in the international inspections, such as PSC or OCMF for shipping companies	**TH1**	Cyber Attacks:	Remaining still cyber vulnerabilities
OP2	Consulting Services:	Adopting consulting services by shipping companies in implementing effective cyber security measures	**TH2**	Regulatory Changes:	Changing regulatory requirements
OP3	Technology Innovation:	Adopting the development and adoption of innovative cyber security technologies and solutions tailored to the maritime industry by shipping companies	**TH3**	Resource Constraints:	Not adopting fully standards due to the limited financial resources and personnel
OP4	Partnerships and Collaboration:	Facilitating collaboration with industry associations, regulatory bodies, and technology providers	**TH4**	Supply Chain Risks:	Introducing supply chain vulnerabilities due to the dependency on third-party vendors
OP5	Market Expansion:	Providing reputation in the market	**TH5**	Cyber Security Skills Shortage:	Hindering shipping companies' efforts to effectively implement the requirements due to the shortage of skilled cyber security professionals in maritime

4.3.2 Results of AHP Analysis

The research question is determining which criteria are the most significant factors in their category (ST, WK, OP, TH) in the Table 3 for IACS E26 and E27 aspect from shipping companies.

The experts provide data by comparing the sub-criteria within the same group and the major criterion. This data is then aggregated using arithmetic to identify the consensus. In order to show as a sample, the pairwise comparison for strength criteria is presented in Table 4. Similar to Table 4 and Table 5, results of AHP analysis for all criteria (ST, WK, OP, TH) are obtained and they are presented in the Annex.

Table 4. Pairwise comparision

	ST1	**ST2**	**ST3**	**ST4**	**ST5**
ST1	1,00	2,42	2,42	2,47	2,86
ST2	0,41	1,00	3,33	1,48	2,19
ST3	0,41	0,30	1,00	1,23	0,83
ST4	0,41	0,67	0,81	1,00	1,17
ST5	0,35	0,46	1,20	0,86	1,00
SUM	2,58	4,85	8,76	7,04	8,05

Table 5 shows pair-wise comparisons of entire sub-criteria, with values in the same column aggregated to prepare for the normalization process in step 5.

Table 5. Normalized Pairwise Comparisons and Criteria Weights

	ST1	ST2	ST3	ST4	ST5	Criteria Weigths	Dİ=∑wi*aij	Ei=wi/Dİ
ST1	0,39	0,50	0,28	0,35	0,36	0,37	1,95	5,22
ST2	0,16	0,21	0,38	0,21	0,27	0,25	1,28	5,20
ST3	0,16	0,06	0,11	0,18	0,10	0,12	0,62	5,04
ST4	0,16	0,14	0,09	0,14	0,14	0,14	0,69	5,14
ST5	0,14	0,09	0,14	0,12	0,12	0,12	0,63	5,13

In the consistency analysis, the values of λmax, consistency index (CI), consistency ratio (CR) and random index (RI) are calculated according to equations in step 6 in the flow diagram. The results of the consistency analysis for each matrix (ST, WK, OP, TH) are shown in Table 6. According to analysis, if CR< 0,10, the result is consistent. All matrix results are valid.

Table 6. Consistency Analysis Results

Matrices	λmax	CI	RI	CR
ST matrix	5,15	0,04	1,12	0,03
WK matrix	5,31	0,08	1,12	0,07
OP matrix	5,36	0,09	1,12	0,08
TH matrix	5,18	0,05	1,12	0,04
Main matrix	4,07	0,02	0,9	0,03

Consequently, the obtained criteria weights are as in Table 7.

Table 7. Criteria Weights

ST Matrix	Criteria Weights	WK Matrix	Criteria Weights	OP Matrix	Criteria Weights	TH Matrix	Criteria Weights	Main Matrix	Criteria Weights
ST1	0,37	**WK 1**	0,30	**OP 1**	0,42	**TH 1**	0,43	**ST**	0,47
ST2	0,25	**WK 2**	0,35	**OP 2**	0,14	**TH 2**	0,06	**WK**	0,16
ST3	0,12	**WK 3**	0,16	**OP 3**	0,29	**TH 3**	0,10	**OP**	0,18
ST4	0,14	**WK 4**	0,10	**OP 4**	0,10	**TH 4**	0,21	**TH**	0,18
ST5	0,12	**WK 5**	0,09	**OP 5**	0,05	**TH 5**	0,20		

5. Discussion

According to the results, the most important factors in the strength, weakness, opportunity, and threat of the IACS E26 and E27 are ST1 –comprehensive standards, WK2 – resource intensive, OP1 – competitive advantage, TH1 – cyber-attacks, respectively. Strength of the standards (0,47) are most important than other main functions. The weights of the main criteria and the weights of each sub criteria are multiple for obtaining final score of weighting. Accordingly, the most important factors in each category are shown as in Table 8.

Table 8. Results Ranking

Ranking	Code	Weight Factor	Sub-factor
1	ST1	0,1736	Comprehensive Standards
2	TH1	0,0774	Cyber Attacks
3	OP1	0,0756	Competitive Advantage
4	WK2	0,056	Resource Intensive

In order that shipping companies benefit from IACS E26 and E27 standards, they should aware these factors and they can develop strategies to maximize the strengths of complying with E26 and E27 requirements while mitigating potential weaknesses and threats. This study provides systematic strategy vector for this purpose.

E26 and E27 provide a detailed framework for enhancing cyber security in the maritime industry, covering various aspects such as risk management, access control, and incident response. They provide ensuring uniformity and consistency in cyber security practices across the maritime sector. They incorporate industry best practices and guidelines for cyber security, providing shipping companies with a roadmap for implementing effective cyber security measures. Due to these strengths of IACS E26 and E27, shipping companies that effectively implement the requirements of E26 and E27 can differentiate themselves in the international inspections, such as PSC or OCMF demonstrating a strong commitment to cyber security, potentially attracting customers who prioritize secure maritime services. Despite compliance with E26 and E27 requirements, shipping companies still remain vulnerable to cyber-attacks, which can disrupt operations, compromise sensitive data, and damage reputation. By adhering to these standards, shipping companies can systematically identify, assess, and mitigate cyber risks, thereby enhancing the resilience of their operations against cyber threats. Compliance with these standards may require substantial investments in terms of time, money, and personnel to develop and maintain robust cyber security measures and processes in terms of resource intensive.

6. Conclusion

The goal of the IACS UR E26 is to establish minimum requirements for ship cyber resilience while providing stakeholders with technology instruments to do so. While IACS E26 and E27 provide benefits to the marine sector through their strengths and opportunities resulting from those strengths, they also contain undetected vulnerabilities and risks. In this study, SWOT Analysis is employed for defining and understanding these elements. Then, their relevance weights are prioritized using AHP Analysis. Recognizing these characteristics allows shipping businesses to build plans that maximize the benefits of meeting E26 and E27 criteria while avoiding potential hurdles and dangers.

According to the obtained results, E26 and E27 outline a maritime cyber security framework for risk management, access control, and incident response. They ensure marine cyber security consistency. Shipping firms can follow industry cyber security best practices and recommendations to create effective cyber security measures. These strengths of IACS E26 and E27 allow shipping companies that effectively implement the requirements to differentiate themselves in international inspections, such as PSC or OCMF, by demonstrating a strong commitment to cyber security and potentially attracting customers who value secure maritime services. Shipping firms are vulnerable to cyberattacks that can interrupt operations, compromise sensitive data, and damage reputation notwithstanding E26 and E27 compliance. These guidelines help shipping businesses detect, assess, and reduce cyber risks, strengthening their operations against cyberattacks. Compliance with these standards may require significant time, money, and staff inputs to build and maintain comprehensive cyber security systems and processes.

The study contributes to the enhancement of cyber security in the maritime industry by providing a structured approach to understanding, prioritizing, and addressing the challenges and opportunities associated with the implementation of IACS E26 and E27 standards. By leveraging this knowledge, shipping companies can strengthen their cyber resilience and safeguard their operations against cyber threats effectively.

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Annex

Table 4. Pairwise comparision

	ST1	ST2	ST3	ST4	ST5
ST1	1,00	2,42	2,42	2,47	2,86
ST2	0,41	1,00	3,33	1,48	2,19
ST3	0,41	0,30	1,00	1,23	0,83
ST4	0,41	0,67	0,81	1,00	1,17
ST5	0,35	0,46	1,20	0,86	1,00
SUM	2,58	4,85	8,76	7,04	8,05
	WK1	**WK 2**	**WK 3**	**WK 4**	**WK 5**
WK 1	1,00	1,65	2,71	2,07	1,78
WK 2	0,40	1,00	4,67	5,00	3,67
WK 3	0,37	0,21	1,00	2,00	3,17
WK 4	0,48	0,20	0,24	1,00	1,47
WK 5	0,50	0,27	0,32	0,68	1,00
SUM	2,75	3,34	8,94	10,75	11,09
	OP1	**OP 2**	**OP 3**	**OP 4**	**OP 5**
OP 1	1,00	5,00	1,84	4,11	5,33
OP 2	0,17	1,00	0,30	2,25	5,05
OP 3	0,54	3,30	1,00	4,33	4,78
OP 4	0,24	0,44	0,23	1,00	3,73
OP 5	0,19	0,20	0,21	0,27	1,00
SUM	2,15	9,94	3,59	11,96	19,89
	TH1	**TH 2**	**TH 3**	**TH 4**	**TH 5**
TH 1	1,00	5,33	4,05	3,38	2,06
TH 2	0,19	1,00	0,50	0,38	0,25
TH 3	0,25	2,00	1,00	0,39	0,39
TH 4	0,30	2,63	2,59	1,00	1,83
TH 5	0,49	4,00	2,59	0,55	1,00
SUM	2,22	14,96	10,72	5,69	5,53
	ST	**WK**	**OP**	**TH**	
ST	1,00	4,06	2,44	2,07	
WK	0,25	1,00	1,19	0,83	
OP	0,41	0,84	1,00	1,23	
TH	0,48	1,20	0,81	1,00	
SUM	2,14	7,09	5,45	5,13	

Table 5. Normalized Pairwise Comparisons and Criteria Weights

	ST1	ST2	ST3	ST4	ST5	Criteria Weigths	Dİ=∑wi*aij	Ei=wi/ Dİ
ST1	0,39	0,50	0,28	0,35	0,36	0,37	1,95	5,22
ST2	0,16	0,21	0,38	0,21	0,27	0,25	1,28	5,20
ST3	0,16	0,06	0,11	0,18	0,10	0,12	0,62	5,04
ST4	0,16	0,14	0,09	0,14	0,14	0,14	0,69	5,14
ST5	0,14	0,09	0,14	0,12	0,12	0,12	0,63	5,13
	WK1	**WK 2**	**WK 3**	**WK 4**	**WK 5**	**Criteria Weigths**	**Dİ=∑wi*aij**	**Ei=wi/Dİ**
WK 1	0,36	0,49	0,30	0,19	0,16	0,30	1,67	5,52
WK 2	0,15	0,30	0,52	0,47	0,33	0,35	2,02	5,74
WK 3	0,13	0,06	0,11	0,19	0,29	0,16	0,83	5,28
WK 4	0,18	0,06	0,03	0,09	0,13	0,10	0,49	4,97
WK 5	0,18	0,08	0,04	0,06	0,09	0,09	0,45	5,02
	OP1	**OP 2**	**OP 3**	**OP 4**	**OP 5**	**Criteria Weigths**	**Dİ=∑wi*aij**	**Ei=wi/Dİ**
OP 1	0,47	0,50	0,51	0,34	0,27	0,42	2,33	5,56
OP 2	0,08	0,10	0,08	0,19	0,25	0,14	0,77	5,41
OP 3	0,25	0,33	0,28	0,36	0,24	0,29	1,64	5,60
OP 4	0,11	0,04	0,06	0,08	0,19	0,10	0,51	5,16
OP 5	0,09	0,02	0,06	0,02	0,05	0,05	0,24	5,08
	TH1	**TH 2**	**TH 3**	**TH 4**	**TH 5**	**Criteria Weigths**	**Dİ=∑wi*aij**	**Ei=wi/Dİ**
TH 1	0,45	0,36	0,38	0,59	0,37	0,43	2,27	5,29
TH 2	0,08	0,07	0,05	0,07	0,05	0,06	0,32	5,18
TH 3	0,11	0,13	0,09	0,07	0,07	0,10	0,49	5,09
TH 4	0,13	0,18	0,24	0,18	0,33	0,21	1,12	5,28
TH 5	0,22	0,27	0,24	0,10	0,18	0,20	1,02	5,08
	ST	**WK**	**OP**	**TH**		**Criteria Weigths**	**Dİ=∑wi*aij**	**Ei=wi/Dİ**
ST	0,47	0,57	0,45	0,40		0,47	1,95	4,12
WK	0,12	0,14	0,22	0,16		0,16	0,65	4,07
OP	0,19	0,12	0,18	0,24		0,18	0,74	4,03
TH	0,23	0,17	0,15	0,19		0,18	0,75	4,08

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Section 10
Seafarers' Wellbeing

A Content Analysis of Blue Crime: Transnational Organized Crime at Sea

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Abstract

One of the significant developments that has implications for international maritime security law is the change in the nature of maritime security. Transnational crimes are now one of the main threats, given that the high seas constitute a transnational environment where multiple states share sovereignty and that the state is just one of many actors involved. Another description of transnational organized crime at sea is "blue crime", involving two or more governments. This concept may be considered novel terminology. Even though most articles on blue crime focus on fishery crimes and piracy, the definition of severe organized crimes or offenses that occur on, within, or across the maritime domain and can cause significant harm has a broader connotation. Indeed, among the three categories of blue crime, fishery crimes constitute merely one subcategory of environmental crime, with the other two being crimes against mobility – including piracy – and crime flow. Regardless of their relationship, terrorism and other acts of extremist violence are not categorized as blue crimes under the UN Convention against Transnational Organized Crime (UNCTOC) definition, which emphasizes political or material profit motives. The present study examined the concept of blue crime, reviewing the relevant literature from the Web of Science and Scopus databases to that end. VOSviewer and MAXQDA 2024 qualitative analysis software were used to analyze the contents of the articles in the relevant literature. The analysis revealed ambiguity in understanding the blue crime concept as well as some terminology contradictions. Further studies in this field is needed.

Keywords: *Blue crime, transnational organized crimes at sea, maritime security, UNTOC, content analysis*

1. Introduction

Blue crime, a relatively recent concept, is alternatively defined as "cross-border (or transnational) organized crimes at sea, involving two or more states." The UN Security Council addressed the matter for the first time in February 2019, describing it as a threat to international peace and security. Today, high-seas crime is becoming more sophisticated, risking human lives on land, regional economic growth, and global security. This highlights the vital role of international legal treaties in combatting the scourge [1]. The multinational nature of maritime crime primarily stems from varying jurisdictions areas such as the high seas, the coastal or port state depending on where the crime is committed and the flag state of the ship.

Maritime piracy, the illicit trafficking of people, narcotics, and arms, along with the environmental crimes such as illegal fishing or pollution are becoming increasingly essential aspects of ocean governance. Such crimes take various forms across the world's maritime regions and have varying effects on human lives, political stability, and economic interests, ranging from the impact on coastal communities to international shipping and even national security [2].

Terrorism or other kinds of extremist violence are not considered blue crime due to one of the preconditions for the concept of "organized crime" which is "profit seeking" according to the United Nations Convention Against Transnational Organized Crime (UNCTOC) definition. Although there is a strong link between the organized crime and terrorism [3], some studies support the idea that terrorism cannot be considered blue crime as it is motivated by political purposes [2,4,5].

There is still a significant confusion around the concept of blue crime, including its meaning, scope, and reach. This confusion reaches to what illicit activities it encompasses and how these activities can be meaningfully structured to recognize the diverse nature of maritime crime while also providing a foundation for an integrated response to it. In the existing literature, blue crime is primarily associated with fisheries crimes due to its close connection to illegal fishing, human rights abuses, money laundering, corruption, document and tax fraud, and smuggling [6-13] and piracy [14]. Furthermore, other studies state that a failure to effectively address organized fisheries crime can result in a widespread inability to fulfil some of the Sustainable Development Goals (SDGs) [7,15,16]. Above all, blue crime extends beyond fisheries crimes or piracy, which constitutes only some part of it.

Bueger and Edmonds [2] identify three fundamental categories of blue crime, each characterized by its distinct connection to the sea and the objects of harm that must be protected. Firstly, there are crimes against mobility aimed at various modes of sea circulation, particularly ships, supply chains, and maritime trade (drug, human, oil, waste, counterfeit, and people smuggling, irregular migration, small arms and light weapons, wildlife and timber trafficking, informal trade, smuggling for tax evasion and maritime illicit trades). Secondly, there are criminal flows aimed at using the sea as a conduit for illegal operations (piracy, cyber-crimes, and stowaways). Thirdly, there are environmental crimes aimed at harming the sea and the resources it provides (illegal, unreported, and unregulated fishing – IUU, marine and plastic pollution, abandoned, lost, or otherwise discarded fishing gear) [2, 17]. Besides these three categories, there is a fourth category also described as a blue crime [17]. This includes using flags of convenience to conceal illicit activity [18], transshipment [19], slavery and labor abuses [20] and illicit bunkering.

Ruiz et al. [21] examined the notion of "eco-crime" – another similar term to blue crime – in the aquatic environment by employing an interdisciplinary approach that draws on criminology of environmental harms, the study of criminal law and environmental law, and marine science. They suggest that crimes and harms affecting the marine environment might be considered as part of a new "blue criminology".

Otto [22] emphasized that a common explanation for maritime crime is transnational organized crime at sea, or Transnational Maritime Crime (TMC), because most crimes that fall under that general category are both organized and international in scope. She further concluded that TMC can be considered to include the crimes of maritime piracy, armed robbery and, kidnap for ransom at sea, IUU fishing, as well as smuggling and trafficking activities.

Recently the use of unmanned systems to conduct attacks from the sea has been increasing day by day [23]. There have been numerous reports of the use of unmanned boats to harm people around or on-board targeted installations, as well as to damage or partially destroy ships, port infrastructure, and offshore facilities. Unmanned surface or underwater attacks are witnessed both in the Black Sea/Russia-Ukraine war and Houthi attacks in the Red Sea. Therefore, the scope and definition of blue crime are changing with the latest developments.

The study's methodology is described in the following section and its results are presented. In the conclusion section, conclusions were drawn based on the data obtained.

2. Methodology

Literature studies reveal discoveries by analyzing primary studies. They are essential for establishing a firm knowledge base and showing areas where more research is needed by checking the studied areas from a comprehensive perspective [24]. One type of literature review is a systematic review. It involves a comprehensive search of all published studies on any subject, determines which publications to include in the research based on various inclusion and exclusion criteria, evaluates these publications, and reveals the similarities and differences through critical analysis.

This study aimed to review the literature on blue crime or transnational organized crime at sea to fill the gap in this area. Scopus was first selected as a database due to its capacity to access the majority of top-ranking publications. Then, search was conducted by employing the following search string: TITLE-ABS-KEY (blue AND crime*), TITLE-ABS-KEY (transnational AND organized AND crime AND at AND sea). Then, the Web of Science (WoS) database was used with the same search criteria. Following the search process, only six articles were found for "blue crime" in Scopus and five articles in WoS. This amount is not enough to make an assessment considering that there is insufficient data for the topic "blue crime". However, when conducting search with "transnational organized crime at sea" 23 articles were found in Scopus and 18 in WoS, incorporated in the literature review process of the present study. The study included all publications with English abstracts, including articles, conference papers, reviews, etc. Additionally, by analyzing some references of this study through MAXQDA software, attempts were made to identify first, the most frequently used words and word combinations in selected studies and then the links among transnational crime categories.

3. Analysis and Findings

3.1. Scopus VOSviewer Analysis and Its Findings

Using a systematic literature review, studies were found in the Scopus database. Articles obtained were examined using the software VOSviewer 1.6.20., a software application that is used to generate and show related maps based on network data.

Within the search conducted and refined through Scopus database, among the keywords, "maritime security" scored the highest with a frequency of four and a total link strength of 20. While the frequency of "blue crime(s)" is two, it is the second keyword with a total link strength of 13. The frequency of "transnational organized crime" is one with a total link strength of four. Figure 1 depicts VOSviewer analysis of documents found in Scopus database.

Figure 1. Mapping analysis based on text data network and density map – Scopus.

Figure 1 indicates that the most frequently repeated terms in the related literature are grouped into five main clusters (red, green, blue, and yellow main clusters). In the red cluster, the words and phrases 'Gulf of Guinea', 'blue crime', 'West Africa', and 'network', came to forefront. In the blue cluster, 'maritime security', 'regime complexity' and 'fragmentation' were observed. In the green cluster, 'Nord Stream attack', 'critical maritime infrastructure', and 'cyber security' became prominent. Finally, in the yellow cluster, 'piracy', 'maritime crime', and 'sustainable development goals' were frequently used in the related articles.

Among the authors, Christian Bueger is the most cited researcher with 36 citations, while Timothy Edmunds ranks the second with 34 citations. Most studies were published from 2019 onwards, with South Africa and United Kingdom being the first two countries where research were conducted.

3.2. Web of Science VOSviewer Analysis and Its Findings

Within the search conducted and refined through Web of Science database, among the keywords, "piracy" scored the highest with a frequency of four and a total link strength of 17. While the frequency of "transnational organized crime" is two, it is the second keyword with a total link strength of 11. The frequency of "maritime security" occurrence is two with a total link strength of 10.

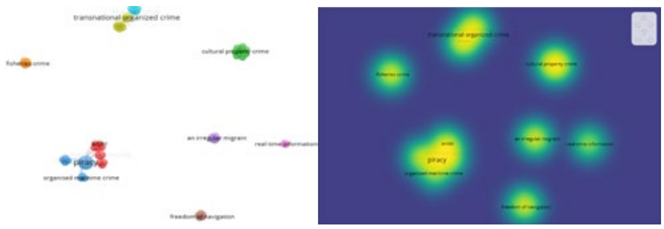

Figure 2. Mapping analysis based on text data network and density map – Web of Science

Figure 2 shows that the most frequently repeated terms in the related literature are grouped into nine main clusters (red, blue, green, orange, purple, pink, brown, yellow and light blue main clusters). In the red cluster, the word 'arctic' came to forefront. In the blue cluster, the 'piracy' and 'maritime organized crime' were seen (maritime security is seen in a faded mode). In the green cluster, 'cultural property crime'; in the orange cluster 'fisheries crime'; in the purple cluster 'an irregular migrant'; in the pink cluster 'real time information'; and in the brown cluster 'freedom of navigation' were prominent. Finally, in the yellow cluster, while the word 'transnational organized crime' was seen on top with a light blue (together with a 'blue criminology' in a faded mode nearby) was frequently used in the related articles.

Among the authors, Christian Bueger and Timothy Edmunds are the most cited researchers, each with a citation number of 37. Most of the studies were published from 2019 onwards, with South Africa (4), United Kingdom (2), Denmark (2), and Australia (2) being the first countries where research was conducted.

3.3. MAXQDA Analysis and Its Findings

Firstly, all references except [1,17,23-26] are coded and their word frequencies are determined using the MAXQDA-MAXDicto function by excluding numbers, years, conjunctions etc., and merging similar words such as "fishing" "fisheries". Figure 3 below provides word cloud.

Figure 3. MAXQDA word cloud

Among the words in the word cloud, maximum frequency of "crime" with the frequency of 1443, and overall percentage of 95.45% amongst documents used. Fishery, maritime, vessel and security are among the most frequently used words. First five most used words and their percentages are shown in Table 1.

Table 1. First five word's weight and percentages within the word cloud

Word	Frequency	Rank	Documents	Documents (%)
Crime	1443	1	21	95.45
Fishery	1398	2	17	77.27
Maritime	839	3	21	95.45
Vessel	666	4	20	90.91
Security	664	5	22	100.00

Secondly word combinations are analyzed. A total of 91-word combinations have been examined. Similar words such as "organized crime(s), criminal network, transnational organized crime etc." are merged. The combination "Organize[d] Crime" stands out with 710 occurrences, indicating that the concept is more generally used instead of "blue crime". Second most frequently used word combination is "fishery crime". Based on these results, it can be inferred that fishery crimes has a strong correlation with [transnational] organized crime. Figure 4 below provides word combination cloud and first five most used word combinations and their percentages are shown in Table 2.

Figure 4. MAXQDA word combination cloud

Table 2. First five-word combination's weight and percentages within the word cloud.

Word	Frequency	Rank	Documents	Documents (%)
organize[d] crime	710	1	18	81.82
fishery crime	468	2	16	72.73
law enforcement	340	3	16	72.73
maritime security	224	4	13	59.09
blue crime	135	5	11	50.00

Thirdly, by coding every document chosen to classify hierarchically "transnational organized crime at sea" and to find subcategories associated with it, the MaxMaps –

"Hierarchy Code-Sub Code Model" function was used. Below is a model depicting hierarchy of sub-crimes related to transnational organized crime at sea and their corresponding code frequencies.

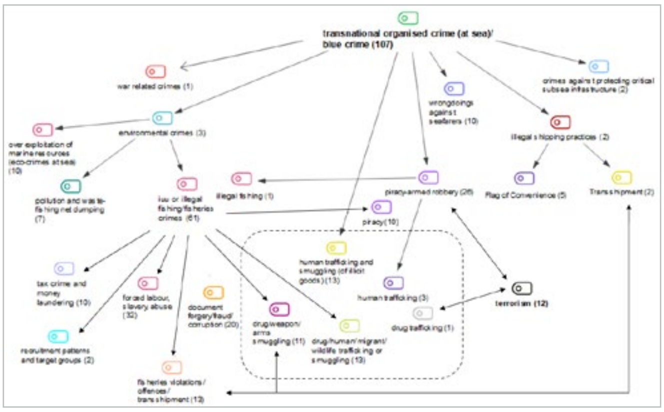

Figure 5. MAXQDA hierarchical classification of transnational organized crime at sea.

The Hierarchy Model shows that among the seven subcategories under transnational organized crime at sea (war related crimes, environmental crimes, human trafficking and smuggling of illicit goods, piracy-armed robbery, wrongdoings against seafarers, illegal fishing practices and crimes against protecting critical infrastructure), environmental crimes along with their subcategories –particularly IUU– has the highest frequency of code followed by piracy and armed robbery. Studies have revealed that IUU is also associated with piracy, with a frequency of 10, while the link of piracy over IUU frequency is very low.

Another remarkable point is the relationship of trafficking and smuggling with IUU, piracy, and terrorism (as shown with a dotted rectangle). Although some studies refer to maritime terrorism as "political piracy" [5], terrorism is depicted not directly under transnational organized crime at sea because it is not included in the definition explained above.

Wrongdoings against seafarers are categorized as both directly under transnational organized crime at sea and a subcategory under IUU. These are not only a crime against fishers but also other seafarers working in different type of ships. These crimes increased significantly and were made more public after coronavirus (COVID-19) pandemic.

Crimes against critical subsea infrastructure represent another significant category of crime although it can be considered a new concept, particularly after Nord Stream 1-2 pipeline sabotages in 2022 [24]. In this area, potential harm to undersea fiber-optic cables could affect the whole world, particularly the global trade, due to interruption in Internet access.

War related crimes, although occurring infrequently, constitute another transnational crime, particularly considering the recent Houthi attacks against merchant and war ships navigating the Red Sea. Its transnational nature comes from –although it is a non-state actor– Houthis' link with Yemen and Iran and different nationalities of the ships attacked. Besides, the use of unmanned vessels both in Russia-Ukraine war and within the scope of Israel-Hamas war, requires attention to this area [25].

Another finding is the absence of cyber-crime related studies discussing transnationality although it is an evolving transnational crime according to United Nations Office on Drugs and Crime (UNODC) [26].

4. Conclusion

Recent changes in geopolitics and technology have had a significant change in the nature of maritime security, with transnational crimes now being one of the primary threats to it. In addition, blue crimes –a respectively new term– replacing transnational organized crime at sea are gaining more attention from academics and policymakers.

Studies on fisheries crimes or IUU within the realm of transnational organized crime at sea constitute a significantly high proportion compared to other types of crime. It may be argued that the high amount of people depend on fishing for their livelihood and the depletion of fish stocks drives people to commit crimes in this area.

Piracy is still a major concern in terms of blue crimes and there is a strong correlation between terrorism and piracy according to the studies examined. There is also strong correlation between terrorism and drug trafficking due to the potential of using sea routes to transport drugs, such as the submerged vessels carrying narcotics (narco-subs) in the South America. Studies have also revealed that smuggling and trafficking are associated with IUU as well.

War related crimes, crimes against protecting critical infrastructure and cybercrimes are also transnational organized crimes at sea. However, there are limited studies examining their link with transnationality.

The concept of blue crime whose subcategories are interwoven and scope is not yet definite, requires more attention. More studies are necessary to explore its subcategories, including connections, common traits, root causes, and to tackle with those crimes, and whether if existing legal frameworks are adequate.

