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Influence of Different Heat Treatments on the Mechanical Properties of 42CrMo4 Steel for the Manufacture of Intermediate Shafts

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Shipbuilding industry is a highly specialized field of engineering that necessitates the use of materials capable of withstanding the demands of extreme operating conditions, including high stresses, corrosive environments, and dynamic loads. In this context, the application of heat treatment to 42CrMo4 steel enables the attainment of the requisite levels of hardness and strength, which directly influence the reliability and longevity of ship parts and components. The objective of this study is to investigate the impact of diverse heat treatment techniques on the hardness and strength of 42CrMo4 steel, with the aim of identifying the most effective heat treatment for a steel alloy intended for the production of an intermediate shaft. The methodology employed a theoretical approach and experimental procedures. A series of heat treatments and hardness tests were carried out, while tensile strength results were obtained using an equation relating the Brinell hardness to the tensile strength of the material. The results of the study indicate that the heat treatments have a considerable effect on the hardness and strength of steel. The International Association of Classification Societies (IACS) Unified Requirement (UR) M68 limits the minimal specified tensile strength for alloy steels to be not greater than 800 N/mm². Upon completion of the heat treatments, it was observed that the steel exhibited tensile strength in both its original and annealed conditions that satisfied the requisite condition as prescribed in the UR M68.

KEYWORDS

Marine shaftline; Heat treatment; Hardness; Tensile strength; 42CrMo4 steel; DIN 743-3

1. INTRODUCTION

Engineering requirements in shipbuilding and ship maintenance are critical to ensure the safety, performance, efficiency and longevity of any vessel. Therefore, the selection of the appropriate material, the right manufacturing process and, in the case of many metallic alloys, the correct heat treatment and surface protection, while taking into account the cost of the entire process, is fundamental.

In addition, the design of any marine propeller shaft or intermediate shaft shall include some basic elements, which are: defining its dimensions, shape, service load, and material selection (IACS UR M68, 2015). To illustrate the shaft system, a conventional marine propulsion system consisting of the propeller, propeller shaft, intermediate shaft, reduction gear and engine is shown in Figure 1. The configuration of the propeller shaft and intermediate shaft depends on the design of the propeller system. In most cases the shafts are supported by the aft stern tube bearing and the intermediate bearing (ABS, 2019). There may be one or more intermediate shafts, depending on the size of the vessel (Ozretić, 1996; Ren et al., 2023).

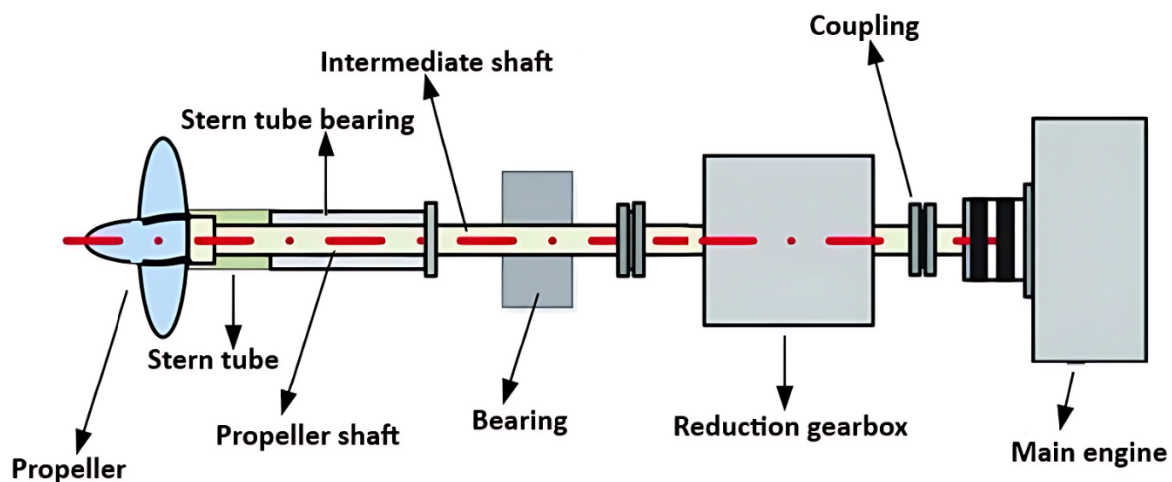


Figure 1. Schematic drawing of marine propulsion shaft system (Modified from source: Ren et al., 2023).

Despite the implementation of proper heat treatment processes for low alloy steel machinery and its components, the long-term maintenance of ship machinery parts necessitates a series of critical considerations to ensure optimal performance and longevity (Apostolov, 2006). The primary considerations are as follows:

1. Regular inspections: These inspections are essential for identifying any indications of wear, corrosion, or fatigue on components such as crankshafts, gears, and shafts. Early detection of issues can prevent more substantial damage and costly repairs.
2. Lubrication: The lubrication of moving parts is crucial in reducing friction and wear. The use of high-quality lubricants suitable for marine environments can enhance the durability of components.
3. Corrosion protection: 42CrMo4 steel exhibits moderate corrosion resistance. The application of protective coatings or cathodic protection can help mitigate the effects of the marine environment.

Regarding the properties of the steel selected for marine propeller shafts and intermediate shafts, the minimum tensile strength must be between (400 and 700 N/mm²). Alternatively, depending on the mechanical properties of the material and its chemical composition, alloy steels can be used. However, their tensile strength should not exceed 800 N/mm² (IACS UR M68, 2015; Croatian Register of Shipping - CRS, 2015). The reason

behind this requirement is the fact that the steel materials with their tensile strength above the prescribed upper limit would have significantly lowered fracture toughness. The diameter of each shaft is calculated using Formula (1), which relates the power developed by the prime mover, several constants and the minimum tensile strength of the material used. This calculation is in accordance with the Unified Requirement (UR) M68 of the International Association of Classification Societies (IACS UR M68, 2015).

$$d_{\min} = F \cdot k \sqrt[3]{\frac{P}{n} \cdot \frac{1}{1 - \left(\frac{d_i}{d_o}\right)^4} \cdot \frac{560}{\sigma_B + 160}} \dots\dots\dots(1)$$

Where:

$d_{\min}$ – required min. shaft diameter (mm),

F – factor for type of propulsion installation ($F= 100$ for all propeller shafts),

k – factor for the particular shaft design features ($k= 1.26$ for key fitted propellers, $k= 1.22$ for flange mounted or keyless taper fitted propellers, and $k= 1.15$ for propeller shaft parts between forward end of aft most bearing and forward stern tube seal),

d_i – actual diameter of shaft bore - may be neglected when $d_i \leq 0.4 d_o$,

d_o – actual outside diameter of shaft (mm),

P – rated power transmitted through the propeller shaft - losses in gearboxes and bearings are to be disregarded (kW),

n – shaft speed at rated power (rpm),

σ_B – specified minimum tensile strength of the propeller shaft material (N/mm²).

The materials selected for the manufacture of the shaft or intermediate shaft are forged steels. They vary between carbon steels, carbon-manganese steels and stainless steels. Their specific chemical composition depends on the application, strength requirements, corrosion resistance, weight and other specific requirements. However, there are certain steels that are the most common choice due to their mechanical properties and availability (DIN 743-3, 2012; IACS UR M68, 2015). Examples of steels commonly used in the manufacture of propeller shafts include stainless steels AISI 316 and AISI 316L, low-carbon and low-alloy structural steels EN S275JR and EN S355JR. For intermediate shafts, reliable options are AISI 1045, 34CrNiMo6 (AISI 4340) and 42CrMo4 (AISI 4140) (Croatian Register of Shipping - CRS, 2015).

42CrMo4 European steel grade, also known as it's American equivalent, American Iron and Steel Institute - AISI 4140, is a medium-carbon and low-alloy steel containing chromium, and molybdenum, used due to its excellent strength, high fatigue resistance and hardenability (Abbaschian and Reed-Hill, 2010; SteelNumber, 2024). Broadly used in the automotive, aerospace and heavy equipment industries, it is also commonly used in marine machinery and parts due to its good wear resistance and toughness. This steel is ideal for components such as crankshafts, gears, and propeller and intermediate shafts that require durability and reliable performance in harsh marine environments (Vukelić and Brnić, 2017; Otai Steel, 2024; DIN 743-3, 2012). Heat treatment, such as quenching and tempering, is an important step in achieving the optimum performance of this steel by adapting its properties to the specific requirements of the final end-use application (Chandler, 1995; Croatian Register of Shipping – CRS, 2015). Forging is highly favorable, while weldability is suboptimal due to its propensity for fracture (Liščić, 1981; Callister Jr. and Rethwisch, 2018).

This steel is utilized in the production of intermediate shafts due to its medium carbon low alloy composition, which renders it both hardenable and cost-effective. AISI 4140 steel, when annealed and normalized under heat treatment conditions, presents ferrite/pearlite microstructures and has low and medium hardness, respectively (Krauss, 2005). Its microstructure in the quenched (hardened) condition consists of

martensite and some retained austenite. Thus, when fully hardened, AISI 4140 steel achieves a surface hardness in the range of 54 to 60 HRC, with variations depending on the carbon content (Chandler, 1995). In this case, for the component to be used, it must undergo a tempering treatment to relieve residual stresses and change the microstructure to tempered martensite.

To illustrate the difference in hardness between EN 42CrMo (AISI 4140) steel samples under various heat treatment conditions, Figure 2 shows a CCT (Continuous Cooling Transformation) diagram of the steel.

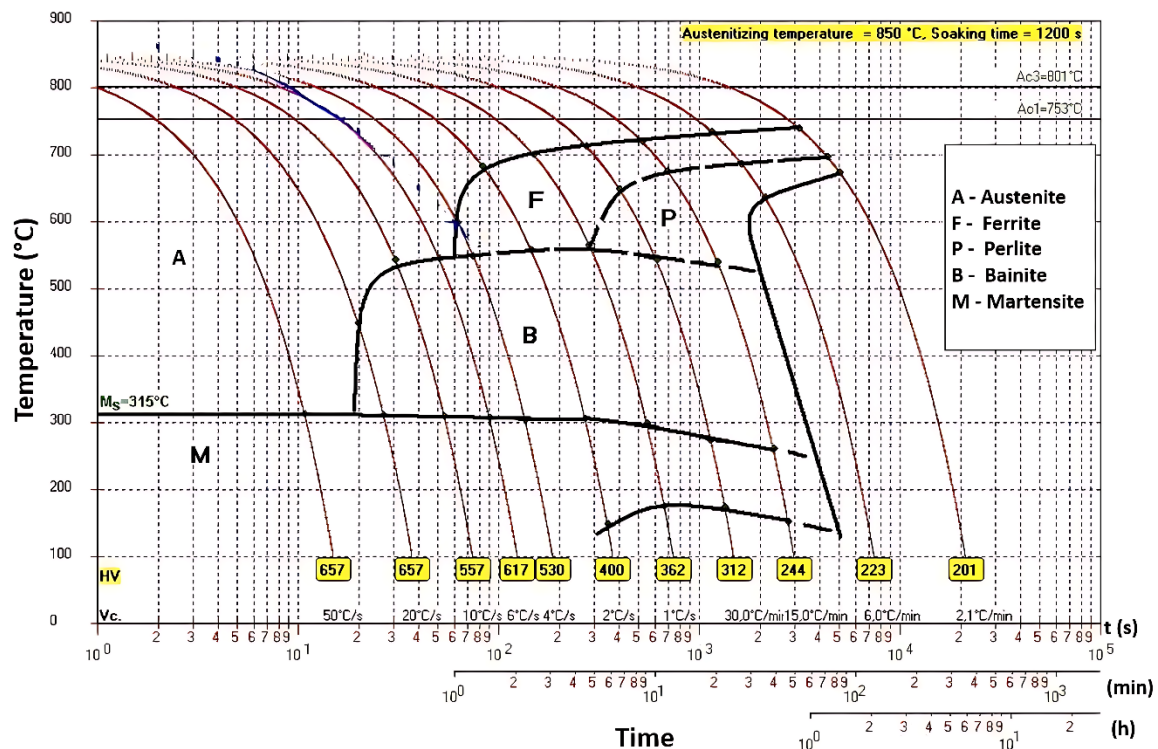


Figure 2. Continuous Cooling Transformation diagram of 42CrMo4 (AISI 4140) steel (Modified from source: Kawulok et al., 2011).

It is important to keep in mind that the development of the desired mechanical properties of a metallic material is the result of work hardening, which generally occurs during the manufacturing process, and appropriate heat treatments - phase transformation (change in the number and/or nature of the phases present in the microstructure of the alloy). Although certain procedures must be carried out by a specialist, the concept of heat treatment (thermal and/or thermochemical processing) is relatively simple and consists of a set of processes aimed at modifying the properties (mechanical, physical, chemical) of steels and other metallic materials through specific stages of heating and cooling of metals under controlled temperature and conditions (Callister Jr. and Rethwisch, 2018; Krauss, 2005).

There are several ways to heat treat AISI 4140. Isothermal or continuous cooling approaches can be applied. However, there are recommended industrial heat treatment practices for this steel. Some of these are described below (Chandler, 1995):

- Normalizing: Heat the component to 870 °C and cool in air after the soaking time.

- Annealing: For a predominantly pearlitic structure, heat the component to 845 °C, cool rapidly to 675 °C, and hold for 5 hours. For a predominantly spheroidized structure, heat the component to 750 °C, cool rapidly to 675 °C, and hold for 9 hours.

- Quenching: Austenitize at 855 °C and quench in oil after the soaking time.

- Tempering: After quenching, reheat the part to the required hardness. Figure 3 shows the tempering temperature curve and corresponding Brinell hardness (HB).

The furnace soaking time is defined as the time required for the temperature in the center of the part to equal the temperature at the surface. In practice, 2 minutes per millimeter of thickness is calculated for carbon steels and 3 minutes per millimeter of thickness for alloy steels (Verhoeven, 2007).

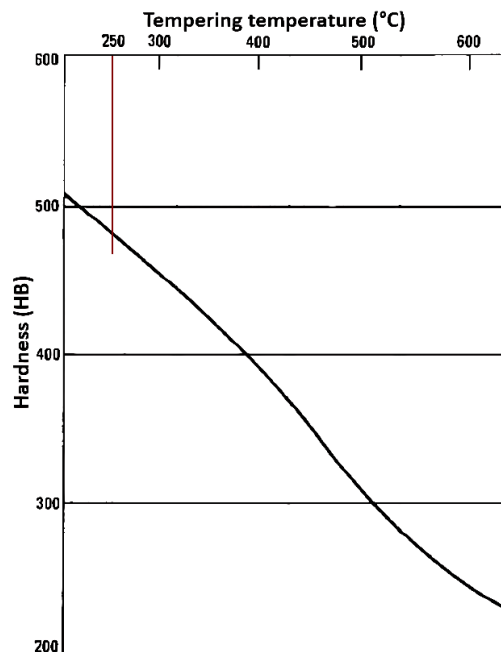


Figure 3. Hardness vs. tempering temperature diagram. The sample was normalized at 870 °C, quenched from 845 °C in oil and tempered. (Source: Chandler, 1995)

2. EXPERIMENTAL

2.1. Material

The steel is designated 42CrMo4+A+C under the EN10277:2018 Classification Standard, which designates an alloyed steel with chromium (Cr) and molybdenum (Mo) and a medium carbon (C) content (Table 1). The presence of the letter "+A" in the designation indicates that the steel was delivered in a soft annealed condition, while the letter "+C" indicates that the steel was supplied in the cold drawn state, which enhances its strength and workability (SteelNumber, 2024). The steel in question was supplied in the form of a bar measuring 300 mm in length and 40 mm in thickness. For the purposes of the heat treatments and subsequent hardness testing, multiple 11-mm-thick samples were sectioned (Table 2).

Chemical composition (wt%)								
C	Si	Mn	P	S	Cr	Mo	Cu	N
0.43	0.26	0.78	0.011	0.030	1.14	0.186	0.03	0.0083

Table 1. Chemical composition of 42CrMo4+A+C steel (Source: Certificate of inspection for steel 42CrMo4+A+C provided by Třinecké Železárny – Moravia Steel).

Sample Condition	Original (+A+C)	Annealed	Normalized	Quenched in water	Quenched in oil	Tempered after water quenching	Tempered after oil quenching
Sample nomenclature	O+A+C	A	N	Q:W	Q:O	T:WQ	T:OQ

Table 2. Nomenclature of the samples determined by their condition. The original sample is designated as sample O+A+C, followed by those that have undergone heat treatment.

2.2. Heat treatment procedure

In the experimental phase, the material's behavior was examined, specifically the alterations in its properties following various heat treatments, including annealing, normalization, quenching with water and oil, and tempering. The OVER industrial electronics heat treatment furnace was utilized, with the XMTG-808 controller employed as the control interface. According to the Heat Treater's Guide (Chandler, 1995), the austenitization temperature ranges from 845 °C to 855 °C. However, as the furnace lacks a controlled atmosphere, it was determined that a temperature range between 880 °C and 900 °C would ensure that all samples undergoing different heat treatments reach the same conditions within the stipulated time.

The composition of the sample, identified as low alloy steel with a thickness of 11 mm, was taken into account in the calculation of the soaking time. This was determined to be 3 minutes per millimeter of thickness, with an additional 20 % allowance for surface temperature variance (Verhoeven, 2007).

For the annealing process, the specimen was placed in an oven at ambient temperature and heated to 900°C, with a soaking time of 40 minutes. Subsequent to this time, the oven was switched off and the specimen was cooled continuously and gradually to ambient temperature (approximately 20 °C). In the normalization process, the oven was heated to 880 °C, and when this temperature was attained, the specimen was inserted. The samples remained in the oven for 40 minutes (soaking time) and were subsequently cooled in calm air. Two types of tempering were performed: in oil and in water. The heating and soaking procedure was similar to that of normalization. After the 40-minute period, the samples were immersed in water and gently stirred for 10 to 15 seconds (room temperature around 20 °C). The second sample was then immersed in 5W-40 synthetic oil from W5 and stirred for about 15 seconds.

The final heat treatment process was tempering, which was performed on the hardened samples, that is, on the samples that were cooled with water and oil. The tempering process entailed heating the furnace to 250 °C, inserting the samples, and maintaining them at that temperature for a duration of 90 minutes. Subsequently, the samples were cooled in an ambient atmosphere (Chandler, 1995).

2.3. Hardness tests and tensile strength calculation

The samples were processed due to the fact that the surface was not smooth enough for hardness measurement. This was done by grinding the samples with sandpaper of different roughness (grit). Grinding is a metal surface treatment process that uses abrasive tools to shape, smooth, or remove irregularities from the metal surface. It is used to achieve smooth surfaces, precise measurements, improve tolerances, or repair surface defects in materials. Grinding is used to provide a smooth and flat test surface that allows accurate and reliable measurement of the hardness of a material (Bramfitt and Benscoter, 2002). The samples surface was progressively sanded using 180#, 320# and 400# grit sandpaper, from coarse to fine for 3 to 5 minutes. The sanding direction should alternate between each sandpaper, rotating the sample 90° to ensure that all marks from the previous step have been removed, resulting in a smoother surface for hardness testing. The samples should be cleaned frequently during the sanding process to prevent particles from further damaging the surface.

The hardness of the samples was measured at six or seven different points (aiming for at least five approximate hardness measurements) following a profile as shown in Figure 4. Hardness testing was performed using a Rockwell hardness tester, model EHT-CE3RN, manufactured by Elephant Manufacturing, Jiangsu, China. The Rockwell hardness test is a very common method of measuring hardness. It is based on the difference in depth of indentation when small and large loads are applied. Several different scales can be used, allowing virtually all metal alloys to be tested. For steels, scales B and C are often used. The Rockwell B scale is more accurate when testing soft metals such as mild steels, brass, aluminium, and mild steel or after annealing heat treatments. The hardness test indenter is a hard metal ball with tungsten carbide (WC) particles, and the load is set at 100 kgf (981 N). For harder materials, the HRC hardness is employed, using a 120° ± 0.35° conical diamond indenter. In this method, the load is set to a force equal to the mass weight of 150 kgf (1471.5 N). Notice that the distance between each indentation should be at least 3 times the diameter of the indentation (Callister Jr. and Rethwisch, 2018).

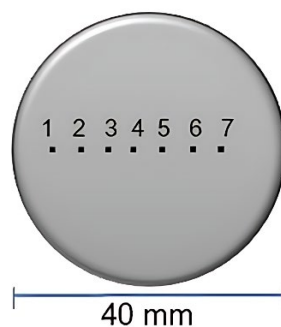


Figure 4. Samples hardness profile.

Following the measurement of the hardness of the samples, the Formula (2) was applied to obtain the tensile strength (R_m) of the samples (Boving, 1989). The DIN 50150 conversion table was used to convert Rockwell hardness to Brinell hardness (DIN 50150, 2000). The ASTM 10-20-1 conversion table, consistent with ASTM E140, was used to convert Rockwell hardness to Brinell hardness for hardness values not covered by DIN 50150 (ASTM, 2019).

$$TS = \frac{HB}{0.3} \dots\dots\dots (2)$$

Where:

TS = tensile strength (N/mm² or MPa)

HB = Brinell hardness

3. RESULTS AND DISCUSSION

3.1. Rockwell B and C hardness test

As presented in Table 3, the findings of the hardness test are displayed for all specimens, which include the hardness measurements of the original sample (as received from the manufacturer in the +A+C condition), as well as the heat treatment conditions that were comprised of the following: annealed, normalized, quenched in water and in oil (followed by tempering).

Samples	Hardness measurement on samples							Mean Hardness
	1	2	3	4	5	6	7	
O+A+C	96.2 HRB	95.5 HRB	95.5 HRB	95.2 HRB	96 HRB	96 HRB	95.8 HRB	95.75 HRB
A	93.8 HRB	91.5 HRB	92.8 HRB	92 HRB	93 HRB	93.8 HRB		92.8 HRB
N	32 HRC	30 HRC	30.5 HRC		30 HRC	32.5 HRC		31 HRC
Q:W			58 HRC	59.5 HRC	58 HRC	59.5 HRC	60 HRC	59 HRC
Q:O	55 HRC	56 HRC	54.7 HRC	54.4 HRC	55 HRC	55.4 HRC	56 HRC	55.2 HRC
T:WQ	51 HRC	52 HRC	52 HRC	52 HRC	51 HRC	51 HRC		51.5 HRC
T:OQ	52 HRC	52 HRC	51.5 HRC	51 HRC	51	51 HRC		51.4 HRC

Table 3. Hardness measurement results.

Table 3 shows that the original sample O+A+C, which was annealed and cold worked, has a higher hardness than the annealed sample A. The mean hardness of sample O+A+C is about 95.75 HRB (225 HV), and that of sample A is 92.8 HRB (205 HV). As shown in the continuous cooling transformation diagram of Figure 2, the microstructure is ferrite and pearlite. The original sample is expected to have higher hardness because it was cold worked "+C" after annealing "+A" (SteelNumber, 2024). In addition, sample A underwent oxidation and surface decarburization when annealed in a furnace with an oxidizing atmosphere (Edenhofer, et al., 2015). It should also be noted that only these two samples can be used in the Rockwell B (HRB) hardness scale, precisely because they are low hardness samples. Table 3 also shows the hardness results of the normalized sample, which has a mean hardness of 31 HRC (approximately 310 HV). Figure 2 shows that the microstructure of the normalized sample indicates the presence of ferrite, pearlite, a large amount of bainite and some martensite.

As indicated by the findings presented in Table 3, a marginally elevated level of hardness was observed in the water quenching heat treatment as compared to the oil quenching process. As can be seen from the CCT diagram (Figure 2), the water quenched sample has a mean hardness of 59 HRC (approximately 674 HV) and its microstructure is practically 95% martensite with some retained austenite. The oil quenched sample has a mean hardness of 55.2 HRC (approximately 600 HV) and shows the presence of bainite and martensite (DIN 50150, 2000).

As illustrated in Table 3, specifically in samples T:WQ and T:OQ, a decrease in hardness due to tempering is observed. The average hardness found was 51.5 and 51.4 HRC, respectively (approximately 486 HB, as shown in Figure 3). This is consistent with the expected hardness for the tempering temperature of 250

°C for this steel, which is the tempering temperature specified in this study. This decrease in hardness can be attributed to the transformation of the martensitic needle-shaped microstructure (BCT, body-centered tetragonal lattice) obtained after quenching to tempered martensite. This heat treatment results in a finer and more textured microstructure of ferrite (BCC) and cementite, which is responsible for relieving residual stresses after quenching and ensuring optimal performance of the final product according to its intended application. It is therefore essential that after quenching the steel undergoes a subsequent tempering heat treatment (Callister Jr. and Rethwisch, 2018). Relieving of residual stresses in such products as marine intermediate shafts by implementation of the proper heat treatment procedure, is essential by the experience of the authors. Otherwise, residual stresses may be relieved during service on the ship, potentially resulting in shaft line deformation around the bearings. This could lead to significant damage to the bearing, including the loss of propulsion. This incident occurred with one of the recently constructed bulk carriers approximately 20 years ago, within a year of its delivery. The damage was attributed to improper heat treatment.

3.2. Tensile strength in relation to hardness

Table 4 presents the calculated tensile strength (R_m) of the 42CrMo4 (AISI 4140) steel resulting from Formula 2. Since both tensile strength and hardness are indicators of a metal's resistance to plastic deformation, they can be considered approximately proportional (Callister Jr. and Rethwisch, 2018). According to IACS UR 68 (2015), the minimum tensile strength should not exceed 800 N/mm² for the use of Formula 1. In this way, it was possible to determine which heat treatment best met the UR M68 requirements for the 42CrMo4 and which did not.

Samples	Calculated tensile strength (N/mm ² or MPa)							Mean TS (N/mm ²)
	1	2	3	4	5	6	7	
O+A+C	720	705	705	698	713	730	710	708
A	677	633	653	642	657	677		653
N	1010	953	963		953	1020		983
Q:W			2050	2147	2050	2147	2180	2113
Q:O	1867	1923	1823	1816	1867	1880	1923	1873
T:WQ	1653	1707	1707	1707	1653	1653		1680
T:OQ	1707	1707	1680	1653	1653	1653		1673

Table 4. Calculated tensile strength of the samples 42CrMo4.

As demonstrated in Table 4, the tensile strength of sample O+A+C (as received from the manufacturer) was calculated and found to be less than the specified maximum, thereby meeting the IACS UR68 standard. Additionally, the tensile strength of sample A (annealed sample, heat treated to relieve stress) was also found to be less than the specified limit, thus meeting the IACS standard.

The tensile strength of the normalized specimen exceeds the specified limit by approximately 25%. The water-quenched and oil-quenched specimens exceeded the minimum tensile strength limit by (140 to 160%), while the quenched specimens exceeded the minimum tensile strength limit by at least 100%. Thus, when the

tensile strength of the 42CrMo4 steel samples was calculated taking into account the Rockwell C hardness scale, it was found that the tensile strength of these five heat treatments substantially exceeded the maximal allowable tensile strength of 800 N/mm². Therefore, due to its chemical composition, excellent mechanical properties and hardenability, 42CrMo4 steel does not require normalizing and other quenching heat treatments to meet the tensile strength criteria specified by IACS UR 68.

4. CONCLUSIONS

This study analyzes the alterations in hardness and strength of 42CrMo4 steel that occur as a result of various heat treatment processes. By comparing the mechanical properties of the steel in the original state and after undergoing various heat treatment processes, such as annealing, normalizing, quenching, and tempering, data were obtained that clearly indicate the significant influence of heat treatment on the structure and properties of the material. The experimental findings demonstrate that heat treatment processes result in a substantial enhancement of steel's hardness and strength.

Following all heat treatments, the tensile strength of the steel satisfies the requirements for both the original sample and the one that underwent annealing heat treatment. A more precise conclusion, derived from the correlation between the measured steel hardness and the tensile strength calculated according to formula (2), suggests that the tensile strength of the normalized sample, as well as those quenched in water and oil, exceeded the predetermined limit of 800 N/mm². This finding indicates that no special heat treatment is required to change the mechanical properties of the EN 42CrMo4 steel for use as a shaft or intermediate shaft, confirming its suitability in its original condition.

In summary, the present study provides fundamental insights into the effects of heat treatment on 42CrMo4 steel and emphasizes the need to adjust manufacture processes, including heat treatment procedures, to the specific requirements of ship components. The results obtained can provide a framework for subsequent research and advancements in steel processing methodologies in the field of shipbuilding and marine engineering. These efforts are aimed at achieving optimal mechanical properties and prolonging the lifespan of ship structures and components.

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Identifying the Risk of Offshore Wind Farm Installation to the Safety of Navigation – an Overview of the Current State

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The increasing number of both fixed and floating offshore wind farms (OWFs) has led to significant concerns regarding their impact on the safety of navigation. The purpose of this conference paper is to provide an overview of existing research on the subject, gathering a reasonable amount of previous studies with an emphasis on methodologies used to address this issue. Strengths and limitations in addressing complex maritime safety challenges such as this are identified through analysis of existing methodologies. This conference paper presents a literature review of the current state of play in the field of problems arising from the theoretical installation of OWFs. Papers reviewed are categorized by multiple criteria and then briefly commented on. The goal of this literature review is to have a deeper look into the research field, categorize methodologies, see the consequent implications, and review the most specific papers on this topic. Furthermore, possible gaps in the existing knowledge about the effects of large-scale OWFs on the control of maritime traffic flows and the resulting possible changes in route patterns are commented on in the end. The insights gained form the basis for further work and suggest a new research direction focusing on the development of a comprehensive risk assessment framework integrating all necessary data in a rather holistic approach. In conclusion, this paper can also be a valuable resource for researchers, policymakers, and maritime industry stakeholders. It aims to broaden the understanding of the challenges associated with OWFs as a relatively new and emerging maritime technology and their impact on the safety of navigation.

KEYWORDS

Risk assessment; Offshore wind farms; Safety of navigation; Automatic Identification System; Collision probability

1. INTRODUCTION

One of the newest and most emerging renewable energy technologies in the last decades that have been in direct relation to the maritime industry are offshore windfarms (OWFs). OWFs are relatively new renewable sources of energy that have excellent potential and a rather promising future. As the world progressively orients toward a green economy, efficiency, environment, and renewable energies, OWFs fit in this scheme almost perfectly. An increasing number of OWFs and their increasing size lead to issues that were never considered before. The main concerns are the increase in traffic density, the creation of congested waterways, and subsequent alterations to maritime traffic flow.

In the planning phase of OWF installation, all the parameters for the safe operation of the OWF and the safety of navigation of all the ships operating in the vicinity of the planned OWF, the potential location of the proposed OWF, scale (size) of the proposed OWF, maritime traffic density evaluated before and after the proposed offshore installation completion, meteorological factors such as wind speed and corresponding sea state in the vicinity of the proposed OWF, and any other remaining elements which are in a relationship to this matter.

This conference paper gives a brief overview of the literature directly connected to the issue of safety of navigation in the vicinity of the existing OWFs. It can be useful for nautical engineers, ocean engineers, MSP experts, and any other researchers as a basis for further discoveries and analyses. It can be a valuable insight into the specific topic of OWFs and the safety of navigation for further research in the field.

The paper is divided into four chapters. The first chapter is introductory and it gives a brief history of OWFs and a few highlights about the safety of navigation itself. In the second chapter, which is the core of this study, scientific papers, dissertations, articles from journals, and conference papers are reviewed. Each scientific paper reviewed is given a short summary of the key factors and points pinned out from that research. Later in the same chapter articles are sorted by methodologies used to approach this topic. In the third chapter discussion and the possible space for further research about this topic is highlighted. Chapter four is the conclusion in which all the key factors and research findings of this paper are consolidated.

1.1. Offshore wind farms (OWFs) – history and classification

Offshore wind power (OWP) or offshore wind energy (OWE) is the generation of electricity through wind farms in bodies of water, usually at sea. There are higher wind speeds offshore than on land, so offshore farms generate more electricity per amount of capacity installed. Additionally, OWFs are also less controversial than those on land, as they have less impact on people and the landscape (Vloemans, 2022).

OWE has evolved significantly since its inception in the early 1990s. The world's first OWF, Vindeby, was established in 1991 off the coast of Denmark, comprising 11 turbines with a combined capacity of 5 megawatts (MW). Following Vindeby's success, the United Kingdom inaugurated its first OWF near Blyth in 2003, which was the largest in the world at that time. The early 2000s marked a period of rapid expansion in OWE, particularly in Europe (National Grid, 2024). In 2016, the United States entered the offshore wind sector by commissioning the Block Island Wind Farm in Rhode Island, featuring 5 turbines with a total capacity of 30 MW (Marine Technology News, 2019).

A notable advancement in the field is the development of floating OWT, enabling energy generation in deeper waters where traditional fixed turbines are not feasible. The concept was first introduced in 1972 by Professor William E. Heronemus (Shea, 2023). The Kincardine project off the coast of Aberdeen, Scotland, is an example of this innovation, featuring some of the world's largest floating wind turbines at its inception, capable of powering approximately 35,000 homes (The Guardian, 2024). As of 2025, OWE continues to expand,

with significant projects underway in Europe, North America, and Asia, contributing to the global transition toward sustainable energy solutions.



Figure 1. The world's first floating offshore wind turbine (Delmar Systems, 2019)

In the general classification, there are two basic types of offshore wind turbines (OWTs) – fixed and floating. Further division of the types of both fixed and floating OWTs can be seen in Figure 2 below. Technical features vary with the depth of the area in which they are installed.