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Comparing The Fatigue Levels Between Maritime Faculty Students and Other Students with Student's t-Hypothesis Test

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Abstract

The word fatigue is defined in many business platforms as the human body being unable to work efficiently. It is well known that this situation causes bad situations such as accidents and injuries. The effects of fatigue at sea are dangerous, as maritime workers must be careful and highly motivated. In addition, they are different from other professionals because they stay away from home, have little contact with their colleagues, and have an intense and demanding work schedule. The health, and even the lifespan, of seafarers working in such conditions can be affected by fatigue and poor performance. Seafarers' health is negatively affected by factors such as sleeping too little, not getting enough rest, headaches and dizziness, poor nutrition, malaise and unnecessary worry, slow reactions and loss of concentration. In addition to the effect of fatigue on sailors, its effect on maritime students is also important. In this study, an attempt is made to compare the fatigue levels of maritime students and other students by the student's t -hypothesis test with two independent samples. The data are collected by Fatigue Assessment Scale (FAS) which is a 10-item scale evaluating symptoms of chronic fatigue.

Keywords: *Fatigue, Maritime, Hypothesis Test*

1. Introduction

The word "fatigue" is used to describe the situation in which the body is not in a position to work efficiently in various working platforms. However, there is no generally used definition of fatigue. This definition is most often used for physical conditions that occur due to intense physical or mental work, anxiety, exposure to adverse conditions, or lack of sleep. Essentially, fatigue results from decreased physical and mental energy during the work performed during the day and the inability to maintain balance in the process of regaining body and mind activities after this energy decrease. Fatigue causes accidents and injuries among many maritime workers. Since maritime workers need to be constantly careful and focused, the negative effects of fatigue are dangerous because maritime life requires particular importance and precautions. Other distinguishing aspects, such as being away from the home environment they live in, not being able to meet with friends and relatives enough, and constantly busy work tempo, also make it different from other work areas. The health, and even the lifespan, of seafarers working in such conditions can be affected by fatigue and poor performance. Therefore, fatigue is very important in maritime work and is due to many reasons such as not getting enough rest, lack of sleep, stress and intense work tempo. It is well known that fatigue poses many risks in maritime operations. It can cause serious accidents, injuries and also adversely affects the health of seafarers by factors such as sleeping too little, not getting enough

rest, headaches and dizziness, poor nutrition, malaise and unnecessary worry, slow reactions and loss of concentration. It has been determined that the rate of falling asleep while on the job is one in four among sailors, that weekly working hours are mostly over 85 hours, that these factors endanger their personal safety and that 25 percent of work accidents occur due to these reasons. Considering these negative factors, fatigue can be reduced by using appropriate statistical methods. Negative factors can be identified through surveys, interviews and observations, and positive corrections can be made in different observation groups with appropriate statistical methods.

The negative impact of fatigue on seafarers and what needs to be done to cope with it have been investigated in many studies in the literature [1-15].

In this study, the fatigue levels of maritime faculty students and other faculty students were compared. An attempt was made to check whether the intense fatigue effect of working life on seafarers also affects them during their student years. It is also important to investigate whether students can foresee the busy working life that awaits them. "The Fatigue Assessment Scale", which has internationally accepted reliability and validity, was used to measure the impact among students [16]. With the data collected from the students with this scale, a hypothesis was created about the effects of fatigue among the students and tested with the t-Hypothesis Test [17].

2. Methodology

In Daily life, it is mostly tried to make decisions about the population with the information which are taken from the samples of the population. The important point is here to determine whether the differences between the samples and the population are due to sampling errors which are the results of random selection or whether there is a real difference. It is decided as results of some tests whether these differences are statistically significant or not. Populations are known with their probability distributions. As these distributions are known, the decisions to be made about the population become certain. Another way to make decisions about populations is by sampling. Parameters of the distribution of the population can be estimated with the help of appropriately selected samples. With the help of these estimate certain assumptions, various decisions are made about populations or their distributions. While making these decisions, either an estimate is made or a certain assumption is made about the subject. Such assumptions whether or not they come true are called hypothesis. A hypothesis is a prediction whose accuracy is tried to be tested with a research or experiment. Hypotheses tests statistical methods that allow making statistical comments on the subject by collecting appropriate population data on various subjects. It is an analysis method that evaluates the collected data and determines the probability that the subject to be tested is correct. In hypothesis tests, a certain number of data about the subject to be examined are taken from various populations and an attempt is made to reach an acceptable conclusion whether there is a significant difference between the populations. Hypothesis testing can be defined as a statistical tool that is used to identify if the results of an experiment are meaningful or not. It based on setting up a Null Hypothesis usually denoted by (H0) and an Alternative Hypothesis denoted by (H1). Null Hypothesis is a starting point, it indicates that there is no significant difference between the groups or populations that are tested. It is tested whether the value stated in the Null Hypothesis is likely be true. Alternative Hypothesis claims that there is a significant difference between the groups or populations that are tested. It is a statement that directly contradicts a Null Hypothesis by stating that the actual value of a population is less than, greater than or equal to the value stated in the Null Hypothesis. Alternative Hypothesis states that the Null Hypothesis is not valid. Alternative hypothesis is set up in two types, these are one-tailed and two tailed tests. A one tailed test is set up to show that the sample mean or proportion is less than or greater than the population mean or to show that the mean or proportion of one population or one sample is less than or greater than the other one. A two

tailed test is set up to show that the means or proportions are not equal to each other. H0 and H1 hypotheses are usually set up as follows:

H0: There is no difference between the value obtained from the sample and the known value of the population.

H1: There is a significant difference between the value obtained from the sample and the known value of the population.

Usually, researchers want the H0 hypothesis to be rejected and the H1 hypothesis to be accepted. The proposition that has been considered valid for a long time becomes the H0 Hypothesis, and the new becomes the H1 Hypothesis.

The FAS scale was used to collect data in this study. This is a 10-item scale evaluating symptoms of chronic fatigue [16]. The score obtained from this scale varies between 10 and 50, and as the score increases, the reported fatigue severity increases. This scale was applied to 108 maritime faculty students and 68 other faculty students in Istanbul Technical University. The average fatigue score of Maritime Faculty students was 28.85, and that of other faculty students was 31.05. Based on these data hypothesis test is constructed as:

H0: The average fatigue score of Maritime Faculty students was 28.85, and that of other faculty students was 31.05.

H1: Students outside the Maritime Faculty feel more tired.

This hypothesis was tested with a two-sample t-hypothesis test and the evaluations are given in the results section.

3. Results

The average fatigue score of Maritime Faculty students as 28.85 and the standard deviation was 10.88. The average fatigue score of other faculty students was 31.05 and the standard deviation was 9.41. Since the general populations' standard deviations were unknown, the student-t test was used. To use this test, it must be checked whether the population standard deviations are equal. This situation is checked with the F-test. The critical value of the designed hypothesis according to the F test was found to be 1.33 and the F critical is 1.56. Since the F value of the hypothesis created is less than the F critical, the standard deviations of the main populations should be accepted as equal. The standard deviation, which is equal for the populations, was calculated as 10.34 and the t-value for the created hypothesis was calculated as 8.9. The critical t-value can be calculated as 1.646 at a significance of alpha 0.05. Since the t-value of the hypothesis created here is less than the t-critical value, the H0 hypothesis is rejected and the H1 hypothesis is accepted. This result shows the students other than the Maritime Faculty have higher fatigue scores.

4. Conclusions

Studies show that fatigue creates many negative effects in business life. According to the Sleep Health Foundation, fatigue "refers to physical and mental symptoms such as slower reaction times, poor mood, inattention and trouble focusing." These poor conditions can prevent safe working and lead to further mental and physical health problems. Research shows that the effect of fatigue on seafarers is similar to the effect of alcohol and that fatigue can cause heart and nervous system diseases. Especially, Seafarers work in a heavily regulated industry, facing a workload that is physically and mentally challenging. In this study, fatigue levels of university students were measured. Maritime faculty and other faculty students were evaluated separately. It was determined that both groups of students had high fatigue levels. This result is important for them to be aware of the high level of fatigue they will experience in their future work lives.

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The Relationship between Workload, Work Stress and Burnout in Masters and Deck Officers

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Abstract

Seafarers may encounter various problems such as excessive workload, unsuitable working environment, irregular and inadequate rest hours, mobbing by superiors and shipowners during their service on ships. In addition, social life and being away from loved ones can lead to burnout, which can affect the whole organisation and create problems in ethical and human values. Emotional burnout and job dissatisfaction may occur in connection with professional burnout of the personnel, and with this, work efficiency may decrease and situations such as leaving the ship and profession may occur. In this study, the relationship between workload, work stress and burnout of ship captains and deck officers was examined, although it is known that every seafarer faces similar situations. In this study, workload and stress levels were examined using the organisational stress scale and burnout status was examined with the Maslach burnout inventory. In this study, 250 people with ship captain, deck officer and deck officer qualifications were reached. Data evaluation of the study was carried out with SPSS 28 programme. As a result of the study, the most important reasons forthe masters and deck officers to feel burnout were stated as being away from land, social life, workload and stress.

Keywords: *Maritime, Seafarers, Burnout, Workload, Work Stress*

1. Introduction

Maritime is a profession that requires attention in difficult sea and weather conditions as well as physical and psychological strength. In working life, the work environment in which the person is in is one of the most important factors affecting performance. In the maritime sector, the ship in which the ship is located, the route on which the ship moves and the facilities of the ship are of great importance due to the fact that the seafarers both work on the ship and have to maintain and live there for a certain period of time. Apart from the difficulties of living on board, the working order and the individual's ability to adapt to this order is extremely important. On the one hand, seafarers will consider the safety of the ship, cargo and the environment and strive to add value to the customer, perhaps without realising it. On the other hand, they struggle with natural conditions, inspections, operational difficulties and the difficulties of being away from the land and social environment that cause deprivation. Seafarers may encounter various problems such as excessive workload, stress arising from the nature of the work, inappropriate working environment, irregular and insufficient rest hours, mobbing by superiors and shipowners during their service period on board.

With intense competition and globalisation, working conditions bring about intensive working hours focused on efficiency and productivity. In this context, the attitudes and behaviours exhibited by employees in environments where working conditions are intense and working hours are uncertain are important [1]. Mo and Zhang (2020) provide insights into the psychological consequences of uncertainty and stress in this population by examining the mediating role of occupational stress, job burnout and psychological capital in Chinese seafarers [2].

In addition to the factors that can cause burnout in different occupational groups, the causes of burnout specific to seafarers within the ship; limited living environments, short port periods and the need to carry out port and flag state controls in these short port periods, shortening of the already short port period, making it difficult for seafarers to get off the ship and increasing the workload, low quality sleep, working even at night, insufficient rest times between shifts, noise and vibration conditions on board can be expressed as factors that may cause burnout in seafarers [3]. There is also a mental dimension of workload. In the study conducted by Özsever and Tavacıoğlu, it was noted that the participants' perceived mental workload (MWL) levels and heart rate variability (HRV) values changed significantly at different levels of different navigation tasks, and MWL and HRV increased as the task difficulty increased. In addition, the relationship between participants' perceived mental workload and heart rate variability was found to be statistically significant [4].

According to the study conducted by Carotenuto and colleagues, which is among the studies examining stress in two ways, objective and subjective, when it comes to subjective factors, people's perceptions are at the forefront and therefore job satisfaction is in question with their individual evaluations. Despite the obvious interest of individual evaluations, it is obvious that it is difficult to determine subjective factors. It is thought that more than half of the accidents at sea are caused by these subjective factors and that these factors are the leading reason for wanting to leave the job. On the other hand, objective factors include the conditions (vibration, temperature change, shaking, noise, etc.) under which the maritime occupation is performed. Apart from the conditions under which the work is performed, objective factors include social and organisational aspects such as excessive responsibilities, sleep problems, being away from loved ones and families, monotony, low job satisfaction, lack of career prospects, work intensity. It is observed that these factors can damage seafarers' physical and psychological competences.

Maritime labourers are exposed to factors directly related to stress such as long and irregular working hours, distance from family and social life, isolation from life on land, exhaustion, danger of pirates, lack of sleep, work stress, risk of work accidents at sea, multinational working environment with various cultures from various countries, diseases (no doctor on board), lack of limited hobby activities, negative external factors, negative abuse of subordinate-superior relationship arising from hierarchical structure. The long separation of seafarers from their families and loved ones increases the stress level and leads to negative consequences for their physical and mental health. According to research, the three main psychological problems identified among seafarers are loneliness, homesickness and burnout syndrome [5]. Due to these stress factors, it can be said that seafarers are at risk of burnout.

Physical or mental stress on board was reported by about %65 of the participants in the total study sample. There are significant differences between respondents' feedback on stress exposure according to their qualification. While %74 of personnel at lower levels of qualification felt physically stressed more often, more than %86 of deck officers experienced mental stress more often. According to the anamnesis data, the average working time on board is 9.5 hours, with officers of the watch having significantly longer working hours than other positions on board [6]. When we examine the literature, in another of the limited publications, Borovnik (2011) stated that the pressure increasing with the time worked on the ship, being away from the family and work stress have effects on the emotional health of maritime labourers, and that work stress is more common on ships in terms of physical and emotional aspects. In addition, he stated that working on ships has two main factors related to health and safety. These are the factors arising from the nature of the profession, such as the type of ship, the department, the movements of the ship due to sea and weather conditions, and social factors related to emotional stress, such as working in a limited space on board, being away from family, loneliness and longing [7].

According to research, the three main psychological problems identified among seafarers are loneliness, homesickness and burnout syndrome [5]. Due to these stress factors, it can be said that seafarers are at risk of burnout. Apart from the difficulties of being in a ship environment, the working order on board and the individual's familiarity with this order are extremely important. On the one hand, seafarers will give serious importance to the safety of the ship itself, the goods carried and the environment, on the other hand, they will struggle with heavy sea and weather conditions, inspections, port operations, lack of social life brought about by life away from land and loved ones in a deprived environment. In all this struggle, it seems inevitable that they will be unhappy, unsuccessful, experience apathy and burnout. In a study conducted using the Maslach Burnout Scale and Personal Information Assessment Form, it is noteworthy that being away from family increased the feeling of personal failure. In addition, when the effect of burnout syndrome on seafarers was examined, emotional exhaustion and depersonalisation were found to be high in half of the employees. When the dimension of Decrease in Personal Achievement was analysed among the findings, it was determined that the majority experienced high levels of burnout. According to the research, the most affected group of seafarers is the group between the ages of 25-29 with 1-5 years of experience [8].

According to a study conducted on cadets and officers, cadets found to be weaker and more sensitive in coping with stress than their more experienced superiors due to their young age, inexperience and concerns about overcoming the problems they face at sea [9].

2. Methodology

This study is a research in 'survey' model. The survey model analyses the existing situation the situation that is the subject of the research, which aims to analyse and describe the situation as it is to explain it in its own terms, as it is, without changing or affecting it [10]. In this study, the existing behaviour of the respondents was also examined. Since it is aimed to examine the existing situation without disturbing its functioning, the survey model is a research. The sample of this research consists of seafarers who have the competency of master and deck officer. In the light of these conditions, a sample group of 250 seafarers was formed.

In the research, both qualitative and quantitative methods were used, questionnaire and semi-structured interviews were conducted. The research questionnaire consists of three sub-sections in total. Informed Consent Form explaining the purpose and content of the research, Sociodemographic Information Form, Organisational Stress Scale, Maslach Burnout inventory were used to obtain demographic information of the participants.

Sociodemographic Information Form was prepared to obtain detailed information about the sociodemographic information of the participants. The sociodemographic information form includes demographic information such as gender, age, education, marital status, marital status, having children, as well as questions about the position of the participant on the ship, how many years he/she has been working on the ship, the duration of the last voyage and the type of ship, the shift hours on the ship, the situations that force the person on the ship and the need for psychological support. The data were analysed using spss 28.0 package programme. Kolmogorov Smirnov test showed that the data were normally distributed. Descriptive statistical methods (mean, standard deviation, frequency) were used to evaluate the study data.

3. Conclusion

In working life, the environment where people work and the people they work with have an important effect. has. Although this situation is important in every field of work, it is more different in the ship sector. It is of great importance because the type of ship, the materials it carries, the travelling a profession that contains quite a lot of risk factors due to its itinerary group. In this respect, the ship environment in which people working on the ship work It is thought to have a significant impact on their lives and the life they lead on board.

When the scores of the seafarers participating in the study from the organisational stress scale are examined, various differences can be seen between demographic information and scale sub-dimensions. When the scale data are examined, there is no difference between the answers given by the participants to the scale questions and scale sub-dimensions according to the variables of ship type, voyage duration and education, while there is a significant difference between the answers given to the organisational stress scale and scale sub-dimensions according to the shift hours they keep on the ship. Long working hours can also cause stress in individuals. As a result of the responses of the participants, there is a significant difference between the shift hours of the seafarers and the workload, control dimension and social support sub-dimensions of the organisational stress scale. there is a differentiation, and it is concluded that the person is under stress according to shift hours concluded.

The relationship between burnout and stress factors in the burnout scale sub-scale emotional burnout, which is one of the dimensions, and job burnout, which is one of the sub-dimensions of the organisational stress scale positive correlation between emotional burnout and social support dimension, emotional burnout and social support dimension There is a negative relationship between depersonalisation and workload. The relationship between depersonalisation and workload a positive relationship between depersonalisation and social support and a negative relationship between depersonalisation and social support was found. There was a negative correlation between personal achievement and workload, and a negative correlation between personal achievement and social support was found to be positively correlated. To determine the relationship between excessive workload and burnout according to the analysis, excessive workload has a positive and significant effect on burnout level as a significant effect on the behaviour. According to the analysis conducted to determine the relationship between excessive workload and job stress, it was found that the excessive workload to which master and deck officers were exposed had a significant positive effect on work stress.

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Continuous Automated Red Teaming Approach For Maritime Security

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Abstract

Continuous Automated Red Teaming (CART) approach presents a transformative paradigm for maritime cybersecurity, offering a proactive and adaptive defense strategy. The goal of this study is to develop and implement a CART framework tailored to the unique challenges of maritime cybersecurity. By simulating realistic cyber-attacks continuously, the framework aims to proactively identify vulnerabilities, assess defense mechanisms, and enhance the overall resilience of maritime cyber assets. The framework continuously generates and executes simulated cyber-attacks, mimicking the tactics, techniques, and procedures employed by real-world adversaries. This enables a dynamic evaluation of the effectiveness of existing security measures and facilitates prompt adjustments to counter emerging threats. Preliminary results indicate a significant improvement in the detection of vulnerabilities within maritime systems. The CART framework is deployed in a real-world environment. The results showed that the framework is effectively revealed vulnerabilities and contributed to risk and management process. Additionally, It was a study that will pioneer scientific research topics in which CART can be used effectively in the development of real-time defense mechanisms and improvement of incident response to simulated attacks thanks to the continuous nature of the red teaming approach. This study sets the stage for further research and development in advancing cybersecurity measures tailored to the unique challenges of the maritime domain.

Keywords: *Red teaming, offensive security, maritime cyber security, continuous security*

1. Introduction

Today's infrastructure, which connects almost all kinds of complex electronic systems and manages them over computer networks to various extents, causes commercial / corporate ships to be managed over network systems. Networked systems are also exposed to cyber security risks at various levels according to their working principles and these risks need to be managed continuously and consciously. However, in order to ensure a continuous and conscious management, it is necessary to train stuffs who have special training for cyber security in maritime industry that can take part in the maritime sector. In addition, considering the fact that these stuffs are constantly employed in ports, institutions and vessels, a great cost arises. For this reason, beyond academic studies, we will discuss how autonomous cyber security methods, which are used in the field and whose scalable structure can be transferred to the maritime sector, can be applied in this sector. Our aim in this study is to present an alternative method for ensuring the cyber security of the maritime sector and vessels.

Continuous Automated Red Teaming (CART), which we will discuss in this study, offers a scalable, continuous, autonomous and low-cost methodology. The purpose of using CART is to continuously detect cyber security risks that organizations may be exposed to by keeping the human factor and cost at minimum, and to inform organizations about these risks instantly and to eliminate risks much faster. Therefore, with the use of CART, the maritime sector and vessels will be continuously tested from an attacker's perspective and risks will be identified as immediately as possible.

Instant detection and prevention of attacks on vessels is as important for organizations as identifying attack points and mitigating vulnerabilities. In this study, while identifying attack points using CART methodology, methods to increase the visibility of attacks and attackers are integrated into the CART architecture and it is aimed to provide a customized method for the maritime sector.

2. Literature Review

The maritime industry has historically focused on physical security threats like piracy and theft. However, the increasing integration of digital technologies onboard vessels has opened new avenues for cyberattacks. These attacks can target various systems, including navigation [1], communication [2], and cargo management [3], potentially leading to disruptions, safety hazards, and financial losses. The 2017 NotPetya attack serves as a stark reminder of the far-reaching consequences of cyber incidents at sea [4].

In response to these growing threats, the International Maritime Organization (IMO) has released resolutions emphasizing the importance of cybersecurity for vessels [5]. Classification societies like the International Association of Classification Societies (IACS) are also developing guidelines for operational technology security onboard ships [6]. While these initiatives represent a positive step, there is a need for more proactive measures to identify and address vulnerabilities before they are exploited.

Traditional cybersecurity approaches in the maritime industry often rely on reactive measures such as vulnerability assessments and patching outdated software. Although these methods are effective, they have some limitations. Vulnerability assessments are typically conducted periodically, leaving a window of opportunity for attackers to exploit newly discovered weaknesses. Similarly, patching can be time-consuming and disruptive to vessel operations.

Red teaming is a well-established cybersecurity practice that involves simulating real-world attacks to evaluate an organization's defenses [7]. Traditional red teaming exercises are typically manual and resource-intensive, limiting their frequency and scope.

CART emerges as a potential solution to overcome the limitations of traditional red teaming. By employing automated tools and techniques, CART can simulate cyberattacks on a continuous basis. This allows for the constant evaluation of a vessel's cyber defenses, enabling the identification and remediation of vulnerabilities in a more timely manner. However, the application of CART in the maritime environment presents unique challenges. Limited bandwidth availability, the harsh physical environment at sea, and the potential for disruptions to critical systems necessitate careful consideration when implementing CART onboard vessels.

While the potential benefits of CART for maritime security are recognized, research exploring its specific application and effectiveness in this context remains limited. This study aims to bridge this gap by analyzing the feasibility and effectiveness of implementing CART on vessels, addressing the unique challenges of the maritime domain.

Red teaming is considered in maritime domain as an identification method against terrorism [8]. Time after time, military based red teaming approach aims to uncover vulnerabilities in operational tactics is proposed with evolvable simulation to automate red teaming activities in operational level [9]. Also, an objective based data farming approach is also used for red teaming again in operational level [10]. Although red teaming approach is considered in maritime domain in operational level, it has never been clearly considered in terms of cyber security or offensive security in the literature.

3. System Design and Infrastructure

The increasing level of technology and autonomy in the maritime industry for many reasons brings new risks. CART methodology provides a method for organizations to monitor cyber security risks or vulnerabilities instantly and eliminate these risks as quickly as possible. For CART to be used in the maritime sector, a generic solution that is suitable for this sector and can be used in almost every vessel and organization should be offered. Figure 1 shows the architecture of a CART software used in a real-world scenario.

As shown in a sample CART architecture in Figure 1, after collecting all information and sub-targets about the target with an input specified via the server, attacks, vulnerability scanning and threat intelligence studies are carried out on the relevant target. If any vulnerability is detected, it is sent to the notification module and instant notification is sent to decision makers.

Within the scope of our study, it is important to determine how the targets will be determined, what the assets on the ships are and therefore what the targets are. While conducting cyber security studies, it is necessary to identify the assets, threats to the assets and the risks posed by these threats. Since this study deals with the application of the CART methodology to the maritime sector, the determination of assets, threats and risks is the subject of another study, but studies on this subject in the literature have been utilized.

Proposed CART system for maritime sector focuses on off-line security research and universalize the attack vectors particular to maritime assets to all targets. To achive this, a continuous connection is a must between the vessels and a command-and-control center (C2) such as a port. The attack vectors developed by the security researchers, red team of the organization, global vulnerability databases or a third party can be transferred from C2 to vessel in a strict data format as proposed in the CART system. Such a methodology set the ball rolling to the creation of a knowledge base in the sector in terms of offensive security.

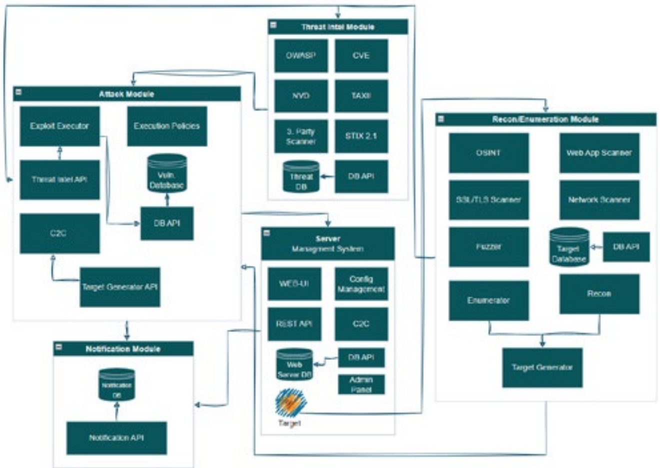

Figure 1. CART System Model Overview

3.1. Identifying Entry Points and Risks

In the study, it was seen that the risks that may occur for ships in the maritime sector can generally arise from three points. These are identified as risks that may arise directly from the ship, stuff and the environment in which the ship is located, risks that may arise from commercial off the shelf (COTS) products on the ship and risks arising from the companies responsible for the operation of the ship. Vulnerabilities identified in the vessels and environments used in this study confirm these risks. In the maritime industry, risks can come from both ships and the industry's supply chain. According to the assets where the risk originates, it is also feasible to identify and rank the attackable points.

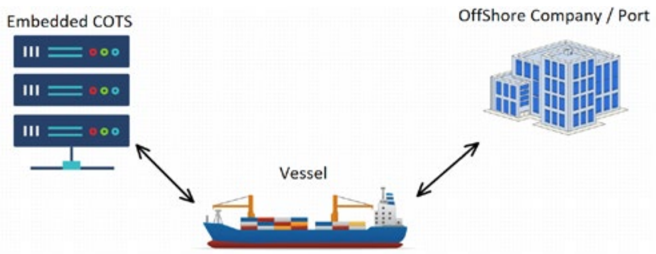

Figure 2. Entry Points That May Pose A Risk

In this study, it has been observed that vulnerabilities on board a vessel affect not only the environment or the vessel where the vulnerability occurs, but also affect the companies that produce COTS products on the vessel and ports or companies operate the vessel. The next section explains in detail how vulnerabilities at vessels affect companies and businesses.

3.2. Implementation

Proposed CART system's feasibility is considered in a real-world scenario. Predefined asset discovery, enumeration and vulnerability scanning methods in the proposed CART system are executed in a vessel. The CART agent is controlled via the remote location over a VPN connection that is already established between C2 and the vessel. The proposed system is initially has nothing much related to maritime security specific attacks. The CART approach forces the security research activities to find the new ways of both asset discovery and attack vector. So, our research team also focused on the identification of the risks and vulnerabilities on the vessel.

In order to identify the risks, studies were conducted in two different environments, both in the laboratory environment where GPS systems identical to the vessel's and on a search and rescue vessel. Our team mainly focused on identifying vulnerabilities rather than developing attack paths in the implementation phase. Since attackers use a wide variety of methods, we believe that it would be more useful to focus on vulnerabilities rather than attacks. In the study, it was determined that the vulnerabilities that may arise on IT systems pose a risk to both the ship, the companies producing COTS systems and the port or companies responsible for the operation of the ship.

During the implementation, it is clearly seen that in a non-interconnected environment, CART approach is not feasible and efficient. According to the recently proposed pure due model for the vessels, interconnection between IT and OT systems will be provided via a network infrastructure and updated OT protocols will be running on ethernet frames. With coming into force of the new standards and pure due model, CART approach will be beneficial and much more efficient for maritime domain.

During the security research on the vessel the most important findings are as follows;

With the passwords obtained from the computers running GPS and ECDIS systems, it is possible to access the servers used by the company producing the COTS system to distribute the maps with a user who has read, write and run permissions. It was found that the relevant server also contained mapping information belonging to other vessels. This is considered as a finding that could jeopardize the security of both the COTS company and other vessels using the same COTS product.

It has been confirmed that data communication (FTP/HTTPS, etc.) between the vessel and COTS product owner companies is done over insecure connections and protocols.

In the computers where ECDIS and GPS systems were running, username and password information belonging to the company that owns and operates the vessel were found in DLL and configuration files. It was determined that some of these passwords were stored as Base64 encoded form and decoded successfully, while some of them were encrypted. The obtained users were determined as active AD users and have access to some SMB shares.

The passwords used to access the web interfaces of the ECDIS system were found to be default or simple passwords. The situation is thought to be similar for ECDIS and other systems.

It was found that communication between computers and devices is carried out via an unencrypted (HTTP) connection and that MITM (Man in the Mittle) attacks are possible and can be carried out. It is also possible that by sending false data to the interface of the GPS system, the positioning system may show another location on the map.

As can be concluded from the above findings, some of the risks affect the ship and onboard systems, while others affect ports, COTS manufacturers and companies. No company that connects to vessels online from shore or operates partially or fully online is immune to these risks. The study also found that some of the most significant attacks tend to damage the ship through the systems of companies and organizations and also been it has been shown that companies and institutions can be harmed through ships.

It has been seen that all of the attacks that may occur in AIS, ECDIS, GPS and IT network systems have been previously mentioned in [11] and it has been seen that the findings identified in our study can be matched with the vulnerabilities in this study.

3.3. Analysis of Findings

In this part of the study, the findings obtained will be presented together with the evidence and the possible effects will be discussed. After analyzing the relevant findings, it is aimed to measure the effectiveness of our proposed solution by discussing whether it can be found using CART methodology and software. The tests in the laboratory environment were carried out on GPS and ECDIS systems, and the serial ports were converted to ethernet ports for seamless attacks on the network.

3.3.1. Insecure Protocols, Using Default Password and Obtaining ECDIS FTP Password

FTP (File Transfer Protocol) is an unencrypted protocol used to allow systems to share files. Due to its unencrypted nature, it is considered insecure and is not recommended to use. During the vulnerability scans, it was found that the computer to which the ECDIS server is connected also has a web application that allows configuration via the web interface. It was observed that the username and password used to access the web interface were left as default. After logging in to the web application, it was found that the company's FTP username and password were also displayed on the interface as cleartext. It was verified that the passwords were correct by logging into the relevant FTP server, and it was observed that this FTP server, which is open to the internet, has all the read, write and execute permissions for the obtained user. It was observed that the FTP server was used for ECDIS and chart updates and uploads as touched upon [11].

In addition, data communication between ECDIS and GPS is carried out over the HTTP protocol. Like FTP, HTTP is a communication protocol that is considered insecure and it is recommended to use HTTPS instead of HTTP. It is thought that this situation is also ignored due to the fact that the systems running on the ship are in a closed network. With a simple python code, the data sent by the GPS to the ECDIS was forged and the fake packet was successfully sent to the ECDIS server.

Using CART methodology and software, the presence of an insecure FTP connection both on board the ship and at the company producing the COTS software can be easily detected with simple scans. The presence of an FTP port open to the internet is reported to the company on the first scan. In addition, it is possible to detect that the HTTP server on the vessel where passwords are captured is not secure, default username and password are used, and FTP password information is available on the interface with a software using the CART methodology. Therefore, in the context of this vulnerability, the security of both the vessel and the COTS company that produces the systems on the vessel can be protected with the use of CART.

3.3.2. Obtaining AD and SMB Users and Passwords of the Company Operating the Vessel

Active Directory is a structure created to ensure that the user and service services in an organization and the accounts of their computers work smoothly and hierarchically on the same network. SMB (Server Message Block) is a network sharing protocol used to share files, printers, network, and processes.

In some configuration files obtained from the computers on board the vessel where this study was conducted, it was found that the usernames and passwords of AD users were stored in base64 encoded or encrypted form. The relevant user accounts are used to share files belonging to systems such as GPS and ECDIS on board and to update these systems. However, it was observed that the obtained accounts were in the company's AD domain and had access to SMB shares on some of the company's internal IP addresses. This is an example that the company or ports that operate the ship can also be affected by vulnerabilities on board.

Even if the use of CART methodology and software here cannot detect the passwords in the configuration files on the ship, the vulnerabilities caused by unauthorized access to the company's AD domain environment and SMB shares can be detected. To detect the vulnerabilities in this section, CART software must be installed on the company's internal network. Therefore, the use of CART helps to reduce or prevent the risks mentioned in this section.

4. Conclusion

The most frequently mentioned and researched cyber security vulnerabilities in the maritime industry focus on the risks posed by GPS, AIS and radar systems. This is because these systems are more important than other systems in terms of navigation and life safety. However, these critical infrastructures on ships bring many risks as they are either outdated platforms or not designed with cyber security in mind.

As a result, it is determined that the use of CART will help reduce the vulnerabilities and risks mentioned in this article in the maritime sector. In this case, the use of CART both in the internal network on the ship and in the internal and external networks of ports, companies and COTS manufacturers will provide great benefits.

Proposed CART approach in this study can pave the way for proactively preventing maritime domain specific threats by combining domain knowledge and offensive security skills. The proposed system also provides an infrastructure for developing domain specific threats, store the know-how in the system and create the lever effect on the target systems by sharing the developed attack vectors between the scopes.

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Women In The Maritime Industry

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Abstract

This study focuses on conducting research to understand the position and experiences of women in the maritime sector. The research is designed to understand the experiences of minority women in the industry, to assess the gender ratios in the industry and to identify potential challenges faced by women working in the maritime industry. The study provides valuable insights into gender dynamics and the role of women in the maritime sector. By highlighting gender inequalities and challenges faced by women in the industry, the research aims to support progress towards creating a more fair and equitable environment in the industry.

Keywords: *Women, Gender Dynamics, Maritime Sector, Equal Environment.*

1. Introduction

In order to ensure that social research is not incomplete and distorted, analytical perspectives need to be handled correctly. The results of research in the sciences show that women are excluded, deprived and rendered invisible in the processes of knowledge production. Therefore, there are parts of the progress of science that are missing or distorted. Feminist research has embarked on inquiries to reveal that the discrimination of women in the knowledge production process is not science but ideology [1].

Feminist historians started to use the concept of "gender" instead of "woman" from the 1980s onwards [2]. With the introduction of the concept of gender into the literature, studies on inequality began to be carried out, analyzing patriarchy as a political institution and analyzing power relations between men and women. With these studies, it has been revealed that differences between genders are more significant and effective than differences between classes [3].

Although the social roles of men and women vary according to culture, in no known society have women been more powerful than men. Society has always glorified the roles of men and avoided putting women in a visible position in society. Women have been pushed to take care of the home and children, while men have been directed to earn money for the welfare of the family. Research shows that men exert pressure and hegemony over women in all areas, including economic, political and familial [4].

Before the industrial revolution, women worked to help with domestic chores, especially in artisan and farmer families, but with the modernization brought about by the industrial revolution, workplaces started to leave the home and shifted to factories.

Especially until the 20th century, women's workplaces, which were mostly composed of jobs such as babysitting and servant work, have now shifted to factories and public spaces. Of course, the effect of the decrease in the domestic workload due to mechanization should not be ignored [5].

According to 2018 ILO data, only 48.3% of women participate in the global labor force. 42% of these women work informally. It is also revealed that women prefer part-time jobs more often than full-time jobs in order to spend time for housework and children.

From the employer's point of view, according to studies conducted in the UK, part-time jobs are low-paid and provide flexibility to the employer rather than the employee [4].

In some sectors, it can be seen that the concentration of employees is different according to gender. Some professions are seen and labeled as 'women's work' and others as 'men's work'. This is referred to as "sectoral segregation".

This segregation prepares the ground for gender-based discrimination. This is because the division of occupations according to gender also determines the values of jobs. Women are directed to occupations deemed 'appropriate' by families and societies. In sectors where women are concentrated, wages are low [3].

It should also be noted that this gender-based segregation is independent of muscular strength or other biological factors. Throughout history, countless women have disguised themselves as men and worked and served as soldiers in jobs that they could not have held simply because of their biological sex [6].

According to the data put forward by Price Waterhouse Coopers (PWC), 50% of working women internationally think that there is wage inequality between the sexes, while this result was found to be 31% in our country. Even in Sweden, the most prosperous country, women earn 18% less than men. This difference, which is easily visible especially in the starting salaries for the same position, reveals how important the gender factor is in the general low wages in so-called 'women's jobs'.

Although neoclassical economists often attribute this to educational attainment, it has been shown that low pay is not a matter of educational attainment. When we need to mention the part related to the problem of education, it is necessary to mention the studies on the fact that women are less educated than men in social structuring or even not sent to school at all [4].

Informal employment is the illegal, unregistered employment of workers away from protective regulations. One of the most important differences that distinguishes women's labor from men's labor is the high rate of informal employment. When women cannot find secure jobs, they turn to unregistered work out of necessity. Due to this situation, especially in small-scale enterprises, women work under conditions deprived of social rights [3].

2. Women in Maritime

The maritime sector is one of the sectors where gender inequality is seen quite intensely. The first known female seafarers in the world, Anne Bonney and Mary Reed, hid their gender, identified themselves as men and lived disguised as men [7].

At the 2010 Manila Diplomatic Conference, resolutions were adopted to promote women's participation in the maritime sector and to emphasize the right to equal access to maritime education. By emphasizing the role of women in maritime, it aimed to promote gender equality in the sector and to ensure equal access between men and women in all aspects of maritime. In addition, at the Millennium Development Goals (MDG) meeting, it was agreed to provide vocational training opportunities for women seafarers to ensure that they have the necessary practical experience to develop their profession [8].

Despite these decisions, women seafarers all over the world face problems that need to be solved. Despite its low rate, harassment is a major problem for women working at sea. Women seafarers can face various forms of harassment, ranging from verbal abuse to physical assault. In addition, women may initially have to seek acceptance and prove themselves. In the past, seafaring was thought to be a profession that required physical strength and therefore men were better suited to it than women, but today, thanks to technology, this idea has changed.

According to BIMCO and ICS data, the proportion of women at sea is 2%. While 1.81% of these employees work on cruise ships, the rate of women on cargo ships is only 0.12%. The majority of women working on cruise ships are hotel attendants. The distribution of ship personnel in the officer class is 8% for women and 42% for men.

The Middle East, Africa and India are the regions where gender inequality is the most prominent, with 25% of women in the maritime sector, while European women are generally concentrated in the sector [9]. In another study, the Maritime HR Association reported that only 5% of women hold managerial positions in the maritime industry. The situation is similar in educational institutions. A very low percentage of female students go on board. Although students aim to work as cooks, engine officers and deck officers, the majority are usually deck officers.

In 2015, the United Nations set a sustainable development goal to eliminate gender inequality. IMO also followed this call and launched a program called "Gender Equality and Capacity Building" in 2017. Within the scope of the program, women have been encouraged to the sector, career development programs have been carried out, and projects have been put in place for women to attend schools, especially in developing countries [10].

One of the biggest problems of women not finding a place in the maritime sector is the social role. It can be said that it is completely out of social roles for a woman to spend months at sea away from home and her family when it is difficult for a woman to even work because men do not take responsibility for starting a family, housework and childcare and all the responsibility is left to women. The main reason why most women give up their maritime career is the desire to start a family and find a job on land [11].

From the early stages of choosing a profession, women find themselves under both family and social pressure. For these reasons, women state that it is not possible to work on board while wanting to be a good mother [12].

It is generally believed that pregnancy and childcare is an important personal reason for leaving the profession, that companies do not want to hire women seafarers due to fear of pregnancy, and that childcare is not an obstacle for women to fulfill their profession. However, it should not be overlooked that women often feel under constant pressure on board and feel that they have to show what they can do [13].Another important problem is that 17% of women working on board have been sexually harassed [14].

The first problem encountered on board is that how sexual harassment is perceived can vary from country to country; a multicultural crew can make it difficult to promote gender equality on board, but can also lead to mistreatment of the other gender. For example, European female seafarers may experience different perceptions and expectations about gender when working alongside Asian male seafarers. This may mean that a German female seafarer may be able to dress sleeveless in front of a Romanian crew, but may be problematic in front of a Filipino crew. According to the report of the Gender Empowerment and Multi-cultural Crew project, it is also difficult to implement a gender equality approach on multicultural ships. This problem can also arise when temporarily posted workers are not aware of the existing legal regulations and procedures. In this context, Council Directive 91/383/EEC guarantees equal treatment for all employees of a company.

Harassment Includes a variety of physical, verbal and non-verbal behaviors. Sexual harassment falls into three categories: (1) gender harassment (verbal or nonverbal behaviors that convey hostility, objectification, exclusion or a second-class status), (2) unwanted sexual attention (verbal or physical unwelcome sexual advances, which may include assault), and (3) sexual coercion (adverse occupational or educational treatment based on sexual activity). However, there remains a problem of perception and therefore rejection of what sexual harassment is across societies, including both perpetrators and victims. Classifications can help us understand the everyday nature of sexual harassment [15]. The unwanted and offensive display of a relationship on the basis of sex or the misdirection of sexual desire is known as sexual harassment.

Sexual harassment has been legalized in many countries, especially after it was conceptualized in legal terms by Catharine MacKinnon in her pioneering book The Sexual Harassment of Working Women, published in the United States in 1979.

The Convention on the Elimination of All Forms of Discrimination against Women (CEDAW Convention), adopted by the United Nations General Assembly in 1979, recognizes acts of physical, mental or sexual harm or suffering against women as discrimination, including threats, coercion or other deprivation of liberty, as defined in Article 1 of the CEDAW Convention.

The 1998 ILO Declaration of Principles and Fundamental Rights states that with regard to the elimination of gender discrimination in the workplace, all ILO member States "have an obligation arising from membership of the organization, whether or not they have ratified the relevant conventions" and that 187 States have an obligation to provide a working environment free from discrimination, including sexual harassment [16].

In 2019, the ILO ratified the Convention on Preventing and Responding to Gender-Based Violence and Harassment, defining the term "gender-based violence and harassment" to include "violence and harassment against persons based on their gender or violence affecting a particular gender".

Another problem faced by women in the maritime sector is promotion. Companies do not allow women to become captains on ships, sometimes citing their 'emotional nature' and sometimes citing problems in ports. It is often easier to be the first female captain of the company. Companies gain prestige in the developing world by being the "first woman captain", but this is often not followed up [17].

When women seafarers start their jobs in most companies, they hear from the staff that there will be no problem in their promotion, but when the time comes, the contracts are extended and the work is dragged out. While many women have to change companies just for this reason, they may experience the same problems in their new companies, starting from the lower ranks and moving to the captaincy.

3. Women seafarers in Turkey

From the beginning of commercial maritime education at the undergraduate level until 1991, it was not possible to admit women students to maritime education institutions. It is noteworthy that most of the women who first went on board in Turkey in the 1960-1970s were the wives of seafarers. Although these women worked as stewards and mates due to their desire to be on the same ship with their husbands, they contributed to the emergence of the concept of women on board. Since the 1980s, Turkish women have started to take an active part in various branches of the maritime sector, but this development has been reflected more rapidly in the figures after 2000. The aim is to encourage the participation of female students in the maritime sector. However, it has been observed that policies and some practices have changed over time [18].

Koca [19] investigated the perceptions of gender discrimination and prejudice of university students studying in the maritime field. The results show that there is a statistically significant relationship between students' gender and gender discrimination and prejudice. This shows that the perception of the socio-cultural family structure in Turkey regarding the role of women causes students to perceive the maritime profession as not being a favorable and positive job field for women.

Out of a total of 190,107 persons holding a seafarer's license in Turkey, 9,434 are women and 180,673 are men [20]. In the Turkish maritime sector, the positions with the highest proportion of women are nurses, doctors and stewards, while the highest number of women are seafarers with 3,729 people. However, it should be taken into consideration that in addition to active seafarers, there were also women who went on board due to their husbands and obtained seaman's licenses. The number of officers is 695 with a rate of 2.6%. Although the rate of officers in Turkey is lower than the rate of officers in the world in general, it is noteworthy that the rate of Turkish licensed women seafarers is higher than the world in terms of women's qualification with 5%.

4. Solutions to sectoral problems

First and foremost, coaching can be used to prevent existing problems. Maritime coaching focuses on developing each and every aspect of the crew on board so that everything works optimally. Many people may dismiss coaching programs as just a passing trend. However, it is a process that can help develop company capabilities [21]. The focus of maritime coaching is on encouraging crew, adapting company and ship employees to changes, building and developing awareness and responsibility, improving onboard and inter-ship communication, and focusing on future possibilities and potentials in the rapidly developing maritime industry. The future-oriented enhancement of coaching and leadership in the maritime sector can provide gender-neutral benefits and can be a solution to gender-based problems.

Kitack Lim, Secretary General of the International Maritime Organization (IMO), stresses the importance of making changes to accept and support diversity. Regarding the World Maritime Day 2019 theme "Empowering Women in the Maritime Community", he stated that "Empowering women is not just an idea or a concept, it is a necessity that requires strong, positive action to address deep-rooted, institutional and cultural barriers."

As another proposed solution, in response to changing maritime workforce demographics, the term "seafarer" has been introduced as a gender neutral term in official documents and international maritime organizations. This change was made to eliminate gender bias in language and recognize the contributions of all those who work at sea.

Organizations such as the International Maritime Organization (IMO) have played an important role in this language shift. Recognizing the importance of inclusive language, the IMO has supported the use of the term "seafarer" instead of "seaman" in its guidelines and resolutions. This change not only reflects the diversity of the maritime workforce, but also aims to equalize opportunities [22]. In Turkey, although there are individual efforts and initiatives by some organizations to replace "seafarer" with "seafarer", there are still no results.

While an appropriate legal environment is necessary to combat sexual harassment in the workplace, it is much more important to prevent it before it becomes a crime. The international nature of seafaring may raise the question of who has the legal jurisdiction in this matter.

While the law of the Flag State is the primary legal system governing the interaction of people on board a ship, maritime employers and employees are subject to different legal frameworks, i.e. different Flag State jurisdictions and possibly other jurisdictions. This leads to different approaches to cultural and sexual harassment.

Guideline B4.3.1, which specifically refers to the latest version of the Guidelines for Eliminating Harassment and Mobbing on Board Ships, published jointly by the International Chamber of Shipping (ICS) and the ITF, is included as an addendum to the 2006 to 2016 amendment by the MLC. Guideline B4.3.1 lists harassment and mobbing in Paragraph 2.

Although only a recommendation, the MLC takes a step forward with the 2016 amendment of the 2006 Guideline to be adopted and implemented on board from 2019 onwards, promoting occupational health and safety policies and programs and combating harassment and mobbing on board. As a result, this amendment emphasizes the responsibility of States and ship owners to ensure a safe and healthy working environment for crew. Without this emphasis, seafarers fear losing their jobs if they report any incident to the company. This also applies to women seafarers because they do not want to be seen as troublemakers or may feel helpless if an incident occurs. Even if they want to report, the shipboard environment may dictate that they do not speak up about their experiences until they reach port.

Inappropriate male behavior towards women seafarers is a serious concern and cannot be prevented for various reasons, such as fear of losing a job. The 2006 Maritime Labour Convention (MLC, 2006) provides certain guarantees for their protection, recognizing that it is crucial to establish reporting mechanisms available to seafarers. It requires all ships at sea to establish procedures to ensure fair, effective and prompt handling of complaints relating to occupational health and safety (OSH) and sexual harassment. These procedures should ensure that seafarers feel comfortable raising their complaints and that Member States do not allow any form of victimization or punishment of seafarers.

The "Guidance on Combating Harassment and Bullying on Board", published by the International Chamber of Shipping (ICS) and the International Transport Workers' Federation (ITF), reinforces these safeguards and highlights the importance of companies having clear policies to prevent harassment and bullying. The Guide recommends that complaints should be handled by an employee of the company or an independent third party, particularly where they relate to sexually harassing behavior.

In 2017, the worldwide #MeToo movement also impacted the maritime industry with the #lättaankar campaign in Sweden. The campaign provided a platform for female seafarers to share their experiences of sexual harassment and bullying, highlighting the challenges of reporting such incidents within the industry [16]. In a culture where reluctance to report is widespread, social media can be crucial in giving victims a voice and shining a light on hidden issues. Victims can use alternative complaint methods offered by these platforms, but this may not always be the preferred option for victims.

Any tool to promote gender equality requires a viable strategy. Therefore, rather than simply establishing anti-harassment policies and complaint mechanisms, training programs may provide better results. While the ICS/ITF Guidelines recognize the importance of raising awareness and changing attitudes about sexual harassment by merely reminding them, there is a great reluctance to make them mandatory. Such training is a very appropriate tool for a wide range of maritime communities. In general, given the reluctance of seafarers to report any problems on board, various reporting mechanisms that can be used by victims should be developed.

Complaint procedures are clearly inadequate, but states and companies should implement strong preventive measures. To ensure a work environment free of gender discrimination, training is crucial to raise awareness among the entire crew. A multicultural crew can make this even more difficult. Therefore, training is crucial for this change. However, there is a risk that anti-harassment measures are only seen as a kind of decoration, especially in terms of preventive measures and complaint procedures. Increasing the gender diversity of the ship is strongly recommended and behavioral change must be structural.

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Beyond Traditional Horizons: Unveiling Anxiety Patterns in HUET with ANFIS

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Abstract

The offshore petroleum industry heavily relies on helicopter transportation for personnel transfer between onshore and offshore facilities. To ensure safety, individuals must undergo Helicopter Underwater Escape Training (HUET). In this study, we utilize the Adaptive Neuro Fuzzy Inference System (ANFIS) to predict HUET participants' anxiety levels. The offshore helicopter transport, a complex socio-technical structure, poses unique challenges, predominantly over sea and variable geographic locations. To mitigate risks, participants undergo comprehensive safety training. This includes OPITO-approved HUET with Compressed Air Emergency Breathing System (CA-EBS), vital for emergency response skills. Acknowledging stressors within HUET, such as physically demanding activities and high-fidelity elements, we aim to predict and understand the anxiety levels of HUET participants by employing ANFIS, ultimately contributing to the enhancement of training programs and the overall safety of offshore helicopter transportation. This approach represents a departure from traditional methods. Knowledge-driven predictive models, like ANFIS, overcome limitations of classical approaches, enhancing accuracy and applicability. In the field of psychology and psychiatry, this innovative approach finds increasing use, evolving psychological prediction models. Ultimately, our research aims to not only advance safety protocols in offshore helicopter transportation but also to contribute to the broader application of machine learning-based predictive models in safety-critical domains.

Keywords: *STAI, Prediction, Offshore, OPITO*

1. Introduction

The offshore petroleum industry heavily relies on helicopter transportation for personnel transfer between onshore and offshore facilities [1]. Ensuring the safety of individuals during these transfers necessitates their completion of Helicopter Underwater Escape Training (HUET), a critical aspect of offshore operations [2]. Operating within a complex socio-technical structure, offshore helicopter transportation presents unique challenges, predominantly over sea and variable geographic locations. To mitigate associated risks, comprehensive safety training is imperative, encompassing to the Offshore Petroleum Industry Training Organization (OPITO)-approved HUET with Compressed Air Emergency Breathing System (CA-EBS) [3].

HUET sessions serve as critical components of safety training within the offshore petroleum industry. These sessions are designed to equip personnel with the necessary skills to respond effectively to emergency situations during offshore operations [4]. The training adheres to the standards set forth by OPITO, a globally recognized authority in offshore safety training. OPITO ensures that training programs meet rigorous standards, enhancing safety protocols and minimizing risks associated with offshore activities [5].

An essential component in understanding the efficacy of safety training programs is the assessment of participants' anxiety levels [6], [7], [8]. The State-Trait Anxiety Inventory (STAI), a widely used psychometric instrument, provides a reliable measure of anxiety by distinguishing between the temporary condition of "state anxiety" and the more general and long-standing quality of "trait anxiety" [1], [9].

In this study, we analyze a dataset comprising anxiety levels of 260 HUET participants assessed using the STAI inventory immediately before training sessions. Leveraging k-means clustering algorithms, we organize the dataset for effective analysis [10]. Subsequently, we employ the Adaptive Neuro Fuzzy Inference System (ANFIS) to predict participants' anxiety levels, marking a departure from traditional methods. ANFIS, an innovative knowledge-driven predictive model, integrates the advantages of both fuzzy logic and neural networks, enhancing accuracy and applicability [11].

Acknowledging stressors inherent in HUET, such as physically demanding activities and high-fidelity elements, our study aims to predict and understand participants' anxiety levels [12]. By doing so, we seek to contribute to the enhancement of training programs and the overall safety of offshore helicopter transportation. Furthermore, our research underscores the broader application of machine learning-based predictive models in safety-critical domains, exemplifying the evolving landscape of psychological prediction models [6].

Our findings reveal a remarkable accuracy rate of 97.3% in predicting participants' anxiety levels using the ANFIS model [7]. Ultimately, this research not only strives to advance safety protocols in offshore helicopter transportation but also aims to foster the widespread adoption of machine learning-based predictive models in safety-critical domains [8].

2. Methodology

This study examines data from HUET training sessions. The training sessions adhere to the OPITO standards and provide participants with the necessary skills for emergency situations in offshore operations. The study commenced with the administration of the STAI TX-1 survey to participants immediately before HUET. Subsequently, data clustering using the k-means algorithm was conducted to identify anxiety profiles. The Elbow Method was utilized to determine the optimal number of clusters. Furthermore, the study employs the ANFIS for predictive modeling, a hybrid computational framework blending fuzzy logic and neural networks.

2.1. Data Collection

In our study, particular focus is placed on the segment of HUET training that simulates escape from a submerged helicopter within a controlled pool environment. This phase of the training is characterized by high fidelity, aiming to replicate real-world scenarios with accuracy [4], [8]. Participants are subjected to physically demanding activities amidst psychologically challenging conditions, fostering a comprehensive understanding of emergency procedures and enhancing preparedness for offshore operations.

Ethical considerations were paramount in our data collection process (Approval of the Ethics Committee No: 21/014). Prior to the commencement of the escape simulation, 260 HUET participants underwent the administration of the STAI TX-1 (State Anxiety) survey. The STAI inventory, developed by Charles D. Spielberger et al., comprises two subscales: STAI TX-1 assesses state anxiety, while STAI TX-2 evaluates trait anxiety [1].

STAI TX-1 focuses on capturing the immediate emotional responses of individuals by measuring feelings of apprehension, tension, nervousness, and worry [9]. The inventory consists of 20 items, utilizing a 4-point Likert scale for responses, with higher scores indicating elevated levels of anxiety. This psychometric tool has been extensively validated and widely utilized in various research contexts, providing reliable assessments of anxiety states in diverse populations [13].

2.2. Data Clustering

Clustering serves as a crucial preprocessing step in our methodology, enabling the utilization of the STAI survey data for predictive modeling. Leveraging the capabilities of MATLAB R2022b, we employed the k-means clustering algorithm to partition the dataset into distinct clusters based on similarities in anxiety profiles.

The k-means clustering algorithm is a widely utilized technique for partitioning data into k clusters, where each observation belongs to the cluster with the nearest mean [10]. This iterative algorithm minimizes the within-cluster sum of squares, effectively grouping data points with similar characteristics into the same cluster. By iteratively updating cluster centroids, k-means converges to a stable solution, facilitating the identification of distinct clusters within the dataset.

To determine the optimal number of clusters (k) for our dataset, we employed the Silhouette Coefficient Method. Figure 1 presents the MATLAB code snippets utilized for this analysis, demonstrating the computational procedure undertaken for determining the optimal clustering solution.

Command Window

```
plot(1:5, error, 'o-');
xlabel('Number of Clusters (k)');
ylabel('Total Within-cluster Sum of Squares');
title('Elbow Method for Optimal k');
>> kmax = 5;
[optimal_k, silhouette_scores] = silhouette_function(normalized_data, kmax);

fprintf('Optimal k: %d\n', optimal_k);
plot(2:kmax, silhouette_scores(2:end), 'o-');
xlabel('Number of Clusters (k)');
ylabel('Mean Silhouette Score');
title('Silhouette Method for Optimal k');
Optimal k: 2
```

Figure 1. MATLAB Code for silhouette method

This method calculates the cohesion and separation of clusters, with higher silhouette scores indicating better cluster distinction [14]. Figure 2 presents the graphical representation of the Silhouette Coefficient Method, illustrating the relationship between the silhouette scores and the number of clusters. This visual depiction aids in understanding the cohesion and separation of clusters, with higher silhouette scores indicating better cluster distinction

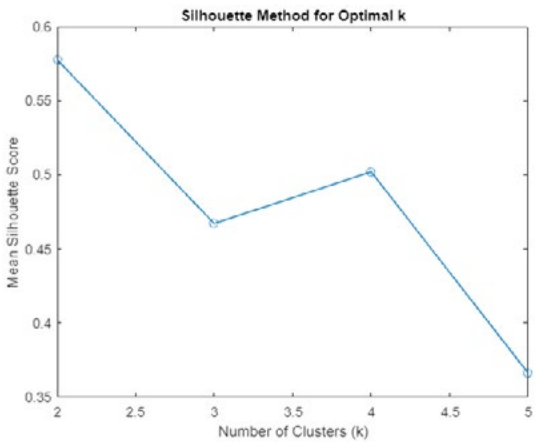

Figure 2. Silhouette method for optimal k

In conclusion, the Silhouette Method converged on the consensus of 2 as the optimal number of clusters for our dataset following extensive analysis. The clustering results for the 20-item STAI TX-1 form are depicted in Table 1.

Table 1. The clustering results

Cluster	Member (Question Number in STAI TX-I)
Cluster#1	4, 7, 18
Cluster#2	1, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20

2.3. Prediction

The Prediction Methodology employed in this study hinges on the utilization of the ANFIS. ANFIS represents a hybrid computational model that combines the capabilities of fuzzy logic and neural networks [15]. Developed by Jang in the early 1990s [16], ANFIS integrates the intuitive reasoning of fuzzy logic with the learning capabilities of neural networks [17]. This amalgamation enables ANFIS to effectively model

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complex nonlinear relationships between input and output variables. Essentially, ANFIS serves as a powerful tool for function approximation and prediction tasks [18]. The basic structure of ANFIS is depicted in Figure 3.