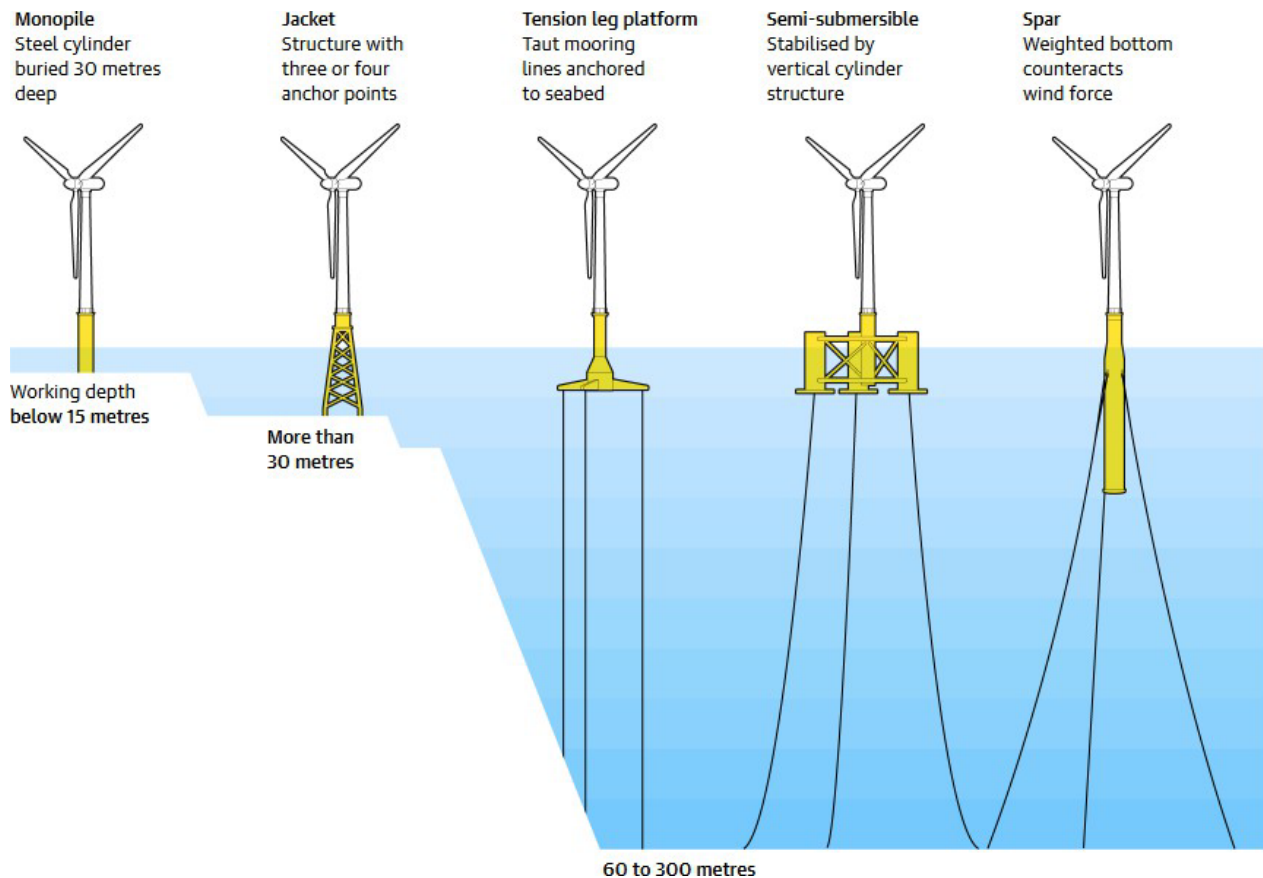


Figure 2. Types of offshore wind turbines, fixed and floating (The Guardian, 2024)

From Figure 2 it can be seen that fixed OWTs are installed in maritime areas with depth ranges from 15 to 60 meters. The typical range of depth for the installation of fixed OWTs is 30 to 50 meters. In areas with high wind potential where the depth is greater than 60 meters floating OWTs have to be considered. Regarding the limitations of floating OWTs and the depth of the sea, there are no strict depth limits since the OWTs are anchored to the seabed using mooring lines rather than fixed foundations. Typical depth ranges lie within a 100 to 700 meters threshold. Some deep-water installations have been considered to reach depths of up to 1000 meters.

1.2. Safety of navigation and incidents including OWFs

Avoidance of collisions with obstacles is a key component of safe navigation (Zhenhua, 2011). Moreover, the safety of navigation in the vicinity of OWFs is a critical concern for maritime operations because it requires careful consideration of vessel traffic, navigational aids, and regulatory frameworks.

OWFs have occasionally been connected to incidents with ships, though serious accidents remain rare. In 2019, a Dutch trawler snagged a wind farm cable, causing a power disruption. In 2022, a cargo ship collided with a turbine at the Horns Rev 2 wind farm off Denmark, causing damage but no casualties. In 2023, a Chinese bulk carrier struck a transformer platform at a German OWF, raising concerns about navigational safety. There have been multiple near-misses reported, especially in high-traffic areas like the North Sea, where wind farms are located in the vicinity of TSS (traffic separation scheme). Some incidents involve fishing vessels unintentionally entering restricted zones and damaging subsea cables (Offshore Wind, 2023.).

The potential threats to OWFs from vessels and existing maritime traffic are various and include the following:

- Collisions (allision)
- OWF gear damage
- Electromagnetic interference
- Construction and maintenance disruptions

Collisions in this sense are various. The most obvious problem would be physical collision with the OWT itself, or in this sense 'allision' is a more suitable word (allision is the act or an instance of a ship striking a stationary object). The second type of collision refers to collisions between two or more ships due to increased maritime density as a consequence of OWF installation occupying navigable waters. Addition to this can be the consequent drift of collided ships that leads to allision with OWT. Finally, in some cases during heavy weather ships can drift and make allision with the OWT itself without collision with another ship prior to allision. OWF gear damage includes anchoring near OWF and fishing gear such as bottom-trawling fishing gear damaging undersea cables that conduct power to shore. Some vessel activities may cause electromagnetic disturbances that interfere with OWF communication and monitoring systems. Unplanned vessel traffic can interfere with construction and maintenance operations, leading to delays and safety risks.

2. MATERIALS AND METHODS

In this chapter, various scientific research, including science journal articles, conference papers, and dissertations will be presented and briefly commented on. Emphasis will be on different methodologies used by researchers to achieve their goals. For this literature review in the specific area of interest, only papers with the cross-section of keywords "*safety of navigation*" and "*offshore wind farms*", were gathered. The intention behind this approach was to collect only the most specific research papers available on the topic of OWFs and the safety of navigation.

The following paragraphs give a brief overview of basic insights and implications of the studies conducted while Table 1 further below gives better visualization and emphasis on the methodologies solely.

(Mehdi et al. 2018) conducted a literature review to understand how navigational risk assessments (NRA) can be improved. A summary of the NRA processes in seven countries is presented, and several shortcomings are identified. Based on the findings of the survey, a list of recommendations is presented to enhance existing NRA processes and to improve the coexistence of shipping and OWFs.

(Zha et al. 2019) published a paper in which a path planning algorithm based on the hybrid method of A* algorithm and reinforcement learning is proposed, which can plan an effective collision avoidance path for the sea area of the wind farm.

(Cao, 2020) made an MSc. dissertation that first adopts the fuzzy comprehensive evaluation method to conduct a risk assessment on navigation safety of the OWF in Putian Port, and obtains qualitative and quantitative analysis conclusions. The study synthesizes the research results of the two assessment methods and summarizes the research experience.

(Chen, 2020) conducted a study assessing the navigational risks of marine man-made structures post-installation using AIS data analysis in Chinese waters. AIS data was gathered and Monte Carlo simulations were used to reveal significant conflicts between proposed engineering plans and existing routes, highlighting impacts on traffic patterns and collision risks.

(Yu and Liu, 2021) presented a study on an AIS data-based framework to assess vessel allision risk near OWFs under complex environmental conditions. Using a Bayesian learning approach, a BN model is developed to analyze ship navigation behavior and evaluate risks under different conditions.

(Tsai and Lin, 2021) examines the impact of OWF on navigation safety in the Taiwan Strait. Using fault tree analysis, the study assesses ship-to-ship and ship-to-turbine collision risks, revealing that uncontrolled ships and ineffective Vessel Traffic Service Systems (VTS) significantly increase collision probabilities.

In (Zhang, 2021) research explores the rapid development of OWFs in China. Key risk factors are identified, and risk control measures are proposed, focusing on maritime safety supervision and navigation services. The study employs a literature review, risk factor analysis, case study, and quantitative risk assessment.

(Peilin et al. 2021) study proposes a fuzzy inference system (FIS)-based navigational risk assessment method to quantitatively evaluate the impact of OWFs construction on maritime safety by analyzing natural conditions and navigational environment factors.

(Naus et al. 2021) research examines the navigation risks associated with offshore renewable energy installations, particularly in high-traffic areas, and emphasizes the need for environmental impact assessments in project planning. Using historical AIS data as big data analysis, a methodology is developed to create both quantitative and qualitative vessel traffic descriptions.

(Rawson and Brito, 2022) analyze maritime accidents at OWFs and compare them with predictions made in Navigational Risk Assessments (NRAs), revealing that NRAs tend to overestimate accident risks, especially for large commercial vessels. The research identifies factors contributing to these discrepancies, such as study design flaws, expert elicitation challenges, and uncertainty in maritime risk modeling.

(Jeong et al. 2022) study proposes a statistical density analysis framework for generating maritime traffic routes based on ship navigation characteristics. Using AIS data preprocessing, ship trajectories are analyzed with the Hausdorff distance algorithm and simplified using the Douglas-Peucker algorithm. Kernel Density Estimation (KDE) is then applied to determine route widths and evaluate main waypoints at 75% and 90% statistical thresholds.

(Haotian et al., 2022) paper proposes a new method for defining the safe distance between ship routes and OWFs, considering factors like wind, waves, currents, and ship traffic flow, using a ship drift model and a tolerable collision probability model.

(Macjan and Kotkowska, 2023) analyze navigational hazards around OWFs in the Southern Baltic Sea, focusing on the safety of both the wind farms and vessel traffic in the area. The study used AIS data from 2019 to 2021 and applied a risk matrix method to assess risks during the construction, operation, and decommissioning phases of wind farms.

(Liu, et al. 2024) developed a novel maritime traffic complexity model for OWF areas, highlighting how OWFs increase navigational challenges in high-density traffic zones, as seen in the Yangtze River Estuary. This was done by comparing traffic dynamics before and after the OWF's construction using AIS historical data analysis.

For the purpose of this study, a total of 3 databases were searched:

- IEEE Xplore
- Web of Science (WoS)
- SCOPUS

Table 1 below represents a better visualization of the findings stated earlier and gives additional emphasis on the methodologies used in reviewed papers. The majority of papers reviewed were journal articles, 9 to be exact (which represents 64%), 3 of them were Masters Dissertations (which are 21%), and finally 2 conference papers (which represent 14%) overall.

Scientific paper	Type of paper	Methodology used
Mehdi et al. 2018	Article	Synthesis, analysis, survey
Zha et al. 2019	Conference paper	Heuristics algorithms, machine learning (ML)
Cao, 2020	Masters Dissertation	Monte Carlo simulations, Fuzzy evaluation method
Chen, 2020	Masters Dissertation	AIS data analysis, Monte Carlo simulations
Yu and Liu, 2021	Conference paper	AIS data analysis, Bayesian net, Neural networks
Tsai and Lin, 2021	Article	Failure analysis, Fault tree analysis
(Zhang, 2021	Masters Dissertation	Synthesis, analysis, survey
Peilin et al. 2021	Article	Fuzzy inference system
Naus et al. 2021	Article	AIS data analysis
Rawson and Brito, 2022	Article	Synthesis, analysis
Jeong et al. 2022	Article	AIS data analysis, Kernel density estimation
Haotian et al., 2022	Article	AIS data analysis
Macjan and Kotkowska, 2023	Article	AIS data analysis, Risk matrix method
Liu, et al. 2024	Article	AIS data analysis

Table 1. Classification of the scientific papers by type and methodology used (made by authors)

From Table 1 it can be seen that there are certain patterns in research regarding the safety of navigation in the vicinity of OWFs. First of all, among the 14 papers reviewed, 3 papers are literature review papers meaning there are no new research methodologies, findings, etc. regarding the issue of OWFs and the

safety of navigation but they are in fact very useful guidelines for further research in the field.

It is very interesting to see that among 11 scientific papers that conduct research that includes any form of formal data analysis, AIS data analysis is present in 7 studies which represent 50% of the reviewed material. As it was expected, It can be concluded that AIS data processing is the methodology of choice when dealing with maritime traffic density. Most of these studies are further linked to at least one other data processing methodology. Furthermore, it can be seen that among papers that use AIS data analysis, there is two papers that use Monte Carlo (MC) simulations, one paper that uses the Risk matrix method (RMM), and one paper that incorporates both Bayesian nets (BN) and Neural networks (NNs). There are two papers that use a form of fuzzy logic, one uses the Fuzzy evaluation method (FEM), and one uses the Fuzzy inference system (FIS). An equal number of papers (2) use machine learning (ML) of which one is NNs and the other one uses heuristic algorithms. One paper uses Fault tree analysis (FTA) as a form of failure analysis. Lastly, 2 papers are review papers and they use methods such as analysis synthesis and survey.

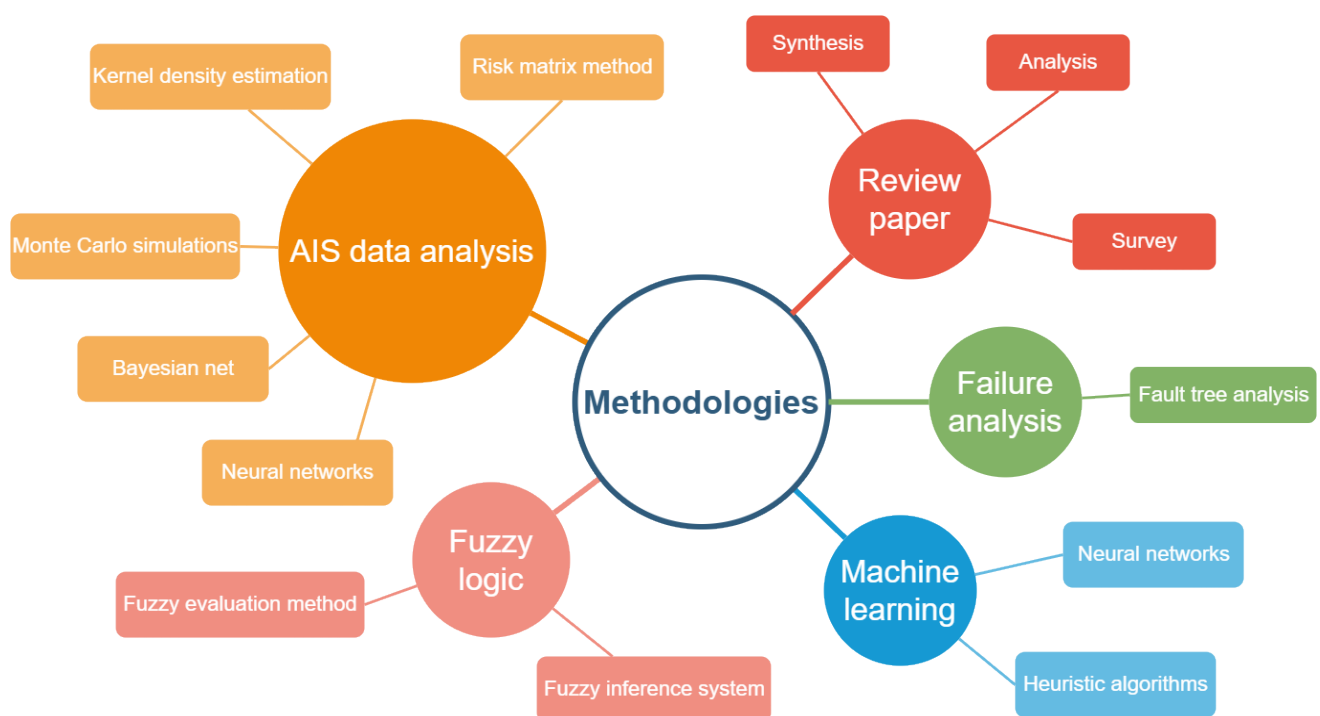


Figure 3. Distribution of the methodologies used in reviewed papers in the form of a bubble map (made by authors)

Figure 3 is a graphical visualization of the distribution of methodologies that the authors of the reviewed studies used. For the purpose of better visualization, it is brought in the form of a bubble map (notice - geometrical figures are not to scale to proportions of distribution of a certain methodology).

3. DISCUSSION

After an overview of the literature, articles, papers, and methodologies in particular, it is more than evident that a decent amount of research has been conducted in the field of the safety of navigation of the seagoing vessels that navigate in the waters where OWFs exist. However, it can easily be concluded that there is much more space for more thorough research regarding the changes in maritime traffic density because one day in the future there is a chance that there will be a large-scale OWF on some exact location. Therefore, it is necessary to conduct research on the theoretical installment of OWFs and their impact on the existing maritime traffic flow. In the case of large-scale OWF installment, there is an obvious risk of maritime traffic congestion

and subsequent changes in its flow. This would represent a new direction of research approach regarding OWF installment and safety of navigation.

One way of looking at the problematics of OWF installation would be what is often called a “holistic” approach. In this context, holistic would mean that all the elements (factors) are looked into as we create a possible set of solutions to the issue. For example, the traffic density map generated from the AIS data processing does not show weather conditions at sea in a given period. It only shows the historical count of ships that pass the arbitrary area over a period of time. The question that arises on that account is – what if there is an excessive wind at sea where the vessels operate in the vicinity of OWF? What is the frequency of that type of wind? What is the corresponding sea state? How would ships behave in that sea state? All of these questions are important to answer in order to have a clear picture of maritime traffic behavior. Weather conditions are one of the most important factors that contribute to or limit the safety of navigation. Not addressing weather conditions when coping with these types of problems would be somewhat unfair, to say the least. To understand the bigger picture of the theoretical installment of OWFs it is of great importance to examine all of the elements and parameters that this process includes.

4. CONCLUSION

A decent amount of research on the topic of the impact of OWF on safety navigation has been conducted in the last decade. The majority of this research is only a few years old meaning that OWP is still an emerging and very potent technology. Additionally, there is still much room for research in this field.

This paper has provided a comprehensive review of the current state of research on the risks posed by OWFs to the safety of navigation. Through an analysis of 14 key papers with very specific almost same domain, including journal articles, master’s dissertations, and conference papers, various methodologies used to assess and quantify these risks were examined. A significant emphasis was placed on methodological approaches, with many of the reviewed studies utilizing AIS data analysis to model vessel traffic patterns, assess collision risks, and evaluate the effectiveness of mitigation strategies. Other methodologies, including simulation and mathematical models, risk assessment frameworks, failure analysis, methodologies based on fuzzy logic, and machine learning have also been identified, providing a holistic perspective on the topic, at least methodology-wise.

From the findings in this study, it can be concluded that the majority of studies conducted in this specific field rely on AIS data processing as a basis or starting point of the research. This methodology is often enhanced when integrated with additional methodologies such as Bayesian nets, Neural networks, Risk matrices, and mathematical modeling and simulations.

In conclusion, the current literature highlights a growing recognition of the complexities connected to assessing the navigational risks posed by OWFs. However, future research should focus on refining methodologies, incorporating real-time data analysis, and developing more robust predictive models to enhance maritime safety. As offshore wind energy continues to expand, interdisciplinary collaboration between maritime safety experts, policymakers, and renewable energy developers will be essential to ensuring that risk assessments remain accurate, comprehensive, and adaptable to evolving maritime environments.

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The Mediterranean Sea as a Security Challenge Today

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Globalization represents a comprehensive economic, technological, informational, political, and cultural connection of the world as a whole, supported by information technologies. In the context of modernization, this process leads to the creation of a "risk society" which must be analyzed through the lens of reflexive modernization. The risk society encompasses the consequences of globalization, including migration, terrorism, changes in sociocultural identity, and the stability of Western societies. Conflicts and the global economic crisis have led to significant migratory flows towards Europe, particularly through the Mediterranean and Balkan routes. At the center of the migration crisis are economic migrants seeking a better life, as well as forced migrants fleeing wars and persecution in their home countries. Today, the European Union faces challenges arising from the influx of migrants, and the legal status of these migrants in international waters is becoming a crucial issue. The Mediterranean Sea has always had strategic importance as a transportation, economic, and geopolitical space connecting Europe, Africa, and Asia. However, contemporary security challenges in the region are becoming increasingly complex and dynamic, primarily due to migration flows, organized crime, maritime disputes, and environmental threats. Additionally, geopolitical tensions among coastal states, energy interests, and the military presence of global and regional powers further affect the stability of the region. The Republic of Croatia and the Croatian Navy have recognized security challenges related to the Mediterranean Sea, including migration crises, terrorism, illegal trade, environmental threats, and geopolitical tensions, and in this context, as a member of NATO, the EU, and the European Border and Coast Guard Agency (Frontex), contribute to collective security through several key initiatives. This article analyzes key security threats in the Mediterranean, their causes and consequences, as well as possible strategies for managing them. Using an interdisciplinary approach, it will demonstrate how international cooperation, maritime security policies, and technological innovations can contribute to the stabilization of this extremely important area.

KEYWORDS

Mediterranean Sea; Refugee crisis; Croatian navy; NATO and EU organization

1. MIGRANT CRISIS AND CAUSES OF THE MIGRANT CRISIS

The causes of the migrant crisis have an extremely complex answer. Certainly, the most important answer lies in the war-affected or crisis-stricken states of Africa and Asia. In this context, the European Union's policy toward migrant labor, which is mainly drawn from these countries, cannot be ignored (Konvencija za zaštitu ljudskih prava, 2017; International migration law, 2019; EU Common Security and Defense Policy Operation, 2020). The influx of migrants was standard and existed even before 2010, which marks the Arab Spring. After the Arab Spring and the destabilization of all public institutions and policies of certain countries in the European Union, there was a massive and uncontrolled migration toward the European Union (Orav, A., 2022).

At the beginning of 2010, a series of uprisings and protests began in Tunisia due to corruption and economic stagnation. The uprisings spread to five more countries—Libya, Egypt, Yemen, Syria, and Bahrain—and took on the characteristics of armed conflicts in which dictators were overthrown: Zine El Abidine Ben Ali, President of Tunisia; Muammar Gaddafi, President of Libya; Hosni Mubarak, President of Egypt; and Ali Abdullah Saleh, President of Yemen. All these presidents had ruled their countries from the late 1970s until 2010 or 2011. Although these states had democratic elections, it is evident that they were actually under dictatorship. The continuation of the Arab Spring affected a series of new countries, and major rebellions and social violence occurred, including riots, civil wars, or uprisings. Continuous street protests were held in Morocco, Iraq, Algeria, Lebanon, Jordan, Kuwait, Oman, and Sudan. Minor protests took place in Djibouti, Mauritania, Palestine, Saudi Arabia, and Western Sahara (UN interregional crime and justice research institute, 2021; Institute of international affairs chatham house, 2018).

1.1. Most Important Migrant Routes in the Mediterranean Sea

According to data from Frontex, in 2015, three routes developed in the Mediterranean Sea: the Western Mediterranean route from Morocco and Algeria to Spain and France, the Central Mediterranean route from Tunisia, Libya, and Egypt, and the Eastern Mediterranean route from Turkey and Egypt to Italy and Greece. Apart from the countries from which the migration crossing routes extend across the Mediterranean Sea, most migrants come from the Middle East and Central Africa to the shores of the Mediterranean Sea, where crossings by boats across the Mediterranean Sea are organized (Frontex risk analysis, 2024; Solas, 2004; SAR, 1979; Refugees on the High Seas, 2011; UN Convention of the Law of the Sea, 1970).

From countries that are not on the Mediterranean Sea, migrants come from Eritrea, Nigeria, and Somalia, and from Asia, specifically the states of Afghanistan, Pakistan, and Bangladesh Kovačević; Rudolf, 2017).

1.1.1. West African Route

The West African route connects western Africa (and further north) with the Spanish Canary Islands. In 2024, the Canary Islands recorded an 18% increase in arrivals to almost 47,000, which is the highest figure since Frontex began collecting data in 2009. This was driven by departures from Mauritania, although flows from other departure points decreased. Malians, Senegalese, and Moroccans were the most common nationalities arriving via this route. In 2023, instability in West Africa was accompanied by a threefold increase in recorded arrivals from that region. Smugglers use cayucos, a type of fishing boat, to transport more migrants. The 161% increase compared to 2022 was mainly caused by direct arrivals from Senegal, followed by Morocco and Mali.

This occurred as some countries in this region experienced increasing instability, such as military takeovers or socio-economic insecurity. In 2022, 15,460 arrivals were recorded, which is 319% less than in 2021. More than two-thirds of the recorded migrants came from Morocco and various sub-Saharan countries. The number of arrivals in Europe via the Western Mediterranean route increased slightly in 2021, with 22,504 cases reported. Algeria was the main country of departure. Most migrants detected on this route were of Algerian nationality, while Moroccans remained the second most frequently detected nationals (Smith, 2017).

1.1.2. Central Mediterranean Route

The Mediterranean Sea between North Africa and the European sides of Italy and Malta is one of the main migration routes to Europe (Smuggling of migrants on the Central Mediterranean Route, 2021). Movements toward the north are joined by migration movements from the Eastern Mediterranean area. In 2024, a significant decrease of 59% in arrivals to the Central Mediterranean was recorded. Despite this decrease, this route still had around 67,000 crossings, making it the second largest among all routes. Bangladeshis, Syrians, and Tunisians were the most numerous nationalities, accounting for about half of all migrants arriving via this route. The year 2023 saw an increase in arrivals to the Central Mediterranean (more than 50,000 compared to 2022) with a total of 158,000 illegal border crossings (50% more than in 2022). Tunisians, Guineans, and Ivorians were the three most represented nationalities reported in 2023, which recorded the highest number of arrivals in this region since 2016, especially during the summer period. Tunisia was the primary departure country, followed by Libya. Smugglers mainly used improvised metal boats to cross the Mediterranean, but there was also a noticeable increase in new methods such as fishing vessels in the Central Mediterranean. Although the number of arrivals decreased compared to the peak years of 2014 to 2016, in 2022, the number of detections in the Central Mediterranean increased by more than half, exceeding 100,000 detections. Egyptians, Tunisians, and Bangladeshis were the three most represented nationalities that year. Arrivals from Libya have been recorded since 2017, with the highest numbers from Tunisia in recent history. In 2021, the Central Mediterranean remained the most used route to Europe, with 67,724 migrants detected on this route. This represents a 90% increase compared to the previous year and accounts for 23% (or approximately one-quarter) of all reported illegal border crossings at external borders. The higher rate of arrivals from Libya made it the main departure country, while increased departures from the coasts of Tunisia and Turkey also contributed to the increased migration pressure on this route. In this region, migrants from Tunisia were most frequently detected, although 2021 saw a return of a larger number of migrants from Egypt, whose numbers increased almost sevenfold compared to the previous year. Bangladeshi nationals were also among the most frequently detected nationalities (IMO, 2025; Frontex Risk Analysis, 2021; Sea Borders Surveillance Report, 2021).

1.1.3. Eastern Mediterranean Route

This migration route encompasses movements toward Cyprus, Greek maritime borders, and toward the Greek and Bulgarian land borders with Turkey. About 69,400 detections were reported in 2024, the third consecutive year with a clear jump (a 14% increase compared to 2023). Syrians, Afghans, and Egyptians were the most frequently reported nationalities. In 2023, around 60,000 detections were recorded, marking the second consecutive year with a clear increase in crossings after the pandemic minimum. Syrians, Afghans, and Palestinians who left Palestine before October 7, 2023, were the most frequently reported nationalities. A higher number of vessel arrivals from Lebanon, Libya, and Syria was recorded. In 2022, 42,800 illegal border crossings were recorded on the Eastern Mediterranean route. Syrians, Afghans, and Nigerians were the most frequently reported nationalities. The figures roughly doubled compared to 2021 but still remained below half of the 2019

figures. The number of arrivals to the EU via this route in 2021 was 20,567, which is at the same level as the previous year.

While the detection of illegal border crossings in Greece continued to decline, Cyprus experienced significantly stronger migration pressure compared to previous years, as the number of arrivals on its coast doubled to around 12,350 (Figure 1). This increase was associated with a larger proportion of Africans among the detected migrants (Frontex Risk Analysis, 2022).

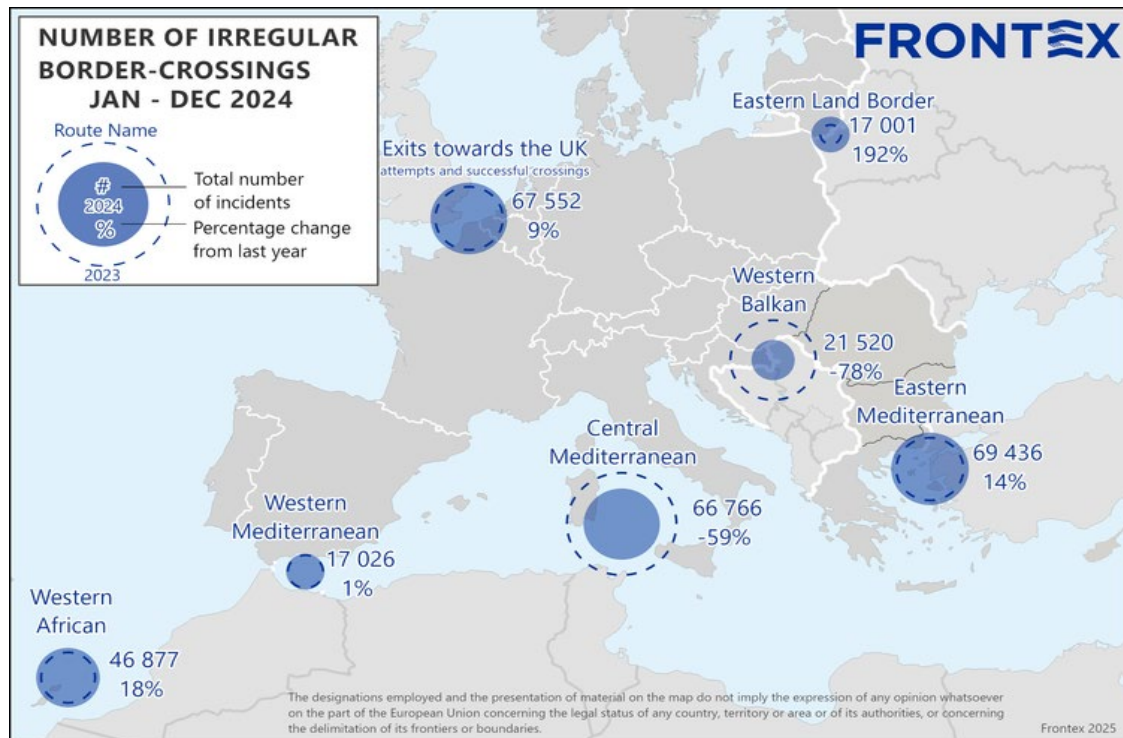


Figure1. Migratory situation in 2024. (sources: <https://www.frontex.europa.eu/what-we-do/monitoring-and-risk-analysis/migratoryroutes/migratory-routes/>)

2. SMUGGLING OF PROHIBITED SUBSTANCES IN THE MEDITERRANEAN SEA

The Mediterranean Sea belongs to Europe, Africa, and Asia. The junction of these three cultures, each distinctive and with its own natural resources, has always been a medium that both separates and connects these three continents. Differences in natural resources have created a need for navigation and trade since ancient times. In recent times, when trade routes are monitored and subject to legislation primarily of the European Union, the United Nations, and even the nations themselves, there is a need for smuggling from and to countries where it is almost impossible to enforce these legal authorities. The collapse of a state's legislation always comes with a revolution that typically overthrows the existing government. Currently, smuggling criminal organizations are flourishing in the Mediterranean Sea, particularly in the areas of human trafficking, weapons, oil, and drugs. All of this stems from instability caused by the Arab Spring and is channeled through Libya as a starting point on the African continent.

2.1. Oil Smuggling

Fuel smuggling in Libya represents a valuable sector with an estimated worth of five billion dollars. Most oil derivatives are imported from Russia, which profits from this enormous black market. This situation emerged from an investigation that began with the seizure of the oil tanker "Queen Majeda" in Albania in September 2022. Libya possesses the largest oil reserves in Africa but has limited refining capacities (A structural threat to Europe, 2021). The National Oil Corporation (NOC), Libya's state oil company, imports fuel at market prices and sells it to citizens at a reduced price, essentially treating it as a social benefit. This practice creates an opportunity for smuggling, as smugglers can sell fuel at higher prices on the black market. According to Khaled Shekshek, President of the Audit Bureau, Libya's fuel subsidy program, which began under Gaddafi in the late 1970s, increased by more than 70 percent and amounted to 62 billion dinars (\$12.8 billion) in the 2022 fiscal year, accounting for half of the state budget. About 40 percent of that amount – approximately \$5 billion – was smuggled, and a significant portion of the imported fuel comes from Russia. Libya is the third largest buyer of Russian diesel in the world and the first in the Arab world. Libya is on the list of major importing countries of Russian oil products, under international sanctions, indicating an increase in purchases of Russian diesel since September 2022, when the country was tenth on the list of international buyers. According to the S&P Global Commodity Insights platform, exports to countries like Nigeria, Tunisia, and Libya have significantly increased since February 2023, when the European Union imposed an embargo on Russian oil products. This complex phenomenon of oil smuggling in Libya implies not only economic but also political and security aspects that affect the stability of the region (Alaraby; Muller, 2020). Oil smuggling in Libya presents a significant challenge for authorities and the international community, and comprehensive measures need to be taken to suppress illegal activities and establish security and stability in the region. (Figure 2.) In accordance with this view, the intention is to create an effect through operations in the Mediterranean Sea, either by NATO or the EU, to discourage any possible fraud in the oil sector and achieve a strategic advantage in the fight against terrorism financing. The changed role of the EUNAVFORMED "Iriní" operation and the NATO-led "Sea Guardian" operation indicates Europe's concern and its intention to solve the problem.