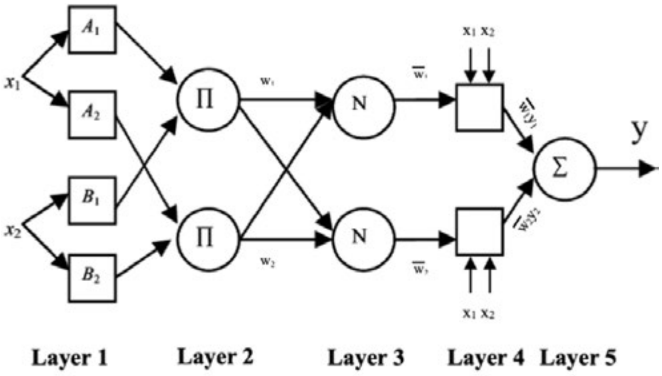

Figure 3. Basic ANFIS structure

In ANFIS, the input layer, also known as the fuzzification layer, transforms crisp input data into fuzzy sets. These fuzzy sets represent linguistic variables and capture the uncertainty inherent in real-world data. The fuzzy sets are then fed into subsequent layers, comprising the fuzzy inference system and the defuzzification layer. The fuzzy inference system computes the firing strength of each rule and aggregates the outputs to generate the overall system output. Finally, the defuzzification layer converts the fuzzy output back into crisp values.

Mathematically, the operation of ANFIS can be represented by a set of equations, including those governing fuzzy membership functions, rule firing strengths, and defuzzification methods, as shown in Formulas 1 through 4.

Fuzzification Layer:
$$A_i^1 = \mu_{Ai}(x) \qquad B_i^1 = \mu_{Bi}(y) \tag{1}$$

Fuzzy Inference System:
$$w_i^1 = A_i^1 x B_i^1 \qquad w_i^2 = w_i^1 x P_i \tag{2}$$

Normalization:
$$w_i^3 = \frac{w_i^2}{\sum_{i=1}^{n} w_i^2} \tag{3}$$

Defuzzification Layer:
$$o = \sum_{i=1}^{n} w_i^3 \; x \; c_i \tag{4}$$

Here:

- A_i^1 and B_i^1 are the membership degrees of the respective fuzzy sets for input variables *x* and *y*.
- $\mu_{Ai}(x)$ and $\mu_{Bi}(y)$ are the membership functions of the respective fuzzy sets for input variables *x* and *y*.
- w_i^1 represents the output of the rule.
- P_i represents the strength of the rule.
- w_i^2 represents the weighted sum of outputs.
- w_i^3 represents the normalized outputs.
- c_i represents the center values of the output sets.

3. Application of ANFIS

The study commenced with the formation of a dataset comprising responses from 260 participants to the STAI TX-1 questionnaire. Prior to analysis, the dataset underwent scrutiny to ensure its statistical appropriateness, which included tests for the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO), Bartlett's test, Total Variance Explained (%), and Cronbach's Alpha values. These measures, conducted using SPSS Statistics Version 27.0 for Macintosh, confirmed the dataset's suitability for further analysis.

The application of the ANFIS methodology began with meticulous data stratification, where the dataset was partitioned into three distinct subsets: training, testing, and validation. This strategic division, with 70% of records allocated to training, 15% to testing, and the remaining 15% to validation, facilitated the development of a robust predictive model.

Following data stratification, the datasets were subjected to 2-factor clustering tailored to their structure. Utilizing k-means algorithms during the clustering phase, we determined the optimal value for k to be 2, ensuring an effective partitioning of the data into distinct clusters. Once clusters were identified, the datasets were loaded into MATLAB for ANFIS prediction implementation, leveraging the Fuzzy Logic Toolbox™ software within MATLAB R2022b.

Subsequently, the loaded data was assigned to ANFIS structures, and Fuzzy Inference Systems (FIS) were constructed to generate accurate predictions. Figure 4 illustrates the ANFIS model structure created for 2-factor clustering with 3 membership functions.

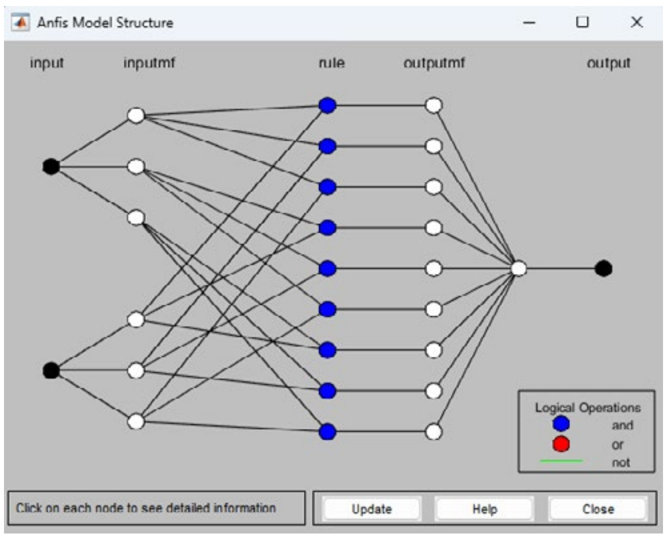

Figure 4. ANFIS structure 2-factor clustering with 3 membership functions

Each ANFIS model, employing different membership functions and mathematical models, underwent iterative training until reaching the lowest error value, followed by testing for each dataset. This iterative process ensured the robustness and accuracy of the predictive models. Figure 5 depicts the visualization of the training data's test output, where the blue circles represent the training data, and the red stars depict the data generated by the model during testing.

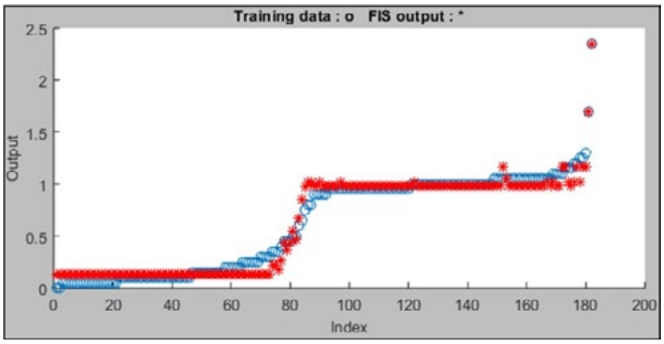

Figure 5. Test output of the training data

In assessing the prediction values generated by our constructed models, we considered the R-squared and RMSE error values. R-squared (R^2) and Root Mean Square Error (RMSE) serve as pivotal metrics in evaluating the performance and accuracy of predictive models. R^2 quantifies the proportion of variance in the dependent variable explained by the independent variables, while RMSE measures the average magnitude of errors between predicted and observed values [19], [20]. R^2 and RMSE are mathematically defined as in formulas 5 and 6 respectively.

$$R^2 = 1 - \frac{SSR}{SST} \tag{5}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}} \tag{6}$$

In Formula 5, R^2 represents the coefficient of determination, calculated as 1 minus the ratio of the sum of squared residuals (*SSR*) to the total sum of squares (*SST*). Formula 6 defines *RMSE*, where y_i denotes the observed values, y_i represents the predicted values, and n is the number of data points. This formula computes the square root of the average of the squared differences between observed and predicted values, providing a measure of the model's prediction accuracy.

Models displaying extreme fit, characterized by R-squared values of 1 and RMSE values of 0, were excluded from our evaluation. Such instances could potentially signify overfitting, where the model performs exceptionally well on the training data but may struggle to generalize effectively to unseen data, leading to uncertain predictions [21], [22].

Indeed, our exploration encompassed numerous model variations. Among these, the ANFIS model structure identified as m18 achieved the highest accuracy rate in prediction. Detailed specifications of this model are presented in Table 2.

Table 2. The specifications and performance metrics of the ANFIS model

Model Name	Generate FIS	Input		Output	Minimal Training RMSE	Minimal Checking RMSE	Training Data R^2	Testing Data R^2	Validation Data R^2
		Number of MFs	MF Type	MF Type					
m18	Grid partition	3 3	trap	const.	0,0763	0,0704	0,9721	0,9712	0,9717

The m18 ANFIS model exhibits a compact structure with a total of 35 nodes, consisting of 9 linear parameters and 18 nonlinear parameters. This configuration results in a combined total of 27 parameters. Trained on a dataset comprising 182 pairs of training data and validated with 39 pairs of checking data, the model operates with a set of 9 fuzzy rules.

4. Discussions

The findings of this study provide valuable insights into predicting anxiety levels among participants undergoing HUET in the offshore petroleum industry. By utilizing the ANFIS, we achieved a remarkable accuracy rate of 97.3% in predicting participants' anxiety levels, signifying the efficacy of machine learning-based predictive models in safety-critical domains.

One of the significant contributions of this research lies in its departure from traditional methods of assessing anxiety levels [23], [24]. While conventional approaches often rely on subjective assessments or simplistic models, our utilization of ANFIS demonstrates a more nuanced and data-driven methodology. By integrating fuzzy logic and neural networks, ANFIS captures complex nonlinear relationships within the dataset, thereby enhancing accuracy and applicability [25].

The application of ANFIS in predicting anxiety levels during HUET sessions has profound implications for safety training programs in the offshore petroleum industry. Understanding participants' anxiety levels enables trainers to tailor interventions and support mechanisms accordingly, fostering a safer and more effective training environment. Moreover, by identifying factors contributing to anxiety, such as physically demanding activities and high-fidelity simulations, training programs can be refined to mitigate stressors and enhance overall participant experience.

Furthermore, the success of ANFIS in predicting anxiety levels underscores its potential for broader application in safety-critical domains. As evidenced by this study, machine learning-based predictive models offer a sophisticated approach to risk assessment and mitigation, transcending the limitations of traditional methodologies [26]. By harnessing the power of data analytics and computational intelligence, industries can proactively identify and address safety concerns, ultimately enhancing operational resilience and reducing the likelihood of accidents or incidents.

However, it is essential to acknowledge certain limitations and considerations in the application of ANFIS [27]. While our study demonstrates high accuracy in predicting anxiety levels, the model's performance may vary depending on the specific context and dataset characteristics. Additionally, ongoing refinement and validation of predictive models are necessary to ensure their reliability and generalizability across diverse populations and scenarios.

In conclusion, this study represents a significant advancement in the field of safety training and risk management within the offshore petroleum industry. By leveraging ANFIS to predict anxiety levels during HUET sessions, we contribute to the ongoing efforts to enhance safety protocols and ensure the well-being of personnel operating in challenging environments. Moving forward, continued research and innovation in machine learning-based predictive modeling hold the potential to revolutionize safety practices across various industries, paving the way for a safer and more resilient future.

5. Conclusions

In conclusion, this study demonstrates the efficacy of the ANFIS in predicting anxiety levels among participants undergoing HUET in the offshore petroleum industry. Through the analysis of a comprehensive dataset and the application of advanced computational techniques, we achieved a remarkable accuracy rate of 97.3% in predicting participants' anxiety levels, highlighting the potential of machine learning-based predictive models in safety-critical domains.

Our findings underscore the importance of understanding and addressing anxiety within the context of safety training programs. By identifying factors contributing to anxiety, such as physically demanding activities and high-fidelity simulations, training programs can be tailored to mitigate stressors and enhance overall participant experience. Moreover, the predictive capabilities of ANFIS enable trainers to proactively assess and manage anxiety levels, fostering a safer and more effective training environment for personnel operating in challenging offshore environments.

The success of ANFIS in predicting anxiety levels during HUET sessions has significant implications for safety practices across various industries. By harnessing the power of data analytics and computational intelligence, organizations can enhance risk assessment and mitigation strategies, ultimately reducing the likelihood of accidents or incidents. Furthermore, the adoption of machine learning-based predictive models represents a paradigm shift in safety management, offering a more sophisticated and proactive approach to ensuring operational resilience and personnel well-being.

In summary, this study contributes to the advancement of safety training and risk management within the offshore petroleum industry. By leveraging FIS to predict anxiety levels during HUET sessions, we strive to enhance safety protocols and promote the well-being of personnel operating in demanding offshore environments. Moving forward, continued research and innovation in machine learning-based predictive modeling hold the potential to transform safety practices and cultivate a culture of safety excellence across industries.

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Technostress Management for Seafarers in the Maritime 4.0 Era

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Abstract

In the maritime industry, unprecedented developments have taken place, particularly since the early 2000s, marking incredible strides. The resultant digitization, stemming from these advancements, holds significant importance for the accurate and swift implementation of operational and decision-making mechanisms within enterprises. To meet the growing trade and market volume in the maritime sector, ships and ports are employing new technologies introduced by Industry 4.0 to facilitate faster and less error-prone operations. Presently, digitization has swiftly permeated the maritime industry, encompassing aspects such as autonomous vessels, smart technologies, sustainable energy management, greenhouse gas reduction, eco-friendly fuel usage, waste management, energy efficiency, environmentally conscious fuel consumption, artificial intelligence, the Internet of Things, digital communication, blockchain, innovative navigation equipment, and remote control systems.

In response to these developments, maritime enterprises are restructuring their organizational frameworks, incorporating new technology-compatible practices and tools into their processes, and providing training to their personnel to adapt to these changes, all with the aim of achieving sustainable competitive advantages and managing ships safely. While technological advancements entering the maritime sector bring about increased operational ease, they simultaneously introduce challenges. The stress incurred by seafarers exposed to technostress, arising from difficulties in learning and applying new technological devices, affects safety at sea adversely.

The inherent challenges of maritime work conditions, such as harsh climates, extended periods of separation from families, and isolation from social life, are compounded by the stress introduced by technology. The added stress necessitates effective management and control, as it combines with conventional stressors in the profession. Support should be extended to employees experiencing technostress-related anxieties, concerns, adaptation difficulties, job disengagement, and professional disillusionment. This study aims to explore technostress situations experienced by seafarers on ships, offering specific contributions to the literature by providing findings on how seafarers can cope with technostress and proposing recommendations for technostress management. While existing literature has explored technostress in various industries, no direct research on this issue has been observed in national and international maritime literature. This study will systematically analyze these existing research efforts in the context of the unique conditions of the maritime industry. By examining research and projects in the literature, this study seeks to provide theoretical and empirical knowledge on managing and reducing technostress among seafarers in the maritime industry

Keywords: *Seafarers, Ship Management, Techno-Stress Management, Maritime 4.0*

1. Introduction

Unprecedented developments have occurred in the maritime sector, especially since the 2000s, and remarkable progress has been made. In light of these developments, digitization, which has emerged, is crucial for the correct and rapid implementation of operations and decision-making processes by businesses. To respond to the growing trade and market volume in the maritime sector, ships and ports utilize new technologies brought by Industry 4.0 to perform operations faster and with fewer errors.

Key workers in the maritime industry, seafarers, play a crucial role in ensuring the smooth operation of the supply chain, safe ship management, and reducing work accidents. The management of seafarer and their work relations present a significant issue due to the current developments in technostress levels. Preventing natural and environmental disasters in the maritime industry is crucial for the well-being of seafarer, a healthy organizational climate, and work relationships.

In this process, maritime businesses strive to achieve sustainable competitive advantage and manage ships safely by organizing their organizational structures, integrating new technology-compatible practices and tools into their processes, and providing training to their staff to adapt to these changes. Technological advancements, which are increasingly entering the maritime domain and are effective with the conveniences they offer, make operations easier but also more challenging. The stress caused by learning and implementing new technological devices, such as technostress, negatively affects safety at sea among seafarers. Besides the already challenging working conditions (harsh climate conditions, shifts, etc.), the stress brought by technology, alongside problems like being away from their families for extended periods and isolation from social life, poses a significant and additional challenge that needs to be addressed. With the addition of technology-induced stress to the conventional stressors of the profession, the increasing stress must be managed and controlled.

Therefore, investigating the technostress situations experienced by seafarers, providing recommendations on how to cope with technostress, and offering insights into technostress management are aimed to contribute uniquely to the literature. When examining the research and projects conducted in the literature, studies have been carried out on the problems caused by technostress on employees in various industries. Considering the unique conditions of the maritime industry, these studies will be systematically evaluated within the literature. Recommendations for reducing and managing technostress among seafarers have been developed by examining the literature, developments, and implementation practices in the maritime industry.

2. The Importance of Maritime 4.0

The industrial revolution, which initially began in England, has influenced and brought about changes in various fields, ranging from production to societal structures and even forms of governance. Over historical periods, industrial revolutions have continually evolved, shaping industrial societies in accordance with the demands of their times. These evolving innovations have kept the dynamism of societies intact, fostering the emergence of new inventions and laying the groundwork for subsequent eras. The convergence and utilization of knowledge with technological factors have paved the way for the industrialization of information, giving rise to information technologies and structures, thereby facilitating the transition from industrial to knowledge societies.

Throughout world history, significant developments have occurred in the economy due to technological innovations and discoveries, ushering in distinct eras. These developments, known as industrial revolutions, can be categorized into four main groups [25]:

Industry 1.0: Spanning from 1760 to 1840, marked by the use of railways and steam engines, leading the way for mechanized production.

Industry 2.0: Emerging in the late 1800s to the early 1900s, characterized by the integration of assembly lines and electricity into production processes.

Industry 3.0: Beginning in the 1960s, with digital technologies replacing electric and mechanical technologies in production.

Industry 4.0: Referred to as the era where digitalization becomes further advanced, integrating artificial intelligence and allowing almost every product and service to be digitized.

Since the 1990s, with the impact of digitalization, information has also been industrialized. We are currently experiencing the Fourth Industrial Revolution, also known as Industry 4.0, marking a transition from industrial societies to an era dominated by information technology.

According to Schwab (2017), the founder and president of the World Economic Forum, three reasons contribute to the advent of Industry 4.0 [25]:

Speed: The fourth wave of industrialization is progressing exponentially rather than linearly. Developing technologies in our world will play a significant role in the emergence of interconnected newer technologies.

Breadth and depth: The digital revolution brought by Industry 4.0 will bring unprecedented paradigm shifts not only in economic factors but also in work life, societal structure, and individuality.

Systemic effect: It encompasses the transformation of countries, companies, sectors, and society.

Furthermore, classical production's inability to meet individuals' needs, the impossibility of producing complex and intelligent products through traditional production processes, and the attractiveness of personalized products in the market have contributed to the necessity of Industry 4.0. The significant technological developments introduced by Industry 4.0 include next-generation software and hardware, along with the Internet of Things. Additionally, features such as big data, autonomous robots, artificial intelligence, system integration, additive manufacturing (3D printers), cybersecurity systems, simulation, smart factories, augmented reality, and cloud computing are part of this framework [28].

Looking back at the history of Maritime 4.0, it's essential to consider how industrial revolutions have impacted the maritime sector. The reflection of the first industrial revolution, Industry 1.0, in the maritime sector began with the discovery of steam-powered machinery. This era saw the advent of steam-powered ships, starting with the introduction of the first steamship, the Clermont, in 1807 in the United States. This development replaced sailing ships, allowing for the transportation of raw materials and goods over long distances, significantly contributing to the advancement of global trade [34].

The commencement of Industry 2.0 in the early 1900s, with the use of electricity in industries and the discovery of assembly lines, also brought about transformations in the maritime sector. This era witnessed the utilization of petroleum and diesel engines on ships, the processing of steel to construct more durable vessels, and further enhancements in global trade.

In 2011, the concept of Industry 4.0 gained significant attention at the Hannover Trade Fair in Germany, swiftly permeating all sectors. This phase introduced digitalization, autonomous and semi-autonomous ships, smart technologies, sustainable energy management, greenhouse gas reduction, the use of next-generation environmentally friendly fuels, sustainable waste management, energy efficiency, environmentally friendly fuel consumption, artificial intelligence, the Internet of Things, digital communication, innovative navigation equipment, and remote-control systems to the maritime industry. This integration of technological advancements and digital processes in the maritime industry is known as Maritime 4.0.

Maritime 4.0 aims to redesign supply chains in the maritime industry through digitalization and interconnectedness. As technology advances, the need arises for the integrated operation of multiple independent systems or devices on ships. Navigation instruments such as radar, VHF radio and television, gyro compass, autopilot, depth sounder, engine RPM indicator, GPS, AIS device, NAVTEX receiver, weather fax receiver, and binoculars are now used instead of ancient navigation tools like the astrolabe [33].

It has been observed that the developments of Maritime 4.0 have impacted ship personnel in the maritime industry, with technology-induced stress being the most significant effect on them.

3. Integration of Technology in the Maritime Sector: Technostress

In the maritime sector, one of the significant inventions during the Industrial 2.0 era was the gyrocompass, discovered in 1911. The invention of the gyrocompass relieved sailors from the need to make calculations to correct deviations in the magnetic compass [34].

During the Industrial 3.0 phase, various technological advancements were introduced to enhance navigational safety in the maritime industry. Technologies such as radar, GPS (Global Positioning System), VDR (Voyage Data Recorder), AIS (Automatic Identification System), ECDIS (Electronic Chart Display and Information System), GMDSS (Global Maritime Distress Safety System), EPIRB (Emergency Position Indicating Radio Beacon), SART (Search and Rescue Radar Transponder), satellite communication capabilities, and automatic machinery control systems were utilized [35]. These independent navigational aids were integrated by Integrated Bridge Systems (IBS) to enhance the navigational skills of watch personnel and improve vessel navigation safety. Information from navigational aids integrated on the IBS is combined and displayed to facilitate the tasks of personnel on the bridge, thus enhancing the efficiency of vessel management [34].

Digitalization, autonomous and semi-autonomous vessels, smart technologies, sustainable energy management, reduction of greenhouse gas emissions, use of next-generation eco-friendly fuels, sustainable waste management, energy efficiency, eco-friendly fuel consumption, artificial intelligence, Internet of Things (IoT), digital communication, innovative navigation equipment, and remote-control systems have rapidly penetrated the maritime industry. During this process, maritime enterprises should restructure their organizational frameworks, incorporate new technology-compatible practices and tools into their business processes, and provide training to their personnel to adapt to these changes to gain sustainable competitive advantages and manage vessels safely. Despite the convenience brought about by technological advancements, the increasing complexity of operations poses challenges. The stress induced by learning and implementing new technological devices, fear of failure to learn, and concerns about inadequacy due to exposure to technostress among maritime personnel adversely affect safety at sea. Eliminating this stress is crucial in the maritime industry for the integration of technology, emphasizing the importance of both in-house and external training programs.

4. Technostress

4.1. Technostress Research in Various Industries

"Technostress: Technological Antecedents and Implications" - This article examines the causes and consequences of technostress associated with technology usage. [1] "Understanding Technostress: A Conceptual Framework for Research" - This study presents a conceptual framework for understanding technostress. [2] E Rohwer, et al. (2022) Overcoming the "Dark Side" of Technology—A scoping review on preventing and coping with work-related technostress [3]. Türen, Erdem, and Kalkın (2015) In their research on technostress among employees in the aviation and banking sectors, they aimed to measure the prevalence of technostress in these sectors and found that the rate of individuals experiencing technostress was around 30% for both sectors. [4] Çetin and Bülbül (2017) Examined the relationship between school administrators' perception of technostress and their individual innovativeness traits. The research findings revealed that the perception of technostress among school administrators was moderate, with administrators experiencing technostress primarily due to the coercive effects of technology. [5] Yıldırım (2021) Investigated the influence of technostress levels among aviation sector employees on their decision-making styles, as well as the regulatory effects of emotional intelligence and perceived job insecurity, which are of great importance for both businesses and employees. [6] Erer (2021) Conducted research on bank employees, and the results of the study showed that the effects of technostress on employees varied depending on several factors. [7] Aydın (2022) In their research on healthcare workers, aimed to demonstrate the impact of healthcare workers' technostress levels on their perceived efficiency. As a result, it was suggested that in order to reduce the negative effects of technostress on perceived efficiency, various individual and institutional measures need to be taken. [8]

4.2. Research in Maritime Literature

Numerous studies have been conducted on seafarers working in the maritime sector, which holds great importance in international trade, from past to present. Some of these studies include Kurt (2010) "The adverse effects of working conditions on seafarers" [9]Özdemir (2017) "The role of job commitment in the relationship between job stress and work-life balance: A study on seafarers" [10]Muradi (2019) "Examination of the relationship between coping styles with stress and job satisfaction levels among individuals working in the maritime sector: A case study of Mersin province" [11] Demir (2020) "Examination of the quality of life in seafarers and its relationship with influencing factors" [12]Uslu (2021) "Examination of stress, burnout, depression levels, and their relationships in seafarers" [13]Özalp (2022) "Examination of psychological well-being in Turkish seafarers based on personality traits and intolerance to uncertainty variables" [14]Uyanık (2022) "The Relationship between Stress and Organizational Commitment: A study on seafarers" [15]. In these studies, the working conditions of seafarers, the impact of job stress on work-life balance, their quality of life, and their job commitments have been investigated as research topics. However, there is no study available regarding the levels of technostress among seafarers.

4.3. What is Technostress?

Technology has been present almost since the existence of humans in the world. The word "technology" is expressed as making or gaining skills. It can be defined as the method and tools used by individuals in carrying out manufacturing and production processes. In other words, technology involves processing information, applying outputs, and processes to meet individuals' needs.

The rapid entry of information technologies into people's lives has led to rapid dissemination and increased usability rates in the workplace, resulting in both positive and negative consequences from both individual and corporate perspectives. As a result, the interaction of individuals with information and communication technologies in their lives leads to stress regarding their attitudes, feelings, and thoughts towards the use of these technologies.

Despite causing stress to workers, information and communication technologies reduce organizational costs, increase process efficiency, and provide opportunities for innovation in organizations. However, despite the comprehensive impact and commercial benefits of information and communication technologies, individuals are exposed to negative effects and various adaptation difficulties.

One of the negative aspects that has entered our lives along with technology is undoubtedly technostress. Consequently, scientists have begun to deal not only with the benefits of technology but also with its negative consequences.

The concept of technostress was first used by psychologist Craig Brod. In his book "Technostress: The Human Cost of the Computer Revolution," Brod defines technostress as a modern adaptation (adjustment) disorder caused by the inability to cope healthily with new computer technologies.

Okebaram and Sunday (2013) similarly define technostress as a modern adaptation disorder resulting from the inability to cope healthily with new technologies. The primary reason for labeling this type of stress as technostress is the rapid changes and developments in technology.

Tarafdar and colleagues (2007) evaluate technostress as a problem resulting from individuals' inadequacy in using information and communication technologies. In summary, technostress is defined as the negative emotions, thoughts, behaviors, and attitudes experienced by workers, regardless of their profession, in coping with the technologies they are obliged to use according to the conditions of the day.

4.4. Sources of reasons for technostress

Organizations' primary causes of technostress include inexperience in computer use, fear of low performance, excessive information load, inability to keep up with rapid change, increasing demands, increasing workload, and staff shortages.

Research on technostress particularly investigates the situations and psychological and behavioral disturbances caused by technostress factors.

Tarafdar, Ragu-Nathan, and Ragu-Nathan (2011) developed a technostress model based on their research, demonstrating that the scope of technostress varies depending on individuals' specific demographic characteristics (gender, age, education, computer literacy and self-confidence, computer experience).

The model discusses five sources of technostress. These are:

- Techno-overload: Reflects the demand for employees to work faster and longer due to their use of specific information technology (IT).
- Techno-invasion: Defined as information technology (IT) eliminating the boundaries between work and personal life and affecting personal life.
- Techno-complexity: Implies employees' belief that they cannot use information technology (IT) because they perceive themselves as incompetent.
- Techno-insecurity: Describes situations where employees fear losing their jobs due to information technology (IT), believing they will no longer be needed.
- Techno-uncertainty: Represents the situation where information technology (IT) is a source of many changes causing uncertainty in an organization.

Researchers in this field have identified individual differences that affect employees' perception of these five stress factors. In this context, studies have shown that men experience more technostress than women; technostress decreases depending on variables such as age, education level, and computer usage experience. The reason men are more exposed to technostress is that women are more likely to give up using technology that they cannot cope with, whereas men insist on using technology.

While studies in sociology focus on individual responses to stressors, researchers in management science focus on issues such as job dissatisfaction, organizational disengagement, role conflict, excessive role demands, inefficiency, and resistance to innovation. In addition to these sources of stress, culture can also be considered a source of technostress. Employees living in a culture resistant to innovation may experience more technostress than those in a society open to innovation.

4.5. Consequences of Technostress

4.5.1. The Individual and Organizational Consequences of Technostress

The consequences of technostress can be profound and impact individuals, organizations, and even society. Some of the key consequences include decreased productivity, reduced job satisfaction, health issues, work-life imbalance, absenteeism, turnover, and reduced employee engagement. Individuals exposed to technostress may not exhibit typical reactions that any person would show in situations they encounter while constantly working with computer systems; instead, they display automatic responses similar to those of computer systems. Technology experts often expect users who work with computers and these systems to respond quickly and attentively to people and organizations, but it is argued that they are emotionally deficient like computers. Such users have been observed to become agitated and enter an alarm state when put on hold during phone calls in their personal lives or when the computer systems they use respond slowly. Symptoms caused by technostress include concerns about making mistakes and losing data while working with computer systems, anger, hostile reactions toward others, problems with patience, fatigue, and irritability [27].