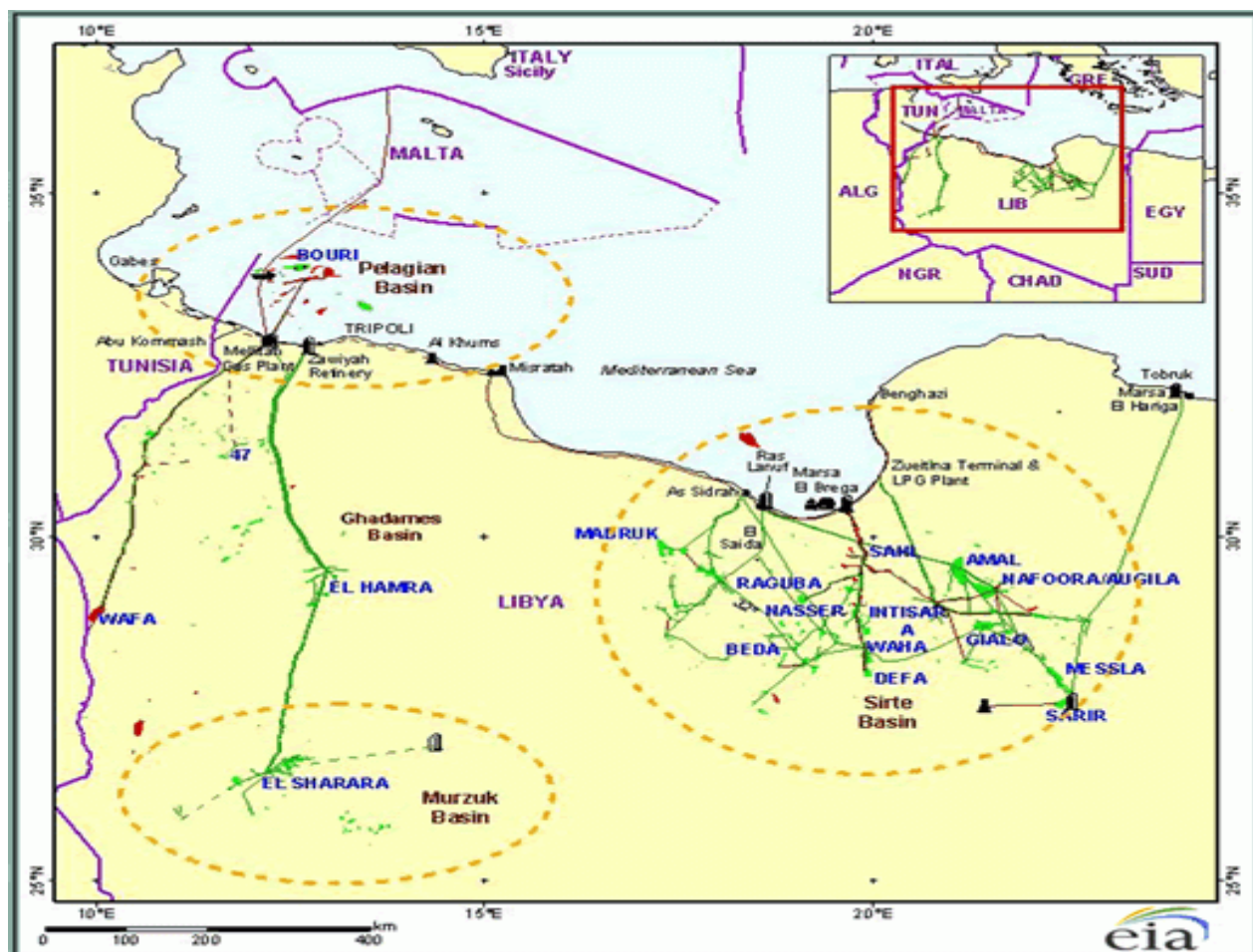


Figure 2. Schematic representation of oil derivative exports from Libya

(sources: <https://libyaherald.com/2016/07/west-and-east-noc-to-reunify-and-hope-to-commence-increased-oil-exports/>)

2.2. Smuggling of Narcotic Substances

During the rule of the Islamic State, research has shown a transactional connection between the Islamic State in Libya and Italian criminal organizations including the Mafia, Ndrangheta, and Camorra. This connection can be analyzed through organized criminal, financial cooperation and human trafficking, arms transactions and money laundering.

According to the European Drug Report 2020, 280 tons of hashish were seized in the Mediterranean Sea, with an estimated value of 2.8 billion euros, noting that no vessels were seized on the Mediterranean route in 2020. (Frontex in European CG Functions, UNCLOS. It has been observed that narcotic substances, mostly from Morocco, did not end up in Libya but, according to research on drug shipment movements, were smuggled through Egypt and then further into Europe through the Balkans. It is estimated that the drug business involving the Mediterranean route and Libyan actors amounts to about 400 million euros annually (A structural threat to Europe, 2021). The armed opposition group Jund al-Khilafa operating in Libya allegedly profited by providing armed protection to cocaine smugglers. The Islamic State was involved in smuggling cannabis from Iraq through Syria and Turkey into Europe. It is known that terrorist groups, according to the American Center for Combating Terrorism, relied on drug smuggling as a means of financing their operations, including acquiring resources needed for planning terrorist attacks such as weapons, vehicles, logistics, and mobile phones. What emerges is

the possibility that the drug trade was part of a larger scheme that includes the arms smuggling business involving Libya and partly passing through Cyprus (Figure 3.).

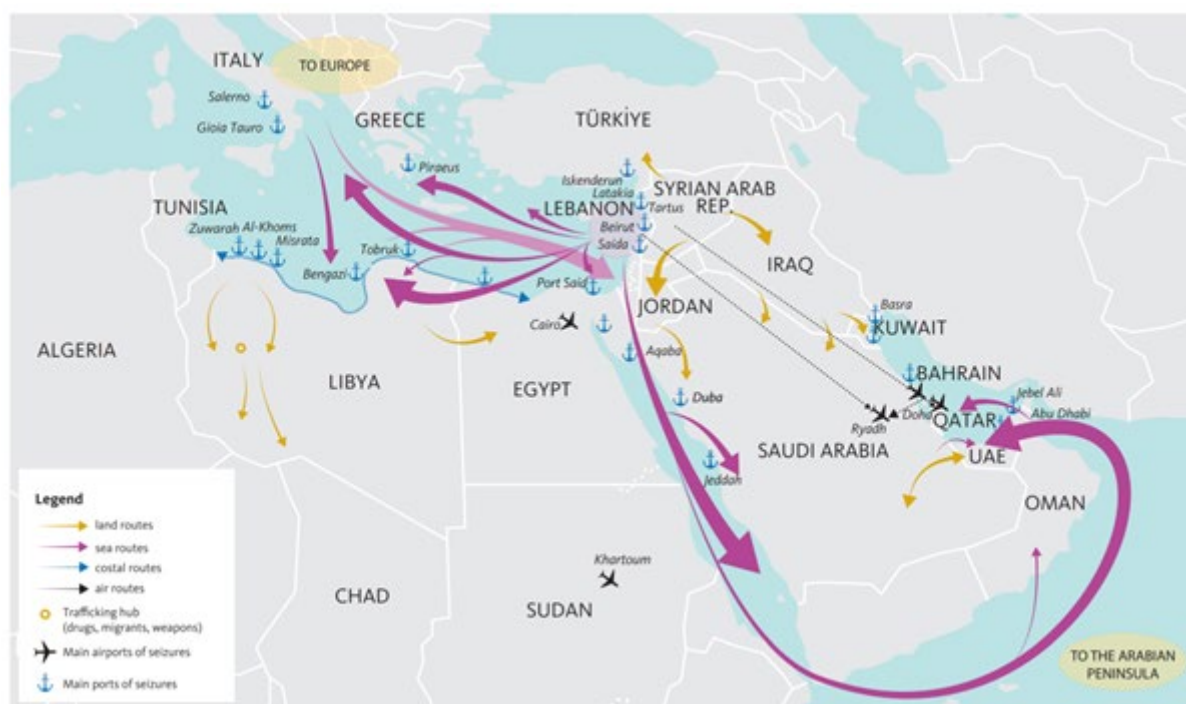


Figure 3. Mediterranean Sea, the drugs routes (sources: <https://north-standard.com/insights-and-resources/resources/news/the-evolving-threat-of-illicit-drug-trafficking-at-sea>)

2.3. Arms Smuggling

Before the conflict in Libya in 2011, the country was one of the largest and most diverse owners of conventional weapons in Africa, and as such, a major source of illegal arms transfers to neighboring states. This trade was largely controlled by groups from Gaddafi's regime, thus complicating political and social tensions, but also integrating a culture of private weapons within Libyan society. During the civil war between the Gaddafi regime and rebels, under the supervision of NATO operations, countries like the United Arab Emirates and Qatar provided the necessary weapons to the rebels. The deteriorated security situation after the collapse of the regime was sufficient incentive for ordinary citizens to stockpile weapons under the pretext of defending their homes. The conflict in Libya became more internationalized in its second phase from 2014, while the UN Security Council arms embargo on Libya was ineffective (UN interregional crime and justice research institute, 2021). After limiting the presence of ISIS groups, the introduction of security contractors (Russian Wagner Group and Turkish Sadat Group) and Syrian, Sudanese, and Chadian mercenaries dominated the Libyan scene from late 2019. Weapons and human transfers became the subject of legal controversies in which each warring party seeks legitimacy and claims to be a state actor.

The spillover effect of the Libyan conflict enables complications in neighboring countries in the region. Several reports show that Libyan weapons were used in the conflict in Sudan, the rebellion in Sinai, and in the areas of Syria and Gaza. With the chaotic situation, the internet market has introduced a new platform for trading Libyan weapons. According to a Small Arms Survey report, weapons produced in 26 countries were offered for sale on the illegal online market in Libya. Most of these weapons were imported by the Gaddafi

regime and were listed as part of his arsenal. Most purchases take place for sports, hobbies, self-defense, or similar purposes, but some participants involved in illegal online arms trade have strong connections with Libyan militia groups.

3. THE RESPONSE OF EU AND NATO FORCES TO CHALLENGES IN THE MEDITERRANEAN SEA

Frontex launched Operation Triton in 2014 with the main goal of monitoring the European Union's maritime borders and rescuing migrants (SOLAS, 2004). The operation under Italian control began on November 1, 2014, and ended on February 1, 2018, when it was replaced by Operation Themis. Operation Themis has an enhanced focus on law enforcement while continuing to include search and rescue as a key component. The operational area covers the central Mediterranean Sea from waters covering routes from Algeria, Tunisia, Libya, Egypt, Turkey, and Albania. Officers deployed by the agency also support Italian authorities in registering arriving migrants. Reflecting the needs of Italian authorities, as well as Frontex priorities, Operation Themis also has a significant security component, including intelligence gathering and other steps aimed at detecting terrorist threats at external borders. In the rescue operation led by Operation Triton in 2015, the Croatian Navy ship "Andrija Mohorovičić" participated, whose three-month stay in the operation resulted in more than two and a half thousand rescued migrants.

Operation EUNAVFORMED was launched by the European Union with the aim of creating a maritime situational picture, and in the early years, the goal was the migrant crisis, protection of free navigation, and prohibition of smuggling/importing weapons into Libya. Operation Sophia, formally a military operation of the European Union that was established as a result of migrant shipwrecks in Libya in April 2015 with the aim of neutralizing established refugee smuggling routes in the Mediterranean (EU Naval Force Med Operation SOPHIA Media and Public Information Office, 2016). Operation Sophia consisted of three phases: the first phase was focused on monitoring and assessing networks for smuggling and human trafficking in the Mediterranean. The second phase involved searching and, if necessary, redirecting suspicious vessels. The third phase enabled the removal of vessels and related assets, preferably before use, and the arrest of traffickers and smugglers. The operational headquarters was located in Rome. The EU mandate for the operation ended on March 31, 2020, with Operation Irini being the successor operation. Operation IRINI (EUNAVFOR MED IRINI) of the European Union Naval Forces was launched on March 31, 2020, with the main mission of implementing the United Nations arms embargo on Libya due to the Second Libyan Civil War (EU Common Security and Defence Policy Operation Eunafor Med Irini, 2020). Operation IRINI is a military operation of the European Union under the umbrella of the Common Security and Defense Policy. In September 2020, a report from the operation showed that within six months, the operation had sent 14 special reports to the UN expert group concerning both sides of the conflict in Libya, conducted 12 transfers onto merchant ships, and monitored 10 ports and landing points, 25 airports and landing strips. The operation headquarters is in Rome. Italy and Greece exchange the force commander every six months (along with the rotation of the command ship). The primary mission of the operation is to ensure the implementation of the UN arms embargo. Other missions include training the Libyan coast guard and navy, disrupting human trafficking, and stopping the illegal export of Libyan oil (European cooperation on coast guard functions, 2017). The secondary task of this operation is rescuing migrants by detecting the position of migrant boats and directing the Libyan coast guard to rescue them. Operation SEA GUARDIAN launched by NATO aimed to monitor maritime navigation and prevent the smuggling of weapons and oil to and from Libya. Operation Sea Guardian is a maritime security operation of the North Atlantic Treaty Organization (NATO) taking place in the Mediterranean Sea.

Operation Sea Guardian was launched in November 2016 and succeeded Operation Active Endeavour. Operation Sea Guardian is an expanded mission of maritime situational awareness, counter-terrorism at sea, and support for capacity-building missions of navies in the Mediterranean Sea to successfully conduct control and protection of their maritime areas. The mission is led by the Allied Maritime Command in Northwood, United Kingdom. If explicitly requested, Sea Guardian can also preserve freedom of navigation, conduct maritime interdiction, counter the proliferation of weapons of mass destruction, and protect critical infrastructure.

4. THE RESPONSE OF THE CROATIAN NAVY TO SECURITY CHALLENGES IN THE MEDITERRANEAN SEA

The Adriatic Sea is an integral part of the Mediterranean Sea, therefore all crises in the Mediterranean Sea spill over to some extent into the Adriatic Sea as well. The Republic of Croatia and the Croatian Navy have recognized security challenges related to the Mediterranean Sea, including migration crises, terrorism, illegal trade, environmental threats, and geopolitical tensions, and in this context, as a member of NATO, the EU, and the European Border and Coast Guard Agency (Frontex), contribute to collective security through several key initiatives. The Croatian Navy participates in maritime operations under the umbrella of the EU's Common Security and Defense Policy through operations EUNAVFOR MED Sophia (2015-2020) and operation EUNAVFOR MED Irini. Croatia contributes by sending officers and members of the Croatian Armed Forces. Croatia, as a NATO member, participates in allied maritime missions through Operation Sea Guardian, where the Croatian Navy occasionally participates with ships and personnel, as well as by delegating officers and sailors to NATO Response Forces (NRF) and Standing NATO Maritime Groups (SNMG, SNMCMG). Furthermore, there is significant cooperation with Frontex where Croatia has been participating through Operation Themis since 2018, in which the Croatian Navy provides support for surveillance and interventions.

In this way, even those Alliance members that have limited resources for conducting operations at sea can contribute to common security, significantly contributing to improving the effectiveness of operations and the economic and social development of NATO, European Union, and Mediterranean region states. Finally, the presence of Croatian naval forces in the Mediterranean Sea also strengthens our influence on shaping the policies of maritime NATO/EU operations, which will result in an impact on increasing the security of the Adriatic Sea, which, in addition to its natural, cultural, and historical importance, is also strategically significant as it represents one of the key economic resources of the Republic of Croatia.

5. CONCLUSION

The Mediterranean Sea today represents one of the key geopolitical and security hotspots in the world. Its strategic importance, as a junction between Europe, Africa, and the Middle East, makes it a scene of complex challenges, including illegal migration, human trafficking, terrorism, maritime security, and geopolitical conflicts. Instability on the southern shores of the Mediterranean, especially in regions like Libya and Syria, further contributes to insecurity, while economic interests and energy resources become a source of tension among states. Additionally, climate change and environmental problems worsen the situation, creating additional challenges for coastal states and the international community. Addressing these problems requires a joint approach from all Mediterranean countries, the European Union, and international organizations. Stronger diplomatic initiatives, better regional cooperation, and investments in security mechanisms are needed to ensure peace and stability in the region. The Mediterranean Sea will remain a key security issue in the future, and the way the international community responds to these challenges will determine not only the fate of the region but also global security and stability.

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Analysis of Fish Fund Exploitation in the European Union, Case Study of the Republic of Croatia, and the Eastern Coast of the Adriatic Sea

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Most maritime states have declared an economic zone that includes all the sovereign rights of the fishing zone, as well as those rights they have based on the continental shelf. In addition, they also have jurisdiction over scientific research and the preservation of waters above that zone. The problem that arose with the entry into the European Union (EU) is that the Exclusive Economic Zone (EEZ) of the Republic of Croatia (RoC) became the "European Sea", allowing fishing by all EU member fishing boats, which leads to increased exploitation. Constant surveillance of the sea area, the fishing sea, should enable the timely detection of all suspicious objects that are potentially poaching or illegal fishing. This paper shows how the RoC supervises and controls the fishing sea, and analyzes data on the national affiliation of fishing boats that fish in the fishing zones of the EEZ of the RoC. It also analyzes the number of observed boats in individual zones, thus visualizing fishing intensity. The collected data were processed in Matlab, and using the approximation model, the ratio between the exploitation of EEZ by Croatian and Italian fishing boats in the observed period and the projection for the next year based on the obtained results was presented.

KEYWORDS

Supervision; Protection; Control; Adriatic Sea; Exclusive Economic Zone; Fishing

1. INTRODUCTION AND BACKGROUND

The interests of the RoC in the Adriatic Sea are very significant in terms of fishing as an important economic branch. The priorities in the context of the preservation and protection of the Croatian fishing sea in the Adriatic are monitoring and controlling fishing boats, protecting the sea from all types of pollution, and the policy of sustainable resource management (Pivčević, 2016). The strategy for the protection of the fish fund, as well as other resources of the Adriatic, was created and is implemented in accordance with the EU's Common Fisheries Policy (CFP). CFP was created to regulate the conservation, management and exploitation of living marine resources. The CFP aims to guarantee the stability of income and jobs of fishermen in the European Union (Blanco et al., 2022).

The Croatian Fishing Sea is administratively divided into 11 fishing zones and 37 fishing subzones. Four of the eleven fishing zones are in inland waters (E, F, G, and part of zone A). The external fishing sea is part of zones A and B, C, D, H, I, J, and K. The administrative division was made for management and data collection. The holder of the protection of the interests of the RoC in the Adriatic Sea is the Croatian Navy, in cooperation with other national services at sea, and as such collects data on all boats in maritime traffic, including fishing boats in individual fishing zones.

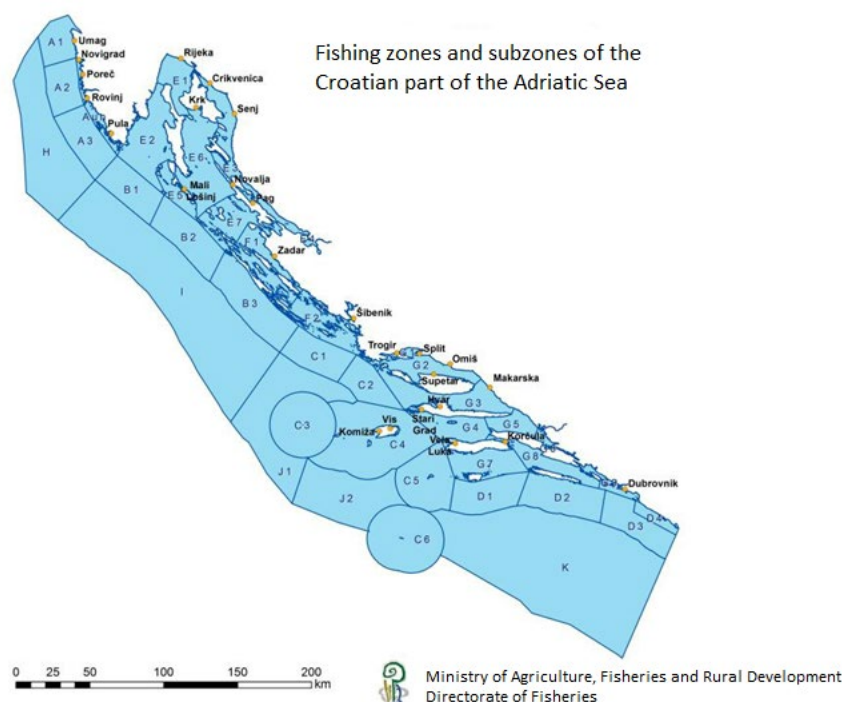


Figure 1. Fishing zones and subzones of the Republic of Croatia (Source: <https://ribarstvo.mps.hr/default.aspx?id=4010>).

The Coast Guard of the RoC, as a unit of the Croatian Navy, is a military organization whose basic job and task is the protection of sovereign rights and the enforcement of the jurisdiction of the RoC in the EEZ, the continental shelf, and the open sea (Amižić, Jelovčić et al., 2010). In that area, it exercises control over all types of boats to prevent poaching and illegal fishing. The Croatian Navy also has a coastal surveillance unit which, with its radar stations along the Adriatic coast, participates in the protection and supervision of maritime traffic and fishing zones, and contributes to the creation of a recognized maritime picture (RMP) (Figure 1.), so that the Croatian Navy, in coordination with other state services, can respond to possible irregularities in fishing at all times.



Figure 2. The process of creating a recognized maritime picture - RMP (Source: Authors).

Consequently, the subject of research in this paper is the fishing zones of the RoC, their division, and the intensity of fishing boats, especially in EEZ. Data on the nationality of fishing boats and the intensity of their activity in individual fishing zones were processed as objects of research.

The work is organized according to the following. In the introduction, the broader research area is described and the research problem is presented. In the second part, the results of the computer analysis of the data collected during the monitoring and control of fishing zones within the EEZ of the RoC are presented, and they are placed in the context of the protection of the fish stock concerning the catch. In the third part, the data for the researched period from January 2020 to December 2022 were processed using the approximation model. About the observed period, a projection of the ratio between Croatian and Italian fishing boats for the year 2023 was made. Finally, a conclusion was reached in Section 5. on the mentioned topic and the analysis carried out, and a complete picture of the fishers who fish in the area of the EEZ was given.

2. MATERIAL AND METHODS

2.1. Previous research

There are a relatively small number of published papers on the research subject of this article. Considering that the Adriatic is a narrow sea, in practice, it means that all fishing is done according to the rules that apply in the EEZ. Bearing in mind the threat of fish species in these areas, all coastal states on the Adriatic should maximize their efforts to prevent further devastation of the fish stock and the environment, which means taking appropriate measures to protect the sea, including the marine ecosystem and the coastal area as indivisible units (Čorić and Debeljak-Rukavina, 2008).

The area of the Adriatic Sea under the sovereignty of the RoC (internal sea waters and territorial sea) is 31,757 km², and over a large part of the Adriatic Sea, outside the state territory, the RoC exercises sovereign rights and jurisdiction through the area of the EEZ, which is 25,207 km² (Dedo et al., 2022). Such a large area, needs to be monitored in an organized and efficient manner. The coastal surveillance and guidance unit of the Croatian Navy, along with the information collected from ships and other sensors, contributes to the creation of a RMP in real-time. The Ministry of Maritime Affairs, Transport, and Infrastructure, with its VTMS (Vessel Traffic Monitoring and Information System) coastal radar network for monitoring and managing maritime traffic, distributed from Istria to Konavle, and thermal imaging cameras with a longer range (up to 20 km), creates a radar image of the real maritime traffic situation in the area of the territorial sea of the RoC. The key function of such a system is close cooperation and integration with all participants and services that participate in or influence the maintenance of maritime traffic, to receive and exchange the most complete amount of data on maritime objects sailing in the area of responsibility (Komadina et al., 2013).

The resources of the Adriatic Sea are almost exhausted, and scientists fear that due to the lack of fish, it could turn into an 'undersea desert'. In the Adriatic Sea, the two main countries responsible for fishing are Italy, which targets anchovies, and Croatia, which mainly targets sardines (Carpi et al., 2017). On the initiative of Croatian and Italian experts, a protected zone project was launched to try to increase the fish population, within the Jabuka basin, the area around the island of Jabuka, west of Vis. Within it, a zone of absolute prohibition of fishing was formed in the area of international waters of the Jabuka basin - that is, in the Croatian EEZ and the Italian part of international waters. Italian fishing boats catch between 70 and 80 percent of all fish caught in the Adriatic, but most fish is found in Croatian waters (Euractiv, 2020). For now, only one percent of the Adriatic is a protected area, but the positive experience with the Jabuka basin represents a model for future protection since the fish population has grown significantly in the period since the zone of absolute fishing prohibition came into force.

2.2. Analysis of data on fishing in the EEZ and comparison of the activities of Croatian and Italian fishing boats

As previously mentioned in this paper, the process of creating and maintaining a RMP and providing integral communication and information support to naval forces and commands in the area of responsibility of the Croatian Navy provides the Naval Operations Center with insight into data on all fishing boats fishing in the area of EEZ. By analyzing the data, collected in the period from January 2020 to December 2022, we can present the difference in the fishing intensity of the Italian and Croatian fishing fleets (Figure 3).

To verify the hypothesis, a quantitative study was conducted on the collected data, which as such deals with the collection and analysis of numerical data. This research method aims to understand and analyze natural and social phenomena objectively. Accordingly, it is commonly used to test cause-and-effect relationships, find averages and patterns, and make predictions. Quantitative research emphasizes the measurement and analysis of numerical data to test hypotheses, identify patterns, and draw statistical inferences. It also relies on objective and standardized data collection methods such as surveys, experiments, or observations with structured instruments. Quantitative research is most often used in economics, medicine, engineering, and natural sciences to generate precise and general knowledge. Correlation research, as one of the types of quantitative research, involves establishing and analyzing the correlation between two or more identified variables. Through this type of research, the collected data is used to analyze the mentioned hypothesis to objectively generate new knowledge that can be precisely applied in the context of the management of the fishing seas of the RoC.

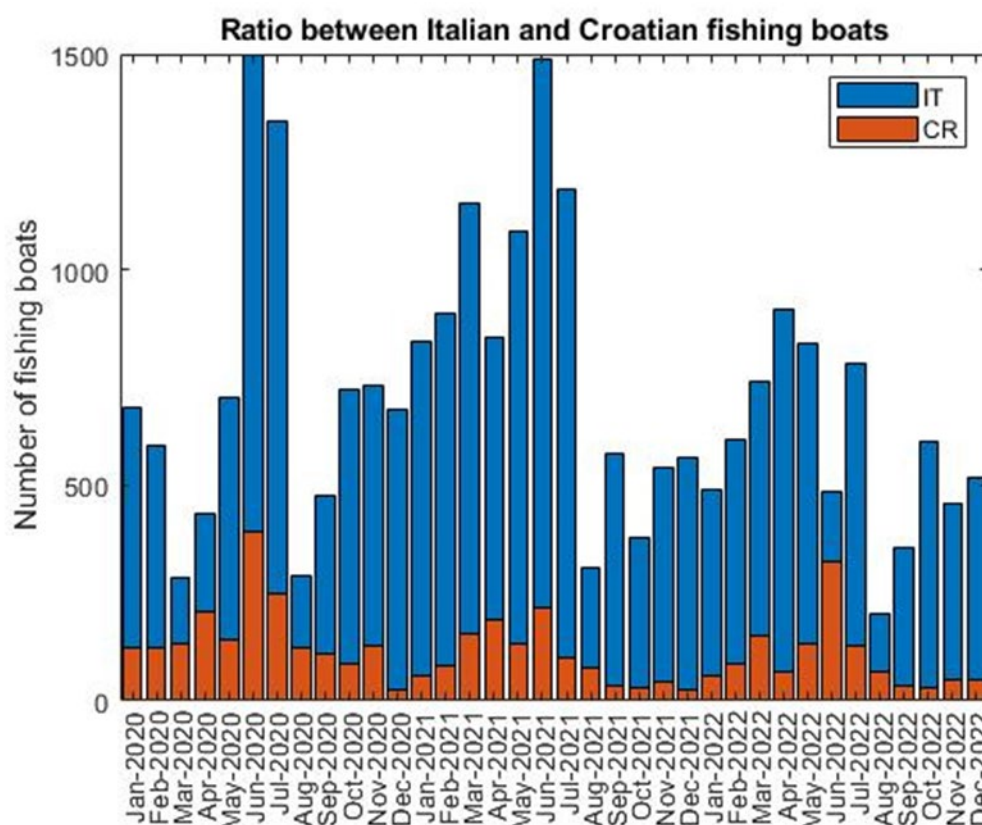


Figure 3. Ratio of observed Croatian and Italian fishing boats in the EEZ zone in the observed period
(Source: Authors).

From the attached graphic representation, we can confirm the previously stated hypothesis that Italian fishing boats catch two to three times the amount of fish compared to Croatian boats. Following on from the mentioned need for sustainable management of the fish fund, it is clear that only through bilateral cooperation between the Republic of Croatia and the Republic of Italy (RoI) can the issue of management of renewable biological resources in the Adriatic Sea be successfully resolved.

2.2.1. Contribution of fishing boats by fishing zone

The fishing sea of the RoC, as previously shown in the text, is administratively divided into eleven (11) fishing zones and 37 fishing subzones. Of the eleven fishing zones, four are in internal waters (E, F, G, and part of zone A), while the outer fishing sea is part of zone A and zones B, C, D, H, I, J, and K. The EEZ of the RoC includes zones H, I, J1, J2, and K.

Croatian EEZ	Fishing zone	Fishing days
	H	9972
	I	7993
	J1	4166
	J2	3480
	K	3870

Table 1. The recorded number of fishing days per fishing zone within the EEZ from January 2020 to December 2022.(Source: Authors)

Analyzing the data collected by the Croatian Navy, and calculating the total number of observed and identified fishing boats by fishing zones within the EEZ (Table 1), it is evident that the highest density of fishing traffic was recorded within zone H, i.e. 35% of all observed boats into the EEZ (Figure 4).

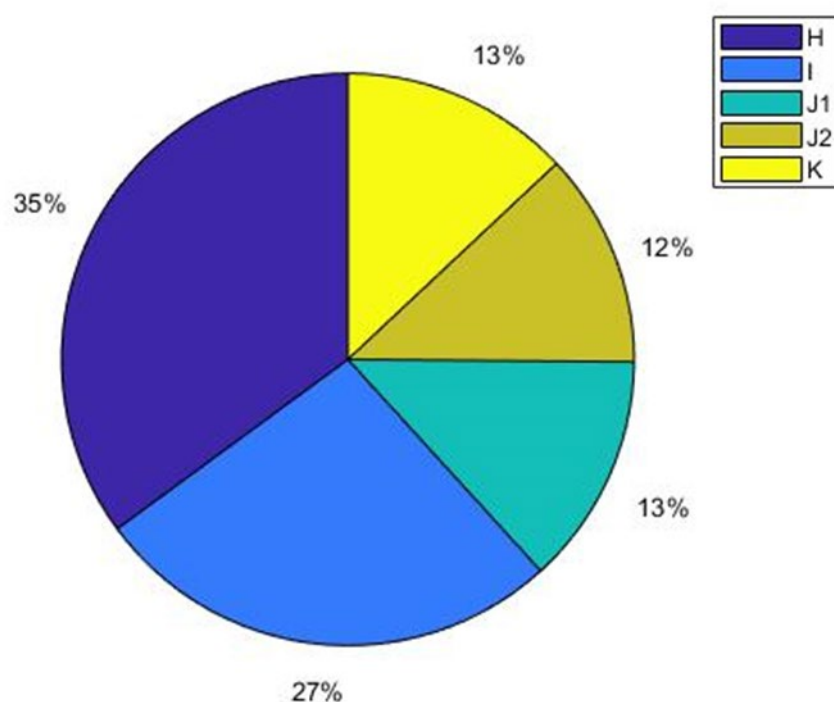


Figure 4. Distribution of fishing boat activity by zone within the EEZ (Source: Authors).

2.2.2. Fishing boats with the most recorded fishing days within the EEZ

Observing the number of recorded fishing days of fishing boats in fishing zones, special attention was paid to the categorization of identified boats by nationality. The analysis of the collected data established the dominance of Italian boats in such a way that in the first 50 boats with the highest recorded number of fishing days there are only three Croatian fishing boats, while in the first 10, as can be seen from Table 2, there is only

the boat "Peter Pan" with 228 of recorded fishing days. Looking at the total number of recorded fishing days in the observed period, a colossal difference in the number of fishing days achieved by Italian fishing boats versus Croatian fishing boats comes to the fore, i.e. 25,278 days compared to 4,156.

Fishing boat name	Country	MMSI	Number of fishing days within the EEZ
'Dante Padre'	Italy	247081380	276
'Joacchi I'	Italy	247071890	273
'Giada'	Italy	247054650	258
'Isabel Cristian'	Italy	247122350	255
'Aurora'	Italy	247053620	242
'Oriente'	Italy	247302920	241
'Peter Pan'	Croatia	238117140	228
'Awenturiero'	Italy	247080290	225
'Vichingo'	Italy	247052440	215
'Gironimo'	Italy	247052570	207

Table 2. Fishing boats with the highest number of fishing days within the EEZ in the observed period from January 2020. to December 2022. (Source: Authors)

Also, about the previously mentioned importance of bilateral cooperation between the RoC and the RoI for the preservation and management of renewable biological resources in the Adriatic Sea, the processing of collected data on the number of fishing days of individual boats resulted in the first fishing boat of a third party (that is, neither Croatian nor Italian) is only in 425th place with 6 fishing days. This is the Albanian fishing boat "Primus", which was identified in fishing zone K. The total number of recorded fishing days in third countries is 38, which is negligible compared to the total number of days in the observed period. Therefore, this analysis also confirms the thesis about the need for a common strategy for the management of renewable biological resources in the international waters of the Adriatic Sea.

3. RESULTS AND DISCUSSION

3.1. Data Processing Using the Approximation Model

3.1.1. Processing of Data Collected in 2020.

By processing the collected data on the number of fishing days of Croatian and Italian fishing boats in 2020. using the approximation model (Figure 5.) was obtained, together with the approximations from 2021. and 2022., provide the possibility of creating a projection of the number of fishing days in 2023.

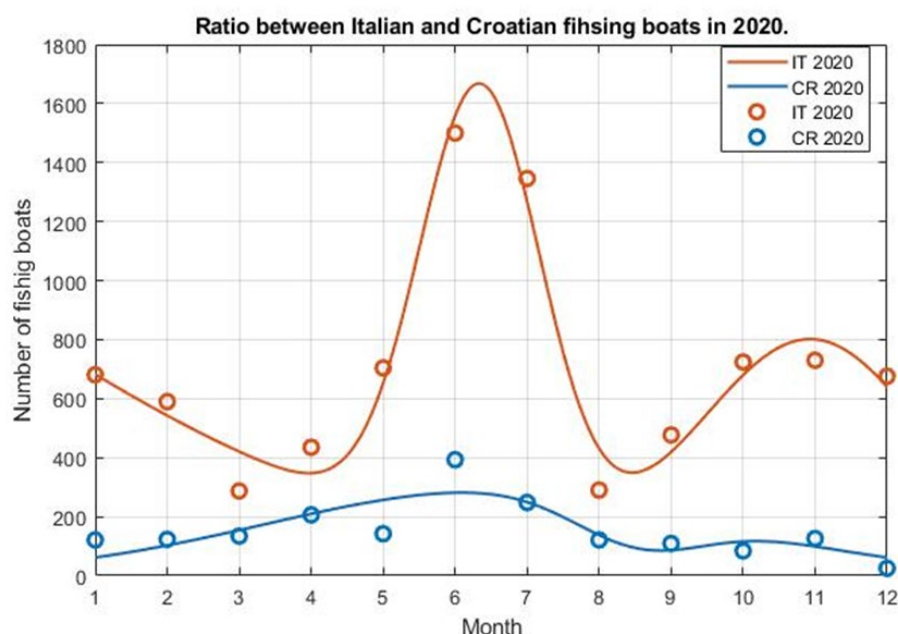
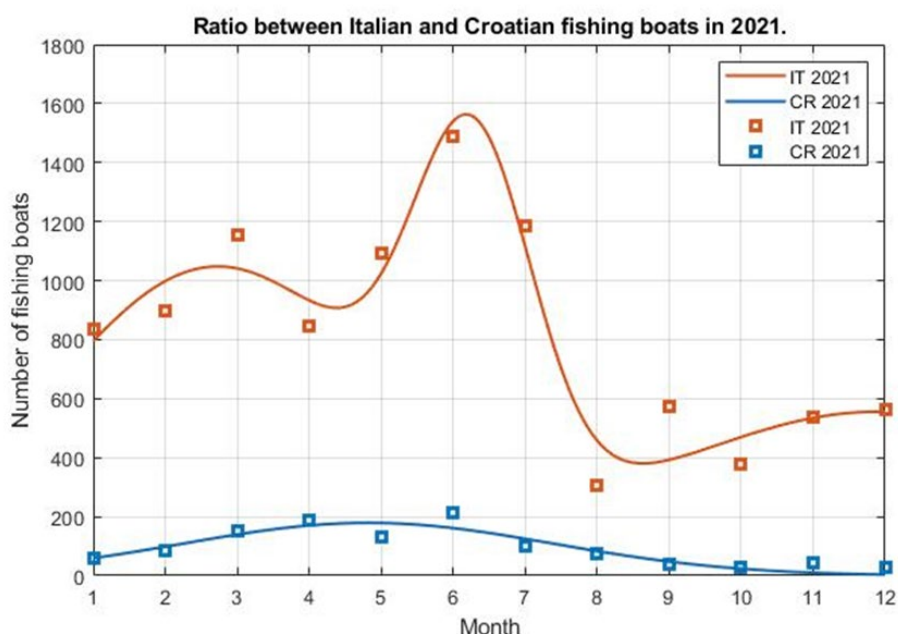


Figure 5. The ratio between Croatian and Italian fishing boats in 2020. (Source: Authors).

The dynamics of the Italian fishing boat are significantly dominant over the dynamics of the Croatian ones. The number of fishing days during the year follows the hunting season, so the observed data should be analyzed through seasonality. A significant drop in the activity of Italian fishing boats was noticeable throughout February 2020., the cause of the mentioned case is most likely the occurrence of the COVID pandemic in the RoI. The fishing days of Croatian fishing boats during the year are mostly at similar levels, apart from June, which, like the Italian fleet, is the most intensive.

3.1.2. Processing of Data Collected in 2021.

As in the previous case, by processing the collected data on the number of fishing days of Croatian and Italian fishing boats in 2021., an approximation of the above data was made (Figure 6).



. Figure 6. The ratio between Croatian and Italian fishing boats in 2021. (Source: Authors).

From Figure 6. it can be concluded that the dynamics of Italian and Croatian fishing boats are significantly different in 2021. In the first quarter, Italian fishing boats are significantly more active than in the same period of the previous year, while Croatian fishers are at approximately the same levels. In the second and third quarters, the ratio of fishing days for Italian and Croatian fishing boats mostly follows the ratio from the previous year, with June being the most intensive, but with an indication that the number of fishing days is significantly lower for both. In the last quarter of 2021., there was a noticeable drop in the activity of fishing boats, and the cause most likely lies in the fact that during that period there were mostly unfavorable weather conditions for sailing, as well as in the fact that due to the COVID pandemic, there was often a situation where ships could not set sail due to the self-isolation measures of one of the crew members.

3.1.3. Processing of data collected in 2022.

The data on the number of fishing days of Croatian and Italian fishing boats collected in 2022. were processed in the same way as in the previous two cases, and the obtained approximation (Figure 7.) concluded the entire period under observation.

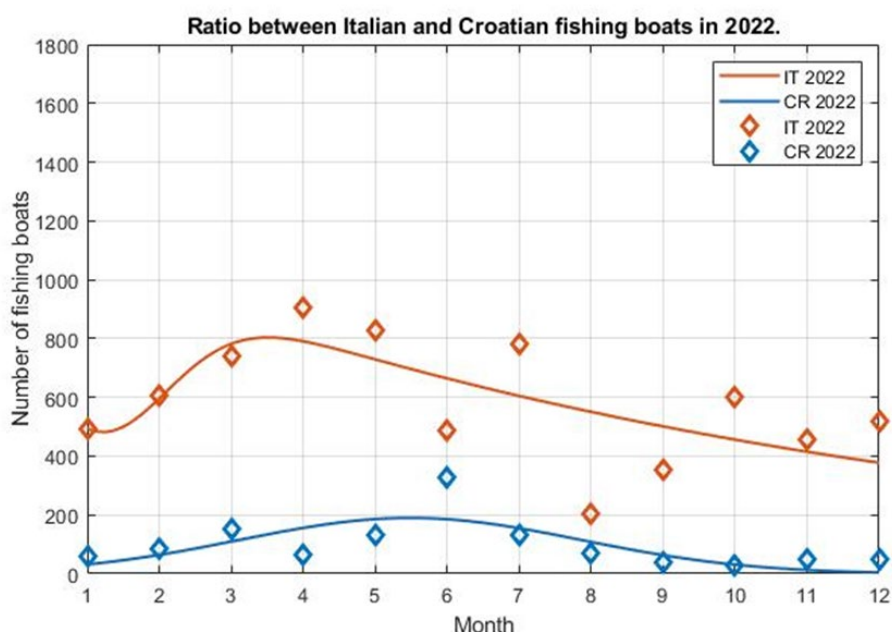


Figure 7. The ratio between Croatian and Italian fishing boats in 2022. (Source: Authors).

Figure 7. shows that the dynamics of Italian fishing boats differ significantly compared to the previous two years, the first, third, and fourth quarters mostly follow the results of previous years, but in the second quarter, and especially in June, there is a significant drop-in activity for unknown reasons. The fishing intensity of Croatian fishing boats throughout 2022., apart from the fourth quarter, mostly returned to the levels of 2020., with June being the most active. Also, despite the lowest number of fishing days in June within the observed period, the Italian fishing boats have a significantly higher number of fishing days compared to the Croatian ones.

3.1.4. Processing of collected data in 2020., and 2021. and 2022. (in total) and the projection for 2023.

The approximation model of the data collected in 2020., 2021., and 2022. (in total) provides a projection of the fishing days of Italian and Croatian fishing boats for the period from January to December 2023. (Figure 8).

From the obtained results, it can be concluded that the projection of the ratio between Croatian and Italian fishing boats for 2023. suggests that there should not be major deviations compared to the data collected in previous years. It also emphasizes the dominant numbers of Italian fishing boats compared to Croatian ones. In the first quarter, the dynamics of Croatian fishing boats should remain at the level of the previous year, while an increase in activity is expected for Italian fishing boats. In the second quarter, the Croatian fishing boats should remain approximately at the level of last year, and the Italian ones, if there is no repeat of the drop-in activity as in June last year, should achieve a significant increase in activity. The projection for the third and fourth quarters of 2023. mostly follows the results of previous years.

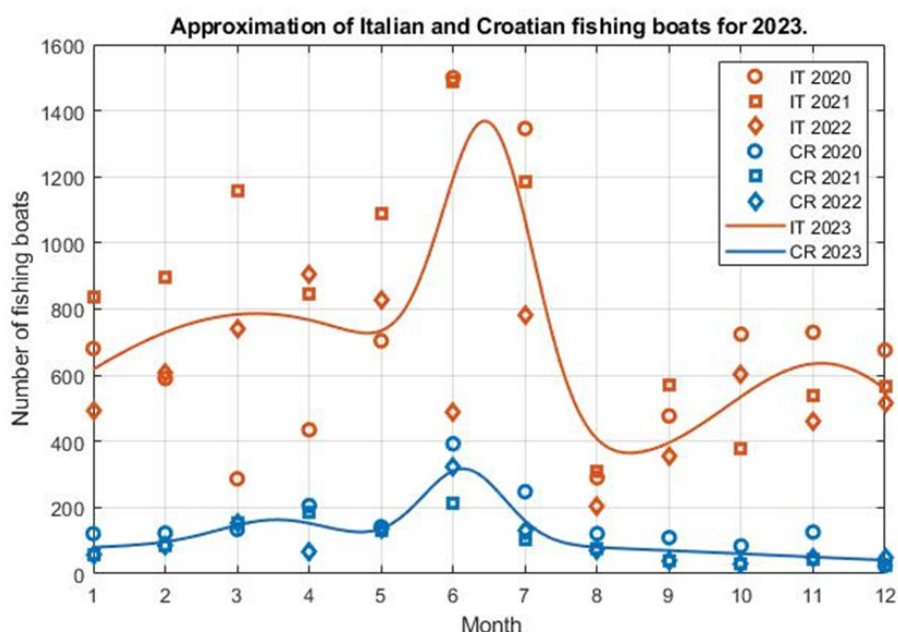


Figure 8. The ratio between Croatian and Italian fishing boats in 2020., 2021., and 2022. with the collected data and the approximation model representing the projection for 2023 (Source: Authors).

In the observed period, the number of recorded fishing days of Croatian and Italian fishing boats was analyzed and processed, since they dominate the area of the EEZ, while the number of recorded fishing days of third-party boats is negligible. Further to the previously mentioned need for sustainable management of the fish stock, only through bilateral cooperation between the RoC and the RoI can the control of fishing in the Adriatic Sea be successfully influenced, and the issue of management of renewable biological resources be solved.

4. CONCLUSION

In this paper, special attention is given to the EEZ through the analysis of collected data on fishing boats observed and identified in fishing zones H, I, J1, J2, and K. Most of the data was collected through the free internet applications (VesselFinder, MarineTraffic). The Croatian Navy with its coastal surveillance radar stations along the Adriatic coast, along with the information collected from ships and other sensors, contributes to the creation of a RMP in real-time in the territorial sea and the EEZ of the RoC. The Ministry of Maritime Affairs, Transport, and Infrastructure, with its VTMS coastal radar network for monitoring and managing maritime traffic, deployed from Istria to Konaval, and with thermal imaging cameras of longer range, creates a radar image of the real maritime situation in the territorial sea of the RoC. The Naval Operations Center uses all the data collected by the sensors of the Ministry of Defense, the Ministry of the Interior, and the Ministry of Maritime Affairs, Transport, and Infrastructure to create a unique realistic RMP in the fishing sea of the RoC. For this work, the data of the Naval Operations Center for the period from January 2020. to December 2022. were used. Considering world trends, as well as the reform of the CFP in the EU, show that most wild fish populations are on the verge of sustainable exploitation, or are already at the level of overfishing. The goal is to reduce excessive fishing capacity and fishing effort in certain forms of fishing and to apply management measures so that fishing effort is appropriate for the reproductive possibilities of fish resources and their sustainable use. The computer analysis of the collected data on fishing in the EEZ of the RoC in the observed period confirmed the hypothesis that foreign fishing boats catch a significantly larger number of fish than Croatian ones, primarily this refers to Italian fishing boats that catch two to three times

more fish than Croatian fishing boat. Also, it is shown through the number of recorded fishing days in the mentioned period that Croatian and Italian fishing boats dominate the EEZ area, while the number of recorded fishing days of third-party boats is negligible. Further to the mentioned need for sustainable management of the fish stock, only through bilateral cooperation between the RoC and the RoI can the issue of managing renewable biological resources in the Adriatic Sea be successfully resolved.

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A Model for Selecting the Most Suitable Renewable Source of Energy on Vessels Using Bayesian Networks

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Maritime transport has a negative impact on the environment. Therefore, the International Maritime Organization and the European Union have adopted legislation that limits the emission of harmful outputs from ships. The basic way to reduce the negative impact is the application of renewable energy sources. However, renewables are not evenly available everywhere. In addition to the above, not all types of ships are equally suitable for the application of different types of energy. As this is a complex problem, a model based on the theory of conditional probability, i.e. Bayesian networks, was made. The proposed model analyzes the availability of a certain type of energy, the energy needs of the ship and the possibility of the ship as a platform for the installation of the renewable energy system. After conducting an energy and economic analysis, the optimal solution is proposed. As such, it can serve in the decision-making process on the choice of renewable energy source.

KEYWORDS

Renewable energy sources; Electrification; Model; Bayesian network; Decision algorithm

1. INTRODUCTION

The amount of energy consumed by the shipping industry is increasing rapidly. Consequently, the negative impact on the environment is also increasing. A generally accepted trend is the introduction of renewables. According to (Issa, M., et al., 2022), RES can be used to produce green fuels or directly for propulsion. Furthermore, RES can be applied as part of the modernization of existing vessels or when designing new vessels. Regardless of the type of energy transition method chosen, it should be technically feasible and economically acceptable. By conducting a technical-economic analysis of the implementation of carbon-neutral fuel, it is assumed that it will generate 2-6 times higher costs compared to the conventional drive (Stolz, B., et al., 2022). As the aforementioned analysis is extremely complex, the use of computer simulation models is almost inevitable. The simulation model should be able to analyze various parameters in order to obtain a comprehensive answer on the selection of the most suitable energy source.

In this paper, the use of Bayesian networks BN is proposed. The general structure of BN is extremely flexible, which is why it is often applied in different areas (Marcot B., et al., 2019). Due to their modular architecture, BNs are increasingly used in environmental applications (Serena H., et al., 2012).

In this paragraph, recent examples of the application of BN in the maritime sector are listed. The most important area of application of Bayesian networks is risk analysis related to maritime accidents (Fan S., et al., 2020, Huanhuan L., et al., 2023, Meizhi J., et al., 2020, Yu Q., et al., 2021). In the aforementioned works, risk factors affecting the safety of the crew, ship, cargo and the environment were taken into account. Observing the incidence of adverse events throughout history, significant risks were identified. Furthermore, using BN-based models reliably and accurately predicts the possibility of an incident. The information obtained is used by ship captains with the aim of increasing the level of safety. In the paper (Bayazit O., Kaptan M., 2023), using BN, the probability of the occurrence of an event that can cause environmental pollution was investigated. A model based on Bayesian networks was applied to analyze safety in the transport of electric vehicles by Ro Pax ships.

2. BAYESIAN NETWORK

Thomas Bayes, a British statistician and philosopher, was the first to present a theorem on conditional probability. In his honor, this theorem is called Bayes' theorem. The theorem justifies a way of thinking in which it is stated that truthfulness theories are confirmed by new evidence. This is conditional probability, the probability that one assumption is true provided that the other assumption is true. The main goal of Bayes' theorem is to formalize information about how one event can help in understanding another. The aim is to find the probability of an earlier event, provided that it has occurred later event (Barnett et al., 2006).

The Bayesian network is a graphical model based on probability theory and represents a group of random variables and their conditional dependence using a Direct Acyclic Graph DAG (Neapolitan, R. E., 1989). A DAG consists of a group of nodes that represent variables, while ends represent a probabilistic random dependence between these variables. Accidental dependence between individual variables is expressed with the help of a structure nodes, which provides and supplies the qualitative part of random reasoning in Bayesian Network (BN).

BN consists of three different types of nodes:

- coincidence node – variable nodes that have ends directed towards the nodes called "children" nodes, a nodes that have links starting from them are called "parents" nodes,
- decision/solution node,
- utility/resource node.

Mathematically, Bayes' theorem can be expressed by the following equation (Stuart, A.; Ord, K., 1994):

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \quad (1)$$

where A and B are events and $P(B) \neq 0$.

$P(A|B)$ is a conditional probability: the probability of event A occurring given that B is true. It is also called the posterior probability of A given B .

$P(B|A)$ is also a conditional probability: the probability of event B occurring given that A is true. It can also be interpreted as the likelihood of A given a fixed B because $P(B|A) = L(A|B)$.

$P(A)$ and $P(B)$ are the probabilities of observing A and B respectively without any given conditions; they are known as the prior probability and marginal probability.

3. PROPOSED MODEL

To select the most suitable RES, a flowchart is proposed that considers various parameters that influence the decision. The decision-making process is shown in Figure 1.

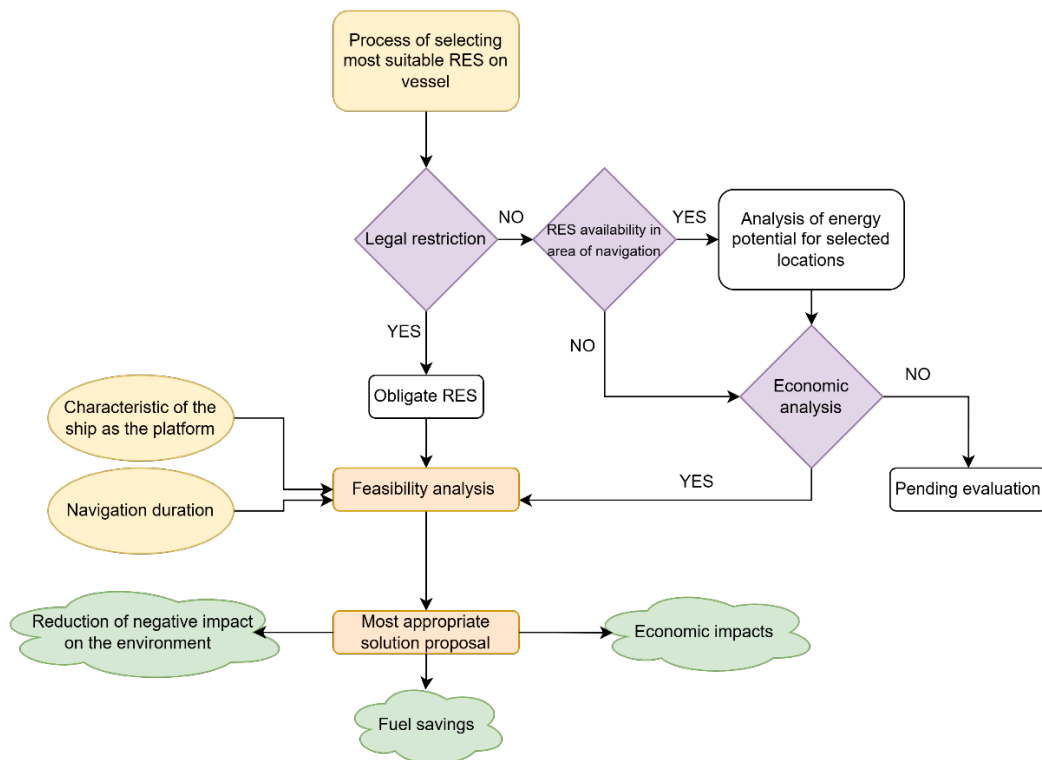


Figure 1. Flowchart diagram of the process of selecting the most suitable RES (Source: Authors)

The legal constraints are the starting point in the flowchart of the proposed model. Namely, there are navigation areas where carbon free zones are imposed, which can only be achieved through the use of renewables. This applies to special environmental areas, for example national parks, special protected areas, and city ports. In this case, an economic analysis is carried out, and regardless of the economic effect, the vessel must make the transition to renewables.

Furthermore, it is necessary to determine the importance of choosing a location that is defined by the energy potential for a specific energy source. Depending on the area of exploitation of the ship, the availability of a certain type of energy can differ significantly. For instance, solar and wind energy are not available at the same intensity in different geographical areas. The availability of electricity charging stations on land is relatively small, and the application is only at local level. Therefore, it is necessary to perform an analysis of the availability of each energy source in relation to the planned operational area of the ship.

When conducting an economic analysis, it is necessary to take into account for each type of RES the total price of the equipment per unit of installed power. However, the price of the equipment is not the only parameter that needs to be considered. The total amount of energy generated by the installed equipment depends on the energy potential hence in certain circumstances more expensive equipment will be more acceptable. There are areas of application where the return on investment in RES is 9 years for photovoltaic modules (Nugraha, I. et al., 2022). Due to the characteristics of the ship and the navigation area, the economic profitability may not be accomplished, thus it is suggested to carry out a re-analysis in the foreseeable future. This makes a lot of sense due to the continuous increase in the efficiency of the equipment while reducing the price. In addition to the above, due to the price and questionable availability of fossil fuels, the transformation to renewable sources is becoming more and more acceptable.

The most important part of the model is the block for energy analysis, which considers all the parameters that influence the selection of the most suitable RES. Each ship as a platform for the installation of RES has its own specifics and is more or less suitable for the installation of a certain type of RES. For example, a ship with smaller dimensions is not suitable because it has less available space for installing photovoltaic modules, hence the installed system would not be able to generate a significant level of energy. On the other hand, the application of large wind turbines is not suitable on tourist ships.

The energy needs of the ship depend on its size, operational profile and sailing length. Based on the above, the size and type of source and storage of electricity should be adapted to the operating conditions of the ship. After the energy analysis, the model assigns a coefficient (or percentage) of suitability for application to different types of RES. In the case of choosing a specific RES, it is possible to observe the effects of implementation.

Different objective functions can also be defined. Most often, the legal restriction to reduce harmful effects on the environment is the driver for the application of RES. However, with the advancement of technology, certain solutions are economically more profitable compared to the use of fossil fuels, which results in a reduction in fuel consumption.

A model for selecting the most suitable RES based on BN is proposed. There are various software solutions that use BN. Part of the software is based on the Java programming language, for example JavaBayes, jBNC, UnBBayes, Banjo. BNFinder is written purely in Python while bnlearn is part of the R package. In this particular case, the Netica program is used. Netica is a powerful, easy-to-use, complete program for working with belief networks and influence diagrams. It has an intuitive and smooth user interface for drawing the networks, and the relationships between variables may be entered as individual probabilities, in the form of equations, or learned from data files (Norsys - Netica Application).

Proposed model shown on Figure 2. enables the setting of initial conditions specific to a certain geographical area. It is also possible to define the capacities of the ship as a platform for RES accommodation. The energy needs of the ship should be taken into account in order to choose a suitable energy source. In accordance with the mentioned feature, the model selects the most suitable energy source. In Figure 2, the initial conditions do not indicate the characteristics of individual types of RES.

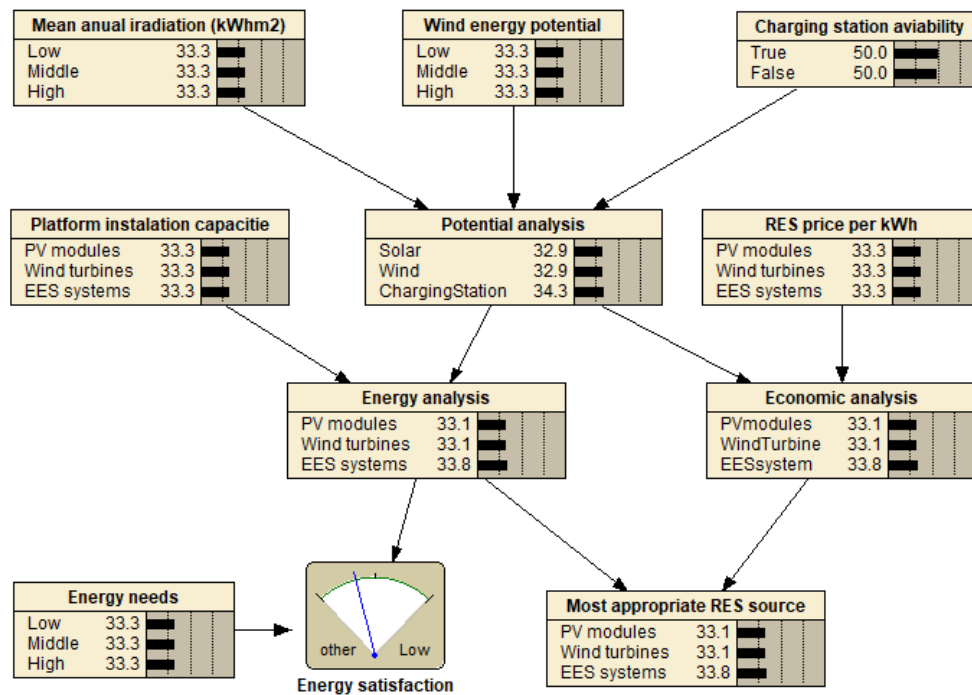


Figure 2. Bayesian network model created in Netica software (Source: Authors)

In accordance with aforementioned, Figure 2 actually presents a Netica model based on BN in which it is possible to discern any outcome, suitable or not. For example, if there is a large wind energy potential, the model will ultimately favor wind energy as RES, as shown in Figure 3.

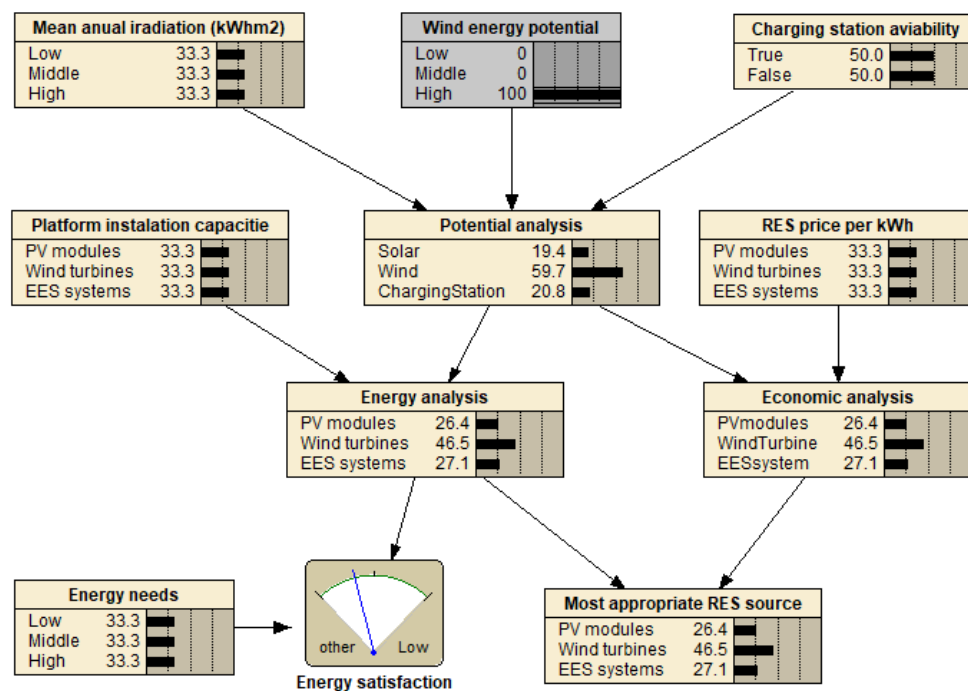


Figure 3. BN model with simulated high wind potential (Source: Authors)

Input parameters of the observed model are Mean annual irradiation, Wind energy potential, Charging station availability, Platform installation capacities, Energy needs, and RES price per kWh. In order for the model to generate accurate and credible output data, it is necessary to quantify and categorize the values that describe certain input parameters. In this process, attention should be taken to ensure that the input parameters are correctly determined so that the model does not favor a certain type of RES. After conducting a potential analysis, energy and economic analysis, the suitability for use in defined conditions is determined for a certain RES. A significant advantage of using BN is that the model can be used in the reverse direction as well. For instance, if we choose the EES system for the outcome, the model will match the input parameters with the selection as shown in Figure 4.

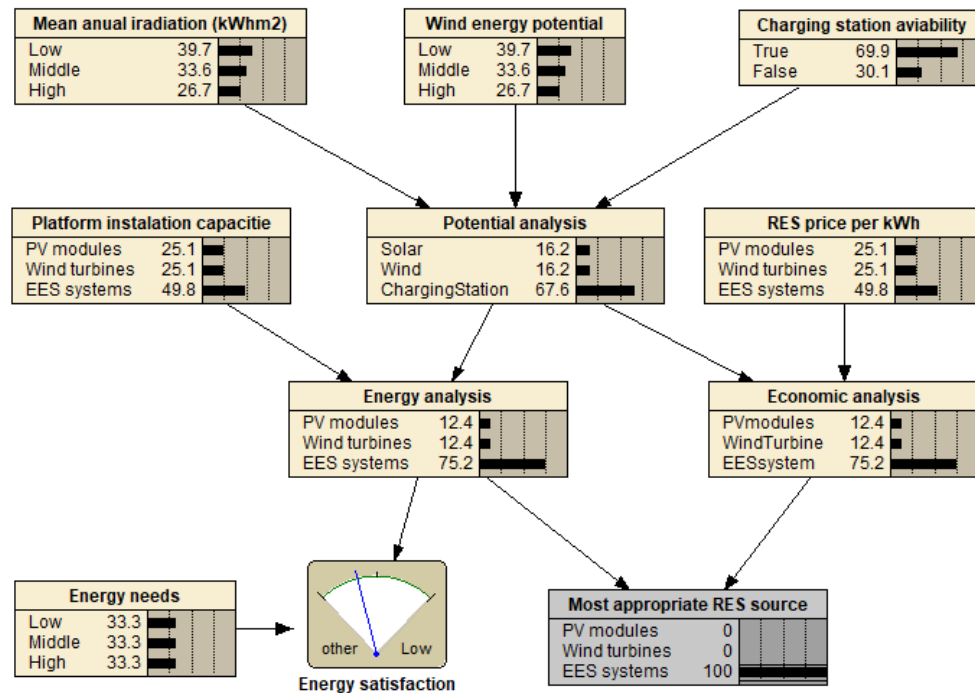


Figure 4. Bayesian Network application in reverse direction – regression (Source: Authors)

4. CONCLUSION

The advantage of using the proposed model is that it considers various parameters that influence the selection of the most suitable renewable energy source. To be functional, the model needs to be adjusted in accordance with the specifics of the energy potential in relation to the geographical position and the navigation area. Moreover, it is necessary to analyze the possibility of accommodating a certain type of energy in accordance with the energy needs of the ship. In future research, the model could be expanded and significantly improved in such a way as to include the flow of the larger geographical area. The limitation of the presented model is that it does not consider the variable input parameters that depend on weather conditions and the time of day, especially related to the availability of solar and wind energy. However, in this case, it is necessary to create a dynamic model that uses an appropriate method to change the input parameters in time and assign new initial values of the Bayesian network. Furthermore, ecological and economic justification can be used as an output variable of the model. The aforementioned variables took into account all aspects of the proposed model with the aim of obtaining an output as to whether the model is ecologically and economically viable.

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Maritime Cyber Risk Management and Cyber Security in Maritime Industry – Regulatory Framework and Cyber Security Requirements

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Maritime industry is increasingly using new technologies and information systems that rely on digitalization, integration, and automation, which call for cyber risk management procedures on board. Both cyber security and cyber risks are important because of their potential effect on personnel, ship, environment, company and cargo. Cyber security is concerned with the protection of information technology, operational technology, information and data from unauthorized access, manipulation and disruption which may cause extremely high financial costs in the case of cyber-attacks on the maritime industry. This brings the greater risk of unauthorized access or cybersecurity attacks to ships' systems and networks as well as maritime industry as whole. Enhancing cyber risk management and cybersecurity on maritime vessels necessitates a comprehensive understanding of relevant standards and regulations, particularly NIS2 and NIST CSF 2.0. Compliance with NIS2 standards is vital, as failure to meet these requirements can lead to operational disruptions and reputational harm within the maritime sector. To effectively strengthen cybersecurity measures, organizations must also integrate best practices based on the approach to cyber risk management described herein provides a foundation for better understanding and managing cyber risks, thus enabling a risk management approach to address cyber threats and vulnerabilities as well as NIST CSF 2.0 framework, which provides structured guidance for improving critical infrastructure cyber security.

KEYWORDS

Maritime cybersecurity; NIS2; NIST; Cyber risk management; Regulation; Standards

1. INTRODUCTION - CYBER SECURITY IN MARITIME INDUSTRY AND ONBOARD SHIPS

In today's maritime industry, ships are not just vessels; they are complex technological hubs. Ships are increasingly using new technologies and information systems that rely on digitalization, integration, and automation, which should be based on cyber risk management procedures onboard ships while facing daunting challenges in cyber risk management and cyber threats. (Akpan, et al., 2022) Cybersecurity involves protecting information technology and operational technology from unauthorized access and manipulation. In maritime operations, cyber risks encompass a variety of threats, including data breaches, system disruptions, and network insecurities, which can have dire consequences on maritime safety and operations. The repercussions of cyber incidents can extend to jeopardizing crew safety, operational integrity, and environmental health. It is of great importance to explore essential strategies for safeguarding the maritime systems against unauthorized access and cyber-attacks (Afenyo, Caesar, 2023). Emerging solutions to strengthen maritime cybersecurity include the application of blockchain technology, as discussed by Peronja et al. (2020).

Cybersecurity is not just a tech issue; it affects crew safety, environmental integrity, and company reputation. The IMO's MSC.428(98) resolution emphasizes that safety management systems must integrate robust cyber risk management approach as shown on Figure 1.