In another study, the effects of technostress were categorized into three different areas and examined as emotional, psychological, and physical effects. Physically, technostress is debated to manifest symptoms such as elevated blood pressure, chest pains, neck and back pains, and headaches. In terms of emotional effects, technostress includes feelings of nervousness, anxiety, spending more time than usual with computer systems, a desire to not be with other colleagues in the work environment, a desire to use computer language outside of work, and adopting bad habits (alcohol, smoking). Ultimately, the research showed that the psychological symptoms of technostress include excessive information overload from storing, classifying, and protecting data on computers, the development of high dependency on technology, uncertainty, and a lack of motivation [27].

4.5.2 Combination with Conventional Stress Factors

The integration of Industry 4.0 components such as the Internet of Things, big data, autonomous robots-artificial intelligence, system integration, additive manufacturing (3D printers-3D printing), cybersecurity systems, simulation, smart factories, augmented reality, and cloud computing structures into the maritime sector brings both conveniences and challenges [26]. While these technological advancements make operations easier, they also introduce new stressors related to learning and implementing new technological devices, as well as concerns about inadequacy and the inability to learn [27]. This technostress experienced by maritime professionals can adversely affect safety at sea.

In addition to the already challenging working conditions (harsh weather conditions, long periods away from family, isolation from social life), the stress brought about by technology poses an additional significant problem that needs to be addressed [28]. With technology-related stress added to the conventional stressors of the profession, it is crucial to manage and control the increased stress effectively.

4.6. Mechanisms for Coping with Technostress

In the process of combating the technostress phenomenon, coping strategies for addressing the root causes can be provided as follows [38]:

- Providing technology-based education and training,
- Developing a positive attitude towards technology,
- Providing adequate equipment and technical support,
- Offering user-friendly hardware and software,
- Creating a more ergonomic work environment,
- Taking regular breaks while using technology,
- Avoiding multitasking,
- Providing stress management training,
- Ensuring effective time management,
- Implementing fair workload distribution,
- Reducing stimulating devices in the work environment,
- Breaking the cycle of being a 24/7 technology user,
- Eliminating distracting elements,
- Engaging in regular physical exercise and meditation

4.6.1. Technostress Management

Research by Harper (2000) has categorized coping methods for technostress into six subheadings: employee responsibility, management responsibility, technology management, redesigning job and organizational structure, complementary medicine and ergonomics, and technological education [39]. These can be explained as follows:

4.6.2. Employee Responsibility

To cope with technostress, it is important for employees to individually prepare themselves for technological changes and developments, embrace and accept technology, rather than waiting for solutions from managers [39].

4.6.3. Managerial Responsibility

Managers also have a responsibility to keep up with technology and stay informed to prevent employees from being affected by technostress. By doing so, they can provide necessary warnings and make plans regarding new technological developments, while involving employees in these plans. It is important to identify training gaps and manage the process by providing the necessary training. Additionally, it is the responsibility of management to ensure an adequate number of support staff are available and undergo training, especially for newcomers to the organization [39]

4.6.4. Technology Management

Managers should be aware of the hazards, especially of older models, of Visual Display Units (VDUs) in order to protect the health of their employees. When ordering new equipment, managers should prioritize the safety of employees by opting for screens with high refresh rates and low radiation levels [39]

4.6.5. Redesigning Job and Organizational Structure

Employees who spend more time adapting to new technology require managers to redefine new job roles and revise job descriptions and salaries due to changes in job structure caused by the adaptation to new technology [39].

4.6.6. Complementary Medicine and Ergonomics

There are some medical interventions to combat technostress. In addition to providing education for both managers and employees to embrace technology, advice can be given on combating stress through meditation or addressing inappropriate ergonomics. Furthermore, techniques such as art workshops, relaxation techniques, reflexology, aromatherapy, color therapy, and nutritional therapy can also be used as treatment methods [39].

4.6.7. Technology-Based Training

The exposure of employees to technostress in the work environment can be transparently identified, and training can be provided based on voluntarism without coercion, focusing on how to benefit from the innovations of technology and express its advantages, as well as providing education on coping strategies [39].

5. Conclusion

The era of Industry 4.0, dominated by concepts such as information, technology, digitalization, artificial intelligence, and the internet, has become a process where technology-based autonomous work systems, communication between objects, and technologies such as cloud computing and augmented reality are developing and affecting every aspect of our daily lives. This process, indicating a transition from an industrial society to an information society, manifests its influence in almost every sector. In order to respond to the growing trade and market volume of the maritime sector, ships and ports have inevitably started to use new technologies brought by Industry 4.0 to carry out operations faster and with fewer errors. Today, with digitization, autonomous ships, semi-autonomous ships, smart technologies, sustainable energy management, greenhouse gas reduction, the use of next-generation environmentally friendly fuels, sustainable waste management, energy efficiency, environmentally friendly fuel consumption, artificial intelligence, the Internet of Things, digital communication, innovative navigation equipment, remote control systems, and similar factors have rapidly entered the maritime industry. While these technological developments make operations easier, they also make them more difficult in equal measure.

The stress caused by learning and implementing new technological devices poses a significant challenge for seafarers, leading to concerns about the inability to learn and feelings of inadequacy, which negatively affect maritime safety. In addition to the already difficult working conditions (harsh weather conditions, shifts, etc.), the additional stress brought about by technology poses a significant and challenging problem that must be addressed. With the addition of technology-related stress to conventional stressors in the profession, the increasing stress must be managed and controlled. To cope with the negative emotional states caused by technostress, such as anxiety, adaptation difficulties, disengagement from work, and disillusionment with the profession, employees need both technical and psychological support. In this context, all stakeholders in the industry, especially the crew management departments of shipping and ship management companies, must carefully address the issue. There is a need for a corporate-level plan to manage technostress in seafarers for the safety of ship management and the supply chain. Shipping companies and ship management companies must create an organizational culture and climate to eliminate technostress. Improving organizational learning at the ship and company organization levels is crucial. It is possible to gradually reduce the impact of technostress with modern management approaches and training programs. It is a well-known fact that the psychological capital of companies affects profitability. Increasing awareness of technostress management in ship operations contributes directly and indirectly to the safe management of the global supply chain and the profitability levels of companies.

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Seafarers' Well-Being at Sea: Exploring the Interplay Between Sleep Quality, Occupational Stress, and Health-Related Quality of Life

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Abstract

The purpose of this study was to identify the effects of sleep quality and occupational stress on health-related quality of life among seafarers.

Methods: 50 seafarers voluntarily participated in the study. In addition to demographic, health-related, and work-related factors, the survey used the Work Stress Scale, the Pittsburgh Sleep Quality Scale, and the 12-Short Form Health Survey version 2.0 (SF-12v2) scale. Analyzes of the research data were made in the SPSS 29 program. The reliability of the Perceived Stress Scale was examined with the Cronbach Alpha coefficient. Relationships between variables were evaluated with Pearson and Spearman correlation tests. In the analysis, p-value <0.05 was considered statistically significant.

Results: The significant variables affecting Physical Component Score (PCS) and Mental Component Score (MCS) were sleep quality and occupational stress, respectively.

Conclusions: Based on this study, seafarers' health-related quality of life needs to be improved in managing both occupational stress and sleep quality.

Keywords: *Seafarer, occupational stress, health of quality, sleep, well-being*

1. Introduction

Seafaring is one of the most ancient and popular ways of trading. It can be claimed that nearly 90% of global transportation is maintained via marine routes [1]. Hence, the continuous movement of vessels' operations requires a 24/7 work plan. Technological developments have enabled the shipping industry to operate even at night, facilitating not only operations on the vessels but also activities during hoteling at berth, regardless of time. Therefore, shift work has become an inseparable part of being a seafarer. It is possible to state that working onboard is an exhausting occupation, and fatigue is a prevalent problem among crew members. The hazardous atmosphere of seafaring significantly impacts the mental and physical state of seafarers. It's not incorrect to argue that working with a shift system disrupts the circadian rhythm, which regulates the biological clock of the human body, including sleep. This study aims to investigate how sleep quality and occupational stress affect the health of seafarers.

The Sleep Foundation defines sleep as "an essential function that allows your body and mind to recharge, leaving you refreshed and alert when you wake up" [2]. In accordance with this definition sleeping is a crucial part of both mental and physical wellbeing. When the conditions of the vessels are taken into account, sleep hygiene needs to be considered as an important component of well-being on board along with sufficient resting hours. Stress was consistently associated with perceived sleep and health across most indicators [3]. More than 20 different stressors identified which seafarers exposed on board and the highest ranked one is separation from family [4]. Kerkamm et al., claim that a huge portion of seafarers stated that they are continually disturbed by at least one or more surrounding circumstances when these stressors are combined with extreme temperatures, odours, noise, poor bedding conditions, or the lightening of their cabins during sleeping [5]. In a study done with offshore workers, most of them stated sleeping disorders and many of the offshore workers who participated in the study agreed that sleeping quality onshore is better [6].

Carotenuto et al. (2012) stated that the shift system on board negatively affects the circadian rhythms of onboard personnel [7]. The concept "sleep debt" is identified as a persistent shortage of sufficient amount of sleep as well as an important threat to seafarers' health and safety "Sleep debt" is a term that defines a constant lack of sufficient amount of sleep and when the features of working on board are taken into account, it presents a threat to seafarers' health and safety [8]. Moreover, the combination of lack of sleep and other factors such as poor social and environmental conditions, long working hours, and workload may increase the risk of errors and accidents on board [9]. A large portion of seafarers stated that resting times are continuously interrupted and they do not sleep well [7]. Interestingly, even though the working hours of masters are generally daytime, their sleep quality is also stated as low because of extreme workload, the need to be alert in case of emergency, and occupational stress [10, 11, 12]. A sleep-related structured interview revealed that over half of the articles rated the quality of their sleep as either fair or low to extremely poor. When the different departments on board were compared, deck crew and officers had a slightly lower ratio of poor sleep than engineers and marine pilots [7]. In a nutshell, although sleep is one of the most important elements of well-being, there are lots of teratogenic factors affecting the sleep quality of crew on board.

Job stress is defined by the Centers for Disease Control and Prevention as the "harmful physical and emotional responses that occur when the requirements of the job do not match the capabilities, resources, or needs of the worker" [13]. In addition to that work performance is unfavorable and affected by occupational stress. Considering widespread categories of the stressors on board, an underestimated ratio of work-related stress is normal due to risky and inappropriate conditions of sea life. Moreover, the long duration of contracts should be taken into account due to extended exposure to stressors having an enhancer effect on the perception of these stressors [14]. In the study about seafarers' well-being, the authors found a positive relationship between fatigue, poor quality of sleep, and the risk of an accident [7].

In today's consensus, health quality encompasses not only physical or biological well-being but also mental health. Moreover, it's widely acknowledged that mental and biological well-being are interconnected. When considering stressors onboard, it's evident that most seafarers are more vulnerable to illnesses and diseases arising from psychological unrest. Sleep, on the other hand, is essential for both biological and psychological well-being. Especially, in an environment in which shift work is a must, seafarers need to make arrangements for their awake and sleep time [3]. Most of the time, this rearrangement and biological clock of being a human conflict. De-synchronization of circadian rhythm may lead to psychological and physiological problems. In a study about shift-work stress and psychological distress, it is stated that working during daytime or night has a differentiative effect on job satisfaction through increased occupational stress and psychological influences of working at night [15]. Also, many other studies put forth that the most fundamental issues of shift workers that changes in working and resting times which bring about circadian misalignment, a significant degree of exhaustion, diminished mental execution around evening time, and prompts sleepness during both constant shifts [11].

However, it is crucially important to investigate the unique features of working on board maritime personnel. Baumler (2020) studied changes over a hundred years of maritime occupation and found out that it can be observed more than a fifty percent increment in the weekly working hours of seafarers [16]. Although the delusion about technological developments reduced the workload of seafarers, it can be stated that working hours have increased since the International Labour Organisation (ILO) was founded.

This study is focused on looking into the impact of occupational stress and sleep quality on seafarers' health-related quality of life in light of the existing literature.

2. Methodology

50 seafarers participated in the research voluntarily yet 3 of the participants couldn't be evaluated due to missing answers. A total of 47 participants' answers were considered in his research. The sample group was selected from officers working or who have worked on board, having a seaman's book was a must to participate in this study. An online form was created to gather data from seafarers containing 59 questions. In addition to demographic, health-related, and work-related factors, the survey used the Work Stress Scale[18], the Pittsburgh Sleep Quality Scale[17], and the 12-Short Form Health Survey version 2.0 (SF-12v2) scale[19]. The analyses of the research data were conducted using SPSS 29 software. The reliability of the Perceived Stress Scale was examined with Cronbach's Alpha coefficient. The normal distribution of the data was assessed using the Shapiro-Wilk test. Descriptive findings were presented with minimum/maximum values, mean, standard deviation, and median values. The relationships between variables were evaluated using Pearson and Spearman correlation tests. A p-value of <0.05 was considered statistically significant in the analyses.

3.Results

Disturbed periods of rest were strongly correlated with higher levels of job-related stress, which in turn had a notable impact on the quality of sleep. Noteworthy factors influencing the Physical Component Score (PCS) and Mental Component Score (MCS) were identified as sleep quality and occupational stress, respectively.

Table 1. Perceived Stress Scale Cronbach Alpha Values

Scale and Sub-Scales	Cronbach Alfa
Insufficient Perception of Self-Efficacy	0,845
Perception of Stress/Discomfort	0,819
Perceived Stress Scale	0,877

The Perception of Insufficient Self-Efficacy sub-dimension, the Perception of Stress/Discomfort sub-dimension, and the Perceived Stress Scale seen in Table 1 were determined to be reliable according to Cronbach's Alpha values.

Table 2. Findings on PSQI score and subscores

Variable	Min	Max	Mean	SD	Median
Subjective Sleep Quality Score	1	3	1,77	0,592	2
Sleep Time Score	0	3	0,9	0,881	1
Sleep Latency Score	1	3	1,87	0,761	2
Usual Sleep Efficiency Score	0	2	0,43	0,649	0
Sleep Disturbance Score	0	3	1,81	0,704	2
Sleeping Medicine Using Score	0	2	0,1	0,371	0
Daytime Dysfunction Score	0	3	1,66	0,907	2
PSQI Score	2	17	8,56	2,508	8

The findings related to the PSQI Score and its subscores are presented in Table 2. According to these findings, the mean score of Subjective Sleep Quality was 1.77±0.592, the mean score of Sleep Duration was 0.90±0.881, the mean score of Sleep Latency was 1.87±0.761, the mean score of Sleep Efficiency was 0.43±0.649, the mean score of Sleep Disturbances was 1.81±0.704, the mean score of Sleep Medication Use was 0.10±0.371, the mean score of Daytime Dysfunction was 1.66±0.907, and the mean PSQI Score was 8.56±2.508.

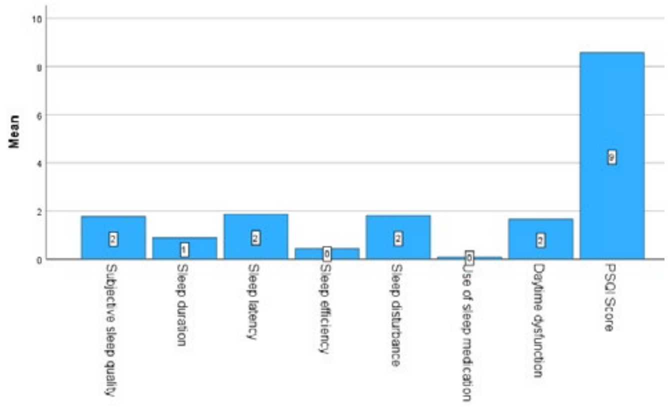

Figure 1: Rates of the PSQI score scale and its subscales.

The Pittsburgh Sleep Quality Index (PSQI) consists of seven components (subjective sleep quality, sleep duration, sleep latency, habitual sleep efficiency, sleep medication use, sleep disturbance, and daytime dysfunction). The score for each component varies between 0 and 3 points. PSQI score ranges from 0 to 21, and a score of 5 or above indicates poor sleep quality.

According to Figure 1. which shows the proportions of the Pittsburg sleep scale and its subscales, the participant's mean PSQI score was above expectations; this is consistent with claims in the previous literature that sailors' sleep standards are moderate, poor, or extremely poor.

Table 3. Findings on the perceived stress scale and its Sub-Scales

Variable	Min	Max	Mean	SD	Median
Insufficient Perception of Self-Efficacy	3	21	12,25	4,117	13
Perception of Stress/Discomfort	6	24	14,77	4,572	15
Perceived Stress Scale	10	44	27,02	7,617	27,5

The findings related to the Perceived Stress Scale and its subdimensions are presented in Table 3. According to these findings, the mean score of Inadequate Self-Efficacy Perception was 12.25±4.117, the mean score of Stress/Discomfort Perception was 14.77±4.572, and the mean score of the Perceived Stress Scale was 27.02±7.617.

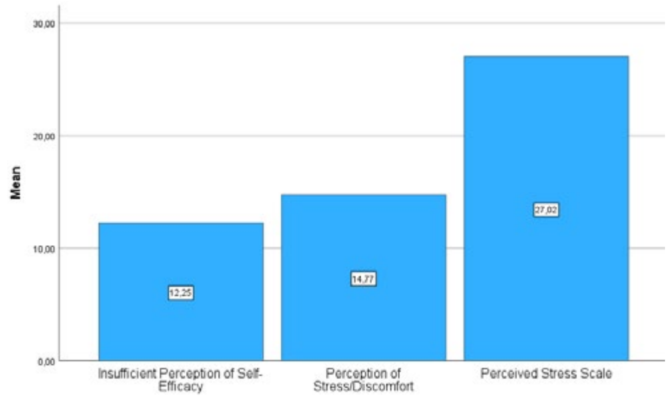

Figure 2: Rates of perceived stress scale and its subscales

Via Figure 2 which represents the ratios of the perceived stress scale and its subscales, the perceived stress score of the participants is higher than the mean which overlaps with claims of the previous literature about working on board having lots of stressors.

Table 4. Findings regarding SF-12 scale subscales

Variable	Min	Max	Mean	SD	Median
Physical Function Score	0	100	86,45	23,609	100
Physical Role Difficulty Score	12,5	100	69,53	24,449	75
Pain Score	25	100	75,52	23,343	75
General Health Score	0	100	48,43	24,95	50
Vitality (Energy) Score	0	100	52,6	22,62	50
Social Function Score	0	100	61,45	27,268	50
Emotional Role Difficulty Score	0	100	59,63	25,427	62,5
Mental Health Score	0	87,5	51,3	23,525	50

The findings related to the SF-12 Scale subscores are presented in Table 4. According to these findings, the mean score of Physical Functioning was 86.45±23.609, the mean score of Physical Role Limitations was 69.53±24.449, the mean score of Pain was 75.52±23.343, the mean score of General Health was 48.43±24.950, the mean score of Vitality (Energy) was 52.60±22.620, the mean score of Social Functioning was 61.45±27.268, the mean score of Emotional Role Limitations was 59.63±25.427, and the mean score of Mental Health was 51.30±23.525.

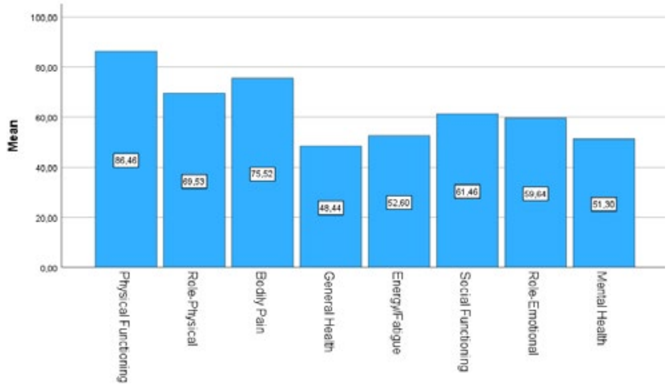

Figure 3: Rates of the health-related life scale (SF-12) and its subscales

Figure 3 is created to interpret the results of the SF-12 scale. The general health score is the lowest one among the participants of this study along with the mental health score. The consensus on the low mental health quality of seafarers is stated once more clearly in this research, also. Even though isolation is labeled one of the most important problems of onboard workers, the results of the SF-12 scale put forward mental health issues might have been more challenging due can be manipulated by all environmental, biological, and mental components.

Table 5. Correlation analysis findings

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1.Subjective Sleep Quality Score[1]	r	1																		
	p																			
2. Sleep Time Score[1]	r	0,199	1																	
	p	0,175																		
3. Sleep Latency Score[1]	r	0,532	0,268	1																
	p	0,000	0,065																	
4. Usual Sleep Efficiency Score[1]	r	-0,051	-0,189	0,066	1															
	p	0,730	0,198	0,658																
5. Sleep Disturbance Score[1]	r	0,245	0,158	0,442	-0,045	1														
	p	0,093	0,284	0,002	0,764															
6. Sleeping Medicine Use Score[1]	r	-0,144	0,069	-0,062	-0,080	-0,022	1													
	p	0,329	0,642	0,677	0,587	0,884														
7. Daytime Dysfunction Score[1]	r	0,310	0,052	0,109	-0,169	0,193	0,210	1												
	p	0,032	0,724	0,463	0,251	0,189	0,151													
8. PSQI Score[1]	r	0,595	0,461	0,733	0,049	0,579	0,189	0,498	1											
	p	0,000	0,001	0,000	0,739	0,000	0,199	0,000												
9. Insufficient Perception of Self-Efficacy[2]	r	0,223	-0,001	0,154	0,029	0,289	0,257	0,271	0,240	1										
	p	0,127	0,996	0,296	0,847	0,046	0,078	0,063	0,100											
10.Perception of Stress/Discomfort [2]	r	0,377	0,100	0,161	-0,244	0,452	-0,032	0,312	0,268	0,535	1									
	p	0,008	0,500	0,276	0,094	0,001	0,831	0,031	0,065	0,000										
11. Perceived Stress Scale [2]	r	0,318	0,036	0,162	-0,160	0,419	0,161	0,337	0,278	0,862	0,890	1								
	p	0,028	0,809	0,271	0,276	0,003	0,275	0,019	0,055	0,000	0,000									
12. Physical Function Score[1]	r	0,034	-0,192	-0,146	0,095	-0,333	-0,509	-0,236	-0,337	-0,323	-0,245	-0,363	1							
	p	0,819	0,191	0,324	0,522	0,021	0,000	0,107	0,019	0,025	0,093	0,011								
13. Physical Role Difficulty Score[1]	r	-0,042	-0,176	-0,206	0,092	-0,330	-0,400	-0,376	-0,378	-0,343	-0,335	-0,388	0,581	1						
	p	0,777	0,232	0,161	0,534	0,022	0,005	0,008	0,008	0,017	0,020	0,006	0,000							
14.Pain Score[1]	r	-0,078	-0,081	-0,232	0,004	-0,479	-0,225	-0,274	-0,339	-0,443	-0,493	-0,513	0,384	0,524	1					
	p	0,598	0,583	0,113	0,979	0,001	0,124	0,059	0,019	0,002	0,000	0,000	0,007	0,000						
15. General Health Score[1]	r	-0,535	-0,067	-0,246	-0,120	-0,309	0,113	-0,325	-0,370	-0,515	-0,482	-0,536	0,291	0,278	0,429	1				
	p	0,000	0,649	0,091	0,416	0,033	0,444	0,024	0,010	0,000	0,001	0,000	0,045	0,056	0,002					
16. Vitality (Energy) Score[1]	r	-0,281	-0,392	-0,197	0,200	-0,126	-0,090	-0,300	-0,286	-0,337	-0,462	-0,456	0,233	0,435	0,271	0,294	1			
	p	0,053	0,006	0,180	0,173	0,395	0,543	0,039	0,048	0,019	0,001	0,001	0,111	0,002	0,063	0,042				
17. Social Function Score[1]	r	-0,433	-0,131	-0,162	0,118	-0,492	-0,072	-0,328	-0,394	-0,487	-0,660	-0,661	0,231	0,323	0,387	0,512	0,352	1		
	p	0,002	0,374	0,271	0,424	0,000	0,626	0,023	0,006	0,000	0,000	0,000	0,114	0,025	0,007	0,000	0,014			
18. Emotional Role Difficulty Score[1]	r	-0,368	-0,264	-0,325	0,193	-0,412	-0,372	-0,432	-0,344	-0,566	-0,390	-0,542	0,479	0,548	0,386	0,334	0,502	0,466	1	
	p	0,010	0,070	0,024	0,184	0,004	0,009	0,002	0,000	0,000	0,006	0,000	0,001	0,000	0,007	0,014	0,000	0,001		
19. Mental Health Score[1]	r	-0,403	-0,080	-0,157	0,096	-0,308	-0,015	-0,196	-0,250	-0,749	-0,680	-0,806	0,268	0,296	0,435	0,617	0,354	0,630	0,535	1
	p	0,005	0,590	0,288	0,517	0,033	0,920	0,183	0,086	0,000	0,000	0,000	0,065	0,041	0,002	0,000	0,013	0,000	0,000	

1: Spearman Test, 2: Pearson Test

Pearson and Spearman correlation analysis findings, which were performed to determine the relationships between variables, are presented in Table 5. According to these findings;

There is no significant relationship between PSQI Score and the Perceived Stress Scale (p>0.05),

PSQI Score with Physical Function Score (r=-0.337), Physical Role Difficulty Score (r=-0.378), Pain Score (r=-0.339), General Health Score (r=-0.370), Vitality (Energy) Score (There are negative significant relationships between r=-0.286), Social Function Score (r=-0.394) and Emotional Role Difficulty Score (r=-0.544),

Perceived Stress Scale with Physical Function Score (r=-0.363), Physical Role Difficulty Score (r=-0.388), Pain Score (r=-0.513), General Health Score (r=-0.536), Vitality (Energy) Score. It was determined that there were negative significant relationships between (r=-0.456), Social Function Score (r=-0.661), Emotional Role Difficulty Score (r=-0.542), and Mental Health Score (r=-0.806).

4.Conclusion

Recent studies emphasize the effects of work-related stress and mental health on the well-being of seafarers. Also, it is highlighted in this study multiple times mental and physical well-being works together. Especially during times that require awareness, the importance of adequate sleep displays crucial roles with its physiological and psychological components. In a recent study, it is emphasized that near-miss accidents are almost certain when the workers are occupied or mentally disturbed [20] as supporting findings in this research. More of the major findings of the study is that shift, and contract workers are more vulnerable to occupational stress [15]. A thesis published in 2022 states the underlying reasons for mental illness among seafarers as well as sleep deprivation, work-related stress, and psychosocial workload compose the major portion of fundamental problems of seafarers' life quality [21]. Moreover, this claim may be supported by a study examining the psychosocial health of offshore workers with the statement that a decline in attention may be observed especially during shift rotations [20].

Circadian rhythm is an important part of human life to live a healthy life as well as sufficient and quality sleep is a crucial component of it. Sleep quality depends on environmental factors and personal characteristics yet, living on board has unique features such as continuous movement, vibration, noise, loneliness, etc. which have a decreasing effect on seafarers' sleep quality. Moreover, there are lots of stressors on board that may lead to sleep deprivation. These characteristics of seafaring create more stress on seafarers which increases occupational stress. This research, it is aimed to investigate the effects of sleep quality and occupational stress on the health-related quality of seafarers. It can be proved along with the previous literature that sleep quality and high levels of occupational stress have negative effects on the wellbeing of onboard workers. It is suggested that improving seafarers' health and quality of life is important to improve both occupational stress and sleep quality management.

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Section 11
Abstracts

Evaluation of Vessel Traffic Operators' Selection Criteria by Using Analytic Hierarchy Process Method

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Abstract

Vessel Traffic Services (VTS) play a crucial role in monitoring the safe and efficient navigation of ships, contributing to the prevention of collisions, groundings, and other navigational hazards in an assigned marine traffic area. Through the years involving many ship accidents and environmental pollution, VTS has become an indispensable component of modern maritime management. This service is mainly presented by Vessel Traffic Service Operators (VTSOs), who are skilled professionals responsible for the day-to-day vessel interactions. Their role is pivotal in ensuring the safety of maritime traffic in busy waterways and ports by giving services such as organizing the vessels in and around ports, guiding them through narrow passages, and intervening to prevent collisions or other incidents. Maintaining the VTS management properly depends on the performance of VTSOs. Hence, the selection of VTSOs should be executed by considering essential aspects. This paper focuses on the selection of VTSO for the VTS in the Turkish Straits area. To selecta VTSO between alternatives, the selection criteria were evaluated using the Analytic Hierarchy Process method with the help of marine experts. According to the findings, the selection of the maritime-origin personnel with the qualification of "Oceangoing Master", particularly who has an experience as "marine pilot" was determined as a priority by the experts. The study could provide valuable insights into the selection criteria of VTSO for the safe and efficient management of vessel traffic services.

Keywords: *Navigational safety, vessel traffic operator, selection, Analytic hierarchy process*

Scale Effects in Oblique Towing Tank Simulations for a Submarine

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Abstract

Due to numerous restrictions, problems, and economic considerations in sea trials, the hydrodynamic behaviour of a marine vehicles is typically investigated using model scales not only in simulations but also in experiments. Therefore, the evaluation of this kind of behaviour of full-scale marine vehicles relies on model scale results. However, the scale effects can introduce significant differences in the evaluated data. Moreover, the scale effects on hydrodynamic performance of marine vehicles still include many uncertainties. With this motivation, in the present study, the oblique towing tank simulations for a generic submarine are conducted for two different scales: model scale and full scale. After validating the numerical results for the model scale using available experimental data from the literature, the numerical analyses are conducted for full scale submarine. The numerical results for different scales are discussed in terms of sway force, yaw moment and wake regions.

Keywords: *DARPA Suboff, yaw moment, sway force, scale effects*

Evaluation of the Risks that Cause Fire and Explosion Accidents on Container Vessel

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Abstract

Container transport is frequently preferred because it allows safe and time-saving handling processes and enables transporting different product groups. Different products carry various risks due to their nature. Developing measures to reduce or eliminate these risks to as low as reasonably practicable (ALARP) level is essential to ensure safe container transport. This study analyses the risks of fire and explosion accidents during the transportation of containers by ship. In this context, 24 fire and explosion accident reports that occurred between 2006 and 2022 due to the cargo carried on container ships were analysed. As a result of this examination, 44 different causes of fire and explosion accidents were found. These accident causes were categorised under seven headings. The relationships between the causes and their effects on each other were quantitatively calculated using the DEMATEL (The Decision-Making Trial and Evaluation Laboratory) method based on expert opinion. As a result of the study, the most important cause of fire and explosion accidents on container ships was the failure to declare dangerous cargo within the scope of the International Maritime Dangerous Goods (IMDG) code. In addition, inappropriate transport procedures were found to be the most important cause of accidents affecting other causes. Suggestions have been made to enable safer transport that will benefit all parties of container transport.

Keywords: *Container, Fire and explosion, DEMATEL, Risk assessment*

Application of Ammonia in Marine Diesel Engines: A Coastal Voyage Case Study

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Abstract

Beginning with a comprehensive analysis of ammonia's properties, storage requirements, and combustion characteristics, the study compares it with conventional marine fuels to assess environmental benefits and challenges. Notably, the research explores emissions from ammonia-powered marine engines during coastal voyages, employing modeling and case studies to predict and analyze pollutants like nitrogen oxides (NOx), particulate matter, sulfur oxides (SOx), and carbon emissions, considering their effects on air quality and environmental sustainability.

Simultaneously, the study investigates potential health effects on coastal communities, employing an interdisciplinary approach to analyze atmospheric dispersion patterns, exposure pathways, and known health impacts associated with pollutants. The goal is to offer a holistic understanding of the advantages of ammonia-powered marine engines for both the environment and human well-being. The research also addresses mitigation strategies and technological advancements to minimize emissions and associated health risks. Recommendations for regulatory frameworks and best practices are presented, aiming to guide the integration of ammonia as a marine fuel in alignment with sustainable development goals and the well-being of coastal populations.

The potential of ammonia as a sustainable alternative to traditional marine fuels, emphasizing its zero-carbon content and potential for zero greenhouse gas emissions. The research delves into the implications of integrating ammonia as a marine fuel, focusing on emission effects during coastal voyages and their impact on human health and associated health expenditures. In conclusion, this study contributes valuable insights into the interplay between ammonia-powered marine engines, coastal emissions, and human health. By advancing understanding, the research aims to inform industry stakeholders, policymakers, and researchers working towards a more sustainable and health-conscious maritime future.

Keywords: *Ammonia, alternative fuel, coastal voyage, case study, maritime transport*

From Catastrophe to Clarity: Advancing Environmental Decision Support Systems for the M/V Lady Tuna Accident and Beyond

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Abstract

The global reliance on oil for economic growth necessitates the safe transportation of oil via maritime trade, making oil tanker accidents an ongoing concern despite international efforts to improve maritime safety. This study addresses the imperative to enhance decision-making in oil spill response through the development of an Environmental Decision Support System (EDSS). The objectives are multifaceted, aiming to minimize environmental impacts, simulate oil trajectories, create an Environmental Sensitivity Map (ESI), and assess the consequences of various response options. The research methodology involves spatial analysis and ESI mapping using GIS (Geographical Information System), oil spill modeling with PISCES 2 and expert opinion techniques for response selection. The study will contribute to efficient decision-making by integrating environmental factors, trade-off analyses, oil weathering simulation, and spatial information into the EDSS. The case study of the M/V Lady Tuna accident serves as a practical application, allowing for the determination of the most suitable response technique through tradeoff considerations. The results showcase the utility of EDSS in enhancing the decision-making process during oil spill response efforts. The case study of M/V Lady Tuna provides valuable insights into the challenges specific to the incident and underscores the importance of tailoring response strategies to the unique characteristics of each spill event. The expected impact of this research lies in the comprehensive analysis facilitated by the EDSS, which provides decision-makers with a holistic understanding of the complex trade-offs associated with different response strategies. By visualizing data and predicting potential outcomes, the EDSS aims to reduce risks, engage stakeholders transparently, and align response strategies with environmental regulations and sustainable development goals. This study contributes to the protection and sustainable use of marine resources in alignment with SDG 14, "Life Below Water."

Keywords: *Environmental Sustainability, Net Environmental Benefit Analysis, Oil Spill Response, Risk Management, Tradeoff Decision*

A Proposal on a Quantified Ship Navigational Assessment and Audit Model

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Abstract

Navigational errors on board ships have consistently been a contributing factor to catastrophic disasters, resulting in substantial loss of human life and extensive damage to the vessel, its cargo, and the surrounding environment. Furthermore, the growing complexity of the integrated bridge layouts and the introduction of sophisticated navigation equipment have inadvertently contributed to an increased risk of navigational errors. This risk is further amplified by inadequate training and insufficient familiarization of navigational watchkeepers with the newly implemented technology and procedures. Despite the implementation of a robust set of navigation and bridge procedures and checklists as per the International Safety Management (ISM) Code, a significant proportion of navigational accidents remain attributable to procedural inefficacy, ignorance of bridge watchkeeping best practice, poor bridge team management, and ineffective communication. This indicates the need for further investigation into the underlying causes of these persistent issues. At that point, navigation audits and assessments, as a requirement of Tanker Management and Self-Assessment (TMSA), would identify gaps in the procedures, bridge team and equipment, thus leading to likely improvements and enhancements of the navigation practices on board ships. Although, "a guide to best practice for navigational assessments and audits" published by the Oil Companies International Marine Forum (OCIMF) provides a scheme, audits and assessments can vary in quality and their value to the end user can be questionable. To develop complete, accurate, objective, clear, and concise navigational assessment and audit reports/results for end users, we propose a quantified navigational assessment and audit model. The proposed model inspires from the guide to best practice for navigational assessments and audits but presents a unique analytic approach. The results obtained by the application of the proposed model provide extremely important information to the end users in order to improve the safety of navigation.

Keywords: *TMSA, Navigational Assessment, Safety Management, Tanker, OCIMF*

Floating Solar Powered Systems: Design, Performance and Environmental Impacts

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Abstract

Floating solar systems have exciting potential for sustainable energy production. In order to effectively implement Floating solar systems, it is important to consider various factors such as design, performance and environmental impacts. In this study, an example application was considered for Muğla, Bafa Lake, and calculations and data were collected to determine the daily average solar radiation. The surface area of Lake Bafa is 65 km2 and the average depth of the lake in the north is around 2 meters, and its middle parts reach 21meters. In this article, floating solar energy systems' a sample application for Lake Bafa is considered 100 panels, panel efficiency is18%, total Installed Power is 30 kW, and Wind Coefficient (Cd): 0.7 (a general value for a circular floating platform), Bottom Depth for Wave Effect Under the Floating Platform (d): 2 m. System parameters, energy production calculations, motion and fluctuation analysis on water, environmental impact assessments, cost calculations and efficiency management strategies are examined in detail in this article and Wind force ≈18312.5N, Moment of Resistance has calculated as 20665.9Nm. Modeling steps of impacts on water quality and ecosystem are considered as Collecting Data, Determining Model Parameters, modeling different scenarios, Analyzing the results of the modeled scenarios and evaluating the effects on water quality, ecosystem health and habitat loss. Additionally, total estimated cost is calculated as 192,000USD. This study can help us understand, the future of the study, the effects of design parameters and various factors on the development of technology and innovations, performance metrics such as energy efficiency, power production, sun exposure times; how these systems can be integrated with other energy sources.

Keywords: *Solar Energy System Design, Floating Photovoltaic System, Solar Energy Technologies, Energy Production on Water by Solar Energy*

Entrepreneurial Tendency of Cadets and the Importance of Entrepreneurial Education in Maritime Universities

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Abstract

This study examines the possible negative effects of technological developments on employment in the maritime sector and focuses on the long-term benefits of entrepreneurship education, which is thought to be a way to address future unemployment problems. For this purpose, a study was conducted to determine the entrepreneurial tendencies of students at a university with maritime-related programs. In this framework, the Individual Entrepreneurial Orientation Scale developed by Bolton and Lane was applied to 267 students. The scale examines entrepreneurial tendencies in three dimensions: risk-taking, innovativeness, and proactiveness. The data were analyzed with the R program, and it was concluded that the entrepreneurial tendencies of the students were high. This shows that if the students are guided properly, they can create new fields of business that can solve the problem of unemployment, or they can be good intrapreneurs. In this framework, it can be useful to provide effective entrepreneurship education to students and to increase the activities aimed at giving them an entrepreneurial mindset at the university. Future research in this area could focus on how ideal entrepreneurship education should be at a maritime university.

Keywords: *Maritime, Cadets, Entrepreneurship Education, Technological Developments, Unemployment*

Problems Faced by Women in the Maritime Sector: A Research on Customs and Ethical Values

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Abstract

Maritime is a service sector traditionally dominated by men, but in which women are also actively involved. The maritime profession serving in this sector is generally a profession that requires long, intense work performance and physical endurance. In this respect, the maritime profession is a physically and mentally challenging profession for both men and women, and sailors have customs and traditions that they follow among themselves. These rules consist of hierarchical order and ethical values. This is an important issue to consider as female employment increases in the maritime sector. Women actively working on ships; It faces various problems such as the lack of homogeneous and consistent application of maritime traditions and customs on the ship, the absence of an ethical working environment on the ship, and the lack of an ethical approach to maintaining talents and skills on the ship. The aim of this study is to prevent the problems faced by women operating in the maritime sector, ensure gender equality in the workplace, support career development and measure general satisfaction levels. The data set to be used for this purpose will be obtained through a survey. With this survey, survey questions consisting of the Maritime Institute Code of Ethics published by the Maritime Institute will be applied to ship personnel and the survey results will be evaluated to obtain information about gender equality of those working on the ship. SPPS method will be used to analyze the data.

Keywords: *Maritime Sector, Women at Sea, Customs and Traditions at Sea, Ethics at Sea*

Analysis of Human and Organizational Factors (HOFs) in Ship Grounding and Sinking Accidents Occurred inthe Black Sea

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Abstract

The Black Sea, renowned as a pivotal link between Europe and Asia, stands as an important sea route for international maritime trade, representing approximately 3% of global maritime trade activities. The Black Sea not only facilitates trade among its coastal countries but also serves as a perpetually active maritime corridor frequented by the global maritime fleet. Undoubtedly, the occurrence of marine casualties and incidents in this region holds critical significance in terms of maritime safety. Despite improved cross-border collaborations among the shoreline countries, technological advancements, and regulatory measures over the last decade, the persistent occurrence of marine casualties remains a significant concern, posing a threat to safety-sustainable maritime transport. Therefore, this study focuses on the human and organizational factors contributing to grounding and sinking accidents, one of the prevalent accident types within the Black Sea from 2019 to 2024. Utilizing the Human Factor Analysis and Classification System taxonomy, reports from 20 recent accidents were analysed, and the findings were compared with existing literature. The objective is not only to analyse these factors and reiterate those already identified in earlier studies but also to assess which extent of the earlier studies' findings have been considered and addressed by the industry and which are the reoccurring ones required to be emphasised. As a result, enduring accident-contributing factors are identified, and recommendations are proposed, aiming at preventing accidents and enhancing maritime safety, drawing from the results of the current study and studies conducted during the past two decades.

Keywords: *Human and Organizational Factors, HFACS, Black Sea, Marine Accidents, Maritime Safety*

Policy-Driven Innovations for Enhanced Blue Growth Impact on Energy Efficiency and Carbon Emission Reduction

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Abstract

The blue economy sectors are poised to unlock their smart, inclusive, and environmentally friendly potential to meet the escalating societal demands for food, energy, raw materials, employment, and economic prosperity. Concurrently, the imperative to address energy efficiency and reduce carbon emissions takes center stage across these sectors, guided by a myriad of policies, initiatives, and programs aimed at fostering the development and implementation of carbon-efficient innovative technologies and practices. This study delves into the energy efficiency and carbon emission reduction potential within the realm of blue growth, with a specific focus on ‘low carbon, ‘’digitalization and industrial transformation,’ and ‘circular economy’ strategies. The analysis draws on technologies and practices developed through EU-funded projects, aligning with key EU priorities, orientations, policies, programs, and initiatives. Blue growth encompasses the evolution of new value chains, markets, and the acceleration of innovations from laboratories to markets. It involves multi-purpose platforms, vessels, services, electronic infrastructures and ‘Blue Cloud’ as well as Marine Spatial Planning. The European Green Deal, Horizon Europe Program, Mission Ocean, Blue Growth Strategy, Blue Economy Strategy, and other frameworks provide the overarching guidance. Specifically, maritime transport is innovating in shipping operations (digitalization, fleet management, onboard energy management, autonomous and cooperative shipping, energy efficient navigation systems), port operations (smart port technologies, autonomous vehicles and drones, renewable energy integration, electrification), and ship building/retrofitting (digital twin technology, hull design and coatings, advanced propulsion systems, alternative fuels, renewable energy, energy recovery systems, fuel cell technology). Marine and coastal tourism explores sustainable vessel technologies, sustainable infrastructure design, renewable energy integration, smart tourism platforms and virtual and augmented reality experiences. Marine capture fisheries focus on selective, low-impact, efficient fishing gears, fuel-efficient propulsion systems and hull design optimization, GPS-based fishing and acoustic technologies, autonomous fishing technologies, and smart trawling systems. Marine aquaculture targets efficient, low-cost production through sensor, IoT and AI integrated intelligent systems, automated feeding, and sustainable water and energy management. Marine biotechnology strives for innovation in biosensors, IoT, and artificial intelligence for efficient production, algae-based biofuel production, electrofuel production and carbon capture by marine microbes. Marine mining drilling leverages technologies for fuel-efficient and electric/hybrid vessels, energy-efficient drilling, renewable energy integration, autonomous underwater and remotely operated vehicles for precise seabed characterization and drilling location optimization, carbon-neutral drilling fluids and subsea carbon injection. Marine energy pursues sustainable and predictable energy production via advanced turbine technologies, wave energy converters, tidal turbines, floating photovoltaic arrays, energy storage, digital twin applications, dynamic cable systems and subsea energy hubs. Marine research aims at remote sensing, carbon-neutral sampling equipment, autonomous research platforms, eco-friendly field stations, energy-efficient data centers, green laboratory practices, green ship technologies, and carbon offset programs. In conclusion, a holistic comprehension of blue growth across policy-making, industrial applications, research, and innovation promises a substantial positive impact on carbon budgeting, ushering in a sustainable and resilient future.

Keywords: *Blue Growth, Energy Efficiency, Carbon Emission Reduction, Policy Driven Innovative Technologies and Practices*

Electronic Design of Free-running Ship Model for Manual Control

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Abstract

Free-running ships are actual ships shrunk to model scale that are controlled remotely and used to conduct standard maneuvering tests to assess a ship's maneuvering capabilities, directly. They also provide a basis to elevate the autonomy level in an aim to respond to poor environmental conditions and perform predefined tasks. Therefore, electronic design of these ships is very important for increasing the capability of the model. This study focuses on a specific free-running ship, a 1/80 scale model of the Duisburg Test Case (DTC) Container Ship. We have previously conducted experimental free-running tests in towing tank using a remote controller (RC) that commanded the older electronic design. Recently, the electronic equipment was renewed and the design enhanced for better model operability. This study describes the two designs and compares their performance while talking about the advantages and disadvantages of each.

Keywords: *Free-running Ship, Ship Autonomy, Duisburg Test Case (DTC), Electronic Design*

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Identification of Uncertainties in Accommodation Fires: A Case Study of the Beata Ship Fire

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Abstract

Ship fires, classified among accident types with destructive consequences and encompassing numerous uncertainties, pose a critical threat to the crew's safety. Particularly, accommodation fires onboard are critical to the safety of crew. When ship fires are of significant scale, they often result in destruction of evidence. The effect inflicted by fire-explosion accidents on the maritime economy should not be underestimated. This study aims to uncover the uncertainties surrounding a fire-explosion accident in the accommodation area of the dry cargo ship named Beata, with a deadweight of 9,215 tons, which occurred off the coast of Sinop in the Black Sea on December 20, 2022.Following the accident, the ship's accommodation area was completely burned, resulting in 9 seafarers being seriously injured and 2seafarers losing their lives. The fire-explosion incident on the ship also destroyed the evidence that could be used to clarify the causes and causal factors of the fire; therefore, the origins and causes of the accident have not been clarified yet. This study will attempt to predict how the fire occurred by examining similar fires in the literature, considering the statements of seafarers, insurance club reports, flag state-port state accident reports, port state control reports, and expert opinions. Recommendations will be provided to maritime authorities based on the study's outcomes for establishing sustainable maritime safety.

Keywords: *Fire-explosion, Marine Accidents, Accident Analysis, Human Factor, Ship Fire*

Analysis of IMO Autonomy levels for Ships

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Abstract

Sea transportation is one of the most important elements of global trade. Considering that world trade is mainly performed by sea transportation, it is of great importance that sea transportation is carried out efficiently, safely and securely. Sea transportation, which has a key role in world trade, receives more than its share from the developing technology. With the impact of rapidly developing technology, the concept of autonomous and unmanned ships has emerged and has been accepted as the future of sea transportation. Autonomous and unmanned ships are new generation ships that have the potential to revolutionize the maritime industry. In recent years, developments in autonomous ship technologies have enabled autonomous ships to become widespread in sea transportation. Autonomous ships can perform operations without human intervention and have the potential to increase efficiency, safety and security in sea transportation. The growing of autonomous ships also requires certain changes in international maritime regulations. The International Maritime Organization (IMO) has classified the concept of autonomous ships into four levels according to the degree of autonomy and human involvement. These levels indicate the degree to which autonomous ships require human intervention. The aim of the study is to analyze IMO autonomy levels by using multi-criteria decision making (MCDM) methods and to reveal the most proper alternative to operate for today's condition from the cost, safety/security, technical and social perspectives. Within the scope of the study, each autonomous degree will be analyzed by considering the main criteria of cost, safety/security, technical and social and sub-criteria to these main criteria.

Keywords: *Autonomous ships, IMO, MCDM, Sea transportation*

PSC Inspection Deficiencies on Turkish Flagged Vessels from the Maritime Labor Convention 2006 (MLC 2006) View

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Abstract

For seafarers, ships are a long-term living space, sometimes even longer than their homes. The fact that the main purpose of the ships is to carry out commercial activities may sometimes cause the standards related to the living conditions on board to be put into the background. Due to these ignored humanitarian living conditions, seafarers have started to move away from ships. The International Maritime Organization (IMO) has put this issue on its agenda and emphasized that working and living conditions on board ships should be regulated and standardized. For this purpose, Maritime Labor Convention 2006 (MLC 2006) has emerged. Within the scope of the MLC convention, there are rules under the headings of minimum requirements for working at sea, working conditions, accommodation and recreation facilities, food and beverage services, health, medical care, social assistance and social security issues and compliance - implementation principles. Countries have the authority to inspect ships as responsible for ensuring that the ships flying their flags meet these standards and the inspection of the compliance of the ships with IMO rules is carried out by port state controls. In this study, deficiencies arising from the MLC convention that cause the detention of Turkish flagged ships in port state controls are examined with statistical methods and data mining algorithms. The analysis is carried out with the dataset obtained in the Paris MOU public database between 2017-2023. It is thought that the scientific findings, results, and achievements obtained as a result of the study will contribute to the improvement of the working and living conditions of seafarers on ships.

Keywords: *PSC, Paris MoU, detention, MLC*

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The Potential of the Maritime Industry in Sustainable and Green Transformation

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Abstract

This article examines the future of electric ships, addressing the key factors in the adoption of this technology. Emphasizing the environmental advantages of electric ship (ES) technology, it analyzes the role of the regulatory framework, standards, incentives and global cooperation in the widespread use of this technology. Additionally, encouraging ES investments, economic advantages, and future potential are discussed, emphasizing how the maritime industry can lead a sustainable and green transformation. This article has been created on the basis of literature review and analysis of industry reports. Many sources have been examined on the current state of ES technology, regulatory frameworks and standards worldwide, policies to encourage investments and global cooperation. Additionally, interviews with industry experts and statistical data on the current state of technology also formed part of the methodology. The findings of the study are as follows: For ES technology to become widespread, regulatory frameworks need to be strengthened, standards should be established and cooperation around the world should be increased. Economic incentives such as government incentives, tax advantages and financial support mechanisms can be effective in directing industry players towards electric ship technologies. Additionally, factors such as advances in energy storage systems, expansion of electric ship infrastructure, and strengthening of the regulatory framework will shape the future of the electric ship industry. These findings can form a basis for determining the measures and strategies to be taken in the process of adopting ES technologies to achieve the environmental sustainability goals of the maritime industry.

Keywords: *Electric Vessel, Marine Engineering, Sustainability, Green shipping, Battery powered vessel, EV Regulations*

Digital Twin Development for Samsung Autonomous Navigation System for Shift Auto Sea Shuttle

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Abstract

In this paper, we introduce the digital twin system development in order design Shift-Auto Perception and Autopilot System for Samsung Heavy Industries (SHI). SHI have been working on Autonomous and Smart Ship solutions as of 2019. SHI is one of the first initiator of the smart digital solutions on ships. SHI initially completed retrofitting the 38m Samsung T-8 Tugboat with Samsung Autonomous Ship (SAS)solution and managed its successful voyage of approximately 10km at Geoje Island without any intervention of the on-board crew on October, 2020. To ensure the proper functioning of a fully autonomous ship, it is necessary to closely monitor its real-time reactions to the surrounding dynamic changes using a digital environment. The controller algorithm is governed by a command and its optimal parameters can be adjusted based on environmental changes. It is necessary to monitor the ship's reaction to changes in the controller parameters to fully comprehend the ship's autonomy. Therefore, the digital replica of a ship is considered a crucial element in the journey towards designing MASS Level-4 Autonomy for ships. Although maritime institutions have not yet acknowledged its significance, the ship digital twin concept is anticipated to become a prominent subject in marine engineering shortly. This study aims to establish the concept of a ship's digital twin about navigation autonomy and perception. This paper begins by outlining the trajectory toward achieving complete autonomy in maritime environments and emphasizes the necessity of a digital twin by providing a clear definition of this concept specifically for ships. A mathematical model of ship maneuvering is employed to depict the ship's physical behavior. The subsequent sections provide the details of the Samsung SAS Hardware-in-the-Loop mechanism and the control implementation. The propeller and rudder models undergo initial validation through free-running self-propulsion and turning circle tests. Consequently, our ship relies on an autopilot system to navigate in a straight line. Various simulation cases are categorized, including manual and autopilot mode during different scenarios, such as mooring, berthing, and zig-zag. An analysis of the obtained outcomes demonstrates the efficacy of the digital twin framework employed in this research. Additionally, we detail the SAS-HIL integration levels during the design of the autonomy for Samsung Sea-Shuttle and Big Ships.

Keywords: *Shift-Auto, Ship Digital Twin, Autonomy, Control System Design, Model Based Design, Hardware-in-the-Loop Implementation*

An Investigation About the EU MRV Data on European Maritime Area

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Abstract

The United Nations Sustainable Development Goals (SDGs) are established by the International Maritime Organization (IMO) as the Initial Greenhouse Gas (GHG) Strategy. This strategy is foreseen to regulate GHG and CO2 emissions. Effective monitoring and management of emissions are crucial for guaranteeing sustainability and environmental responsibility in the maritime industry. Obtaining accurate data on this subject can be rather difficult. To tackle this problem, the European Commission and IMO have devised data-gathering systems to monitor emissions and ensure that vessels are adhering to the prescribed Strategy. The EU Monitoring, Reporting, and Verification (MRV) framework was designed by the European Commission, while the International Maritime Organization (IMO)implemented the Data Collection System (DCS). This study seeks to delineate the distinctions between the European Union Monitoring, Reporting, and Verification (EU MRV) system and the International Maritime Organization Data Collection System (IMO DCS). Although the EU MRV data has been made available to the public, the DCS data remains inaccessible to the public by IMO. There are a couple of aims of this study, one of them is to set out differences between IMO DSC and EU MRV, other is to examine the findings obtained from the European Union Monitoring, Reporting, and Verification (EU MRV) data gathered from 2018 to 2022. Another is to identify trends and patterns in the retrieved data, focusing on achievements in emission reduction within the marine industry.

Keywords: *EU MRV data, International Maritime Organization, Data Collection System*

Factors affecting the selection of ship recycling country: A binary logistics regression approach

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Abstract

The shipping industry is facing the need to shape a sustainable future with more environmentally friendly technology. This change affects all shipping markets as well as the ship recycling market, and a strong increase is expected. At the same time, the ever-growing fleet is expected to put upward pressure on the ship recycling industry. Even though the ship recycling industry is often criticized for health and safety reasons, it can develop its potential for a greener market if it implements Hong Kong and makes the necessary transformation. Turkiye, one of the five countries with the largest market share in the ship recycling industry, also stands out for its green approach. Turkiye's potential to adopt sustainable ship recycling practices needs to be revealed. Therefore, it is important to investigate the potential of the recycling market for Turkiye. In this regard, this study analysed the factors that influence the decision of owners to recycle their ships in Turkiye. Binary logistic regression was applied to the dataset to analyse the variables that contribute to the decision to recycle in Turkiye. The dataset was obtained from the NGO Shipbreaking Platform and includes a total of 3264 recycled ships between 2018 and 2022. Unknown sources were deleted so that a total of 3249 recycled ships were included in the analysis. A total of eight predictor variables such as ship types and sizes, flag, flag change, country, age levels, arrival date, country of registered owner were identified with the dependent variable country. To identify the variables former studies and database was considered. The chi-square value of 895.728 with a p-value of 0.000 shows the statistical significance of the model containing the predictors examined. This is also supported by the results of the Hosmer and Lemeshow test. This model explained between 24.1% (Cox and SnellR2) and 44% (Nagelkerke R2) of the variance in the decision to recycle ships in Turkey and correctly classified 88.2% of the cases. This study finds that cruise ships, drilling, and platform are 21.151, 11.800 and 6.405 times respectively more likely to be recycled in Turkiye compared to tankers. Ships flying flag of Togo were 3.256 times more likely to be recycled in Turkiye compared to ship flying the flag of Panama. Ships which changed their flag at the end of their life were more likely to recycle in Turkiye compared to ships did not change their flag. The ships which have beneficial owner countries Japan (OR 47,61), China (31,25), United Arab Emirates (29,41), and Singapore (13,69) were more likely to recycled in countries other than Turkiye compared to Greece located beneficial owners. Registered owner countries Marshall Islands (OR=2.312) and Norway (OR= 4.033) were more likely to be recycled in Turkiye than Panama registered owners. This study serves as an initial step in identifying the market potential of the ship scrapping market in Türkiye. However, the study is limited to ship related variables. Future study is planned to expand the scope by incorporating economic factors such as steel prices and recycling prices.

Keywords: *ship recycling, binary logistics regression, market potential*

Determination of Primary Personality Traits for Seafarers Using the AHP Method

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Abstract

Although maritime is one of the oldest professions in the world, it is constantly transforming with the developing technological conditions and changing political conditions. However, despite this developing and changing system, the daily lives of seafarers are often different from the lives of people living on land. This difference is generally thought to be caused by narrow living spaces and limited social environment. As a result of these differences, which are known to have negative effects on the psychological health of seafarers, it is seen that crimes such as murder, detention, injury, extortion and many other behaviours that can be associated with crime occur on ships. In these incidents, it is seen that the main reason for the poor psychological health of the seafarers at the time of the incident is mostly their pre-ship experiences. As a result, it is considered to be very important to determine the psychological state and/or personality traits of seafarers, as in most occupational groups, before the ship life with personality inventories that are currently used in psychology or customised for the maritime profession. In this study, it is aimed to make a hierarchical ranking of the personality traits that should be focused on in personality inventories to be applied to ship employees. For this purpose, a sample application was made using the AHP (Analytical Hierarchy Process) method for 15 people who are experts in the field of psychology and maritime. Microsoft Excel software was used for the application. In practice, the personal characteristics previously determined from the literature were weighted by experts, and in this way, important personality characteristics were placed in a hierarchical order. Then, the most suitable personality traits for the maritime profession were determined.