Figure 1. *Cyber risk management approach* (Source: The guidelines on cybersecurity onboard ships version 5, 2024, Available at: https://www.maritimeglobalsecurity.org/media/g3qlxdaw/2024-11-14-guidelines_on_cyber_security-v5-final.pdf)

This isn't merely compliance; it's about creating a culture of vigilance that permeates every layer of your organization to get ready to protect the ship from emerging cyber vulnerabilities. Both cyber security and cyber risks are of great importance because of their potential effect on personnel, ship, environment, company and cargo. (Cheung, Bell, Bhattacharjya, 2021) Cyber security is firstly concerned with the protection of information technology, operational technology, information and data from unauthorized access, manipulation and data

disruption. This brings the greater risk of unauthorized access or cybersecurity attacks to ships' systems and network in digitalized surroundings. (Bolbot, et. al., 2022)

2. REGULATORY FRAMEWORK

2.1. Resolution MSC.428(98) and cyber risk management onboard ships

In the maritime sector, cybersecurity is defined as the measures and practices used to protect ships' information systems and networks from cyber threats. This includes safeguarding sensitive data, ensuring operational continuity, and maintaining secure communication channels amidst evolving cyber threats and cyber trends. (Androjna, 2020) Approaches to cyber risk management will be company and ship specific but should be guided by the requirements of relevant national, international and flag state regulations and guidelines. (Kechagias, et. al., 2022. In 2017, the International Maritime Organization (IMO) adopted resolution MSC.428(98) on Maritime Cyber Risk Management in Safety Management System (SMS). The resolution stated that an approved SMS should consider cyber risk management in accordance with the objectives and functional requirements of the (International Safety Management) ISM Code. It further encourages administrations to ensure that cyber risks are appropriately addressed in SMS no later than the first annual verification of the company's Document of Compliance (DoC) after 1 January 2021. The same year, IMO developed guidelines that provide high-level recommendations on maritime cyber risk management to safeguard shipping from current and emerging cyber threats and vulnerabilities. As also highlighted in the IMO guidelines, effective cyber risk management should start at the senior management level. Senior management should embed a culture of cyber risk management into all levels and departments of an organization and ensure a holistic and flexible cyber risk governance regime, which is in continuous operation and constantly evaluated through effective feedback mechanisms. (Peng, P., et al, 2025)

2.2. NIS2 Cybersecurity Requirements

NIS2 outlines essential cybersecurity measures for operators of essential services, emphasizing risk management, incident reporting, and resilience. (Vandezande, 2024.) Compliance with NIS2 is crucial for enhancing the cybersecurity posture of maritime operations globally. (Maraveas, et. al., 2024.) The NIS 2 Directive's measures are based on an cybersecurity risk-management measures that aims to protect network and information systems and the physical environment of those systems from incidents, and will include "at least" the following: (a) policies on risk analysis and information system security; (b) incident handling; (c) business continuity, such as backup management and disaster recovery, and crisis management; (d) supply chain security, including security-related aspects concerning the relationships between each entity and its direct suppliers or service providers; (e) security in network and information systems acquisition, development and maintenance, including vulnerability handling and disclosure; (f) policies and procedures to assess the effectiveness of cybersecurity risk-management measures; (g) basic cyber hygiene practices and cybersecurity training; (h) policies and procedures regarding the use of cryptography and, where appropriate, encryption; (i) human resources security, access control policies and asset management; (j) the use of multi-factor authentication or continuous authentication solutions, secured voice, video and text communications and secured emergency communication systems within the entity, where appropriate. (NIS 2 Directive, Article 21, paragraph 2) The NIS 2 Directive replicates the Council's General Approach on incidents that are significant and that trigger the notification obligation in its Article 23(1) and (3). Changes to the Council's compromise text mainly relate to the wording of the respective provision when 'the potential to cause/affect' is replaced by 'capable of causing/affecting'. Further, the obligation to notify the service recipient of measures or remedies that they should take in response to a significant cyber threat is adopted. (NIS 2 Directive, Article 23, paragraph 2). Also, the approach to voluntary information sharing of cyber threats and near misses is maintained in Article 30 NIS 2 Directive. (Schmitz-Berndt, 2023)

According to Article 20 (Governance), the governing bodies of essential and important entities must approve the cybersecurity risk management measures taken by those entities, monitor their implementation and "may be held responsible for violations". (Boban, 2024) Also, in accordance with Article 20, Member States shall ensure that "members of the management bodies of essential and important entities must attend training" and shall encourage essential and important entities to regularly offer similar training to their employees, so that they acquire sufficient knowledge and skills to enable them risk identification and assessment of cybersecurity risk management practices and their impact on the services provided by the entity. (NIS 2 Directive, Article 20)

According to Article 21 (Cybersecurity risk management measures), essential and important entities must take appropriate and proportionate technical, operational and organizational measures to manage risks for the security of network and information systems that these entities use for their business or to provide their services and prevent or minimize the impact of incidents on the recipients of their services and on other services. (NIS 2 Directive, Article 21) Considering the "state-of-the-art" and, where applicable, relevant European and international standards, as well as implementation costs, the above measures ensure the level of security of network and information systems appropriate to the risks. (Boban, 2024) When assessing the proportionality of these measures, it is necessary to consider the entity's degree of exposure to risks, the entity's size and the probability of occurrence of incidents and their severity, including their social and economic impact. (NIS 2 Directive.com, 2025)

2.3. NIST CSF 2.0 Framework

The NIST Cybersecurity Framework (CSF) 2.0 provides a flexible structure for managing cybersecurity risks, tailored to the maritime industry. In whole, it encourages organizations to adopt a risk-based approach, aligning with industry standards and best practices to manage and reduce their cybersecurity risks. It is useful regardless of the maturity level and technical sophistication of an organization's cybersecurity programs. Nevertheless, the CSF does not embrace a one-size-fits all approach. Each organization has both common and unique risks, as well as varying risk appetites and tolerances, specific missions, and objectives to achieve those missions. By necessity, the way organizations implement the CSF will vary. Ideally, CSF will be used to address cybersecurity risks alongside other risks of the enterprise, including those that are financial, privacy, supply chain, reputational, technological, or physical in nature. The CSF describes desired outcomes that are intended to be understood by a broad audience, including executives, managers, and practitioners, regardless of their cybersecurity expertise. Because these outcomes are sector-, country-, and technology-neutral, they provide an organization with the flexibility needed to address their unique risks, technologies, and mission considerations. Outcomes are mapped directly to a list of potential security controls for immediate consideration to mitigate cybersecurity risks. (The NIST Cybersecurity Framework (CSF) 2.0, 2024)



Figure 2. CSF Functions (Source: The NIST Cybersecurity Framework (CSF) 2.0, <https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.29.pdf>).

Figure 2. shows the CSF Functions as a wheel because all of the Functions relate to one another. For example, an organization will categorize assets under IDENTIFY and take steps to secure those assets under PROTECT. Investments in planning and testing in the GOVERN and IDENTIFY Functions will support timely detection of unexpected events in the DETECT Function, as well as enabling incident response and recovery actions for cybersecurity incidents in the RESPOND and RECOVER Functions. GOVERN is in the center of the wheel because it informs how an organization will implement the other five Functions. (The NIST Cybersecurity Framework (CSF) 2.0, 2024)

ID	Priority	Risk Description	Risk Category	Current Assessment			Risk Response Type	Risk Response Cost	Risk Response Description	Risk Owner	Status
				Likelihood	Impact	Exposure Rating					

Figure 3. Stage 2 CSF 2.0: Analyzing And Prioritizing Risks (Source: CSF 2.0: Cybersecurity, ERM And Workforce Management Quick Start Guide, March, 2025, Available at: <https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1308.ipd.pdf>).

Figure 3. shows relevant CSF Core Category and Subcategories - Risk Management Strategy (GV.RM) The organization's priorities, constraints, risk tolerance and appetite statements, and assumptions are established, communicated, and used to support operational risk decisions.

- GV.RM-05: Lines of communication across the organization are established for cybersecurity risks, including risks from suppliers and other third parties:
- GV.RM-06: A standardized method for calculating, documenting, categorizing, and prioritizing cybersecurity risks is established and communicated. (CSF 2.0: Cybersecurity, ERM And Workforce Management Quick Start Guide, 2025)

Although not prescriptive, CSF assists its users in learning about and selecting specific outcomes. Suggestions for how specific outcomes may be achieved are provided in an expanding suite of online resources that complement the CSF, including a series of Quick Start Guides (QSGs). Cybersecurity risks are expanding constantly, and managing those risks must be a continuous process. This is true regardless of whether an organization is just beginning to confront its cybersecurity challenges or whether it has been active for many years with a sophisticated, well-resourced cybersecurity team. The CSF is designed to be valuable for any type of organization and is expected to provide appropriate guidance over a long time. (The NIST Cybersecurity Framework (CSF) 2.0, 2024)

2.4. International Guidelines for Cybersecurity

Key international guidelines from entities like the Maritime and Coastguard Agency (MCA) and NCSC provide essential practices for safeguarding maritime cybersecurity. These guidelines aid the development of robust cybersecurity protocols and risk management strategies. The purpose of the guidelines on cyber security onboard ships, issued, is to improve the safety and security of seafarers, the environment, the cargo, and the ships aiming to assist in the development of a proper cyber risk management strategy in accordance with relevant regulations and best practices on board a ship with a focus on work processes, equipment, training,

incident response and recovery management. (BIMCO Version 4, 2021) Shipping is relying increasingly on digital solutions for the completion of everyday tasks. The rapid developments within information technology, data availability, the speed of processing and data transfer present shipowners and other players in the maritime industry with increased possibilities for operational optimization, cost savings, safety improvements and a more sustainable business. (BIMCO Version 4, 2021) The guidelines explain why and how cyber risks should be managed in a shipping context. The supporting documentation required to conduct a risk assessment is listed and the risk assessment process is outlined with an explanation of the part played by each component of cyber risk. In 2017, the International Maritime Organization (IMO) adopted resolution MSC.428(98) on Maritime Cyber Risk Management in Safety Management System (SMS). The resolution stated that an approved SMS should consider cyber risk management in accordance with the objectives and functional requirements of the (International Safety Management) ISM Code. It further encourages administrations to ensure that cyber risks are appropriately addressed in SMS no later than the first annual verification of the company's Document of Compliance (DoC) after 1 January 2021. (Guidelines on maritime cyber risk management MSC-FAL.1/Circ.3, 2021). The same year, IMO developed guidelines that provide high-level recommendations on maritime cyber risk management to safeguard shipping from current and emerging cyber threats and vulnerabilities. As also highlighted in the IMO guidelines, effective cyber risk management should start at the senior management level. Senior management should embed a culture of cyber risk management into all levels and departments of an organization and ensure a holistic and flexible cyber risk governance regime, which is in continuous operation and constantly evaluated through effective feedback mechanisms. (Nganga, 2024) Also, in 2021 IMO guidance the DoC audits have included cyber risk management on a global level and in this sense it is essential for the key responsible person from a ship manager or owner to prepare, deploy and continuously manage an effective cyber risk management system onboard addressing the IMO Resolution MSC.428 (98), MSC-FAL.1-Circ.3, as well as critical parts of IACS UR-E26 and UR-E27, and industry practices which is aligned with the NIST Cybersecurity Framework tailored to the maritime industry. It supports the ship manager/owner in maintaining compliance with these rules and effectively minimizing cyber security risks over time. (Farah, et. al. 2022)

In addition to the IMO resolution, the U.S. National Institute of Standards and Technology (NIST) Cybersecurity Framework Version 1.1 (April 2018) has also been considered in the development of these guidelines. The NIST Cybersecurity Framework assists companies with their approach to risk assessments by helping them understand an effective approach to manage potential cyber risks both internally and externally. As a result of applying the Framework, a "profile" is developed, which can help to identify and prioritize actions for reducing cyber risks. The profile can also be used as a tool for aligning policy, business and technological decisions to manage the risks. Sample framework profiles are publicly available for maritime bulk liquid transfer, offshore, and passenger ship operations. (NIST Cybersecurity Framework, 2025) These profiles were created by the United States Coast Guard and NIST's National Cybersecurity Centre of Excellence with input from industry stakeholders. The NIST's profiles can be used together with these guidelines to assist industry in assessing, prioritizing, and mitigating their cyber risks. Guidelines are also available from other associations, such as the Digital Container Shipping Association's (DCSA) "DCSA Implementation Guide for Cyber Security on Vessels v1.0". DCSA's guidelines are based on an analysis of version 3 of these guidelines and the NIST framework. While the target audience for DCSA's guidelines is the container industry, other segments of shipping may also find them worthwhile reading. The International Association for Classification Societies (IACS) has issued a "Recommendation on Cyber Resilience (No. 166)". This recommendation consolidates IACS' previous 12 recommendations related to cyber resilience (Nos. 153 to 164) and applies to the use of computer-based systems, which provide control, alarm, monitoring, safety or internal communication functions that are subject to the requirements of a classification society. The IACS recommendation applies to newbuild ships only but can also serve as guidance for existing ships. In due course, IACS is expected to develop Unified Requirements, which will also apply to newbuilds only.

3. NIS2 DIRECTIVE VS. NIST CSF 2.0: NAVIGATING CYBERSECURITY COMPLIANCE NEEDS AND SOLUTIONS

Navigating cybersecurity compliance can be complex, especially when managing different standards like the European Union's NIS2 Directive and the U.S.-based NIST Cybersecurity Framework (CSF) 2.0. The organizations, in order to meet the requirements of both, ensuring comprehensive risk management and regulatory adherence should firstly raise awareness on the key differences between NIS2 Directive and NIST CSF 2.0. NIS2 Directive is primarily applicable to European Union member states, focusing on critical infrastructure sectors such as energy, healthcare, and digital service providers based on enhancing cybersecurity measures and stricter incident reporting. While NIST CSF 2.0: presents voluntary framework widely used in the United States which is applicable across various industries. It is based on emphasizing and improving overall cybersecurity practices and resilience but lacks the regulatory enforcement seen in NIS2. On regulatory enforcement of NIS2 it is noted that it is obligatory regulation in European Union and non-compliance may lead to significant penalties, including fines and restrictions in EU member states which enforce compliance, making it mandatory for covered entities according to the Cyber security law of each EU state since October 2024 which was the deadline for each country.

NIST CSF 2.0 is while widely adopted as best practice, adherence is often voluntary or driven by contractual obligations, not regulatory enforcement mostly in United stated. Which provides a flexible risk management framework adaptable to various organizational needs, with a strong emphasis on identifying, protecting, detecting, responding to, and recovering from cyber incidents. NIS2 brings strong emphasis on assessing and mitigating cybersecurity risks specific to critical sectors, with an added requirement for vendor risk management methodology. Both regulations enhance the maps controls and processes of risk management which is brought directly to the NIS2 Directive's mandates and the NIST CSF 2.0's categories and subcategories, ensuring all requirements of cybersecurity controls are covered. Also, both regulations strongly support integrated risk management which facilitates risk identification, assessment, and prioritization tailored to the specific needs of NIS2 and NIST CSF 2.0, supporting proactive incident response and ongoing risk reduction method. Automated Compliance Checks are implemented in both regulations and can be given through scans and automated assessments to validate adherence to both frameworks, minimizing manual workloads and ensuring continuous compliance. As well as the incident response tools which should provide built-in capabilities for incident reporting, investigation, and remediation, fulfilling both NIS2's stringent reporting timelines and NIST's recommended response practices. Assessing the third-party suppliers' cybersecurity readiness, on vendor risk management addressing NIS2's supply chain requirements and supporting NIST CSF 2.0's broader risk management approach while giving advanced reporting and analytics threw generated tailored reports that demonstrate compliance status for both NIS2 and NIST CSF 2.0, aiding in stakeholder communication and regulatory audits. Whether the organization operates in the EU and must comply with NIS2, or follows NIST CSF 2.0 as part of its security posture, it is important of build the platform providing the comprehensive tools needed to stay compliant and enhance cybersecurity resilience.

4. EXPECTED FUTURE DEVELOPMENTS AND CONCLUSIONS

The evolving landscape of cyber threats necessitates a proactive approach to cybersecurity in maritime operations. By aligning with NIS2 and NIST CSF 2.0 requirements, shipping organizations can enhance their resilience against cyber incidents and ensure the safety and security of their operations based on recommendations for Cybersecurity Onboard Ships which are based on:

1. Integration into Safety Management - Cyber risk management must be integrated into the overall safety management systems of vessels. This includes conducting regular risk assessments and ensuring that cybersecurity measures are part of safety drills and protocols.

2. Compliance with Regulatory Frameworks - Organizations should demonstrate compliance with relevant regulations, including NIS2 and IMO guidelines. This involves maintaining documentation of cybersecurity policies, incident response plans, and compliance audits.

3. Incident Response Planning - Organizations should develop and maintain an incident response plan that aligns with NIST CSF 2.0 recommendations. This includes preparing for potential incidents, reducing their frequency and impact, and ensuring efficient recovery.

4. Training and Awareness - Crew members should receive training in cybersecurity with the best practices and the specific risks associated with their roles. Regular drills and updates on emerging threats are essential.

5. Collaboration and Information Sharing - Engaging with industry groups and sharing information about threats and vulnerabilities can enhance collective cybersecurity posture. Organizations should participate in forums that focus on maritime cybersecurity. (Guidelines on Cyber Security Onboard Ships by the International Maritime Organization (IMO), 2022 / NIST Cybersecurity Framework (CSF) 2.0 documentation, 2025)

The approach to cyber risk management presented in the paper provides a foundation for better understanding and managing maritime cyber risks and cyber security onboard ships giving an overview of regulatory framework and cybersecurity requirements thus enabling a risk management approach to address cyberthreats and vulnerabilities. For detailed guidance on cyber risk management, organizations should also refer to Member Governments' and Flag Administrations' requirements, as well as relevant international and industry standards and best practices. As the list of additional guidance and standards it may include, but of course it is not limited to:

- The Guidelines on Cyber Security Onboard Ships produced and supported by ICS, IUMI, BIMCO, OCIMF, INTERTANKO, INTERCARGO, InterManager, WSC and SYBAss.
- Consolidated IACS Recommendation on cyber resilience (Rec 166).
- ISO/IEC 27001 standard on Information technology – Security techniques – Information security management systems – Requirements. Published jointly by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).
- United States National Institute of Standards and Technology's Framework for Improving Critical Infrastructure Cybersecurity (the NIST Framework).
- IAPH Cybersecurity Guidelines for Ports and Port Facilities. (IMO Guidelines on maritime cyber risk management, 2022)

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Mediterranean Sea Emission Control Area Implementation Challenges

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Mediterranean countries have since 1975 endeavoured to protect the Mediterranean Sea under the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC 79) adopted on 15 December 2022 the Mediterranean Sea Emission Control Area for Sulphur Oxides and Particulate Matter (Med SOx ECA) to further limit air pollution from ships, pursuant to Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL), it being the fifth ECA following the Baltic Sea, North Sea, North American, and US Caribbean Sea. Hence, from 1 May 2025, ships operating in the entire Mediterranean Sea will be required to burn fuel with a sulphur content not exceeding 0.1%. The paper focuses on analysing the extent of improvements accomplished in the ECAs that had been proclaimed previously, the issues still outstanding, and the effects of Med SOx ECA on ship operators, flag states and port control. The authors applied qualitative research based on official documents, literature surveys, current research reports on the subject, as well as authors' previous experience and research. Given the impacts of emissions on public health and that of the ecosystems and long periods necessary for achieving positive effects following regulatory changes in shipping sector, ECA in the traffic-busy and heavily populated Mediterranean being created with substantial delay. There is a need to introduce nitrogen oxides emission control in the zone as well. The application of alternative compliance solutions such as scrubbers should be closely monitored for their potential polluting effect on seawater. The availability of low-sulphur fuel and proper fuel changeover procedures should be ensured from the part of operators.

KEYWORDS

Emission control area; Air pollution; Mediterranean Sea; Sulphur oxides

1. INTRODUCTION

By the end of this decade the emissions from shipping could become the main cause of adverse impact on health in European coastal communities (EMSA, 2025). However, despite representing a significant source of air pollutants both at sea and in ports, shipping is not targeted by emission control legislation implemented in land-based sectors. Such emissions can have a detrimental impact on inland land quality as well, owing to the complexity of pollutants chemistry and the transport long-range nature. Namely, ship emissions contain toxic gases like nitrogen oxides (NO_x) linked to peak combustion temperature, sulphur oxides (SO_x), as well as particulates which, when released into atmosphere, have adverse effects on the health of humans and ecosystems and on cultural heritage.

It is therefore necessary to devise, develop, and implement globally, particularly in traffic-intense seas such as the Mediterranean, the measures to reduce and possibly eliminate such pollution. One of the instruments are emission control areas (ECAs) which can be defined as sea areas where stricter controls are introduced to minimize airborne emissions originating from ships, as defined by Annex VI of the 1997 MARPOL Protocol. Limits are applied to reduce sulphur oxides (SO_x) or nitrogen oxides (NO_x) emissions, or both. Four ECAs currently exist under the MARPOL Convention. EU hosts two, the Baltic Sea area and the North Sea area. As of May 1, 2025, the Mediterranean will finally become the fifth ECA. The ships will be required to use fuels with a sulphur content not exceeding 0.10% in this region. It will however only have the status of a sulphur emission control area (SECA), with no nitrogen emission control yet in place.

The paper presents current situation in the Mediterranean Sea and the chronology of Med ECA concept development which are relevant for its future development and the designations of new ECAs, reflects on the implications of ECA implementation and compliance challenges, and tackles the situation in the Adriatic Sea.

The authors applied qualitative research based on literature surveys, official documents, reports, as well as authors' previous experience and research.

2. MEDITERRANEAN SEA

Some of the world's busiest maritime routes are in the Mediterranean Sea which supports 20% of seaborne trade. In 2019 as much as 24 per cent of the global fleet and more than 17% of all cruises operated in the Mediterranean Sea (UNEP/MAP, 2022), see figure 1.

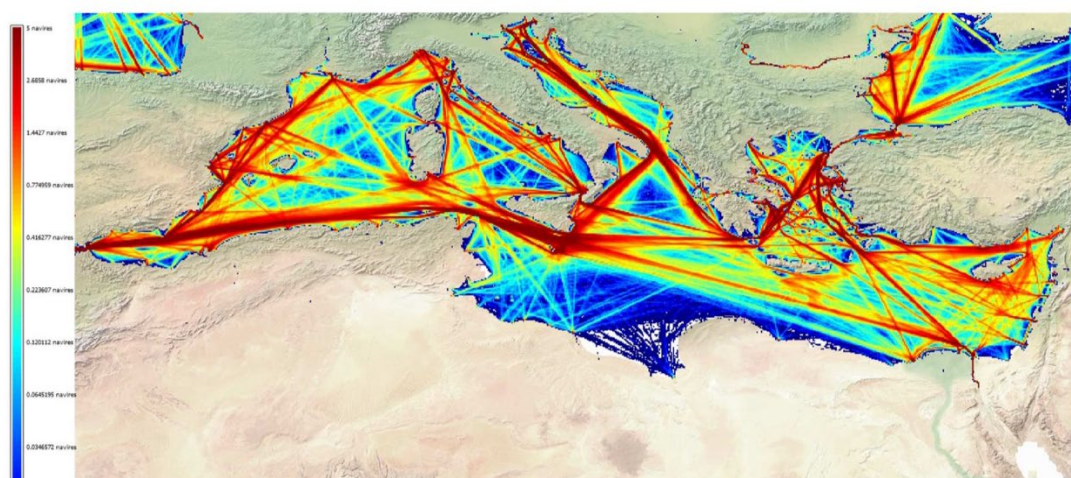


Figure 1. Traffic density in the Med Sea Area. Source: INERIS, 2019.

Between 2015-2023 the highest average yearly SO_x emissions, precisely 482 Gg/year occurred in the Mediterranean. Atlantic followed with 255 Gg/year and the North Sea with 29 Gg/year. Cruiser ships emitted 7 kg/km in 2015-2023 period, which is 11-fold compared to conventional passenger ships (0.7 kg/km) (EMSA, 2025).

Thus, the threat from shipping emissions to about 250 million residents of the Mediterranean is substantial. The World Health Organization (WHO) air quality guideline levels are often exceeded more than five-fold, whereby about 70% of littoral states cities by far exceed the recommended concentration levels of PM_{2.5}, which very much correspond with the shipping routes. Annual health costs related to air pollution from ships in the EU reach about 60 billion EUR (NABU, 2025).

The Contracting Parties to the Barcelona Convention and its Protocols had effectively reached consensual decisions pertaining to creation of the Mediterranean sulphur oxides emission control area (Med SO_x ECA) at their 21st meeting in Naples on 2-5 December 2019 and 22nd meeting in Antalya on 7-10 December 2021) (UNEP/MAP, 2022).

The creation of a Sulphur Oxides and Particulate Matter Emission Control Area (Med Sox ECA) covering the entire Mediterranean Sea was approved on 15 December 2022 at IMO's 79th Marine Environment Protection Committee (IMO, 2022). IMO also designated a Particularly Sensitive Sea Area (PSSA) (IMO, 2023) in the North-Western Mediterranean Sea.

It is to be noted that since 2014 SO_x emissions in the European Union fell by about 70% following the introduction of SECAs in Northern Europe. Similar achievements are therefore expected from the Mediterranean SECA. The establishing of ECA is also considered by North-East Atlantic countries, possibly by 2027. On the other hand, maritime sector NO_x emissions evidence a significant average rise of 10% in the EU in 2015-2023 period although both the North Sea and the Baltic Sea hold NECA designation since 2021. That is the result of penetration rates which are low, since the requirements only apply to new ships. North, Black and Baltic Seas record NO_x decrease of 17%, 7%, and 6% respectively (EMSA, 2025).

The projections are that SO_x and PM from shipping will drop significantly by 2050., and that NO_x will increase and exceed land-based emissions after 2030 (EMSA, 2021).

3. MED ECA CONCEPT

The introduction of an ECA has been considered by Mediterranean countries since 2004 (Thébault Guët, 2024).

The French National Reduction Plan of Atmospheric Pollutants Emissions (PREPA) adopted in 2017 in the French law envisages the implementation of new low emission zones in the Mediterranean Sea. The French Ministry for the Ecological and Inclusive Transition (MTES) was interested in assessing the feasibility and the potential benefits of the implementation of a NECA (NO_x emissions control area) or/and SECA (SO_x emissions control Area) in the Mediterranean Sea. French National Institute for Industrial Environment and Risks (INERIS), Climate and Clean Air Coalition (CITEPA), French public agency for developing public expertise in the fields of urban planning, regional cohesion and ecological and energy transition (CEREMA), and Plan Bleu (one the Regional Activity Centres of the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP) partnered in order to estimate the benefits and costs of ECA implementation in the Mediterranean. Models were used considering the scenarios involving IMO Global Sulphur Cap 2020, the implementation of SECA, the implementation of NECA, and the combination of SECA and NECA (INERIS, 2019).

Also, the alliance of organizations from Spain, France Italy Greece, Malta Portugal, but also Germany, adopted in 2017 a "Declaration to designate the Mediterranean Sea an Emission Control Area to limit air pollution from ships" as its mission statement in Rome (NABU, 2017). The Declaration raises the issue of disparate levels of protection of coastal communities and the environment from shipping emissions applied in the North and in the Mediterranean stating that instituting of a Mediterranean ECA is to restore equal treatment in the single European market.

Mediterranean countries agreed on a roadmap to establish a sulphur emission control area (SECA) following three comprehensive impact assessments that demonstrated significant socioeconomic and environmental benefits (Marlinblue, 2025)

Although final decision was welcomed by environmental organizations, criticism arose due to the delayed implementation schedule and the exclusion of nitrogen oxide (NOx) regulations (Marlinblue, 2025). Also, the agreement proposal to the IMO comes two years later than what France originally planned (Sefety4sea, 2019). Furthermore, effective SECA implementation date lags significantly in respect of taking effect of similar regulations in Northern European countries (Baltic 2006 and North Sea 2007 for SOx, both 2021 for NOx), with the designation of a NECA still undefined. It is to be noted that Technical and feasibility study (REMPEC, 2019) had not tackled NOx control. Indeed, NOx control from ships was not considered in the submission to the IMO, but it was agreed to bring forward NECA in coming years (NABU, 2025). On Fifteenth Meeting of the Focal Points of the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC, 2023) it was proposed to establish the NOx ECA Technical Committee of Experts and to prepare the Technical and Feasibility Study to examine the possibility of designing Med NOxECA.

The programme of work and budget for 2024-2025 of UNEP/MAP envisages delivering studies for a possible designation of Med NOx ECA (UNEP/MAP, 2023) Plan Bleu set out to contribute to UNEP/MAP efforts by producing auxiliary outputs such as policy-oriented technical papers in order to provide additional insights and perspectives on the potential socio-economic impacts of the possible designation of the Med NOx ECA (Plan Bleu, 2024)

Thébault Guët et al. (2024) point out that in the complicated environmental policymaking in the maritime sector at international level, the achievement of MedSECA demonstrates the importance of reaching regional agreement before approaching IMO global level, which could be a pertinent lesson in maritime policy making.

4. IMPLICATIONS OF INTRODUCING ECA'S

The implementation of Med SOx ECA should result in a significant drop of SOx and particulate matter emissions. Lower levels of pollutants will benefit aquatic and land ecosystems, notably by preventing acidification. Health benefits are reflected in preventing 1,100 premature deaths and 2,300 childhood asthma cases annually. Lower SOx emissions will also enhance the visibility and safety of transport at sea and inland (UNEP/MAP 2022).

ECAs in the Mediterranean will significantly impact various sectors, particularly the insurers, reinsurers, cargo owners, and shipping companies. Regulatory change is expected to significantly influence marine claims, as stricter regulations may lead to heightened scrutiny and potential disputes related to non-compliance. Cargo owners will face additional financial pressures as the costs associated with compliance, such as the transition to low-sulphur fuels or the installation of scrubbers, are likely to be passed down the supply chain. This may result in higher freight rates and necessitate logistical adjustments to accommodate the new requirements. Shipping companies will have to bear compliance costs and the investments in cleaner technologies and operational adjustments will increase their financial burden (Marlinblue, 2025).

The benefits of designating the Mediterranean as both SECA and NECA are shown in table 1. The costs are expected to outweigh the benefits by a factor of 4.4. (NABU, 2025). The effect of an ECA zone on the levels of nitrogen dioxide could result in significant reductions all along the Mediterranean coast, particularly in Eastern Adriatic area (UNEP/MED and Plan Bleu, 2020).

Reduction of air pollutants from international shipping	Annual avoided premature deaths	Cost benefits	Countries/regions which benefit most
• 95% of SO_x • 20-70% of NO_x • 11% of PM 2.5	• 4,100 by 2030 • more than 10,000 by 2050	• 8-14 billion EUR in avoided health costs • cost benefits 4.4 times higher than the costs in 2030 and 7.5 times higher in 2050	Greece, Turkey, Albania, Italy, Algeria, Egypt, Israel, Tunisia, Croatia, Morocco, Malta

Table 1. Benefits of the Mediterranean SECA and NECA. Source: NABU, 2021.

Policy instrument such as NECA is justified according to Åström, S. et al. (2018). The cases of Baltic and North seas demonstrate that unit control costs diminish significantly with more intense use of the control technology.

5. COMPLIANCE CHALLENGES

Main technological alternatives for compliance with SECA involve low-sulphur fuels or the installation of scrubbers. It is to be noted that IMO 2020 global sulphur cap, the introduction of SECAs, and the implementation of the Sulphur Directive did result in reducing SO_x emissions. There is however a risk of transferring pollution from one environmental component to the other, more precisely from air to the aquatic ecosystems when open-loop exhaust gas cleaning systems (ECGS) are used. It is to be noted that 98% of water discharge volumes consist of wash water from ECGS and the remaining 2% comprises primarily grey water and sewage. The share of open loop scrubbers is 74% (EMSA, 2025).

Compliance with SECA regulations furthermore involves a combination of monitoring, inspections, and advanced technological tools to ensure adherence to the stricter emissions standards. The methods to be employed are onboard fuel sampling, document reviews, emission testing by portable emission measurement tools to test sulphur oxide levels, fixed sensing stations, and remote sensing technologies using drones to measure Sox emissions from ship exhausts in real-time, where the “sniffers” fly into the plume, collect samples and analyse SO_x and NO_x. Necessary is also a collaboration with regional authorities as well as charging the penalties for non-compliance (Marlinblue, 2025). Observations of SO_x from remote piloted aircraft systems to date provide for instance the evidence of delaying vessels switchover to low-sulphur fuel upon entering SECA (EMSA, 2025). There is a problem of higher costs of low-sulphur fuel and of the availability sources of its supply.

The approach to regulation and the enforcement related to NO_x is more complex than it is for SO_x. It involves a tiered system for limit values which depend on the date of keel laying and engine's rated speed. The US Environmental Protection Agency (EPA) states in its paper submitted to IMO that the fuel sulphur control measures applied in the North American ECA have resulted in considerable reductions of PM emissions, while the expected reductions in NO_x emissions have not been achieved owing to slow fleet turnover to Tier III ships. Also, even the ships equipped with Tier III engines avoid engaging the emission control technology for much of the operation time with the intention to protect engines during slow steaming (Gard, 2024). There are ongoing

discussions about the effectiveness of the current NO_x regulations and potential shortfalls regarding the compliance approach (EMSA, 2025).

NO_x reduction technologies involve selective catalytic reduction (SCR), exhaust gas recirculation (EGR), dual fuel, and gas fuelled (Otto) engines. Other potential options are lowering the combustion temperature through wet or dry method or secondary aftertreatment systems (ABS, 2020)

Assessing of the environmental impacts is often hindered by actual absence of the monitoring data and of standardized reporting requirements for various pollutants (NO_x, VOC, PM, and black carbon) in the maritime sector. Advanced remote and in-situ monitoring technologies could certainly assist in overcoming these gaps. New challenges in emission assessment and safety risks are furthermore created by rapid advancements related to alternative fuels and propulsion systems. Although there is a potential of using the services of satellite, modelling and in-situ data, maritime transport sector has not benefited sufficiently from their development, particularly in respect of air emissions and water discharges. Main difficulties are associated with the monitoring of moving point sources (vessels) over high resolution temporal and spatial scales and with the sensibility of sensors. Therefore, in the development of new services and tools, the needs and requirements of the industry should be considered (EMSA, 2025).

6. ADRIATIC SEA

Semi-enclosed Adriatic Sea hosts busy maritime traffic (see fig. 1), with a significant number of cruise calls.

According to the study by INERIS (2019), health benefits of designating SECA and NECA in the Mediterranean are particularly pronounced for countries of the Adriatic Sea (Croatia, Bosnia and Herzegovina, Albania), as well as Greece, Cyprus, Malta, Tunisia, Israel, Palestine and Syria, see Figure 2.



Figure 2. Health benefits per capita of the implementation of the SECA/NECA compared to 2020 legislation (Euro/capita/year). Source: INERIS, 2019.

The idea of a Med ECA limited to the Adriatic Sea had been pursued by Italy, although it was later dropped for the foreseeable future. Croatia should have stood for high environmental standards in transportation sector, and it has been in its long-term interest to strive for proclaiming the Adriatic Emission Control Area

(Runko Luttenberger, L. et al., 2013). It is possible for the states to set up their domestic emission control areas to improve the air quality of their coastal areas and inland rivers (EMSA, 2021).

Therefore, in authors' opinion the countries bordering the Adriatic, with Croatia included, missed the opportunity to secure some form of protection for the Adriatic Sea and its coastal communities. Most of them did not show proactive role in protecting the Mediterranean nor the Adriatic.

With expanding recognition of common interest shared by mankind, the states are considered obliged to act within the limits of their jurisdiction on behalf of a mankind (Luttenberger, 2007). The designation of the Adriatic Sea or parts thereof as a particularly sensitive sea area should be seriously contemplated by Adriatic states and proposed to IMO. The Republic of Croatia for instance should resolve its institutional and capacity issues when it comes to the protection of its seas and the coast.

7. CONCLUSION

An emission control area is a sea area in which stricter controls to minimize airborne emissions from ships are established. This regulation was initially aimed to reduce sulphur oxides and is extended in 2005 to include nitrogen oxides for several areas.

Although as many as 22 countries situated on three different continents have their shores on the Mediterranean, the process of protecting coastal populations, ecosystems and cultural heritage from pollution emitted by shipping has been too protracted and substantially delayed compared to protection of the seas in northern part of Europe.

Also, the opportunity was missed to introduce the nitrogen oxides emission control area, besides the now formally designated sulphur oxides emission control area, despite the original initiatives to control both.

The delays and postponements in designating ECA have had and will continue to have detrimental effect on health and thus the costs.

Countries in the Adriatic area should embark actively on protection of the Adriatic Sea and the Mediterranean.

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Decarbonization and Energy Efficiency Through Smart Shipping

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Climate change is a demanding problem whose impact is already substantial. Around one-fifth of global greenhouse gas emissions (GHG) belong to transport, while maritime transport accounts for 3% with a constantly rising trend. IMO's target is to reduce CO₂ emissions by 70-80% up to 2040, therefore, maritime companies will have to pursue operational excellence and modernization of existing fleet to reduce energy consumption and thus GHG emissions, while adopting the transition to decarbonized fuels for the new build vessels. This research exposes attainable ways of optimizing energy consumption on the fleet of liner vessels by analyzing and fine-tuning the vessel's operational profile during the voyage. Along with the establishment of enhanced connectivity and smart vessels, the operational profile can be settled for the vessel, enabling monitoring and assessment of data after which a request for eventual optimization of operational condition can be sent to the vessel in real-time from the shore, concurrently enhancing safety and support. The fleet of liner vessels has been monitored from the fleet navigation center established ashore, and the flow of operational data has been set up through various software and reports from vessels as well as through established sensors onboard. Using action research methods in correspondence with captains and line managers analyses and optimization have been carried out on the fleet of vessels with different sizes and capacities. Through comparative analysis of data, it has been discovered that significant fuel savings thus reduction of GHG emissions as well can also be achieved by optimization of excessive use of power on the vessels and establishment of adaptive routing. While the adoption of decarbonized fuels for newbuild vessels is set up as a long-term solution for maritime companies, these measures are showing a large potential for the existing fleet by offering instant implementation and solutions for energy consumption optimization to meet recent and future IMO criteria of air pollution prevention and energy efficiency.