Keywords: *Seafarers, Maritime Psychology, AHP*

Cognitive Assessment of Tugboat Captains During Port Maneuvers: A Neurophysiological Approach

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Abstract

This study investigates the cognitive levels of tugboat captains, key players during port manoeuvres, which are a crucial part of sea navigation. The objective is to reveal the main neurophysiological findings related to the measurements of the tugboat captains' brain activity during real port manoeuvres and to investigate the relationship between this brain activity and situational awareness. The research employed an experimental approach, recording the brain waves of tugboat captains using an EEG device and relevant software during actual port maneuvers. Within this framework, the situational awareness levels of four tugboat captains were assessed, with a focus on the Fast Fourier Transform (FFT)/Band power graph values during 38 maneuvers. The peak moments of situational awareness in sea navigation were identified, shedding light on the correlation between brain waves. Additionally, disparities in brainwaves among tugboat captains and variations in brain waves based on whether the port maneuvering occurred during the day or night were scrutinized. Within the scope of the research, to analyze the FFT values of the participants, significant number of differences were detected through the non-parametric Spearman correlation test. Subsequent to the Post-Hoc analysis of the Kruskal Wallis test results, significant differences were observed in Fc5 Beta H, Fc 5 Gamma, and O2 Gamma waves among individuals. Lastly, the Mann Whitney test indicated a significant difference in the Fc6 Theta variable between day and night conditions. As a result of the research, it was determined that there is a functional relationship between the neurophysiological findings of tugboat captains and that brain waves exhibit variations among individuals and according to the moment of maneuver. Consequently, this study contributes to the literature by demonstrating that situational awareness detection in real sea navigation can be achieved through the use of an EEG device with a neuroscience approach.

Keywords: *Situational Awareness, EEG, Tugboat Captains, Fast Fourier Transform, FFT, Sea Navigation*

Engine Room Resource Management Training Model with Collaborative Teamwork and Using the Engine Room Simulator

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Abstract

Effective teamwork is crucial for ensuring safety and success in shipping operations. Several International Maritime Organization (IMO) model courses are utilized in Engine Room Resource Management (ERM) training; however, not having a single model course leads to various approaches. The aims of the ERM training for students of Maritime Education and Training (MET) institutions are achieved usually by one or more courses in the curricula. However, the institutions specifically offering ERM training need guidance on how the model courses can be combined in a relatively short yet efficient training program using an engine room simulator (ERS). This study presents the details of the proposed ERS model with collaborative teamwork training by utilizing the ERS. The model integrates the IMO Model Course 2.07 and Standards of Training, Certification, and Watchkeeping (STCW)competencies. Leveraging ERS, the model optimizes training hours while maintaining efficacy. Compliance with STCW 2010 requirements is achieved through collaborative teamwork training, emphasizing leadership and communication. The proposed ERS model facilitates practical scenario development, mirroring real-world challenges and enhancing decision-making skills. The study presents diverse training scenarios, demonstrated with ERS and pilot studies with different configurations, and adaptable by various institutions. This research contributes to optimizing ERM training, aligning with regulations, and promoting a culture of effective teamwork.

Keywords: *Engine Room Simulators, Maritime Education and Training, Teamwork, Collaborative Teamwork*

Development of Maritime Autonomous Surface Ships (MASS) using Model-Based Systems Engineering (MBSE) Processes

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Abstract

Autonomous Surface Vehicles (ASV) have witnessed significant global interest in recent years. Various classification approaches for unmanned maritime vehicles are discussed, shedding light on diverse projects within this domain. The International Maritime Organization's autonomy levels are a foundation for defining maritime autonomous surface ships (MASS). With this new definition, a new approach in maritime projects must also conclude the product at the end as needed. This approach is defined as Model-Based Systems Engineering (MBSE) which has a wide range of applications in different areas for requirement management. The basic concepts of systems engineering are outlined to facilitate the application of Model-Based Systems Engineering (MBSE), emphasizing its broad applicability. MBSE, a contemporary approach, is compared with document-based systems engineering (DBSE), focusing on its advantages. The introduction of System Modeling Language (SysML) and its schemas provides the foundation for this study. Using SysML on a MBSE tool a case study is demonstrated for a MASS Project. Following systems engineering processes, this paper explores business, stakeholder, and system needs studied in accordance with international standards and regulations. After applying the systems engineering processes, technical requirements are derived. In the implementation phase, the requirements serve as the basis for defining the concept design in a program dedicated to a specific MASS project. Structural and behavioral diagrams are crafted using SysML, aiming to serve the collaborative efforts of diverse stakeholders and streamline engineering activities. Recognizing the complexity of implementing all systems engineering processes, the paper emphasizes the subject with demonstrations, showcasing the feasibility of the proposed MBSE approach for developing MASS and associated interfaces.

Keywords: *Maritime Autonomous Surface Ships (MASS), Model-based Systems Engineering (MBSE), Requirements Management, IMO*

Analysis of the Impact of Daylight on Grounding and Collision Accidents

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Abstract

Accident investigations are essential for preventing future accidents. According to investigation findings, the number of accidents that happen at night is higher, and the consequences are more severe. The difference in the number of accidents and their causes between day and night is a critical issue that requires attention. The Canakkale and Istanbul Straits should be investigated in terms of these distinct differences in accident times. These straits have considerable marine traffic both day and night, increasing the potential for accidents. The aim of this study is to analyze the accident times in the Istanbul and Canakkale Straits in terms of ship watches. Between2001 and 2016, 451 grounding and collision accidents occurred in the straits. The accident data were analyzed using SPSS and the Chi-Square test. Examining the data reveals a considerable difference in the number of accidents occurring between night watches and day watches, with night watches having more accidents. The tests revealed this difference to be statistically significant. The findings of this study support previously discovered links between circadian rhythm and ship watches.

Keywords: *Istanbul and Canakkale Straits, Grounding Accidents, Collision Accidents, Ship Watches*

Maritime Supremacy in Foreign Policy of States

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Abstract

It can be said that the seas are indispensable for humanity. Humanity's utilization of the seas is realized within the framework of two main purposes: The first is the use of the seas for transportation and communication; the second is the exploitation of the seas for the exploration and exploitation of natural resources and wealth. Since 85% of international trade is conducted through the seas, the foreign trade sector through maritime transportation has become the backbone of global capitalism, and the merchant fleets and ports of states have become the critical infrastructures of global trade. Maritime transportation is the most preferred mode of transport due to its low cost, price stability and security. Therefore, the seas have served as a catalyst for the economic development, prosperity and progress of states. States connected to the seas have engaged in global trade and are better positioned for sustainable development. However, it is important that the seas are controlled by powerful navies to ensure geopolitical dominance and supremacy. Since the seas are a necessary resource for defense as critical elements of geopolitics, states invest in shipping to both dominate and benefit from the seas. The issue of maritime supremacy in the foreign policies of states covers three main elements: Maritime economics, sea power and maritime domain studies. Today, maritime supremacy is used in line with the national interests of states. The resulting "sea blindness" is more often the case for states that see the advantages of their geopolitical position and military interests as maritime superiority. However, this only constitutes the sea power (military/security/defense) dimension of the maritime supremacy approach. The other two elements, maritime economics and maritime domain studies, include maritime industry, maritime trade insurance, foreign trade, logistics, fisheries, protection of the marine environment, maritime safety and security, seafaring and seafaring humanity. The fact that these issues are now on the foreign policy agenda of states reveals the need for international cooperation. The set of rules that express the political and technical dimensions of maritime security and law in an international character can only be possible within the framework of the mechanism established by states and international organizations and through consensus. A state that is aware of the importance of the seas in the context of foreign policy making can become a powerful actor in its region. A strong navy and also commercial navy that enriches the state, as well as scientific research and planning related to ports and the geography of seas and waters, significantly increase the political and economic power of *states. In this framework, this study will analyze the need for states to determine a maritime supremacy strategy in order to avoid sea blindness in foreign policy.*

Integration of Ballast Water Treatment System Simulation into Ship Engine Room Simulator and MET Curricula using UML Design Approach and NI LabVIEW

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Abstract

Many invasive aquatic species worldwide were carried only by ships' ballast water. To prevent this, the International Maritime Organization (IMO) implements regulations on ballast water management. To adhere to these regulations, numerous ships are now equipped with Ballast Water Treatment Systems (BWTS). This study involves the development of various theoretical and mathematical models to simulate ballast operations and BWTS installed and operated onboard ships. The parametric simulation also models various failure scenarios and operations in the actual operational environment. This research provides a comprehensive understanding of BWTS and offers a valuable tool for simulating real-world scenarios, enhancing the maritime training experience for cadets. There is currently a gap in the BWTS training using simulators due to the lack of an exercise on BWTS in IMO Model Course 2.07. This research integrates BWTS by utilizing National Instruments (NI) LabVIEW and Unified Modeling Language (UML) design approach into the Ship Engine Room Simulator (SERS™), certified by Class NK, thereby bringing a new approach to the training of cadets in maritime education and training (MET) curricula under the framework of both IMO STCW 2010 with Manila Amendments and IMO Model Course2.07. The paper also presents the experience of cadets training using the BWTS newly coupled with the curriculum.

Keywords: *Maritime Education and Training, Ballast Water Treatment System, Ship Engine Room Simulator, Unified Modeling Language*

Design and Evaluation of Hybrid Power Propulsion System for a Ferry

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Abstract

The International Maritime Organization has implemented new strict shipping regulations. To comply with these restrictions, the maritime industry is making significant efforts to improve the energy efficiency of vessels and reduce ship-based emissions. In this regard, various approaches are investigated by researchers and maritime companies. Implementing a hybrid propulsion system on ships is one of the most effective strategies for achieving this objective. This study analyses a hybrid propulsion system belonging to a ferry with a capacity of 248 passengers and 80 small vehicles, cruising between Stranda and Liabygda in Norway. The ferry is able to be operated by both electric motors driven by battery power and diesel engines. In the first stage of the study, design steps are discussed. Then, information about the operation of the ferry is provided. Lastly, the scenarios are created for examination. Accordingly, the emissions released in each case and their running costs are calculated by considering operational status such as navigation and maneuvering within four different scenarios. The first and second scenarios represent navigation with alone diesel generator, and navigation with just batteries, respectively. In the third scenario, the navigation is realized with a diesel generator while maneuvering is made with a battery system. In addition, the navigation is simulated with the battery power system while the maneuver is performed by the diesel generator in the fourth case. The comparative analysis ensures significant results regarding the utilization of the battery system onboard. The analysis highlights the advantages of battery power from the perspective of emission.

Keywords: *Maritime, Energy efficiency, Hybrid power unit, Battery, Diesel generator*

Hybrid Ferry Propulsion System Design Methods

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Abstract

In recent years, studies on limiting greenhouse gas emissions, especially in the maritime field, have led ship owners to take precautions to eliminate ship-based pollutants. Ferries, especially performing coastal voyages, are the ship type initially impacted in this sense. Inspections on ferries have been increased both because they sail in areas close to living spaces and because of the sensitivity of port authorities in passenger transportation. Therefore, ship operators have recently begun to prefer a more environmentally friendly ship production method. There are different methods for each ship produced according to different requirements. One of the influential methods among environmentally friendly and sustainable approaches is to use hybrid power in the propulsion system. In this regard, the most important knowledge regarding the design of hybrid power systems for ferries is knowing the load characteristics of the ship planned to be used. For a ship whose load characteristics, voyage region, and operating process are known, the battery to be used can be selected, appropriately. Since the power demand on ships is received from the battery system, the energy requirement is also taken into consideration when choosing the equipment to be used on the ship. The other essential issue when planning a hybrid power system for a ferry is charging stations. In this type of ship, which is planned to be used for passenger transportation, the batteries must be constantly charged for people to have a comfortable and uninterrupted voyage. Therefore, during the design phase, it is necessary to choose places suitable for charging stations at the piers.

Keywords: *Maritime, Energy Efficiency, Hybrid Power Unit, Battery, Diesel Generator*

Application of the Fuzzy Topsis Method for Recruiting Ship Captains: A Case Study on Chemical Tanker Management and Operations in the Era of Maritime 4.0

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Abstract

This research was conducted with the aim of identifying and evaluating the competency criteria involved in the process of finding and selecting ship captains in chemical tanker companies engaged in international dangerous goods transportation. It is well-known that a significant portion of maritime accidents are attributable to human error. Irreversible environmental disasters occur in maritime accidents involving tankers transporting dangerous goods on the seas worldwide. Chemical tanker transportation involves carrying lower volumes but more valuable hazardous cargoes. Despite representing only 3.1% of the total world maritime transportation volume according to the2022 figures, its importance in the supply chain is much greater. Chemical tanker transportation is an international maritime transport method with unique characteristics and dynamics, and as such, the criteria considered in the recruitment and selection processes for ship personnel can vary significantly. When it comes to ship captains, the criteria in the recruitment and selection processes become vitally important. The certifications, mandatory training and essential skills that ship captains must possess are regulated by international agreements. However, with the developments brought about by Maritime 4.0, various changes have been observed in the maritime industry, as seen in other industries. The required skills have changed and diversified. In addition to hard skills, soft skills have gained additional importance in ship captain appointments. Chemical tanker captains are crucial for the smooth operation of the global supply chain. The seamless functioning of ship operations, the reduction of delays, and the mitigation of unforeseen expenses are directly and indirectly shaped by the abilities of the appointed ship captain. Therefore, industry stakeholders pay special attention to the appointments of ship captains in the chemical tanker sector. Chemical tanker transportation is an international form of transportation with its own unique characteristics and dynamics. Moreover, the rapid technological changes necessitate ship captains to develop diverse skills. Considering the recruitment and selection processes for chemical ship captains, expert opinions, chemical tanker experience, communication skills, stress management, leadership, individual well-being, digital literacy, remote monitoring and control, security and cybersecurity awareness, environmental awareness, and sustainability Consciousness, as well as Hazardous Material Knowledge, will be examined with empirical knowledge to reveal the preferred qualifications for captain candidates in chemical tankers in line with the demands of global markets. In the research, after determining the criteria that captains working on ships carrying hazardous materials must possess through literature review and expert opinions, the degrees of importance of the criteria were identified using the Fuzzy TOPSIS method, and an application was carried out based on a sample involving three candidates.

Keywords: *Recruitment Criteria, Crew Resources Management, Chemical Tanker Operations, Ship Management, Maritime 4.0, Fuzzy TOPSIS Method*

Assessment of Inspection Processes During Liquid Bulk Cargo Handling Period

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Abstract

When the cargoes handled in Turkish ports are grouped according to their types as solid bulk cargo, liquid bulk cargo, general cargo, container and vehicle, the most handled cargo type in 2022 is liquid bulk cargo. The majority of liquid bulk cargo consists of fuel oil products. Therefore, it is important for Turkey's energy security that the handling of liquid bulk cargoes is carried out uninterruptedly, sustainably and in accordance with standards. An important process among liquid bulk cargo handling activities is inspection services. Inspectors, who are responsible for most of the processes involved in the loading and unloading of tankers and act as independent supervisors between the cargo owner, the terminal and the tanker, manage a very critical process. The performance of inspectors during their activities directly affects handling efficiency. In this study, it was aimed to evaluate the performance of inspectors involved in the liquid bulk cargo handling process. In this work, where two terminals serving in the field of liquid bulk cargo in Turkey were taken as samples, the duties of inspectors in the handling of tankers were determined according to the flow chart and a time study was conducted to evaluate their performance. By comparing the data regarding both terminals, detailed analyzes were made regarding the services carried out by the inspectors.

Keywords: *Terminal, Port, Liquid Bulk Cargo, Handling, Surveyor*

Naval Vessels for Distribution of Disaster Relief Materials by Using the Multi-Criteria Supply Chain Model

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Abstract

Countries located in devastating earthquake zones need to create supply chain management models that can meet the material requirements that will arise after disasters in a short time and at minimum cost. In this study, a multi-criteria stochastic optimization model was created, which envisages the supply, storage and delivery of materials that may be needed after the disaster by Naval Forces ships to distribution centers and then to disaster areas. Disaster Task Group. The aim of the model is to deliver relief materials to the affected population via Maritime Disaster Task Group ships and air transport vehicles in minimum time and with minimum total cost, including inventory and operational costs. The decision variables in the model are the sources from which relief materials will be provided, the location of warehouses and distribution centers, and the type and number of distribution vehicles. Supply Chain structure was taken as abasis in creating the model. This model allows decision-makers to choose the most suitable locations and delivery vehicles for different disaster scenarios.

Keywords: *Disaster Relief, Naval Disaster Task Group. Multi-Criteria Stochastic Optimization Model, Supply Chain Management*

Company Attractiveness and Ship Type Preferences of Maritime Faculty Students

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Abstract

Company Attractiveness is the potential benefit that an employee envisions when working for a particular organization. In essence, the stronger an organization's employer brand equity, the more appealing it is to potential employees. Recruitment is a crucial technique for attracting applicants and influencing their job choices. Career decision making is the choice of a person about a career, education program, or a profession. Individuals who possess knowledge about careers and their defining characteristics are more likely to make informed decisions during the career decision-making process. This can lead to greater success and happiness in their lives. Within the scope of this purpose, two-week career days is organised in maritime faculties annually. During career days, professionals communicate directly with students and explain the processes involved in entering their field. This attitude can have a positive impact on students. This research is to determine company attractiveness effective or not during career days. For this aim, 61 students participated pre and postsurvey during career days. Paired sample t-test were used via SPSS WINDOWS 25.0 analysis program was used to analyze data in this research. The sigma values obtained as a result of the paired sample t-test applied within the scope of the study show that career days are not effective in the process of deciding on the company (sig. 2-tailed- 0,528) and ship type (sig. 2-tailed- 0,831).

Keywords: *Company Attractiveness, Carrier Days, Decision Making, Paired Sample T-test*

Examination of Time-Dependent Components on Ships Using Alternative Marine Fuels with Chemical Kinetics

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Abstract

The use of alternative fuels, especially in internal combustion engines, plays an important role in reducing emissions. However, it is important to select some parameters for combustion reactions to occur in the most efficient way. These parameters are basically parameters that directly affect the combustion mechanism, such as temperature and air fuel ratio. In this study, the combustion performance of alternative fuels at different temperatures and air excess coefficients was evaluated parametrically. The fuels used are carbon-free fuels such as ammonia and hydrogen, which are the fuels most likely to be used in the future, and conventional fuels. As a result of the study, the combustion performances of traditional fuels and clean alternative fuels were evaluated comparatively. The study was basically carried out theoretically using the chemical kinetics method and according to the Arrhenius equation with time-dependent components.

Keywords: *Alternative Fuels, Chemical Kinetics, Hydrogen, Ammonia, Decarbonization*

Evaluation of Turkey's Ship Recycling Industry Policies in Terms of Transition to Circular Economy and International Trade in the Maritime Sector

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Abstract

Policy makers around the world, including Turkey, are exploring new production models that aim to increase circularity within the framework of sustainability and innovation. These models involve re-evaluating product design with the aim of reducing waste generated during production and throughout the life cycle of the goods. The transition to a circular economy that prioritizes effective resource use contributes to international trade in issues, such as supply chains, value chains and service trade. International trade also makes important contributions to the circular economy, such as the transition to economies of scale, sustainable use of raw materials and efficient use of resources. For the shipping industry, the transition to a circular economy is leading to changes in how ships are designed, maintained and recycled. In particular, the increase in the number of ships expected to be built with low carbon technologies and ships undergoing dismantling creates both opportunity and urgency for circular innovation. In recent years, significant developments have been made in the ship recycling industry, considered a "green industry". This industry supports the renewal of the global ship fleet and balancing ship supply-demand in the freight market, also contributes to sustainability by recycling millions of tons of scrap materials. Today, Bangladesh is the leader among ship recycling countries, followed by India, Pakistan, Turkey and China, respectively. These countries dismantle 98% of the total LDT (Light Displacement Tonnage). Turkey is the only country in the Mediterranean basin where ship recycling activities are carried out as a sector. Turkey is the first country among the leading countries in ship dismantling signing the "Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships". Turkey is an important ship recycling center, especially for the recycling of military ships and EU flagged ships. In Turkey, ship dismantling operations are currently carried out only in Izmir Aliağa, where 22 companies operate. Turkish ship recycling sector has risen to the fourth place in the world in terms of capacity and has become a leader in IMO's list, thanks to its advanced technology equipment, environmental awareness and sensitivity to occupational and worker health. The ship recycling industry contributes to the Turkish economy in terms of raw materials, added value, energy savings and employment. Iron and steel scrap is one of Turkey's most imported products, and it is possible to reduce the trade deficit in this field by developing the recycling industry. This study aims to reveal the impact of Turkey's policies on ship recycling on the transition to a circular economy and international trade in the maritime sector. In this context, the Turkish ship recycling industry has been examined in line with international agreements such as the Basel Convention, the Hong Kong Convention, the data of organizations such as the International Maritime Organization, the International Labour Organization, Turkish Chamber of Shipping, and regulations such as the EU Circular Economy Action Plan, the EU Ship Recycling Regulation and legislation in Turkey. In addition, Turkey's ship recycling industry has been compared with the leading countries in the industry.

Keywords: *Circular Economy, Foreign Trade, International Logistics, International Trade, Maritime Sector*

Biofouling Awareness and Antifouling Practices among Fishing Vessels: A Questionnaire Survey Assessment

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Abstract

The management of antifouling strategies for fishing vessels involves the active participation of fishermen and other stakeholders. However, this approach may inadvertently lead to potential mistakes, resulting in increased ship hull maintenance and fuel costs as well as the release of toxic substances into the marine environment and additional CO2 emissions into the atmosphere. The engagement of stakeholders, and more importantly, raising awareness about biofouling among them, is crucial, especially in cases where decision-makers lack the knowledge or resources for implementing effective policies. While most of the research conducted has focused on the hydrodynamic performance of ships and the biological characteristics of fouling organisms, there is currently a lack of studies addressing biofouling awareness within the fisheries industry. These 'data-limited' areas are of regional and global significance for achieving sustainable fisheries goals. To address this, sustainable management of data-limited antifouling strategies in industrial fisheries can be enhanced through the implementation of decision-support tools. In this research, initial underwater hull inspections were conducted on industrial fishing vessels, and fouling characteristics were determined for those operating in the Black Sea region. Following that, an attempt has been made to understand the awareness of biofouling and antifouling strategies followed among the stakeholders of the industrial fishing vessels operating in the Black Sea via a questionnaire survey. Questionnaire aims to determine current knowledge on biofouling, antifouling strategies, preferences, and behaviours as a social science research relevant to the biofouling phenomenon. Survey results thoroughly analyzed and results presented as an outcome. Based on the survey, a further study was conducted to present the impacts of biofouling. Results revealed that while increasing biofouling awareness among stakeholders of the industrial fishing vessels could lead from 6% up to 10.26% savings, from 18790 litres to 28530 litres of fuel could be saved for an industrial fishing vessel operating in the General Fisheries Commission for the Mediterranean (GFCM) area. Consequently, a significant amount of fuel cost saving could be possible with reduced Greenhouse Gas emissions released into the atmosphere.

Keywords: *Biofouling, Antifouling Coatings, Biofouling Awareness, Fishing Vessels, Industrial Fisheries*

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Modeling Troubleshooting Exercises Using UML Design Diagrams and Fault Trees with Scenarios Demonstrated Using the Ship Engine Room Simulator

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Abstract

Unified Modeling Language (UML) has emerged as a standard modeling language for specifying, designing, constructing, and documenting software systems. This paper explores the integration of UML design diagrams and fault trees in the modeling troubleshooting exercises in marine engineering education and training. Leveraging the capabilities of Ship Engine Room Simulators (SERS), this study institutionalizes a methodology for root cause identification, which is crucial for rapid response to emergencies in engineering operations. Engine Room Simulators (ERS) have become an invaluable training tool, particularly for training for problem identification. Root cause investigation into maritime engineering operations demands quick and precise action, making repeated in an ERS environment is therefore essential in Maritime Education and Training (MET). Key components of the methodology include the utilization of UML design diagrams, encompassing use cases, swim lane and activity diagrams, and state machine charts. This approach provides a visual representation of the relationships between entities involved in troubleshooting exercises, aiding in the comprehension and efficient application of root cause identification techniques. The fault tree analysis further enriches the methodology, systematically assessing the probability and consequences of various failure scenarios with the trainees' assessment. The methodology is encoded into the SERS, facilitating seamless integration into training programs.

Keywords: *Engine Room Simulator, Software Design, UML Diagrams, Troubleshooting, Root Cause Identification*

Analysis of Casualty Investigation Reports in the Mediterranean and Black Sea Region

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Abstract

Despite many precautions taken, maritime accidents are one of the most important problems of the maritime sector in terms of loss of life and property as well as the risk of environmental pollution. This study aims to statistically analyze maritime accidents in the Mediterranean and Black Sea in terms of accident severity and total loss. For this purpose, 408 maritime accidents between 2013 and 2023 were analyzed and Chi-square analysis and Association Rule Mining were performed on these data. For this analysis, casualty type, flag type, ship type, ship age, ship gross tonnage, ship length, cargo load status, weather condition, waterway type, casualty region, severity level, and situation of total loss were selected as variables. In the chi-square analyses, firstly, severity level was selected as the dependent variable. In this analysis, a significant difference ($p<0.05$) was found between severity level and ship type/ship gross tonnage. Secondly, situation of total loss was selected as the dependent variable. In this analysis, a significant difference ($p<0.05$) was found between situation of total loss and cargo load status/ship gross tonnage/ship length/casualty region. Association rule mining analysis was performed with threshold values set as 0.2 for support value and 0.8 for confidence value. In the association rules with the highest support value, "hull/machinery type accidents", "ships over 12 years old", "the accident occurred at the open sea" and "ships with a FOC flag" were found as prominent states. On the other hand, "ships over 12 years old", "general cargo ships" and "ships between 95 and 120meters length overall" were the prominent states in the association rules with the highest confidence value. It is thought that the research findings will be a guide for the authorities in the analyzed regions and ship owners/operators operating in these regions in terms of ship accidents.

Keywords: *Maritime Accidents, Casualty Severity, Total Loss, Association Rule Mining*

Effects of Near-Field Earthquakes on the Marine Structure

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Abstract

It is important that the maritime structures are designed accurately and in accordance with their intended use. Realistic modeling of seismic loads in their designs is a sensitive issue, especially when they are built in regions where destructive earthquakes can occur, such as the Sea of Marmara. The fact that the existing fault systems that can trigger earthquakes in the Sea of Marmara are very close to the ports makes this issue even more complicated. The determination of the physical elements of the characteristic ground motion in the near-field region and the possible effects of these elements on engineering structures is still an issue that has not been fully clarified. The current specifications for seismic design of ports in Turkey do not consider near-field effects in order to provide adequate safety conditions for structures located in reasonable proximity to an earthquake source. Generally, accelerations derived from classical probabilistic seismic hazard analyzes are used in the design of port facilities. These are based on ground motions in the far field and are then modified to account for local conditions. For this reason, the ground motions and associated seismic loads to which the structures are subjected may differ from the design criteria for the seaport, both in terms of the characteristics and the severity of the motions. Therefore, if port structures are located close to an earthquake source, they may not have the appropriate level of safety. In this study, the vulnerability of port facilities in the Ambarlı region of Istanbul to the effects of a near-fault earthquake was investigated. The distance of Ambarlı port facilities to faults is about 10 km according to the Renewed Turkey Active Fault Map on the MTA website(http://www.mta.gov.tr). The studies available in the literature on the effects of earthquakes near faults, Somerville et al. (1997) and Abrahamson (2000), have performed calculations by considering the change in average spectral accelerations depending on the orientation of the fault rupture. The results are presented by comparing the normal, parallel and average spectra as well as the geometric mean and maximum rotated spectra calculated for different earthquake magnitudes taking into account the orientation effects. The results show how important it is for ports, which may be exposed to the effects of near-field earthquakes, to achieve an adequate level of safety. They also show how important it is to clarify where and how near-field earthquakes should be considered in seismic design specifications.

Keywords: *Earthquake, Near-Field Ground Motion, Marine Ports*

Comparison of Offshore Fish Cage Systems' Floating Collar Designs with Finite Element Method

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Abstract

Aquaculture is a method of fish production using cage systems established on water mass, such as inland waters or seas. With the help of cage systems, this method controls the fish population and harvests them when they reach maturity. Although it seems like a modern production method, the first examples of this method date back to BC times. Today, decreased fish populations in the sea, caused by unregulated hunting, environmental disasters, and global warming, have led to aquaculture becoming a viable alternative to meet society's protein needs from seafood. However, the environmental factors required to establish these cage systems are only sometimes optimum. For this reason, analyzing the cage system elements under environmental effects will prevent any negativities and product losses that may occur during application. This study examines the designs of floating collars, which are the main elements of cage systems, enabling fish cages to remain balanced in the water and serve as a secure and stable platform for operational activities when required. The floating collars designed in different geometric shapes used in the application were modeled in 3D using AutoCAD. To simulate different scenarios, floating collar models were analyzed under different flow velocities (0.5 m/s, 0.7 m/s, and 1 m/s) using the Finite Element Method (FEM), and the results were compared. The mesh structures of the floating collar models were created using a 3Dtetrahedral element (tetrahedron), and the mooring systems in practice were simulated by defining fixed support on four surfaces. Analyzes were performed with the FSI: Fluid (Fluent) module of the ANSYS Workbench program, which allows the use of Finite Element Method (FEM) and Computational Fluid Dynamics (CFD) together and used to solve general engineering problems. The analysis results aimed to determine the criteria that should be considered during the design phase and to have an idea before implementation.

Keywords: *Finite Element Method, Computational Fluid Dynamics, Floating Collar*

An Analysis of Yacht-Related Incidents in Mediterranean Region

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Abstract

This study investigates maritime incidents involving yachts in the Mediterranean region, addressing a notable gap in existing literature concerning the specific needs and risks associated with this type of vessel, which has received less attention from maritime academics. The data sourced from S&P Global Inc., an American publicly traded corporation recognized for its expertise in financial information and analytics, to acquire all incidents reported over the previous ten years, specifically focusing on the Mediterranean region. The choice of S&P Global Inc. as the primary data source was motivated by its comprehensive coverage and authoritative standing in the field. The reports are analyzed thoroughly and visual presentations are created to picture the yacht related incidents nature. This work analyzed 65 maritime incidents within the Mediterranean region reported by S&P Global over the past decade (2013-2023). Notably, 31 incidents (48%) were classified as "serious" by S&P, defined as "vessels incurring significant damage and/or withdrawn from service" and 13 of these resulted in Total Loss. Among these serious incidents, fire and explosion emerged as the most frequent cause (13 incidents), followed by hull/machinery damage (12). Some fire incidents resulted in hull or machinery damage rendering the incident serious. The incidents were reported from nine different Mediterranean countries mostly from Greece (22), Spain (16) and Italy (12). This exploratory research provides a comprehensive decade-long overview of yacht incidents in terms of location, incident type, seriousness level and occurrences of total loss, and it creates opportunities for future studies to go farther into these aspects and beyond.

Keywords: *Maritime Safety, Marine Tourism, Yachting, Maritime Accidents*

The Role of Women in the Maritime Sector: Challenges for Female Seafarers in Türkiye

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Abstract

Diversity is a valuable resource of wealth in the maritime sector. Employees with different talents and perspectives can bring positive outcomes, such as creativity, problem solving, and innovation, to the global maritime community. The inclusion of women in the work force is crucial to the effective use of this resource and it is important to assess this development sector by sector. This study aims to examine the challenges faced by female seafarers in the maritime sector in Türkiye. Existing literature indicates that these seafarers face several challenges on board, such as gender inequality, work-family conflict and work pressure. However, there is no comprehensive study that examines the low female seafarers rates caused by these challenges and the impact of this situation on the sector. This study will be an important step towards increasing the number of female seafarers in the sector and promoting gender equality. It will be a valuable resource for policy makers and practitioners who aim to improve the position of female seafarers.

Keywords: *Women, Seafarer, Maritime, Gender Equality*

The Collection and Processing of Passenger Name Record Data to Fight against Terrorism and Serious Crimes in the Maritime Transportation in the European Union Law

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Abstract

Directive (EU) 2016/681 of the European Parliament and of the Council of 27 April 2016 on the use of passenger name record (PNR)data for the prevention, detection, investigation and prosecution of terrorist offences and serious crime (the PNR Directive) entered into force on 24 May 2016. Member states had to transpose the PNR Directive by 25 May 2018. All European Union (EU) Member States except Denmark transposed the PNR Directive. The aims of the PNR Directive are to ensure security, to protect the life and safety of people, and to create a legal framework for the protection of PNR data with regard to their processing by competent authorities. PNR data is data that contains personal information of the passenger such as the date of reservation/issue of the ticket, date(s) of the intended travel, name(s), frequent flyer information, travel agency, and all baggage information. According to the PNR Directive, air carriers operating extra-EU flights must transmit PNR data collected as part of the reservation and check-in process to a national passenger information unit (PIU) in the EU to find connections among the passengers to fight terrorism and serious crimes. As stated in the PNR Directive Member States may extend the collection of PNR data for intra-EU flights. The novelty of the PNR Directive is to identify people who were previously unsuspected of involvement in terrorism or serious crime. The PNR Directive brings a pre-emptive, risk-based approach that is a new method in the EU data exchange field. Although other forms of transportation means are not regulated at EU Law some Member States like Belgium collect and process PNR data from other means of transportation, like maritime transportation, under their national laws. The possibility of extending PNR collection to other means of transportation was discussed within the Council Working Party on Information Exchange and Data Protection under the Finish Presidency in 2019. This extension possibility was also discussed during the review of PNR Directive Report in 2020.Impact assessment was recommended on widening the scope of the PNR Directive to other means of transportation other than air transportation in all of these official documents. Judgement by the Court of Justice of the EU on PNR has implications on transport operations carried out by other means within the EU. In its judgement, the Court of Justice of the EU ruled that in the absence of a genuine, present or foreseeable terrorist threat to a Member State, EU Law precludes national legislation the transfer and processing of PNR data by other means of transportation. The aims of the article are to analyze the implications of the judgement by the Court of Justice of the EU on PNR about the collection and processing of PNR data in the maritime transportation in the EU and the necessity, proportionality of collection and processing of PNR data in the maritime transportation considering the relevant legislation in the EU Law.

Keywords: *European Union Law, Passenger Name Record, Maritime Transportation*

A Comprehensive Analysis of Vessel Traffic Services Researches Using Bibliometric and Scientometric Methods

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Abstract

Vessel Traffic Services (VTS) is a system regulating and planning maritime traffic by monitoring changing traffic conditions to enhance maritime safety and efficiency. It provides navigational assistance, traffic organization, and information services within boundaries established by the competent authority in critical areas. EMSA records indicate that almost 80%of marine incidents take place in inland, territorial, and internal seas that may be within the jurisdiction of the VTS area. In this regard, VTS operating in risky and congested waterway splays a critical role in ensuring maritime safety. Motivated by this, the purpose of this study is to provide a comprehensive summary of research conducted in maritime literature on VTS and to investigate the trends of these studies over the years. In this study, a bibliometric and scientometric analysis has been conducted. The search was performed in the Scopus database using keywords "TITLE-ABS-KEY ("vessel traffic service") OR (TITLE-ABS-KEY (VTS) AND (maritime OR ship* OR marine OR pilot* OR captain* OR operator*))". The search was limited to articles and conference papers published within the last 21 years. After excluding irrelevant studies, 484 were retained for analysis. The number of publications increased over time, from 3 in 2003 to 38 in 2023. The document types comprised 254 (52.5%) articles and 230 (47.5%) conference papers. China led with 124 publications, followed by South Korea (62), Poland (27), and Sweden (25). Türkiye ranked 14th with 14 publications. Despite being one of the top countries in terms of publications, South Korea showed a lower tendency for collaborative authorship with other countries. The Journal of Navigation had the highest number of publications. Five sources included the Journal of Marine Science and Engineering (12), Ocean Engineering (12), IOP Conference Series Earth and Environmental Science (9), Lecture Notes in Electrical Engineering (8), and WMU Journal of Maritime Affairs (8). Ocean Engineering ranked 2nd overall in recent years, with 9 of its publications being authored by Chinese authors. Regarding institutions, Dalian Maritime University led with 41 publications. Istanbul Technical University ranked first among Turkish institutions with 8 publications. The analysis of keywords extracted from the abstracts revealed common terms such as "information", "data", "AI", "navigation", "safety", "port", "area", "radar", "operator", "risk", "analysis", "time", "communication", "algorithm", and "accident". Between 2004and 2013, studies on collision, AIS, and radar were more prevalent compared to the period between 2014 and 2023. In terms of word combination, the following are listed respectively: "automatic identification system (217), collision avoidance (84), VTS operator (76), navigation safety (58), ship collision (53), ship trajectory (53), ship detection (52), radar station (44), human error (39)." Studies focusing on "vessel speed" intensified in 2023, while "machine learning" was not encountered in studies before 2017. Human error and VTS operator studies increased between 2019 and 2023, while collision avoidance and radar studies were more prevalent before 2018. Studies on autonomous ships began after 2014 and accelerated after2019. This comprehensive analysis underscores the evolving focus within VTS research.*

Keywords: *Vessel Traffic Services, Maritime Traffic, Bibliometric Analysis*

Private Sector Participation or Privatization? What are the Effects of Maritime Industry on the Maritime Education Policies of Türkiye?

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Abstract

Globalization is a prevalent feature of the maritime industry. Approximately 75%-80% of the transportation in the world is carried out by maritime lines. Due to the universal nature and significant capitalization of the maritime industry, maritime education also possesses a universal character. The human factor is the most important element of merchant shipping which directly affects the safety and security at sea. Thus, the maintenance of sectoral wealth heavily relies on marine education and training programs. Since its introduction in the1960s, the Neoliberal Economy has impacted education at all levels and fields, including maritime education and training where sector-oriented policies were implemented. Education, traditionally viewed as a process facilitating individual adaptation to society, is now treated as human capital and increasingly perceived as an economic investment tool. Although subsequent investigations concluded that mariners' errors resulting from poor training and lack of competencies were the main causes of accidents, maritime education policies are organized for the short-term needs of the sector in Türkiye. The rise in personnel needs in the maritime sector caused drastic increments in public and private maritime faculties, vocational schools, and private maritime courses, and quality concerns in maritime education became an important subject in Türkiye. Furthermore, the required experience for officers' proficiency to attain a higher rank fluctuates based on the shortage or abundance of personnel in related rank levels. This article aims to discuss the sectoral effects of the increasing numbers of maritime schools and private courses, as well as the impacts of sector-oriented maritime education policies in Türkiye.

Keywords: *Maritime Education, Maritime Sector, Neoliberal Education, Maritime Policy, Education and Training*

Greenport Alliances – One Step Further for a Greener Maritime Transport

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Abstract

The sustainability of maritime transport is an essential area of concern not only for the future of shipping but also for the future of humankind. Yet this future must be shaped with a ceaseless endeavour to reduce all the environmental harm humanity has created so far. One of such endeavours is the "Greenport Alliances" project, which is awarded under the Erasmus+ Programme Partnerships for Innovation-Alliances (ERASMUS-EDU-2023-PI-ALL-INNO) and co-funded by the European Commission. Abbreviated as GREENPORT, the project focuses on a neglected segment within the European Union's (EU) Green Deal's strategy for the decarbonization of the maritime industry, namely in-port services. Green Deal's 'Sustainable and Smart Mobility Strategy' intends to reduce transport emissions by 90% until 2050. Nevertheless, the EU's emission reduction targets do not include in-port operations due to their small size, considering that larger vessels pollute much more. To protect port assets and vessels while in port, tug boats and pilot boats, as well as their personnel, play an important role, and their actions contribute to the problem both directly and indirectly. Yet, the absence of mandated targets does not necessarily mean that the sector does not pollute at all or that does not have a room for further improvement. On the other hand, the actors of in-port operations are in fact eager to lower emissions. It is possible to modify day-to-day operations, together with the usage of existing digital technologies, that would result in a significant reduction in emissions. At this point, GREENPORT project is being developed to encourage a change in human behaviour and conventional routines to reduce the environmental impact of in-port services. Bringing together 10 organisations in education, research, and industry from 8 countries, GREENPORT started officially on February 1, 2024, and it will be finalized within 36 months. This study aims to delineate the goals that GREENPORT will achieve, the mechanisms of this endeavour, and the impact that will be created after the implementation of the deliverables of the project. Managerial, financial, and marketing-based implications of the project will also be discussed.

Keywords: *Sustainability, Maritime Transport, Decarbonization, In-port Services*

The Role of Computational Fluid Dynamics in Refining Tugboat Operations and Escort Forces

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Abstract

The efficiency and safety of maritime operations, especially in confined spaces such as harbors and narrow passages, are critically dependent on the tugboats. This study leverages Computational Fluid Dynamics (CFD) to provide a detailed analysis of tugboat stability and performance, focusing particularly on the escort forces and moments essential for aiding larger vessels. By examining the complex fluid-structure interactions during tugboat operations, with an emphasis on heave motion, we aim to deepen the understanding of hydrodynamic behaviors impacting tugboat efficacy. The research highlights the significant role of CFD simulations in predicting and enhancing tugboat performance metrics, offering profound insights for naval architects and maritime operators. The findings not only contribute to the advancement of operational safety and efficiency in maritime engineering but also underscore the potential of CFD methods to revolutionize maritime operational protocols and design considerations.

Keywords: *Tugboat, CFD Analysis, Escort Forces*

The Condition of Seafarers at Substandard Ships: An Ethnographic Study from A Bulk Carrier

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Abstract

According to the IMO (International Maritime Organization), a substandard ship is a ship whose hull, machinery, equipment, or operational safety is substantially below the standards required by the relevant convention, or whose crew is not in conformance with the safe manning document. I argue that it is also "a culture of doing things fast", and "based on to create temporary solutions on board" as a strategy to keep the vessel operational at the lowest cost possible. This culture is also effects seafarers' life onboard various ways and differentiates their well-being from others who work at commercial cargo ships, which meet industrial standards. There are three aims of this paper. The first is to focus on the basic dynamics of the daily life of seafarers on board substandard bulk carriers, which are extra risky working places. The second aim is to understand the operating principles of the shipping companies which run substandard ships and finally the third aim is to understand the main dynamics of the labour market for these substandard ships. To achieve these aims, this paper relies on qualitative data and ethnography as a method. The author conducted participatory observation and interviews onboard a substandard ship in 2021 for 59 days and in 2023 for 75 days. Face-to-face semi-structured in-depth interviews were conducted in between 2017-2022. The author also visited a substandard bulk carrier with the company's DPA (designated person ashore) in 2018, and participated in professional organizations and maritime industry events in Istanbul in 2019 and 2021.

Keywords: *Substandard Vessels, Maritime Anthropology, Maritime Ethnography, Seafarers, Working Conditions*

Risk Assessment of Vessels with Dynamic Positioning Systems Using Fault Tree Analysis

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Abstract

Dynamic positioning (DP) systems are used to maintain the vessels' position for particular offshore purposes, mainly in the petroleum, natural gas, and aquaculture industries. The system has evolved through the years by developing technologies, however, there are some risks when using those systems which may lead to undesired events such as loss of position. It is one of the frequent incidents on vessels using the DP system and can cause significant damage to property, marine pollution, delayed operations and economic loss. This study analyses the risks of performing DP operations onboard ships using the Fault Tree Analysis (FTA) methodology. Loss of position is defined as the top event, and a series of basic events are also presented. Marine experts who work in the industry evaluate the probabilities of basic events, and their judgments are quantified in a fuzzy logic environment. The findings of the study could help explore and highlight the risks of practicing safe DP operations.

Keywords: *Dynamic Positioning, Risk, Fault Tree Analysis, Fuzzy Logic*

Evaluation of Well-Being of Maritime Students: An Application of Dokuz Eylül University

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Abstract

Seafarers, who are a crucial element of world trade, work under many challenging conditions. Many adverse conditions such as exposure to hazardous cargoes, intensive work under long working hours, being away from their families, and working in environments with noise and vibration affect the health of seafarers both physically and mentally. Well-being, which depends on the personal evaluations that people experience in their lives, can vary depending on many judgments, and emotions such as life satisfaction, responsibilities, health, work, entertainment, and relationships. The "Seafarers Happiness Index" for 2023 showed a decline from 7.12 in the first quarter to 6.36 in the last. In the last quarter data of 2023, it is seen that the catering department is the happiest rank with a value of 7.1 among 14 ranks, while the deck and engine cadets have the 3rd and 4th lowest values. Therefore, this study aims to assess the well-being of cadets, who represent the initial stage in officer formation. The students studying at the departments of Marine Transportation Engineering (MET) and Marine Engineering (ME) of Dokuz Eylul University Maritime Faculty were chosen as the sample. The PERMA-Profiler questionnaire, which consists of 23 questions and measures well-being with the dimensions of Positive Emotion (P), Engagement (E), Relationship (R), Meaning (M), and Accomplishment (A), was applied to the participants via Google Forms. After data cleaning, 164 students were included in the analysis. The Independent Samples T-test, ANOVA, and correlation tests were applied since all sub-dimensions of the well-being scale remained within the ±1.5 boundaries of normality. The statistics were formed based on gender(female/male), department (MET/ME), and internship duration (junior/senior). When the analyses are examined, it is seen that female students feel more loneliness than male students. According to the departments, there is a significant difference in all dimensions except the relationship dimension and overall well-being (OWB) score. ME students had higher mean scores in all dimensions. There is a strong, positive relationship between OWB and P, M, E, A, and R dimensions respectively. There is no significant relationship between students' grade point averages and their well-being. It was observed that senior group students had higher averages than junior group students in all dimensions except the engagement dimension and in the OWB score. Additionally in the questionnaire, students were asked an open-ended question about the situations that affect their well-being positively/negatively. When the responses were grouped within themselves, social environment/friendly relations, academic/professional success, engaging in hobbies, economic conditions, and family relations were the most recurring factors, respectively. In this study, the well-being of maritime students holds great importance in connection with the fact that a large portion of accidents at sea are attributed to human factors. It represents a critical step towards determining the psychological and social supports required for ship safety and efficiency.

Keywords: *Seafarer, Well-Being, PERMA-Profiler, Deck Cadet, Engine Cadet*

Historical Development of ITU Maritime Faculty: 140-Year-Old Sycamore's Albatrosses on Seven Seas

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Abstract

A beacon in maritime education for a century and a half, ITU Maritime Faculty boasts a rich legacy dating back to 1884. Its journey commenced with the Merchant Captain Schools, evolving through the National and Private Captain and Engineer School established by Hamit Naci Özdeş, and the Merchant Marine School bearing Atatürk's signature. In the 1930s and 40s, it operated as the Higher Maritime School, later transitioning to the Maritime School. Finally, in 1988, it proudly affiliated with Istanbul Technical University (ITU), becoming the ITU Maritime School and eventually the ITU Maritime Faculty. Now nearing its 150th anniversary, the Faculty holds its head high, having nurtured nearly 8,500 qualified professionals and solidifying its position as the doyen school in its field. This study meticulously explores its historical journey, detailing the evolution of its flags and pennants, the number of graduates it has produced, and its notable achievements since inception. By presenting source documents, it aims to illuminate the Faculty's remarkable saga, ensuring its legacy continues to inspire future generations.

Keywords: *Historical, Development, Maritime, Faculty, ITU*

An Investigation on Seafarer Selection Criteria and Recruitment Methods of Turkish Maritime Companies

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Abstract

The percentage of human error in ship accidents is more than 90%, and one of the most important causes of maritime accidents is considered to be the human factor. For the safe navigation of ships, certain requirements must be fulfilled by both the ship and the ship's personnel, but despite this, personal competencies are most prominent at the time of decision-making. Recently, the human factor issue in maritime has been added as a separate evaluation element to ship inspections carried out by international organizations and increases its importance in maritime transportation. In addition, on ships with a limited living and working space, both the work and social lives of the personnel take place in the same environment. Considering long contract periods, communication and understanding between ship personnel is important for the safe navigation and operations of the ship. Under these circumstances, it is inevitable to pay more attention to the selection processes of ship personnel. The study aims to investigate the criteria and recruitment methods of Turkish maritime companies in the selection of ship personnel. With the survey conducted, the criteria are determined based on expert opinions, and the order of importance of the criteria is determined using the Delphi technique. The study also aims to define the criteria separately for both officers and ratings.

Keywords: *Personnel Selection, Seafarers Selection Criteria, Recruitment Methods, Delphi Technique*

Evaluating Engine Emission Reduction Methods: A Comparative Analysis of Available Technologies

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Abstract

The International Maritime Organization (IMO) has established determined targets under MARPOL Annex VI for the reduction of sulfur oxides (SOx) and nitrogen oxides (NOx) emissions by 2050, as part of its broader strategy to decrease the environmental impact of international shipping. This regulatory framework compels shipowners to explore and adopt a variety of strategies and technologies to comply with these environmental standards, where various options are available for reducing SOx and NOx emissions, including advancements in engine performance optimization, scrubber systems, injection methods, fuel cells, and alternatively, retrofitting ship engines with alternative fuels —such as liquefied natural gas (LNG), biofuels, methanol, ammonia, and hydrogen— which presents a transformative approach with the potential to comply with the SOx emission targets. These options introduce new challenges to the maritime industry regarding availability, infrastructure, higher upfront costs and numerous operational risks. Risk analysis methodologies and Monte Carlo simulation support a systematic study of potential failure modes, whilst Cost Benefit Analysis, Techno-Economic Assessment, and Life Cycle Cost Assessment provide shipowners with implications for these constantly changing technologies and fuel options. This study aims to offer shipowners valuable insights into the feasibility, reliability, and safety implications of adopting these alternatives, a comprehensive examination of the diverse approaches for mitigating Greenhouse Gas (GHG) emissions, with a focus on advancements in engine and propulsion technologies, thereby contributing to an informed decision-making process.

Keywords: *Exhaust Emissions, Alternative Fuels, Retrofit, Energy Efficiency*

Could the Escalating Red Sea Crisis Shift Attention to Turkey as Reconfiguring Global Maritime Trade?

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Abstract

Global maritime trade always prefers the shortest routes in terms of cost and time until factors that may pose a risk to the safety of the ship and the goods it carries emerge. Security risks at sea mostly occur on canals, passages and straits, which are located on the main routes of maritime transportation and are called strategic choke points. There are 7 globally accepted strategic choke points: Turkish Straits, Strait of Gibraltar, Suez Canal, Babülmandeb Strait, Strait of Hormuz, Strait of Malacca and Panama Canal. Approximately 12 percent of global trade takes place through the Suez Canal. The Suez Canal, the shortest sea route between Asia and Europe, is an important route for the transportation of products such as commodities and energy that provide input to European industry from Asia and the Middle East to Europe. One of the most important factors of global economic stability is uninterrupted maritime transportation. Following developments such as Covid 19 and the Russia-Ukraine War, a new crisis in the Suez Canal has disrupted maritime transportation. Due to the attacks of the Houthis, a group based in Yemen, on commercial ships in the Red Sea since the beginning of November 2023, international shipping companies whose navigation route is the Suez Canal have changed their routes to the Cape of Good Hope. This situation causes trade to slow down and costs to rise. Extended routes for security reasons cause extension in the delivery time of the goods, disruptions in supply chains, increase in the operational costs of shipping companies, the reflection of these costs on the consumer, and increased freight costs. It is stated that if the attacks are directed at bulk carriers carrying important raw materials such as iron ore, grain and timber and oil tankers carrying crude oil, the crisis may lead to an increase in energy and commodity prices, higher interest rates, lower growth, permanent inflation and more geopolitical uncertainty. This study aims to reveal the impact of the increasing threat to international maritime transportation in the Red Sea on Global maritime trade and the opportunities it creates for Turkey. In this context, data from institutions such as the International Maritime Organization, the World Bank, the Turkish Chamber of Shipping, the Turkish Statistical Institute and analysis and forecasts of leading economic consultancy companies have been examined. According to the findings, the fact that container companies diverted their routes from the Red Sea caused a delay of 8-10 days in cargo deliveries. Container prices from Asia have increased 2.5-4 times compared to last year. As of December 18, 2023, ships passing through the region are required to obtain extra war insurance. Countries dependent on fresh food imports and certain sectors in Europe that use inputs imported from Asia are at risk. Long routes also cause environmental problems. If the crisis is prolonged, global inflationary pressure may increase exponentially in Turkey, which is trying to reduce inflation. On the other hand, some of the trade through Asia may shift to Turkey, which is safer.

Keywords: *global maritime trade, international logistics, international maritime transportation, international shipping companies, international trade, Suez Canal crisis*

Cybersecurity Incident Analysis in the Maritime Sector

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Abstract

The maritime industry is undergoing a digital transformation characterized by extensive automation and increased connectivity with external networks, making maritime facilities vulnerable to cyber threats. Beyond the potential economic and reputational damage for the shipping companies, a cyber-attack on maritime systems could lead to serious incidents such as the discharge of dangerous substances, collisions, grounding, fires, hence presenting substantial hazards to both maritime personnel and the environment. This study delves into cybersecurity incidents within the maritime industry. The primary aim is to develop a comprehensive understanding of cyber-attacks targeting systems in maritime facilities, drawing insights from past occurrences. The study entails the creation and analysis of a database comprising 146 cybersecurity-related incidents gathered from Maritime Cyber Attack Database (MCAD), which belongs to NHL Stenden University of Applied Sciences. An investigation is conducted to discern temporal patterns, spatial distribution, sectoral impacts, and characteristics of these cyber-attacks, including the identity of the attacker, intent (whether intentional or accidental), and the affected systems in the scope of maritime field. By scrutinizing specific incidents, the study identifies the key stages of a cyber-attack on systems in maritime facilities, the primary tactics utilized by attackers, and suggests typical cybersecurity measures to mitigate such threats. The study's contribution involves the systematic mapping of the cyber security landscape specific to the maritime sector.

Keywords: *Maritime Cyber Attack Database, maritime cybersecurity, maritime cybersecurity incident*

Explore the Green Energy Options Available for Tugboats

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Abstract

The maritime industry is undergoing a significant transformation as it grapples with the urgent need for decarbonization. Alternative fuels are emerging as viable solutions to reduce greenhouse gas emissions, and this shift extends to tugboats. In order to make maneuvers at ports, it is necessary to have purpose-built and advanced equipment. Among them, tugs have a vital role in terms of ensuring faster and safer maneuvers in ports. Tugboats have evolved significantly over time, driven by environmental concerns and efficiency demands. In the early 19th century, steam-powered tugboats emerged, increasing power and maneuverability. The middle of the 20th century saw the transition to diesel engines, enhancing efficiency and safety. Traditional diesel engines are being replaced by electric propulsion systems, which emit fewer pollutants and require less maintenance. Alternative fuels and innovations on engines, hold promise greener future in the industry and more sustainable maneuvers. Policymakers should incentivize ship owners to transition toward sustainable energy sources by addressing infrastructure gaps and providing economic incentives. As the industry navigates this transition, alternative fuels will play a vital role in shaping the future of transportation. In this study, a review was conducted to explore green energy options available for tugboats. Research is being developed within the scope of the thesis titled "The effect of alternative fuel tugboats on ship maneuvers" and literature review and bibliometric analysis have been carried out. These options were classified based on their economic, environmental, and maneuvering safety aspects.

Keywords: *Alternative Fuels, Tugboats, Maneuver, Marine Engine, Bibliometric Analysis*

The Impact of Student Club Participation in Maritime Education

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Abstract

Student clubs at universities are very important in providing students with many skills and competencies, especially personal, cognitive, and social development, to support their professional and academic success. Similarly, it is known that students' participation in professional organizations through these clubs provides them with skills such as leadership, teamwork, confidence, and time management. University students' involvement in non-academic activities and student clubs varies depending on their study disciplines. Students studying at maritime faculties have to go through a different preparation period because they have to work and live on ships fora certain period, apart from the living conditions they are used to during their internship on ships. The benefits of these student handles are obvious in terms of accelerating the adaptation process to their hierarchically structured professions. Therefore, student clubs are important for maritime students to develop social skills such as communication and teamwork, which are very important for their future professional roles, as well as to gain extra-curricular activities that balance academic knowledge with practical skills and personal development. This study aims to evaluate the perspectives of over 200 students studying at ITU Maritime Faculty towards student clubs and to investigate the reasons for their preference and the relationship between the demographic parameters of these clubs and the students. The results also examined the effects of student clubs on preparation for the maritime profession and their belonging to the faculty.

Keywords: *Student Club, Maritime Education, Maritime Profession*

Application of Ammonia in Marine Diesel Engines: A Coastal Voyage Case Study

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Abstract

Beginning with a comprehensive analysis of ammonia's properties, storage requirements, and combustion characteristics, the study compares it with conventional marine fuels to assess environmental benefits and challenges. Notably, the research explores emissions from ammonia-powered marine engines during coastal voyages, employing modeling and case studies to predict and analyze pollutants like nitrogen oxides (NOx), particulate matter, sulfur oxides (SOx), and carbon emissions, considering their effects on air quality and environmental sustainability.

Simultaneously, the study investigates potential health effects on coastal communities, employing an interdisciplinary approach to analyze atmospheric dispersion patterns, exposure pathways, and known health impacts associated with pollutants. The goal is to offer a holistic understanding of the advantages of ammonia-powered marine engines for both the environment and human well-being. The research also addresses mitigation strategies and technological advancements to minimize emissions and associated health risks. Recommendations for regulatory frameworks and best practices are presented, aiming to guide the integration of ammonia as a marine fuel in alignment with sustainable development goals and the well-being of coastal populations.

The potential of ammonia as a sustainable alternative to traditional marine fuels, emphasizing its zero-carbon content and potential for zero greenhouse gas emissions. The research delves into the implications of integrating ammonia as a marine fuel, focusing on emission effects during coastal voyages and their impact on human health and associated health expenditures. In conclusion, this study contributes valuable insights into the interplay between ammonia-powered marine engines, coastal emissions, and human health. By advancing understanding, the research aims to inform industry stakeholders, policymakers, and researchers working towards a more sustainable and health-conscious maritime future.

Keywords: *Ammonia, alternative fuel, coastal voyage, case study, maritime transport*

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