KEYWORDS

Decarbonization; Greenhouse gas; Power management; Constant power; Smart ships; Energy efficiency

INTRODUCTION

Since 2019, the EU countries have committed to achieving climate neutrality by 2050, delivering on the commitments under the Paris Agreement. The European Green Deal (Figure 1.) is the EU's strategy for reaching the 2050 goal (IMO, 2014). The Green Deal provides an action plan to boost the efficient use of resources by moving to a clean, circular economy and to restore biodiversity and cut pollution. The plan outlines investments needed and financing tools available (Rizzuto, Ruggiero, 2022). The "Fit for 55" package is a set of proposals to revise climate, energy, and transport-related legislation and put in place new legislative initiatives to align EU laws with the EU's climate goals (Shaw, Tzu, 2019). The Member States committed to cutting net greenhouse gas emissions in the EU by at least 55% by 2030, compared to 1990 levels (IMO, 2023). The European Commission tabled the 12 proposals that are part of the Fit for 55 Package in July 2021. The following 5 regulations will directly impact on the shipping sector (EU, 2023):

- EU ETS Directive,
- Fuel EU Maritime Regulation,
- Alternative Fuel Infrastructure Regulation (AFIR),
- Renewable Energy Directive (RED)
- Energy Taxation Directive (ETD).

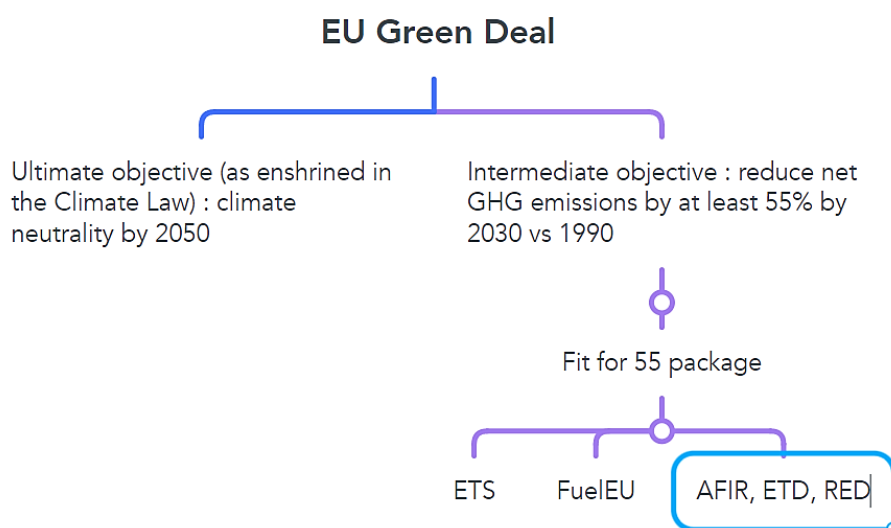


Figure 1. EU Green Deal to achieve climate neutrality (Authors).

The IMO continues to work on the adoption of concrete measures to achieve its levels of ambition through dedicated intercessional working groups (ISWG-GHG) and Marine Environment Protection Committees (MEPC). Candidate measures set out in the initial strategy are classified into short, mid and long-term measures (Psaraftis et. al., 2019):

- Short-term measures: finalized and agreed before 2023.
- Mid-term measures: finalized and agreed between 2023 and 2030.
- Long-term measures: finalized and agreed beyond 2030.

A first set of short-term measures was adopted in June 2021, the Carbon Intensity Indicator (CII) and the Energy Efficiency Existing Ship Index (EEXI). Dedicated guidelines were adopted in June 2022 and provide details on CII correction factors, exemptions, Ship Energy Efficiency Management Plan (SEEMP), and EEXI calculation. The short-term measures entered into force on 1st January 2023.

Technical Measure: the EEXI

The EEXI imposes very similar requirements to the later phases of EEDI, to all existing vessels (IMO, 2021). The attained EEXI and the required EEXI shall be calculated following MARPOL Annex VI. The new regulation requires existing vessels to improve their technical efficiency, so they are comparable to an equivalent new vessel of the same type and deadweight which would be required to comply with the applicable EEDI phase. Vessels of 400 GT and above must comply with their first IEEC (International Energy Efficiency Certificate) annual or renewal survey on or after 1st January 2023. (Cruells Palomino, 2024). Required EEXI includes specific reduction factor per size of vessels, relative to EEXI reference line:

- 10,000 and above but less than 15,000 DWT (-1,500 TEU): 0
- 15,000 and above but less than 40,000 DWT (1,500 – 3,500 TEU): 20
- 40,000 and above but less than 80,000 DWT (3,500-7,000 TEU): 30
- 80,000 and above but less than 120,000 DWT (7,000 – 11,000 TEU): 35
- 120,000 and above but less than 200,000 DWT (11,000 – 20,000 TEU): 45
- 200,000 DWT and above (+ 20,000 TEU) : 50

Where engine power limitation or shaft power limitation is used, an onboard management manual will be required and verified onboard.

Operational measure: the CII

The attained annual operational CII determines the ratio of the total mass of CO₂ emitted to the total transport work undertaken in a given calendar year as described by the formula (1) (IMO, 2021).

$$CII = CO_2 \text{ emissions} / \text{Deadweight} \times \text{Distance} \quad (1)$$

The annual reduction factor will ensure continuous improvement of the vessel's operational carbon intensity within a specific rating level. Annual reduction factors from the 2023 to 2026 period (versus the 2019 baseline) of 2% are defined as per Table 1. below:

Year	2023	2024	2025	2026
Reduction factor	5%	7%	9%	11%

Table 1. Annual reduction factors (Authors).

Values from 2027 to 2030 have not been set yet. They will be defined before January 2026. The vessel must report total fuel oil consumption, total hours underway and total distance traveled, which means that attained CII and attained CII before any correction factors will both appear in IMO DCS reporting. The IMO adopted guidelines on correction factors and voyage adjustment:

- A correction factor adjusts the calculation of the CII formula. A specific correction factor dealing with reefer consumption has been adopted.
- A voyage adjustment deducts fuel consumption and distance traveled from the calculation of attained CII regarding specific situations: any emissions necessary for securing the safety of a vessel or saving life at sea.

The attained annual operational CII must be documented and verified against the required annual operational CII. Vessels will be rated accordingly: A, B, C, D or E. The vessel rated D or E for three

consecutive years, will be required to submit a corrective action plan, to show how the required index would be achieved (Murat, Yuksel, 2023).

MATERIALS AND METHODS

A Fleet of nearly 600 container vessels of different sizes and capacities have been monitored from the fleet navigation centers (FNC) established ashore, providing 24/7 coverage and support. Data from the vessels is sent ashore via digital watch reporting programs such as V2PS, while on newer and fully upgraded vessels, operational data has been automatically extracted and stored on the cloud, enabling real-time access and processing from the shore. In the FNC experienced Captains analyze data by the use of “in-house” developed “vessel tracking application”. Event management tools in the program enable to manage the large number of vessels by the use of alarms associated with predefined events and set according to performance needs. Then a systematic analysis must be led by an experienced captain to take into account the context and the reasons of the event before sending instructions to the vessels. In case of eventual optimization, fuel saving is then calculated based on the difference between fuel quantity the vessel would have consumed without any contact, based on the checked average speed or percentage of MCR and the fuel quantity the vessel consumes upon instructions. Based on the saved amount of fuel it's calculated quantity of reduced CO₂ emissions.

SMART SHIPPING

The reinforcement of environmental constraints (Piccolo, 2023) and strong environmental ambitions require maritime companies to search for less carbon fuel alternatives but as well to improve vessels operational profile of their existing fleet and to get a compliant CII mark by reducing fuel consumption which is in direct relation with the amount of CO₂ emission as the main part of CII calculation formula. Today's situation in most maritime companies is not up to the challenges, with manual reporting, low frequency and accuracy of data as well as non-ownership of the collected data it's impossible to establish a vessel's operational profile and provide continuous support and analysis from the shore. Companies must work on the improvement of the operational profile for their vessels, therefore, the data flow of the vessel's operational parameters to the shore in real-time plays a crucial role in establishing such profile and enabling the following:

- Accurate vessel performance monitoring and forecasting.
- Identification of potential areas of improvement.
- Decisions support to the onboard personnel through shore-based data analysis & business intelligence tools.
- Dynamic weather routing & early detection of hydrodynamic loss of performance.

The scope of this paper is to show how to reduce a vessel's fuel consumption and achieve efficient use of the vessel's power by shore-based performance analysis of the operational data received from the vessels to reach maximal energy efficiency and reduction of CO₂ emissions with the application of the following measures:

- Smart speed approach
- Adaptive routing
- Proper Auxiliary engine management
- Trim optimization

Smart Speed Approach (SSA)

Berth congestion is one of the events with a high impact on maritime shipping and vessel efficiency. With the present system in place, there is potential wastage of fuel and energy consumption under uncertainty of berth schedule that is usually arranged by the terminal which provides a firm schedule within a certain time in advance to the operational department which then directs vessel via one of communicational methods such as phone, telex or email. Apparently when a vessel receives such notification fuel is already consumed at a higher speed that must be maintained as per coastal schedule speed. With SSA in force such wastage of fuel is being minimized. This procedure is applied for vessels calling the next port with a high possibility of schedule delay considered by four following factors, except for vessels with speed instruction of super slow steaming (SSS) and/or ports type of "First Come First Served":

- Required pilot on board time (RPOB) is 2 hours delay of schedule.
- Average berth delay of more than 2 hours in the last quarter.
- Foreseen port congestion.
- Predicted bad weather impact on port operation.

The purpose of SSA is to minimize idle time induced by berth schedule uncertainty to achieve the goals of optimizing fuel consumption using forwardly reducing speed to adapt an estimated new berth schedule and be able to recover an original schedule in case a delay didn't occur, as well as to avoid unnecessary drifting in congested coastal waters. Main terms used in SSA:

- SSA Speed: The speed required for new ETA including an estimated schedule delay.
- Schedule Recovery Time (SRT): The timeline of increasing speed to recover to an original schedule if the estimated schedule delay cannot be confirmed.
- SRT Deadline: The timeline of increasing to maximum sea speed to recover to an original schedule.
- SRT Speed: The speed required for the original ETA.

Figure 2. shows real case scenario of SSA applied on one of VLCS with a capacity of 18000 TEU for the arrival in Tanger Med port with an estimated and potential fuel saving of 23.6 t while there is 0.3 tons of potential loss if recovery speed for initial ETA will be applied at SRT. The required speed for the initial ETA of the vessel is 17.5 knots with a remaining distance of 705.93 NM while total fuel consumption for that leg would be 179.07 tons. If SSA is applied in the next 2.17 hours of the initial event with a new speed required for a potential pilotage delay of 4 hours, then the required speed would be 15.55 knots for the distance of 668.65 NM while total fuel consumption for that leg would be 155.5 t resulting in saving of 23.6 tons of fuel in such case. Meanwhile, if the delay has not been confirmed by the SRT Deadline vessel it would be required to increase speed to 20.4 knots for the remaining distance of 261.96 NM resulting in a total consumption of 179.35 for the leg which represents a loss of 0.3 tons of fuel.

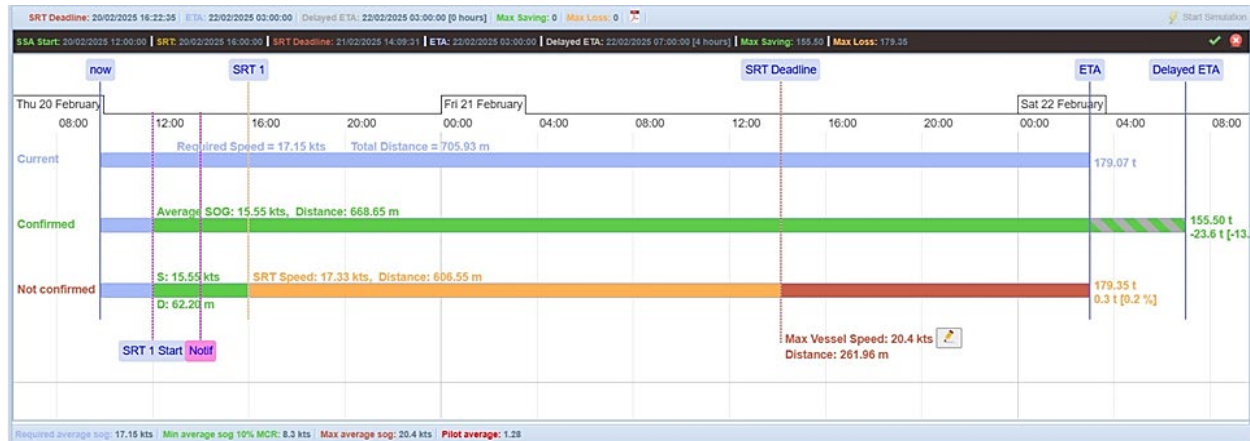


Figure 2. SSA application on 18000 TEU vessel (Authors).

Adaptive Routing

The accurate knowledge of ocean weather forecasts and the associated risks is a major challenge that requires constant questioning and monitoring of the information disseminated during voyage planning and execution. Thanks to the IT means implemented, access to the most recent and highly qualified data in the meteorological and oceanic fields is possible, which allows shore-based fleet support centers to have the indispensable expertise to support vessels in this field through the following:

- Sharing high-resolution weather information and sending alerts to the concerned vessels at sea or in port of call.
- Optimal routing of vessels to avoid bad weather areas and tropical phenomena as well as to maximize benefits from the current and weather factors along their routes.
- Analysis of resonance risks (parametric and synchronous rolling) to which large vessels are particularly sensitive through analysis of the vessel's operational data in real-time and alerting.

With fuel differential costs as well as energy optimization and operational efficiency index, the methodology for voyage planning has a completely new perspective. We approach the problem from a cost savings perspective, with an improved optimization algorithm that finds the least cost route for fixed arrival, based on the effects of the meteorological and oceanographic data. Optimization uses an operational model of the vessel with the required speed and fuel consumption curves to produce accurate estimates of fuel costs. It allows us to perform dynamic routing, with a review of routes every 6 hours, compliant with the last forecast. The used algorithm in conjunction with the higher resolution data makes it an essential tool for both trans-ocean voyages as well as coastal or short routes. Due to present IT limitations algorithm is not yet in use on board, but as a support tool from FNC. Vessel's planned route is analyzed with the support of an algorithm, if the criteria for optimization are met, the optimized route is suggested to the vessel. Final decision is always made by the captain onboard. Using global and regional high-resolution meteorological & oceanographic data with region-specific current models and establishing the vessel's profile in real-time enables us to optimize fuel consumption with high accuracy for any weather condition while providing all along the route insightful information such as RPM or total power reading). Figure 3. shows real case example of the route optimization for VLCS with capacity of 21000 TEU on its voyage from Charleston (USA) to Port Kelang in Malaysia. Even though the initial route was 145 NM shorter, the optimized route had a better weather factor (WxF) of -0.16 instead of -0.23 and a better Current factor (CuF) of -0.25 instead of -0.32 resulting in an estimated 91.52 tons of fuel savings and required calm sea speed (CSS) 16.5 kts instead of 16.8 kts which would reduce total

amount of emitted CO₂ by 288.38 t. On the aspect of safety optimized route benefitted with less average wave height as well as reduced time of exposure to waves over or equal to 5 m along the route.

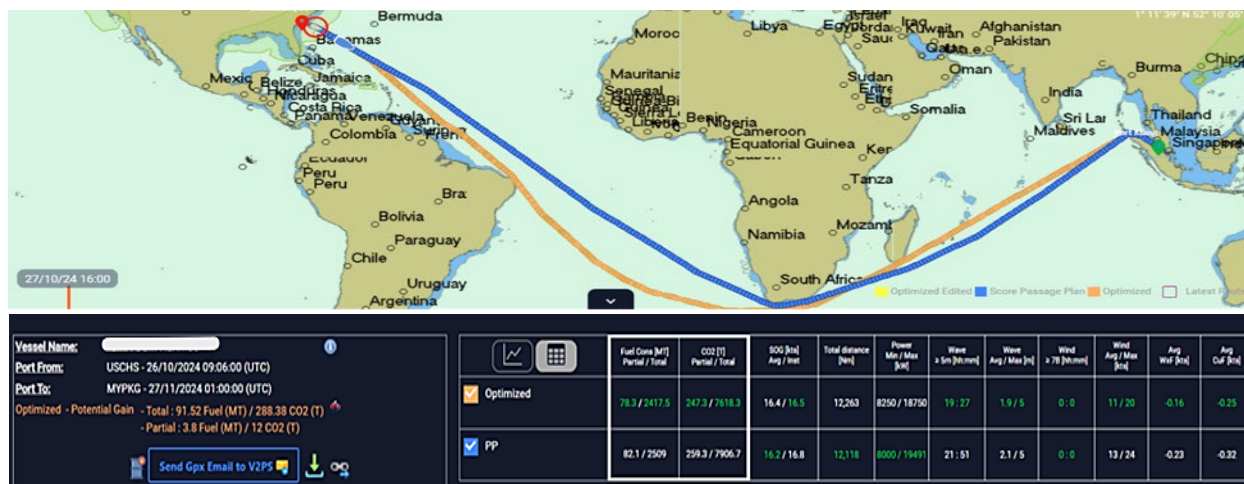


Figure 3. Route optimization for 21000 TEU vessel. (Authors).

Auxiliary Engine Management

Most auxiliary engines have been designed to run with an optimal load of 80% MCR. Vessels have been designed to have enough auxiliary engines to run with maximal power. Depending on the operational profile, running only one auxiliary engine may be sufficient. On several occasions throughout the fleet (safety reasons excluded), 2 engines have been observed to be running instead of one on multiple vessels. This operational set-up leads to non-optimal load on the used engine and therefore, overconsumption, which means unnecessary CO₂ emissions. Figure 4 shows the actual case scenario from one of the monitored vessels. It can be noted that the general need of the vessel is at around 60% MCR of a single auxiliary engine. The circled area shows that 2 auxiliary engines have been used reducing their load at around 30% MCR each. To give an example, an auxiliary engine used on several vessels consumes 15 tons of fuel per day for a 70% MCR load. Two of the same DGs loaded at 35% MCR consume 17 tons of fuel per day. Reducing the number of DG used as much as possible can lead to around 2 tons of fuel per day which is equivalent to 6,4 million tons of CO₂ per vessel per year. Such practice increases the overall consumption but also leads to premature wear of the equipment and increases the maintenance costs.

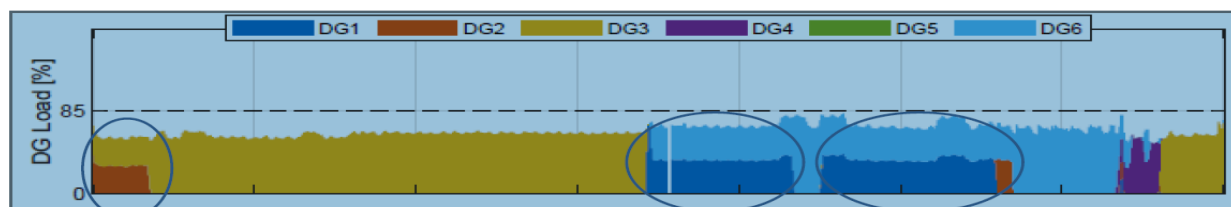


Figure 4. Auxiliary engines management (Authors).

Trim Optimization

Many authors have been lately researching this method for fuel saving (Zwart et. al., 2023), (Musulin, et. al., 2024), with positive findings in the way of energy efficiency and fuel consumption optimization by optimal trim range. For most recent classes of vessels, the trim optimization study is performed through model

tests executed in towing tanks. These model tests provide theoretical results that can be used to estimate fuel consumption for each tested configuration. Like the CFD numerical calculations, trim optimization tables done in model tests consider the dynamic behavior of the vessel at sea. For older vessels, without model tests or CFD analyses, actual trim tests were performed to create optimal trim range tables for the respective vessel's draft. The results accuracy depends on the quality and quantity of the data provided by each test, therefore large number of tests was performed to establish reliable references for the entire fleet. Figure 5. shows an actual example of fuel saving by trim optimization on one of the container vessels with a capacity of 9400 TEU. The vessel's initial departure condition was trimmed by stern 0.96 with a required speed of 20 knots and an average daily consumption of 132.66 t of fuel during the 20-day long voyage. Upon correspondence with the Captain, the trim has been optimized to even keel resulting in a reduction of fuel consumption by 1.55 t daily.

Present situation

Real (draft, speed, trim) 11.28 20 0.96

Wind (force, direction) 3 ENE (Face)

Consumption 132.66

Optimal / Simulation

Optimal (draft, speed, trim) 11.5 20 0

Wind (force, direction) 3 ENE (Face)

Consumption 131.11

General | Constants | **Tanks** | Stability | Strength | Container | SinglePage | Crane Split | Dead Load | Squat |

Drafts(P) Aft: 11.51 m Mid: 11.12 m Fore: 11.50 m Trim 0.02 m GM Corr. 2.66 m List 0.1 ° Displ. 104225 t Max. rel. SF 88 % Max. rel. BM 92 % Max. rel. TM 56 % Sea 1.0250 IMO_SOLAS SUMMER

Figure 5. Trim optimization of 9400 TEU vessel.

CONCLUSION

Analyses of the results for the above-mentioned methods of optimization on the level of the entire fleet show significant savings of fuel for the long-term period representing an improvement of operational profile for the vessels and better CII mark due to better efficiency and reduction of CO₂ emission. Figure 6. shows a comparative view of all mentioned methods with saving results within a 1-month period.

Saving method	Quantity of fuel saved in metric tons	Percentage of total savings	Ease of implementation	Applicability to different vessel types
Smart speed approach (SSA)	584 mt	13.2 %	- Quickly established without a large investment	Applicable to all vessels
Adaptive routing	3 000 mt	68.2%	- Quickly established without a large investment	Applicable to all vessels
Trim optimization	656 mt	14.9 %	- Requires time and investment to create the vessel's profile	Applicable to all vessels
Auxiliary engines management	160 mt	3.7 %	- Quickly established without a large investment	Applicable to all vessels

Figure 6. Comparison of saving methods within a month.

Upon comparison of the mentioned saving methods, it's visible that the adaptive routing method brings the largest amount of saving with minimal investment required. The trim optimization method shows certain potential but requires tests and building up of trim models to find the optimal trim for each class of the vessel.

Smart shipping plays a crucial role in the achievement of such efficiency as well as in the improvement of general safety and support to the vessels from the shore while enhancing the reduction of GHG emissions and the achievement of decarbonization. The development of artificial intelligence, machine learning, and neural network algorithms and their implementation to decision support systems enables monitoring and support of a large fleet of vessels. As mentioned, to have such a level of operation, digitalization, and flow of operational parameters must be established from each vessel to the shore to create an operational profile and provide monitoring and support to the vessel in real-time. Top management onboard the vessels should be aware as well of the importance and contribution of such measures, their support is crucial to its implementation as there are still cases of non-cooperation from the vessel's side without solid grounds in explanation. The safety of crew and vessel must remain a top priority during any decision-making process but among safety, operational efficiency is a key to reducing carbon footprint. With the modernization of the vessels, improvement in connectivity and digitalization, implementation of support decision tools onboard the vessels should become standard under the terms of smart shipping which will provide the captain's insightful view on the situation, enabling easier multitasking and decision-making while enhancing operational efficiency and efficient use of vessel's power.

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Review of the Decision-Making Process for the use of Monitored Systems On-Board

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In general, the basic duties of a nautical officer on duty on the bridge during navigation include planning and monitoring the navigation route, avoiding collisions, supervising and managing navigational data and handling the internal and external communication system. The nautical officer is exposed to various types of stress during navigation. Regulation V/15 of the SOLAS Convention (Safety of Life at Sea-SOLAS) states that the navigating bridge of the ship should not be used for purposes other than navigation, communication and other functions necessary for the safe handling of the ship, machinery and cargo; on this basis, bridge positions should be such that the bridge crew and the pilot have easier access to assess the circumstances, perform tasks and safely control the ship under all operating and navigational conditions (International Maritime Organization, 2011). The excessive workload of the navigation officer leads to an increased risk in decision-making during difficult navigational procedures. The purpose of this paper is to propose measures that can help reduce the workload of the navigation officer by evaluating the priority of tasks and the importance and urgency of messages received, as well as the process of sending or receiving messages, notifications, and warnings via ship communication equipment.

KEYWORDS

Navigation officer; Decision-making; Navigational bridge; Time.

1. INTRODUCTION

A modern approach to the concept of control and implementation of processes on the ship's navigating bridge implies the synergy of different systems and devices. Today's technology is the Navigational Integrated System (NIS) (International Maritime Organization, 2024). The basic tasks of the duty officer on the navigating bridge during navigation include: planning and monitoring the navigation route, avoiding collisions, monitoring and managing navigation data, managing excitations, and internal and external communication. The safety of all passengers, crew members, ships and cargo during the navigation venture depends on the successful performance of work processes, efficiency and training of officers on the bridge. The most common cause of maritime accidents while sailing is human error. Human error can be caused by ignorance, negligence, fatigue and poor organization that leads to omissions and unawareness of the impending danger. One of the possible approaches to eliminating human error is to define the minimum time required to.

2. ONBOARD WORK PROCESSES AND TIME

The importance or significance of the decision — this is where decisions are divided into strategic, tactical and operational. Strategic decisions, as the name suggests, are related to the change of a certain strategy and goals. They are high-risk decisions and can result in success or otherwise result in failure. Only one wrong decision can lead to failure, and therefore it can be concluded that the responsibility of strategic decision-makers is very great. Decisions of strategic importance represent the framework within which tactical decisions must move. Through tactical decisions, decisions of strategic importance are realized. They are lower-order decisions with one ultimate goal - to increase efficiency. Tactical decisions are medium-term, and their nature of risk is moderate. Operational decisions are decisions of the lowest order and are most often made by junior officers. Through them, tactical decisions are realized. They are most often programmed, that is, they occur when some routine problems or recurring situations are solved. Operational decisions are short-term and the risk of decision-makers is low. The basic tasks of the officer on duty on the navigating bridge during navigation include: planning and monitoring the navigation route, avoiding collisions, monitoring and managing navigation data, managing excuses, and internal and external communication. One of the possible approaches to eliminating human error is to define the minimum time needed to make work processes safe and thus reduce and/or eliminate fatigue factors and poor organization, eliminating fatigue factors and poor organization through consistent use, supervision and ergonomic organization of workplaces on the bridge. The amount of workload is influenced by work tasks and a range of information provided by navigation, communication, safety and other systems within the command bridge. The problem is that the time it takes for the MSI (Maritime Safety Information) that is received by the display on the corresponding displays, digital and analog indicators, digital and analogue indicators, auditory sources and in printed form, received and understood and properly implemented on the navigation process is an important segment of safe operation (International Maritime Organization, International Hydrographic Organization, World Meteorological Organization, 2025). Therefore, due to lack of time and overload with tasks and information, the officer is put in a situation of reduced attention, making it difficult for him to make timely and important decisions, especially during difficult navigation circumstances. Work overload can be defined as a level of workload that exceeds a person's ability to properly process information cognitively and perform actions, therefore negatively affecting awareness of circumstances.

3. ERRORS DUE TO WORK OVERLOAD

During the voyage, officers also perform additional tasks that they should not do while performing guard duties on the bridge. These tasks include, for example, correcting nautical charts and publications, preparing official documents of the ship for the next port, preparing various reports related to the next port,

preparing various reports related to travel, cargo or the ship's safety management system, etc. The causes of such work can be external influences (e.g. short voyages between two ports, overload with other tasks outside the guard, pressure from the company or superior officers on board, lack of organization and control of work) and personal error or conscious non-compliance with the rules. Carrying out such tasks can significantly reduce the officer's awareness of the circumstances and concentration, and therefore increase the risk of human error (International Maritime Organization, 2024).

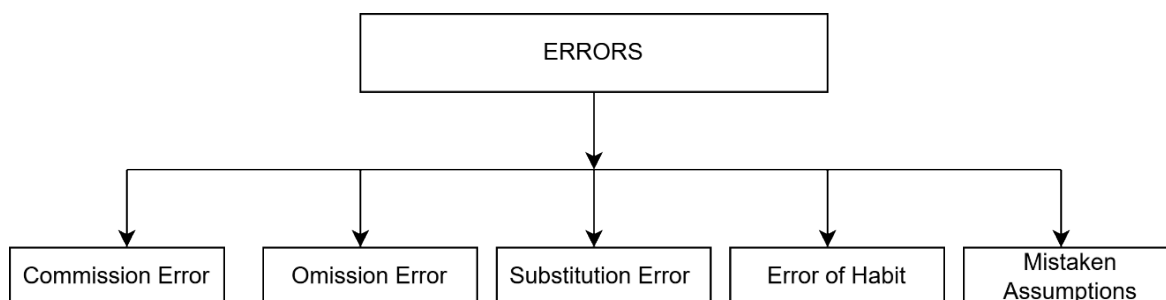


Figure 1. Errors (Source: authors)

Very important factors that affect work are: sleep, rest, years of life, emotional state, psycho-physical health, prohibited substances and overload. Overloading is one of the significant causes of marine accidents and can impair almost all physical abilities including: speed, reaction time, coordination, decision-making ability and balance. The overload of officers' work can be reduced by discarding the number of work tasks performed simultaneously, and the inclusion of additional officers in the work.

4. RECOMMENDATIONS OF AUTHORIZED ORGANIZATIONS

The IMO (International Maritime Organization - IMO) has adopted a number of regulations and recommendations for the ergonomics of the space and equipment of the commander's bridge and the ways of displaying information on navigation systems. Regulation V/15 of the SOLAS Convention states that the ship's navigating bridge should not be used for purposes other than navigation, communication and other functions necessary for the safe handling of the ship, machinery and cargo. However, with the development and introduction of new technologies on ships, the problem of using an increasing number of automatic systems and an excessive number of information displayed (digital and analogue, visual and auditory) has emerged. In the case of an excessive amount of information that the officer needs to process cognitively, there may be a work overload and a decrease in awareness of navigational Circumstances. In addition to numerous researches, this problem, which should be taken into account when introducing new technologies on ships, is also pointed out by the IMO. The total number of alarms that can sound on the navigating bridge can vary significantly depending on the type of ship, the level of equipment, the manufacturer of the equipment and the decision of the company. During construction, the company may determine that the same system of machine and cargo supervision be installed on the navigating bridge, although this is not necessary or obligatory by regulations. Such a decision can significantly affect the subsequent workload of the officer during sailing. In accordance with the IMO, a list of mandatory navigation alarms and all other alarms related to essential ship systems is prescribed.

The total prescribed number of different alarms that can be sounded on the bridge exceeds the officer's ability to inspect and check everything within the given time frame. If the display of both machine and cargo alarms is enabled on the navigating bridge in the same way as in the control room of the engine room or control room For cargo management, according to the presented overview, hundreds of different alarms can be sounded depending on the type of ship, which further increases the existing problem of lack

of time. This overview includes the alarms of the most important systems, but not all alarms that can be sounded on the bridge (e.g. alarms of communication systems, navigation lights, etc.). Furthermore, the number of alarms can vary significantly between manufacturers, so based on experience and conversations with active officers, it is estimated that the number of different alarms can be over 1000, and overloading becomes a real danger to the safety of conducting work processes during the time prescribed by the protocols for performing them.

5. IMPLEMENTATION OF THE DECISION-MAKING PROCESS

As a rule, the methods of supervision and implementation of tasks include the main tasks of officers: measuring the speed and accuracy of navigation planning, monitoring navigation and avoiding stranding, avoiding collisions, monitoring navigation devices and data, supervising the safety of the ship, maneuvering the ship, communication and managing alarms and the number of errors made. In addition to the main reasons, there are additional reasons related to the control of the ship's mechanical system, power system, cargo system, ballast and bilge system, and others ship systems that can increase the risk of increasing the burden in the decision-making process and the occurrence of errors. By measuring the number of errors in the implementation of the main or the possibility of carrying out additional tasks, it can indicate the level of overload. The following new model can be used in the analysis of the realization of decision-making:

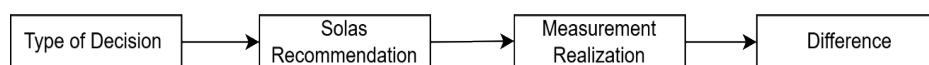


Figure 2. Decision making model (Source: authors)

The decision-making model uses data to describe the state of the environment, with the assumption that they can be measured or retrieved from shipboard installations in technical terms, and includes; traffic situation downloaded from ARPA (Automatic Radar Plotting Aid-ARPA) devices (e.g. number of plotted ships in the vicinity, CPA (Closest Point of Approach), TCPA (Time to Closest Point of Approach) and others, configuration of the planned navigation route downloaded from ECDIS (Electronic Chart Display and Information System), communication (flow of sending or receiving messages, notifications and warnings via GMDSS (Global Maritime Distress and Safety System) and other communication equipment), the state of safety on board (extraordinary circumstances, alarm status of various navigational, mechanical, cargo and safety systems) (IMO, 2024). The author conducts research on this topic in a certain longer period of time in which models and algorithms of the newly proposed approach have been developed, which are expected to achieve scientific results that would be an important contribution to the safety and reliability of the implementation of scientifically studied decision-making processes.

6. CONCLUSION

Despite the high degree of application of electronic navigation devices, navigation integrated systems and applied automation processes. Overloading with tasks and information leads to a decrease in attention and makes it difficult for the officer to make timely and important decisions, especially during difficult navigation circumstances. Work overload can be defined as a level of workload that exceeds a person's ability to properly process information cognitively and perform actions, therefore negatively affecting awareness of circumstances. On the way to the expected application of artificial intelligence. It can be emphasized that the role of man in the processes on board is still significant. Therefore, the author continues to engage in research related to the psycho-physical characteristics of man in the processes on board. With special emphasis on the time that a person spends in them. The overload of officers' work can be reduced by discarding the number of work tasks performed simultaneously, and the inclusion of additional officers in the work. During the performance of work processes under time load, the officer of the

navigational watch makes a mistake. Errors are caused by external factors or personal/conscious non-compliance with the prescribed rules and/or protocols. It is reasonably assumed that the proposed methodological approach will yield results in the future on the basis of which navigation safety could be raised to a higher level.

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AI Meets Maritime Training: Precision Analytics for Enhanced Safety and Performance

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Traditional simulator-based training for maritime professionals is critical for ensuring safety at sea but often depends on subjective trainer assessments of technical skills, behavioral focus, communication, and body language, posing challenges such as subjectivity, difficulty in measuring key features, and cognitive limitations. Addressing these issues, this study develops an AI-driven framework to enhance maritime training by objectively assessing trainee performance through visual focus tracking, speech recognition, and stress detection, improving readiness for high-risk scenarios. The system integrates AI techniques, including visual focus determination using eye tracking, pupil dilation analysis, and computer vision; communication analysis through a maritime-specific speech-to-text model and natural language processing; communication correctness using large language models; and mental stress detection via vocal pitch. Models were evaluated on data from simulated maritime scenarios with seafarers exposed to controlled high-stress events. The AI algorithms achieved high accuracy, with ~92% for visual detection, ~91% for maritime speech recognition, and ~90% for stress detection, surpassing existing benchmarks. The system provides insights into visual attention, adherence to communication checklists, and stress levels under demanding conditions. This study demonstrates how AI can transform maritime training by delivering objective performance analytics, enabling personalized feedback, and improving preparedness for real-world operational challenges.

KEYWORDS

Artificial Intelligence; Maritime Training; Simulator Assessment; Situational Awareness; Computer Vision; Speech Recognition

1. INTRODUCTION

Traditional simulator-based training has long been a cornerstone in preparing maritime professionals, offering a controlled environment to practice and refine essential skills. This method allows trainees to engage in realistic scenarios, enhancing their technical proficiency and decision-making abilities without the immediate risks associated with real-world operations. However, despite its widespread adoption, this training approach is not without limitations.

A key challenge in performance assessments is the subjectivity of instructor evaluations, which rely on personal judgment to assess technical skills, communication, and behaviour. This approach can lead to inconsistencies and biases, as interpretations vary among instructors. Additionally, the simultaneous monitoring of multiple competencies can overwhelm instructors, increasing the risk of oversight and reducing assessment accuracy. (*Malik A.A. & Zafar Nargus, 2015*)

Traditional simulator-based training lacks tools to objectively measure critical factors like visual focus and stress levels, which are vital in high-risk maritime scenarios where situational awareness and emotional regulation impact safety. Without precise measurement, assessments may miss key indicators of trainee readiness. While simulation training provides immersive experiences, studies highlight its limitations in capturing complex human factors, such as stress responses and attention management, essential for maritime operations. (*Emad Gholam Reza & Kataria Aditi, 2022*)

Addressing these challenges requires an objective, scalable, and scientifically grounded approach to improve maritime safety and training. AI integration offers a promising solution by enabling real-time, objective assessments of trainee performance.

2. RELATED WORK

2.1.1. Artificial Intelligence in Simulator Based Training

The aviation sector has extensively explored AI-enhanced training methods. For instance, (*Guevarra Michael & Das Srijita & Wayllace Christabel et al., 2023*) presented an intelligent tutoring framework that autonomously trains pilots in flight simulators using a simulated teacher. This system provides visual feedback to correct errors, reducing reliance on human instructors and enhancing learning efficiency. Similarly, (*Yang Shuiqiao & Yu Kun & Lammers Thorsten et al., 2021*) developed a real-time feedback framework for pilots, utilizing supervised models trained on standard operational patterns for various manoeuvres. These systems demonstrate AI's ability to offer tailored, data-driven feedback, significantly improving pilot competency.

In another groundbreaking study, (*Mohan Dilli Babu & Divya Venkatesh Jeevithashree & Prabhakar Gowdham et al., 2019*) estimated pilots' cognitive load in real-time using ocular parameters such as fixation, saccades, and pupil dilation. This approach provides deeper insights into pilots' mental workload, helping identify stress points and adapt training scenarios accordingly. These advancements in aviation highlight AI's capacity to augment traditional training by addressing cognitive and operational aspects.

2.1.2. Artificial Intelligence in Maritime Training

In maritime training, researchers are leveraging AI to enhance simulator-based learning. For instance, (*Munim Z & Kim T, 2023*) applied anomaly detection techniques to simulation log data, identifying performance deviations.

Eye-tracking technology has emerged as another valuable tool. (*Atik Oguz & Arslan Ömer, 2019*) employed heatmaps and comparative analysis between novice and expert ship officers to study differences in visual focus, aiding skill development in electronic navigation.

AI-driven speech analysis is also advancing maritime training. (*Jatta Lamin, 2024*) integrated text embeddings and large language models to improve Automated Speech Recognition (ASR) accuracy in maritime communication, ensuring precise interactions during high-stress scenarios.

Cognitive load and stress analysis represent critical applications of AI in this domain. (*Žagar Dejan et al., 2020*) explored cognitive load during simulated navigational tasks, using metrics like pupil diameter, electrodermal activity, and heart rate. Similarly, (*Xue Helene et al., 2024*) linked stress levels, measured through bio-signals, with training outcomes, finding that stress induced by reduced visibility or equipment failures impairs performance.

3. METHODOLOGY

3.1. Dataset

In our study, we utilize two datasets: one for training, fine-tuning and validating the various models, and another for evaluating our framework to demonstrate its benefits.

3.1.1. Training and Validation Dataset

For the vision dataset, participants wore Tobii Pro Glasses 3, which recorded egocentric video and gaze data as they navigated the simulator, intentionally focusing on various panels and equipment while varying their distance from these objects. This data was manually annotated to include panel and sub-panel detection and segmentation. For the audio dataset, participants with diverse South-East Asian accents read a conversational-style script related to maritime activities and were recorded using the integrated microphone of Tobii Pro Glasses 3. This dataset was manually annotated using timestamps and the script as transcriptions. For the stress dataset, the DAIC-WOZ (*Gratch Jonathan & Arstein Ron & Lucas Gale et al., 2014*) open-source dataset serves as a benchmark for validating models on distress.

3.1.2. Evaluation Dataset

The data was collected at Advanced Navigation Research Simulator at *Centre of Excellence in Maritime Safety, Singapore*. The participant performed two simulation-based navigation exercises one with good visibility and the other with reduced visibility conditions. During these exercises, demanding events such as potential collisions, engine failures, and squalls were introduced, simulating high-stress scenarios to assess participants' responses in dynamic maritime environments. The participant wore Tobii Pro Glasses 3, which recorded egocentric video and gaze data, along with an integrated microphone for audio capture.

3.2. Visual Focus

3.2.1. Eye Tracking

Eye-tracking technology monitors eye positions and movements to pinpoint where a subject is focusing. Modern wearable eye trackers, resembling regular eyeglasses, enable free movement while capturing gaze data. These devices integrate scene cameras for recording the user's perspective, infrared illuminators for precise gaze detection, and cameras to track pupil and corneal reflections. Advanced image processing

triangulates these reflections, estimating the gaze vector and direction in 3D space. The gaze data is synchronized with the scene video, enabling real-time analysis of eye movements. Key features relevant to this study include:

- *Gaze Position* determines the horizontal and vertical coordinates of the gaze on the scene frame.
- *Gaze Depth* provides information about the distance of the object in focus.
- *Pupil Diameter* records the diameter of the pupil, which is an indicator of changes in cognitive attention. (Reimer Jacob & Froudarakis Emmanouil & Cadwell Cathryn et al., 2014)
- *Gaze Direction* represents the trajectory of eye movement and indicates where the user is looking relative to their head position.

3.2.2. Panel and Subpanel Detection Model

Using the egocentric perspective from eye-tracker glasses and corresponding gaze data, we developed an object detection model to identify the panel or equipment a subject focuses on in each frame. This system fine-tunes a pre-trained Vision Transformer (ViT) model (Dosovitskiy Alexey & Beyer Lucas & Kolesnikov Alexander et al., 2020), originally trained on ImageNet-21k with 14 million images and ~21,000 classes, and fine-tuned on the training dataset.

Panels and equipment, such as the Ship Management System or ECDIS, often feature large screens with multiple layers of information. To refine detection, the bounding box identified by the panel detection algorithm is used as a cropped frame for subpanel identification.

For this task, we employ a SegViT model (Zhang Bowen & Tian Zhi & Tang Quan et al., 2022), pre-trained on the ADE20k dataset for diverse semantic segmentation tasks. The model is fine-tuned on the training dataset. This approach enables precise subpanel detection within the bounding box, allowing for granular analysis of specific areas of interest in the subject's focus.

3.2.3. Attentional Focus

Research by (Reimer Jacob & Froudarakis Emmanouil & Cadwell Cathryn et al., 2014) suggests that pupil dilation is a reliable indicator of cognitive attention. Building on this, we define an attentional focus (AF) metric to differentiate between inattentive gazing and genuine focus on the gaze location by combining pupil dilation and gaze stability.

Pupil dilation (*PD*) reflects cognitive load and attentional state. The normalized pupil dilation, is calculated as:

$$PD_{norm} = \frac{PD - PD_{min}}{PD_{max} - PD_{min}} \quad (1)$$

Gaze stability (*GS*) measures how consistent the gaze point is across consecutive frames. Volatility in gaze is indicative of distractions or scanning behavior, while stable gazing suggests focused attention. It is computed using the Euclidean distance between gaze points across N frames using gaze point G and diagonal dimension of the screen d_{screen} :

$$GS = 1 - \frac{1}{N} \sum_{i=1}^{N-1} \frac{G_i - G_{i+1}}{d_{screen}} \quad (2)$$

The attentional focus (AF) metric combines these two features using a weighted sum:

$$AF = w_1 PD_{norm} + w_2 GS \quad (3)$$

We validated our methodology and determined the weights w_1 and w_2 empirically on Ego Motion dataset. (K. Ogaki & K. M. Kitani & Y. Sugano et al., 2012)

By applying this methodology, we ensure that our attentional focus detection accurately reflects whether the subject is genuinely focusing or merely glancing at the gaze location.

3.3. Communication Analysis

3.3.1. Speech Recognition

OpenAI's Whisper model (Radford Alec & Kim Jong & Xu Tao et al., 2022) was designed as a versatile, plug-and-play speech recognition system, minimizing the need for extensive fine-tuning for specific applications. While this broad applicability is beneficial in many contexts, it leads to reduced performance in specialized domains with constrained vocabularies, such as maritime communication. Governed by the Standard Maritime Communication Phrases (SMCP), maritime communication often faces inaccuracies when transcribed with the generic Whisper model, particularly with terms related to ports and locations.

To address this, we enhance Whisper's performance through contextual biasing, which adapts the model to prioritize maritime-specific vocabulary and reduce errors. Our model is fine-tuned on a maritime-specific vocabulary dataset (Lall Vishakha & Liu Yisi, 2024), constructed from audio recordings collected at the Centre of Excellence in Maritime Safety, Singapore, featuring speakers with various South-East Asian accents.

3.3.2. Communication Entity Extraction

Communication entity extraction identifies the recipient of a communication, revealing who the subject is alerting or informing. This is achieved through a fine-tuned Named Entity Recognition (NER) model.

We use a fine-tuned BERT (Devlin Jacob & Chang Ming-Wei & Lee Kenton et al., 2018) model for NER to detect and classify entities as internal (within the ship) or external (outside the ship). The model was fine-tuned on maritime communication datasets to recognize domain-specific entities like vessel names, port authorities, and onboard roles (e.g., captain, officer).

3.3.3. Communication Correctness

For triggered events like engine failures, predefined checklists outline required actions, such as contacting the engine room or preparing anchoring stations. These actions gauge the subject's readiness to handle emergency scenarios.

To assess checklist completion, we use a self-hosted pre-trained LLaMA 7B (Touvron Hugo & Martin Louis & Stone Kevin et al., 2023) Large Language Model (LLM). The checklists, created by trainers, serve as prompts for the model, which processes the subject's verbal responses and compares them to the checklist items. For each item, the model outputs a true/false value indicating whether the action was acknowledged or completed.

This method enables scalable, objective evaluation, leveraging the LLaMA model's contextual understanding to handle phrasing variations while aligning with trainer expectations.

3.4. Stress Detection

Traditional stress monitoring relies on bio-signals like heart rate variability and electrodermal activity, measured by wearable sensors. While accurate, these methods can be intrusive and uncomfortable. For simulation trainees, raw audio input offers an accessible, non-invasive alternative for stress detection, enabling real-time monitoring without the need for sensors.

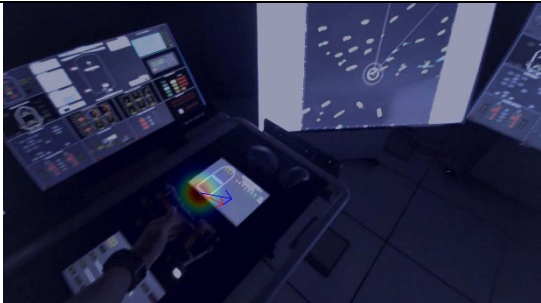
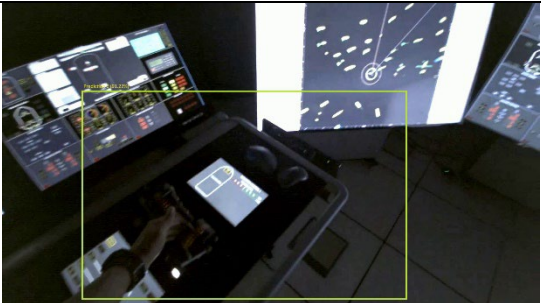
Human communication involves non-verbal cues, such as rhythm, timbre, tone, and pitch, which are influenced by stress-related changes in muscle tension and respiration rate. (Ju Hong & Frauendorfer Denise & Rabbi Mashfiqui et al., 2012)

To capture these subtle variations, we use a transformer-based model to detect stress-induced acoustic changes in maritime training contexts.

4. RESULTS

4.1. Visual Focus

The results of the trained panel and subpanel detection model are presented in Table 1. For panels with multiple subpanels, the subpanel detection algorithm provides more granular insights, such as identifying 'Lateral Speed' within the 'Ship Management System.'

Eye tracker frame with gaze (gaze fixation is plotted as a concentrated heatmap, arrows indicate gaze direction of the left and right eye)	Model Detection	Detection
		Panel: Bow Thruster Subpanel: NA
		Panel: Radar Subpanel: Radar

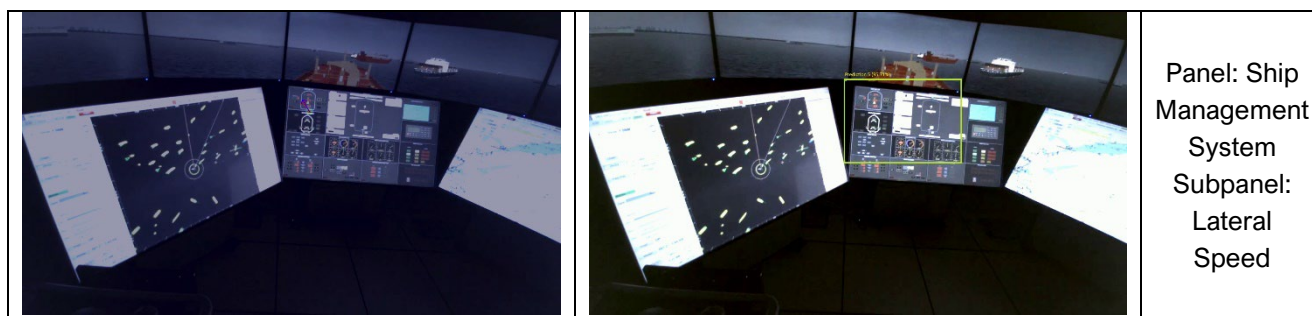


Table 1: Panel and Subpanel Detection Results

Our method achieves panel detection performance of **95.04%** on the validation dataset.

4.2. Communication Correctness

Our approach significantly reduced the Word Error Rate (WER), demonstrating the impact of contextual adaptation. (Lall Vishakha & Liu Yisi, 2024)

Table 2 presents sample transcriptions on the test dataset produced by original Whisper model and contextually biased Whisper model against the ground truth. Upon closer examination, the qualitative benefits of contextual biasing become apparent. While the non-biased model exhibits erroneous transcriptions for locations such as 'Keppel' and 'Brani', the biased model accurately identifies these locations.

(Lall Vishakha & Liu Yisi, 2024) demonstrates a classification accuracy of 98% on the validation dataset.

Ground Truth from validation dataset	Transcriptions generated from original Whisper model	Transcription generated from contextually biased Whisper model
Keppel Control Keppel Control this is SMA Voyager, we are headed for Brani 7 and we have a vessel crossing ahead of us. Can you give us the name of that vessel over?	Capital control, capital control, this is SMA Voyager. We are headed for Brani's 7 and we have a vessel crossing a herbivast . Can you give us the name of that vessel over?	Keppel Control, Keppel Control, this Is Sma Voyager. we are headed for Brani 7 and We have a vessel crossing ahead of us . Can you give us the name of that vessel over?
Can you advise which berth is the vessel on my starboard side going to? Is it also berthing at brani over?	can you advise which birth is the vessel on my star but side going to is it also birding at brownie over?	Can You Advise which berth Is the Vessel On My Starboard Side Going to? Is It Also berthing At Brani Over?

Table 2: Sample transcriptions from original and improved Whisper model (Lall Vishakha & Liu Yisi, 2024)

4.3. Stress Detection

Table 3 demonstrates that our model outperforms contemporary models, highlighting its superior capability in detecting stress on the validation dataset.

Model	Accuracy
RNN	76%
CNN+LSTM	76%
CNN+GSOM	89%
Our model	90.33%

Table 3: Performance metrics against contemporary models

4.4. Framework Dashboard

The dashboard consolidates analysis across multiple modalities for each subject, providing a comprehensive evaluation of compliance with procedures, adherence to safety measures, and task correctness within the simulator environment. It enables trainers to pinpoint potential areas of weakness and compare performance across participants.

In the following results, we examine a case study involving a Main Engine Failure scenario for the subjects from the evaluation dataset. The subject was exposed to the same type of demanding event during two exercises: Exercise 1 with good visibility and exercise 2 under poor weather conditions with reduced visibility.

Figure 1 depicts the subject's visual focus during the Main Engine Failure scenario, emphasizing behavioral differences between good and poor visibility conditions. Under low-visibility conditions, the subject notably reduces reliance on visual observation and increasingly depends on the ECDIS for navigation. Additionally, there is a heightened emphasis on the main engine screen, which is expected and critical during such a demanding event. These charts effectively assist trainers to identify abnormal visual focus patterns based on the navigation task and highlight instances where the subject may not allocate sufficient attention to critical equipment.

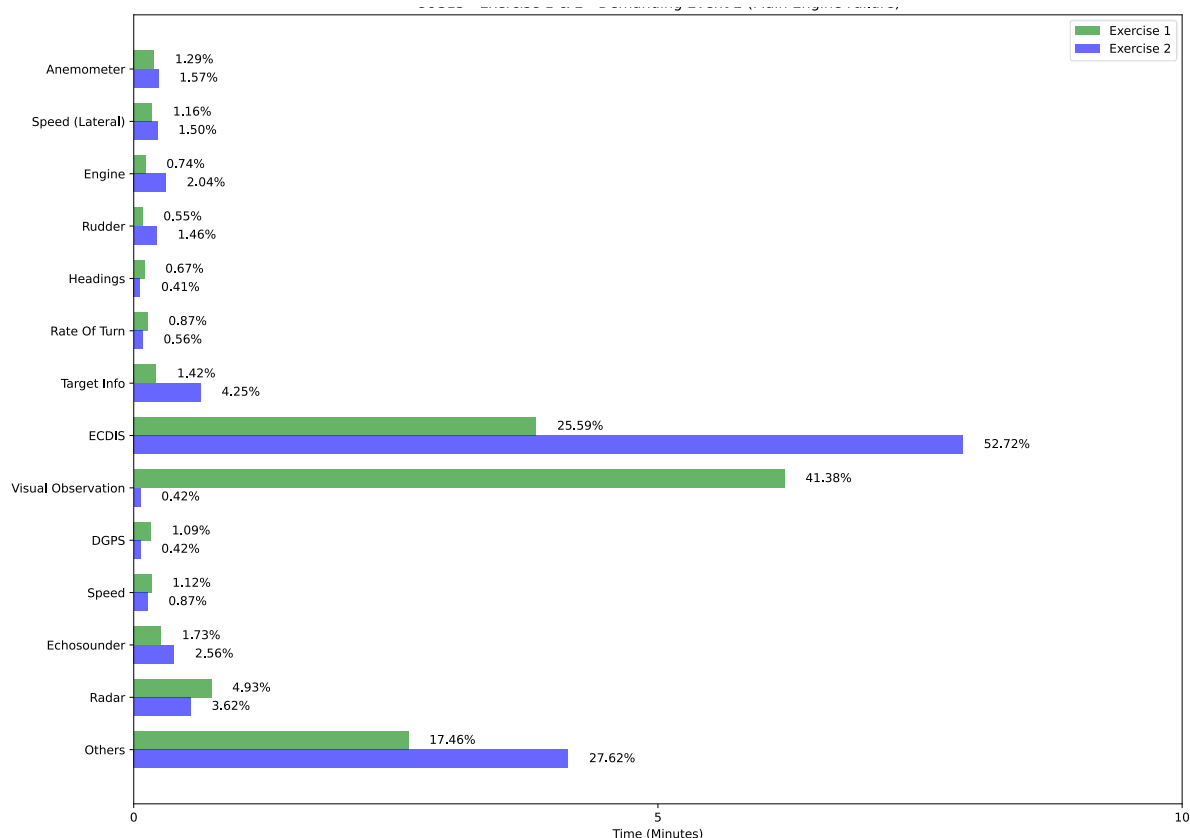


Figure 1: Visual focus on various equipment in exercise 1 good visibility and exercise 2 poor visibility

Figure 2 illustrates the subject's shift in attentional focus when the Main Engine Failure is triggered by the trainer. The focus intensifies sharply at the onset of the event and gradually diminishes as the situation stabilizes. These charts are instrumental in assessing whether the subject remains focused and attentive during training, providing insights into their potential performance during real-life scenarios.

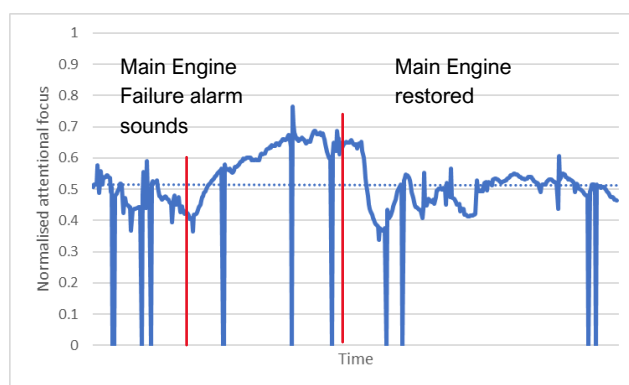


Figure 2: Attentional focus of subject during Main Engine Failure

Figure 3 illustrates the communication entities the subject interacts with, categorized as internal or external to the ship. In response to the engine failure, the subject communicates with the Engine Room and the Engineer to assess and address the issue. Under poor visibility conditions, there is an increased level of communication with the external entity, Port Control, reflecting a prudent and safety-oriented approach. These charts provide valuable insights for trainers, enabling them to review the exercise, ensure all necessary entities are engaged, and identify any safety-critical entities that may have been overlooked by the subject.

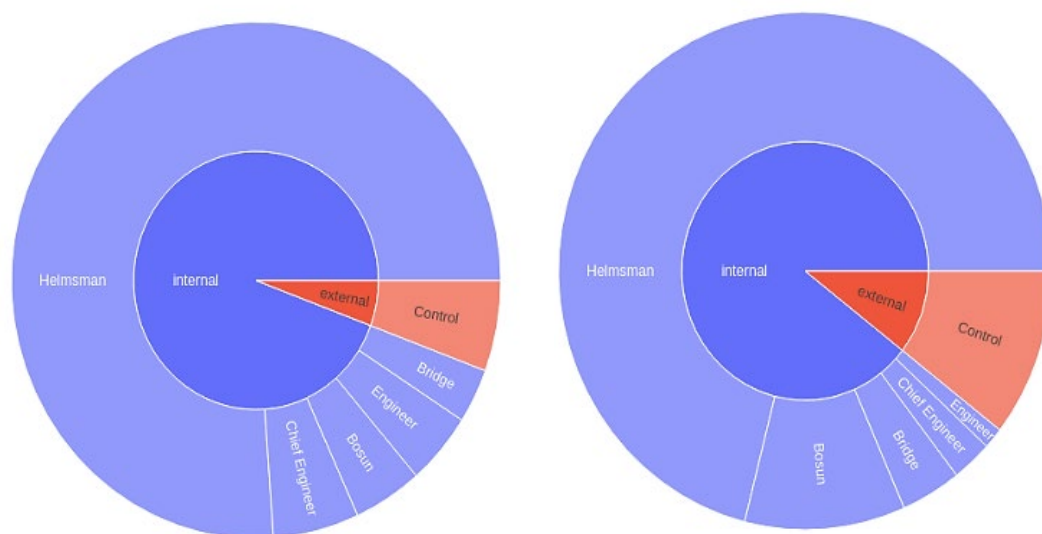


Figure 3: Communication entities in exercise 1 good visibility (left) and exercise 2 poor visibility (right)

Figure 4 provides deeper insights into the subject's communication patterns, revealing partial adherence to the required checklist guidelines for handling such scenarios. Specifically, the subject did not communicate with nearby ships to update them of an engine failure situation, nor kept the anchoring stations on standby which should be followed in a real scenario in cases when the engine does not get back up in time. Also, the checklist adherence builds upon the communication entity detection demonstrated earlier and even though the subject communicates with Port Control as highlighted Figure 3, they did not update them of the engine failure which is captured in the checklist adherence. Such charts highlight areas for improvement that trainers can objectively measure and provide as feedback to the subject.

checklist	is_completed
Contacted engine room to know status	yes
Updated nearby vessels	no
Kept anchoring stations on stand by	no
Updated port control	yes
Contacted tug assistance	no
Contacted port marine safety	no

Figure 4: Checklist adherence during Main Engine Failure event

Figure 5 illustrates the variation in the subject's stress levels throughout the exercise with 0 indicating no stress and 1 indicating stress, providing insights into their physiological response to the demanding event. A sharp increase in stress levels is observed immediately after the engine failure alarm is triggered. This heightened stress gradually subsides as the situation is brought under control and the subject resumes navigation. Stress levels recorded throughout the exercise offer trainers valuable insights into moments when the subject experienced anxiety, potentially triggered by the simulated danger or unfamiliarity of the scenario. These responses serve as an indicator of the subject's preparedness to handle similar situations in real life.

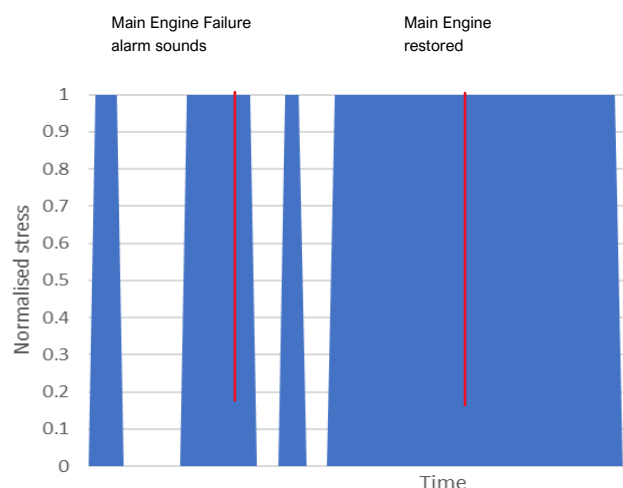


Figure 5: Stress experienced by subject during Main Engine Failure

5. CONCLUSION

This study demonstrates how AI can significantly enhance simulated maritime training by providing objective insights into trainee behaviour. Through personalized feedback and identification of key improvement areas, AI-driven analysis helps optimize training effectiveness and better prepares trainees for real-world operational challenges and potential mishaps.

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Augmented Reality as a Tool to Maritime Traffic Safety

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Predicting possible ship collisions is a challenging task for computers under real conditions. In small areas with many different types of ships, most of which do not have an automatic identification system (AIS), this task is even more difficult. In this paper we look at a new technique to help port authorities with this task. The paper aims to propose the use of augmented reality for presenting possible risks to Vessel Traffic System (VTS) center operators, port authorities, etc. This solution should be easily accessible. The input for the proposal was the camera installed in the port. The video recordings were used to recognize sailing objects. The artificial neural network (ANN) YOLO v9 (You only look once, version 9) was the framework for this task. The considered framework includes an Android application based on the Unity platform for data visualization. The results suggest that the framework is promising. The current progress visualizes the speed of the detected vessel by tracking its center of frame that surrounds it. This is tracked in successive frames. Although the research framework is promising, some obstacles were mentioned in the paper. For example, the ANN recognizes two sailing objects in some cases where there are no two objects in that image region.

KEYWORDS

Augmented reality; Video surveillance; Collision avoidance; Artificial neural network

1. INTRODUCTION

Augmented reality (AR) is already a topic that many research teams are working on. However, apart from low-level intelligence, e.g. in entertainment or visualization in tele-surgery or education, AR is only used in other applications as a surface for non-visible core technologies, i.e. only for the visualization of processes that are not visible at first glance. The role of artificial intelligence (AI) and AR technologies in maritime medicine was considered in (Battineni et al., 2024). The application of AR to support the shipbuilding process is presented in (Kunkera et al., 2024). The effects of AR on the operator's situational awareness were discussed in (Houweling et al., 2024). The visualization of maritime navigation data with AR is discussed in (Laera et al., 2024). Maritime training in advanced techniques is considered in (Christopoulos & Stylios, 2024). AR/VR technologies are examined in relation to the digital twin of a ship (e.g. in (Fujikubo et al., 2024; Wei et al., 2024)).

The EMSA report for 2024 reports on state-of-the-art learning tools as used in the EMSA Academy (EMSA Outlook 2024, 2023). An overly commercialized example of a state-of-the-art application in the maritime sector is AR (Seatrade Maritime News, 2021). The system uses a camera that is directed towards the front of the ship. An image of the front view is projected onto a display. All necessary navigation information is superimposed on this live video image using FURUNO AR technology. The commercial solution called BRIZO was developed for use during the day and at night. It offers the possibility of using AR in such a way that you can immerse yourself in the ship's environment (Brizo, 2020). Remotely controlled maintenance is proposed in (Karakostas & Katsoulakos, 2024). The proposed data display on the collision avoidance system is one that manipulates the augmented reality display device. It is used in cars. This technology has undergone rapid development in recent years. Starting from the presentation of the technological elements that need to be considered when implementing the Seaborne Collision Avoidance System (SCAS) (Kang et al., 2020.). The desktop bridge view implemented in AR is presented in (Mallam et al., 2024.). The paper (Grundmann et al., 2023.) first presents a brief study on pilot transfers. With safety and sustainability as motivation, the mentioned paper then outlines trust requirements of pilots and navigators in remotely piloted systems. This information is presented through the capabilities of Extended Reality (XR) in the form of highlighted requirements for the human operator. (Voloshynov, 2021.) provide an analysis of best practices in their article. These practices include the application of simulation technologies in maritime training.

1.1. Relevant state of the art research

To get an overview of the field, we searched the Web of Science Core Collection (WoSCC) database for the keywords „ship collision risk” and “augmented reality” (AND operator). The search yielded only 6 articles, of which only one is from Current Contents (CC), namely (Khan et al., 2024.). There are only two articles from 2024 (Khan et al., 2024; Hoon, 2024). There is also a paper from the prestigious conference index in WoSCC (Takenaka et al., 2019). In this study, a navigation support system using AR to detect the position of collision risk in the current sea area was proposed. The effectiveness of the developed system will be tested. This will be conducted as a simulator experiment. Hyundai Heavy Industry has developed an advanced navigation assistance system. It is called Hi-NAS. The Hi-NAS uses radar ARPA, AIS and a forward-looking camera for data fusion. The output of Hi-NAS is an AR-based display. The AR system overlays information about the status of the own ship and other ships as well as collision risk indices (Jeon et al., 2019.). The article (Hoon, 2024) highlights the introduction of AI-based collision prediction systems and the use of augmented reality technologies. The published study looks at the combination of AI and AR. The risk analysis method uses AI technology from the operator's perspective. In addition, the study explains the Maritime Traffic Safety Monitoring System, which incorporates AR technology to increase the efficiency of ship control. The presented system has proven the ability to predict hazards and risk priorities. Consequently, it leads to a sequential elimination of dangerous situations (Kim, 2019.). Based on these findings, practical measures were proposed in the study.

These measures are, for example, the use of tracking and monitoring systems together with third-party audits for effective handling, augmented and virtual reality for advanced training and automation technology for reduced human tasks to reduce risks to port infrastructure and promote uninterrupted operations (Khan et al., 2024.). Figures 1-3 are graphical representations of the searched results in WoSCC.

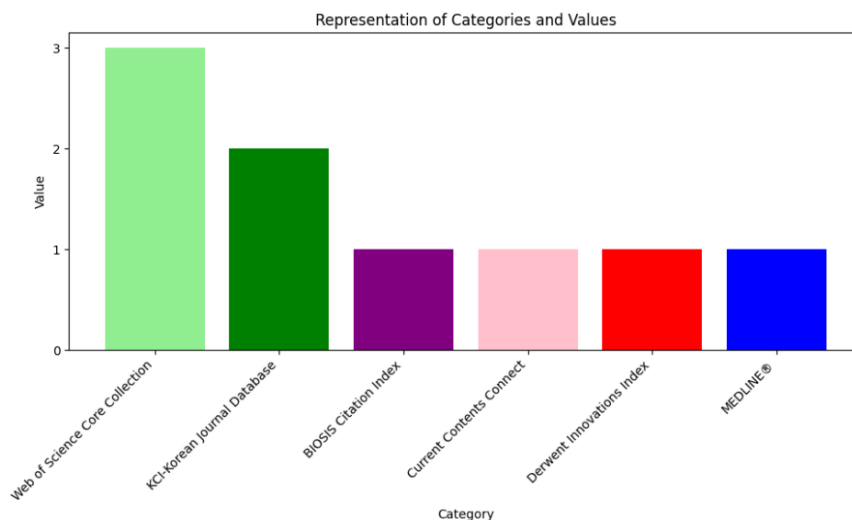


Figure 1. Spread of published relevant papers in WosCC by index database.

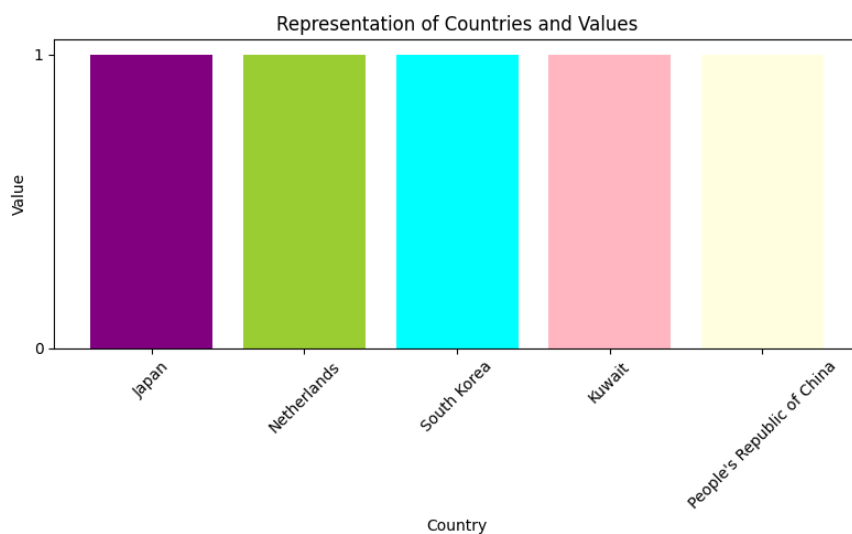


Figure 2. Geographical spread of relevant paper in WosCC.

Based on this review analysis, it is obvious that we are dealing with a kind of niche, which is a motivation for further research. The aim of the research is to improve maritime safety by introducing AR overlay for situational awareness.

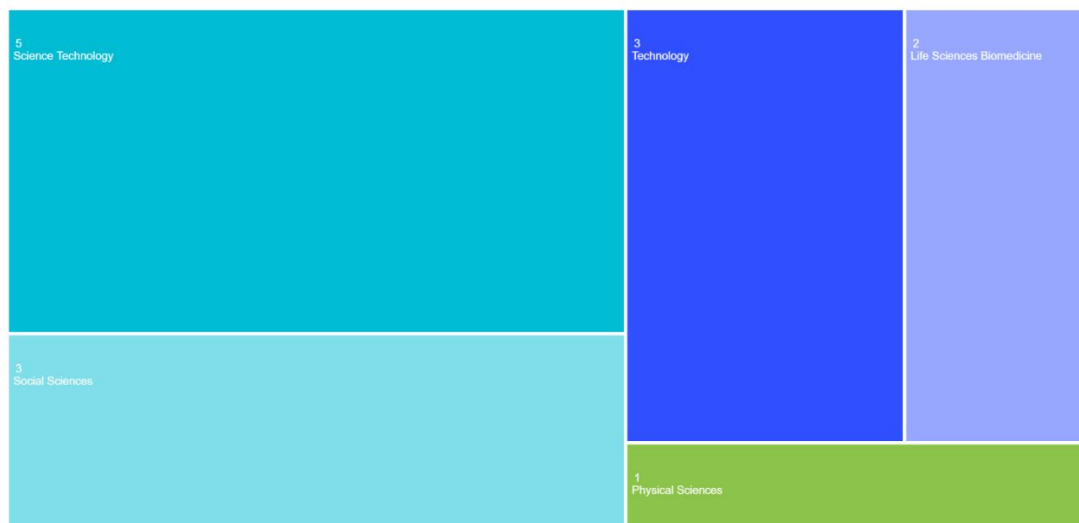


Figure 3. WoSCC categories for the indexed papers in WoSCC.

The paper is organized as follows. The second section describes the methodology and settings. The third presents results. Finally, conclusions are given.

2. METHODOLOGY

For real-time object recognition, we used the YOLOv9 model trained on an image dataset captured by a camera mounted at the entrance of the split ferry. The dataset contains 11,925 images for training and 1,688 images for testing and validation. The images from the surveillance camera were taken in different weather and lighting conditions to achieve more accurate results. Training takes place over 100 epochs on different classes of vessels, including sailboats, speedboats, high-speed craft, ferries, large ferries, pleasure craft, fishing trawlers and small passenger vessels.

The risk of collision is assessed on the basis of the distance between the vessels and the direction and speed of the ship's movement. To determine the speed of an object captured by a single stationary camera, in this article we first determined the distance between the camera and the observed vessel at two different times, t_1 and t_2 . The distance from the camera to the ship is defined by the position in the coordinate system. The point $P_{t1}(X_{t1}, Y_{t1})$ describes the position of the ship at the moment t_1 as a function of the two coordinates, X_{t1} and Y_{t1} . From the distances obtained at two different moments, we have calculated the distance traveled by the ship in the observed interval:

$$d = P_{t1} - P_{t2} \dots \dots \dots (1)$$

We have divided the calculated distance by the time it takes the ship to get from point A to point B, which gives us the average speed of the ship.

$$v = \frac{d}{t_1 - t_2} \dots \dots \dots (2)$$

The direction of movement is determined from historical data on the movement of the center of the detected ship. Position of center of detected ship is memorized for last 3 seconds of video and drawn as point on image to create trajectory of movement. The length of the observed tracks depends on the speed of the ship and its direction of movement relative to the position of the surveillance camera. By applying a linear regression,

Figure 6. shows the result of our detection and tracking model with the trajectories indicating the direction of movement of the vessels.



Figure 6. Camera stream with detected vessels

The following results are an example of calculating the distance from the camera to the moving ship and the distance travelled in a selected time interval for a ship captured by a surveillance camera by estimating the direction of movement and the speed at which the ship is moving.

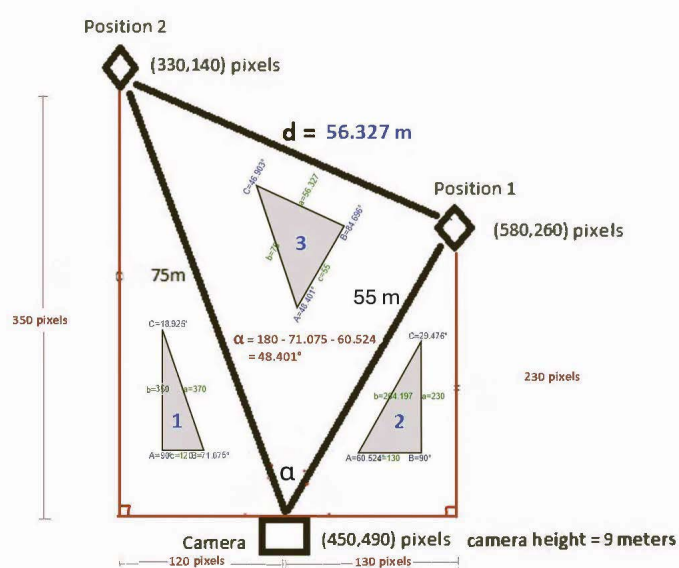


Figure 7. Estimation of covered distance in given time period

Figure 7. shows the entire distance estimation procedure. The procedure involves the use of trigonometric functions and the calculation of the distance travelled by the vessel under consideration. If we have determined the distance from the camera at two different moments, knowing the distance travelled and

the time interval between the moments in which the ship was in certain positions, the speed of movement can be determined, which is the case in this example:

$$v = \frac{d}{\Delta t} = \frac{56.327m}{5s} = 11.26 m/s \dots \dots \dots (3)$$

In order to determine the direction of movement, we have specified the central position of the observed ship with the position in the x-y coordinate system. The linear regression between these points through all images during the observed time interval provides us with the route, that represents the direction of movement.

The route is described by the equation:

$$y = B_0 + B_1 x \dots \dots \dots (4)$$

where:

$$B_1 = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^n (x_i - \bar{x})^2} \dots \dots \dots (5)$$

$$B_0 = \bar{y} - B_1 \bar{x} \dots \dots \dots (6)$$

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \dots \dots \dots (7)$$

$$\bar{y} = \frac{\sum_{i=1}^n y_i}{n} \dots \dots \dots (8)$$

The proposed calculations are performed for all ships detected on the video to determine whether and between which vessels there is a risk of collision.

The intersection of the lines indicates the distance at which there is a risk of collision. In situations where the intersection point is relatively close to the time it takes a vessel to manoeuvre if the vessels continue to move at the same speed, the vessels at risk of collision must be signalled and warned. The manoeuvring time is a separate part of the observation, that includes various parameters such as wind speed, wind direction, ship structure and the human factor. The collision avoidance procedures themselves, the sufficient time needed for a safe manoeuvre to avoid a collision, and the method of communicating information about the collision risk are the subject of further research in order to obtain a complete collision avoidance system based on video data obtained from a single stationary camera at the port entrance.

4. CONCLUSION

This paper presents an attempt to increase the safety of maritime traffic in ports and coastal regions. It utilizes advanced technologies by combining AI and AR, object recognition based on the developed model and an augmented reality application for Android to display the results to users. It should be noted that the method utilizes the problem of a single stationary camera, which makes accurate distance estimation difficult. Systems with two or more cameras could make distance estimation more reliable, but we are limited with funding and available equipment. Another limitation is that the current state of our work only uses visual spectra, which makes the proposed method useless at night. Further work should therefore incorporate infrared for night or fusion of sensors so that the method can be used 24 hours a day.

Although the training dataset include various weather conditions, further research should include tests of robustness to adversary weather conditions. Also, this preliminary research results in the project, which is accepted, but not started yet. The project budget includes validation equipment, which will improve scientific merit of the research.

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Reliability and Validity of the Questionnaire for Examining the Integration of Ergonomic Practice Among Seafarers

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The aim of this study was to examine the reliability and validity of a newly constructed questionnaire for ergonomic practice integration assessment among seafarers. In doing so, test-retest reliability and factor analysis were applied to a sample of 45 experienced seafarers. Results indicated that the questionnaire is highly reliable and valid, demonstrating statistically significant reliability identified through non-significant difference between test and retest ($p > 0.05$). Factor analysis revealed a two-dimensional latent structure, namely Knowledge and Application of Ergonomic Principles, and Health Issues and Efficiency, explaining 33% and 24% of the variability of manifestations, respectively. It can be concluded that this newly constructed questionnaire is a reliable and valid tool for assessing the integration of ergonomic practice among seafarers and can be used in contemporary practice.

KEYWORDS

Ergonomic Practices; Seafarers; Reliability; Validity; Factor Analysis

1. INTRODUCTION

Ergonomics, formally defined by the International Ergonomics Association (IEA) (*What Is Ergonomics (HFE)? | International Ergonomics Association*), is the scientific discipline concerned with understanding interactions between humans and other elements of a system (Karwowski, 2005)(Sun *et al.*, 2019). It applies theory, principles, data, and methods to design systems that optimize human well-being and overall system performance (Dul and Weerdmeester, 2001). At its core, ergonomics aims to design devices, technical systems, and tasks in a way that enhances human safety, health, comfort, and performance. By focusing on human capabilities and limitations, ergonomics seeks to eliminate unsafe, unhealthy, uncomfortable, or inefficient solutions in both work and everyday environments. Key factors considered include posture and movement (e.g., sitting, standing, lifting), environmental conditions (e.g., noise, vibrations, lighting), and information processing (e.g., visual displays, control systems) (Dul and Weerdmeester, 2001).

Ergonomics is inherently multidisciplinary, drawing on knowledge from mathematics, biology, physics, and sociology. Within mathematics, it relies on statistics and biometry; in physics, it incorporates mechanics, statics, dynamics, biomechanics, and optics; in biology, it integrates anthropometry, environmental physiology, anatomy, and biomedicine; and in sociology, it leverages industrial and experimental psychology, philosophical psychology, and industrial sociology (Kaljun, Obad and Dolšak, 2011). Beyond these core disciplines, ergonomics also incorporates insights from fields such as mechanical engineering, industrial design, information technology, and management (Gupta, 2024). This integration of knowledge enables the adaptation of environments, workplaces, and processes to align with human needs, thereby improving safety, efficiency, and overall well-being.

The application of ergonomic principles contributes significantly to human well-being by reducing the risk of musculoskeletal disorders (e.g., lower back pain) and psychological illnesses (e.g., stress-related conditions), which are leading causes of sickness absence and work incapacity (Dul and Weerdmeester, 2001). Moreover, ergonomics enhances societal well-being by increasing productivity and reducing healthcare costs. A fundamental principle of ergonomics is that equipment, technical systems, and tasks must be designed to suit the majority of users, with special considerations for vulnerable groups such as disabled individuals, pregnant women, and those with extreme body dimensions, who constitute approximately 5% of the population.

Human error is a common factor in accidents across various domains, including workplace incidents, traffic collisions, and industrial disasters. Analyses of such events often reveal that poor human-system interactions are a root cause. By accounting for human capabilities and limitations in the design of work and everyday environments, the likelihood of accidents can be significantly reduced. In complex technical systems, ergonomics plays a critical role in minimizing operator errors and enhancing system reliability.

Ships represent one such complex technical system, where the application of ergonomics has a profound impact on navigation safety and crew performance. A ship can be viewed as a socio-technical system comprising individuals with unique psychological and physiological capabilities and limitations, as illustrated in Figure 1 (Grech, Horberry and Koester, 2019).

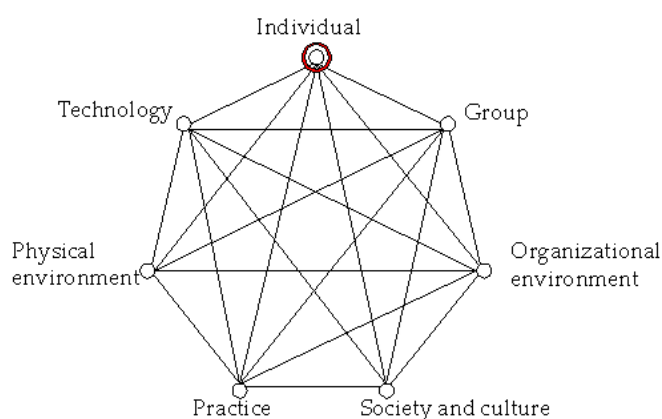


Figure 1. Model of a Socio-Technical System Focusing on the Individual Factor (Grech, Horberry and Koester, 2019)

Maritime environments are characterized by long and irregular working shifts, which often lead to suboptimal work-rest cycles. Fatigue, a key factor influencing crew performance, must be carefully managed through ergonomic design of both physical and organizational environments onboard. The consequences of human errors caused by fatigue can be catastrophic, underscoring the importance of ergonomic interventions in maritime settings.

Human error, defined as the failure to execute planned mental or physical activities due to incorrect decisions, is the leading cause of maritime accidents (Maternová *et al.*, 2023). Fatigue, both general and muscular, is a significant contributor to such errors. Recognizing this, international maritime conventions, such as the International Labour Organization (ILO) Convention No. 180 and the International Maritime Organization (IMO) Standards of Training, Certification, and Watchkeeping (STCW) Convention, have established guidelines to mitigate fatigue and stress among seafarers (Dohrmann and Leppin, 2016). These regulations address working hours, crew size, and onboard living conditions, including noise control and air conditioning.

To assess the current application of ergonomic principles in maritime environments, it is essential to conduct targeted surveys among active seafarers. Such surveys can provide insights into how shipboard work and living conditions affect the physical and mental health of crew members and their ability to perform daily duties effectively. As a first step, this study aims to develop and validate a survey questionnaire designed to evaluate ergonomic practices in maritime settings. The methodological approach includes a series of statistical procedures to ensure the reliability and applicability of the questionnaire.

2. DEVELOPMENT OF THE SURVEY QUESTIONNAIRE

The process of developing the questionnaire and its analysis includes several stages:

- Collecting data on the perception of ergonomic practices among seafarers through a detailed questionnaire.
- Assessing the reliability of measurement instruments through repeated measurements (re-test).
- Analyzing descriptive statistics to determine general trends and distribution of responses.
- Examining the relationship between different variables in the questionnaire through correlation analysis.
- Identifying latent factors that affect the perception of ergonomics using factor analysis.

Three key research questions have been defined to assess the implementation of ergonomic practice in the maritime environment:

- How familiar are seafarers with the concept of ergonomics and its impact on daily life aboard ships?
- How aware are employers of the importance of implementing quality ergonomic practices on ships within their fleet?
- What role does ergonomics play in the physical and mental health of seafarers aboard ships?

The questionnaire is intended for use in an online survey that allows for quick and economic data collection. A total of 45 respondents participated in the initial testing of the survey. After the initial testing, a re-test was conducted after 15 days to check the accuracy and credibility of the respondents' opinions. A total of 10 out of 45 participants took part in the re-testing. During this, attention was paid to the ethical principles of the Helsinki Declaration (*Declaration of Helsinki – WMA – The World Medical Association*) concerning the protection and use of collected data.

The research instrument, i.e., the questionnaire, was designed based on reviewed scientific and professional literature and previous research on similar or identical topics (Tsai and Liou, 2017)(Janssen *et al.*, 2024). Specific areas necessary to be covered by the questionnaire were first identified, followed by the composition of specific questions exploring these areas. The questionnaire consists of a total of 10 questions, of which nine are answered on a Likert scale ranging from 1 to 5 (Joshi *et al.*, 2015). Here, the number 1 indicates "strongly disagree," while the number 5 indicates "strongly agree" with the statement. The last question is descriptive and relates to suggestions for improvements and advancements in the implementation of ergonomics in maritime practice. The questionnaire was compiled based on scientific and professional literature on similar or identical topics (Grech, Horberry and Koester, 2019),(Delleman *et al.*, 2000)(Reilly, 2010)(Seif, Degiuli and Muftić, 2003). It considers studies dealing with ergonomics in the working environment on ships and its impact on the work efficiency of employees, as well as studies related to the education, professional training, and education of employees to increase the implementation of ergonomics on ships and raise awareness of the importance of ergonomics among seafarers, especially employers.

The respondents are divided into three demographic groups based on their navigational work experience. The first group includes seafarers who have less than 5 years of navigational work experience. The second group relates to seafarers who have between 5 to 10 years of experience in navigation, and the last group comprises seafarers who have more than 10 years of experience in navigation. Such a demographic structure provides insight into the connection between navigational work experience and the opinions and perceptions of respondents about the implementation of ergonomics in work aboard ships. The questionnaire used in this study consisted of ten questions, labeled from Q1 to Q10, aimed at assessing the understanding and application of ergonomic principles among seafarers. A detailed review of each question, including their formulation and purpose, can be found in Appendix 1.

3. STATISTICAL PROCESSING OF SURVEY RESULTS

The survey data were quantitatively analyzed using Statistica 14, with results presented in both tabular and narrative formats (*TIBCO Statistica™ 14.0.0*). The analysis incorporated a range of statistical parameters, including:

- Central tendency: mean, median, and mode.
- Variability: minimum and maximum values, standard deviation (std. dev.).
- Distribution shape: skewness and kurtosis.

To assess the reliability of respondents' answers, a dependent sample t-test was conducted. This test identified statistically significant differences between initial and retest responses, providing insights into the stability of respondents' perceptions over time. For each variable, additional parameters were calculated, including differences (diff.), t-values, degrees of freedom (df), and p-values. Statistically significant differences ($p < 0.05$) indicated variability in respondents' opinions regarding ergonomic practices in the maritime industry (Hatcher, 2013).

The analysis also included:

- Correlation Analysis: Pearson's correlation coefficient (r) and coefficient of determination (r^2) were used to evaluate relationships between variables, identifying areas for targeted interventions.
- Factor Analysis: employing Varimax rotation, this method identified latent factors influencing respondents' perceptions of ergonomics in maritime work.

3.1. Structure of Respondent Samples

The sample comprised 45 active seafarers, stratified into three groups based on navigational experience:

- Group 1: less than 5 years of experience ($n=10$).
- Group 2: 5–10 years of experience ($n=15$).
- Group 3: more than 10 years of experience ($n=20$).

The predominance of respondents with extensive experience (Group 3) ensured the integrity of the data, as their long-term exposure to maritime environments provided deeper insights into ergonomic challenges. This demographic structure also revealed variations in perceptions based on work experience, highlighting the influence of tenure on ergonomic awareness and health outcomes.

3.2. Descriptive Statistical Analysis

3.2.1. Mean

The mean values reflected respondents' overall perceptions of ergonomic knowledge, satisfaction with ergonomic practices, and the impact of ergonomics on health and efficiency. Figure 2 illustrates that respondents generally held positive views, with higher means indicating favorable opinions. However, lower means for health-related variables suggested concerns about the adverse effects of poor ergonomics.

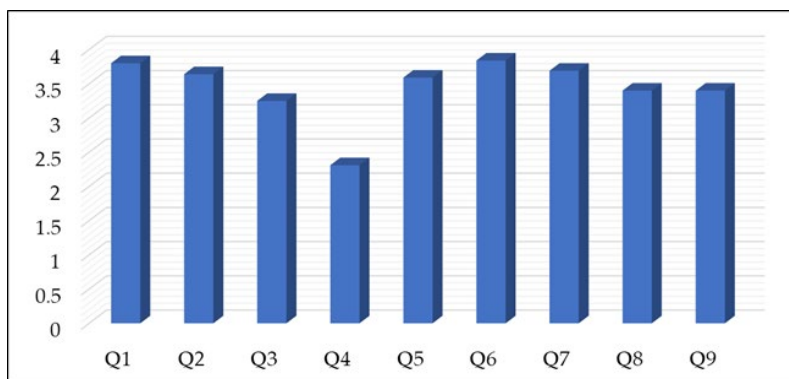


Figure 2. The mean values of all responses

3.2.2. Median

The median provides insight into the central tendency of respondents' opinions and perceptions about ergonomics in maritime work. Unlike the mean, the median is not influenced by extreme values, making it a more reliable measure.

Figure 3 presents the median values for each variable. Variables are rated on a Likert scale from 1 to 5, with a median of 4 being the most prevalent. This indicates a high degree of agreement among respondents with positive statements about ergonomic practices and the need for additional education. Notably, a median of 2 for health-related variables suggests areas requiring urgent intervention, reflecting lower agreement with statements about health issues caused by poor ergonomics.

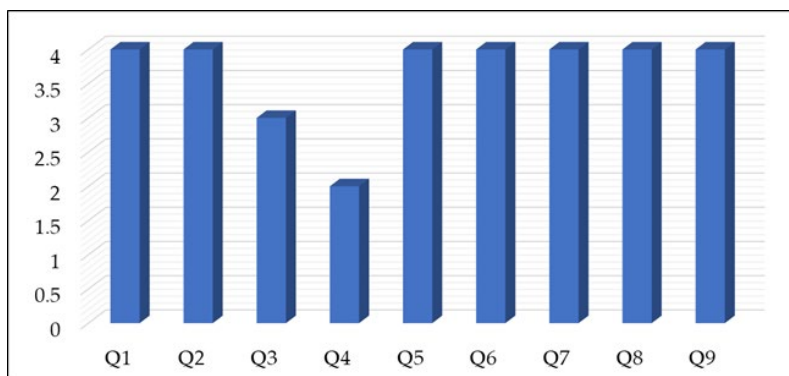


Figure 3. Median values for each survey question

3.2.3. Mode

The mode values, depicted in Figure 4, revealed the most frequent responses, reflecting the dominant opinions and perceptions of respondents. A mode of 4 for knowledge and training variables indicated widespread positive perceptions and attitudes when it comes to knowledge of ergonomics and additional training about ergonomics. A mode of 1 for health-related questions suggested a lack of awareness about the impact of poor ergonomics, which can be explained by insufficient awareness and knowledge of the impact of ergonomics on health.

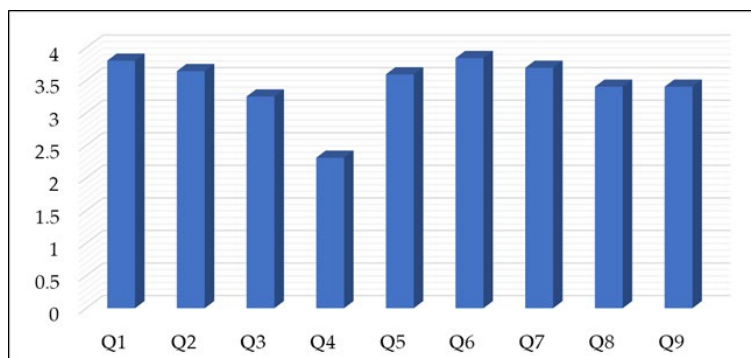


Figure 4. Mode values for each question

3.2.4. Response Frequencies

Figure 5 displays the frequency distribution of responses. While most respondents demonstrated a high level of ergonomic knowledge, the results underscored the need for improved training and awareness, particularly regarding health issues.

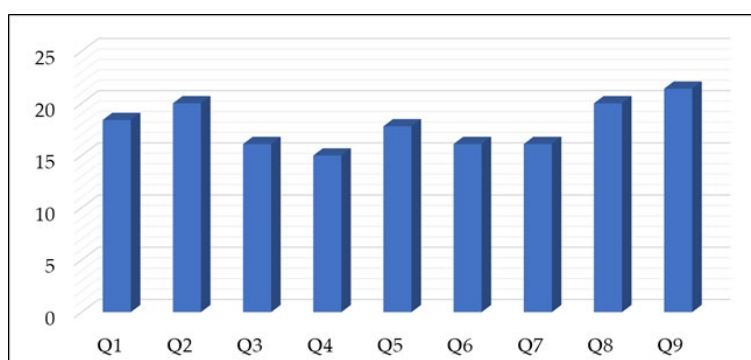


Figure 5. Frequency of respondents' responses to questions on ergonomic practices

3.2.5. Minimum and Maximum Values

The range of responses, illustrated in Figure 6, highlighted the diversity of opinions, perceptions, and attitudes. For example, health-related variables showed extreme values (min=1, max=5), reflecting varying experiences based on work tenure.

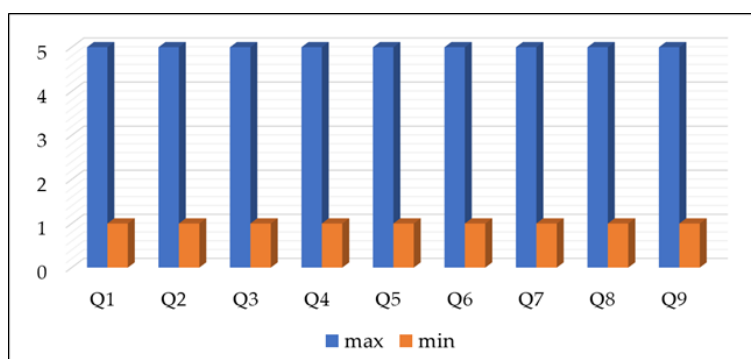


Figure 6. Minimum and maximum values for each question

Some respondents reported serious health issues, while others did not. These differences can be attributed to varying levels of work experience, with those having more than 10 years of experience likely experiencing more health-related challenges due to the physically demanding nature of their work.

3.2.6. Standard Deviation

The standard deviation measures the variability or dispersion of the data set, indicating how much the respondents' responses deviate from the mean for each variable [17]. Figure 7 graphically displays the standard deviation values for each variable, revealing differences in respondents' opinions, perceptions, and attitudes regarding the implementation of ergonomics on ships. Standard deviation values around 1 indicate moderate variability, reflecting minor differences in responses. Higher values, however, suggest greater variability, highlighting significant differences in respondents' opinions and attitudes toward ergonomic practices.

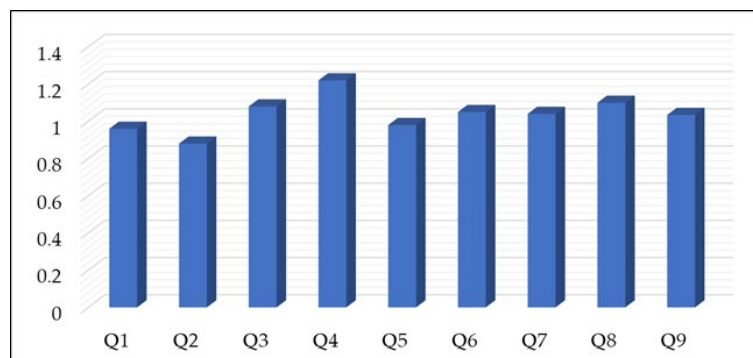


Figure 7. Standard deviation values for each question

3.2.7. Skewness and Kurtosis

Skewness and kurtosis parameters describe the distribution of respondents' responses for each variable. Skewness measures the asymmetry of the distribution, while kurtosis assesses the height and width of the distribution peaks relative to a normal distribution. Together, these parameters provide deeper insights into respondents' opinions, perceptions, and attitudes regarding ergonomic practices in maritime work. Figure 8 illustrates the skewness and kurtosis values for each question.

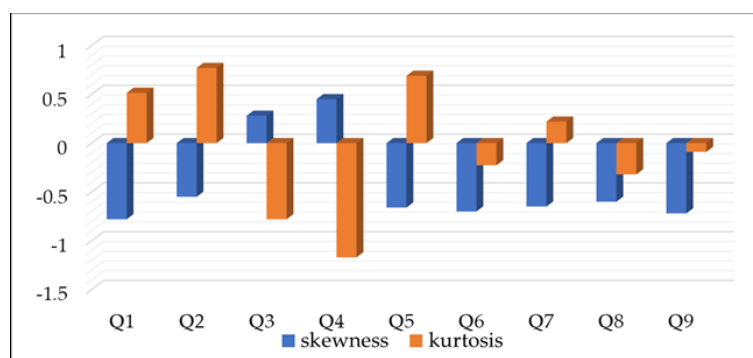


Figure 8. Skewness and kurtosis values for each question

In Figure 8, negative skewness values indicate that responses are concentrated on the right side of the distribution, reflecting positive opinions and attitudes toward ergonomic knowledge, implementation, and the need for additional training. Conversely, positive skewness values, where responses are concentrated on the

left side, reveal negative perceptions, particularly regarding health issues caused by poor ergonomics. Kurtosis values close to zero suggest a distribution close to normal, while deviations from zero indicate outliers or extreme responses. For example, variables related to health issues and employer concern about ergonomics show distributions farther from zero, reflecting negative perceptions among respondents.

3.3. Reliability and Correlation Analysis

3.3.1. Test-Retest Reliability

A dependent sample t-test was conducted to assess the reliability of respondents' answers by comparing initial and retest measurements. Statistically significant differences between the two measurements were observed, indicating variability in respondents' perceptions over time. Table 1 presents the numerical results which are critical for evaluating the consistency of respondents' opinions and attitudes regarding ergonomic practices in maritime work.

Variables	Mean	Std.Dv.	N	Diff.	Std.Dv.	t	df	p	-95% Ci	+95% Ci
Q1	4,5	0,71								
Q1	4,6	0,70	10	-0,10	0,32	-1,00	9	0,34	-0,33	0,13
Q2	4,1	0,88								
Q2	4,1	0,74	10	0,01	0,47	0,01	9	1,00	-0,34	0,34
Q3	3,5	1,51								
Q3	3,6	1,43	10	-0,10	0,32	-1,00	9	0,34	-0,33	0,13
Q4	1,7	0,95								
Q4	2,1	0,99	10	-0,40	0,70	-1,81	9	0,10	-0,90	0,10
Q5	4,1	0,88								
Q5	4,1	1,10	10	0,01	0,47	0,01	9	1,00	-0,34	0,34
Q6	3,5	1,08								
Q6	3,6	1,51	10	-0,10	1,10	-0,29	9	0,78	-0,89	0,69
Q7	3,9	1,29								
Q7	3,5	1,08	10	0,40	1,17	1,08	9	0,31	-0,44	1,24
Q8	3,3	1,16								
Q8	3,2	1,14	10	0,10	0,88	0,36	9	0,73	-0,53	0,73
Q9	3,6	1,17								
Q9	3,6	1,26	10	0,00	0,82	0,00	9	1,00	-0,58	0,58

Table 1. Results of the t-test for dependent samples: analysis of differences between initial and repeated measurements

The dependent t-test revealed statistically significant differences between test and retest, confirming the stability of respondents' perceptions over time. High correlation coefficients (e.g., $r=0.98$ for Q3) further validated the reliability of the questionnaire.

3.3.2. Correlation Analysis

Table 2 displays the numerical results of the reliability and correlation analysis. The mean values and standard deviations remained consistent across initial and retest measurements, indicating stable responses. High correlation coefficients (e.g., $r=0.98$ for Q3 and $r=0.91$ for Q5) confirm strong positive relationships between variables, demonstrating the reliability of respondents' answers.

Variables	Mean	Std.Dv.	r(X,Y)	r ²	t	p
Q1	4,50	0,71				
Q1	4,60	0,70	0,90	0,81	5,80	<0,01
Q2	4,10	0,88				
Q2	4,10	0,74	0,84	0,71	4,43	< 0,01
Q3	3,50	1,51				
Q3	3,60	1,43	0,98	0,96	13,35	< 0,01
Q4	1,70	0,95				
Q4	2,10	0,99	0,74	0,55	3,13	0,01
Q5	4,10	0,88				
Q5	4,10	1,10	0,91	0,83	6,25	< 0,01
Q6	3,50	1,08				
Q6	3,60	1,51	0,68	0,47	2,65	0,03
Q7	3,90	1,29				
Q7	3,50	1,08	0,52	0,27	1,72	0,12
Q8	3,30	1,16				
Q8	3,20	1,14	0,71	0,50	2,84	0,02
Q9	3,60	1,17				
Q9	3,60	1,26	0,78	0,61	3,51	0,01

Table 2. Correlation Analysis results: reliability assessment and statistical significance

Statistically significant differences ($p < 0.05$) were observed for almost all variables, further validating the consistency of responses over time. Results indicate that consistency and stability of responses in opinions, attitudes, and perceptions about the implementation of ergonomics on ships have been statistically proven.

3.3.3. Factor Analysis

Table 3 presents the results of the factor analysis using Varimax rotation, which identified two main factors explaining variability within the data set:

- Factor 1 - Knowledge and Application of Ergonomic Principles: this factor, explaining 33% of the total variance, includes variables such as familiarity with ergonomic principles (loading=0.83), application of ergonomic practices (loading=0.80), and employer attention to ergonomics (loading=0.78). These variables highlight the importance of ergonomic knowledge and its practical implementation in maritime work.
- Factor 2 - Health Issues and Efficiency: this factor, explaining 24% of the total variance, includes variables such as health problems caused by poor ergonomics (loading=0.71), the need for additional training (loading=0.72), and the impact of ergonomics on work efficiency (loading=0.65). These variables underscore the link between ergonomic practices and crew health and productivity.

Variables	Factor	Factor
Q1	0,83	0,13
Q2	0,80	0,09
Q3	0,78	-0,12
Q4	-0,05	0,71
Q5	0,79	0,16
Q6	0,21	0,72
Q7	0,40	0,65
Q8	-0,08	0,76
Q9	0,39	-0,25
Expl.Var	2,94	2,17
Prp.Totl	33%	24%

Table 3: Factor analysis results

Together, these factors account for 57% of the total variance, providing valuable insights into the key dimensions influencing ergonomic practices in maritime environments.

4. CONCLUSION

The application of ergonomics in the workplace is essential, particularly in physically demanding roles such as seafaring, where ergonomic principles can significantly enhance employee satisfaction, health, and productivity. This study developed and validated a survey questionnaire to assess the impact of ergonomics on seafarers' satisfaction and health, as well as employer approaches to ergonomic practices. The questionnaire was tested on a group of active seafarers, and the results were subjected to comprehensive statistical analysis, including dependent sample t-tests, correlation analysis, and factor analysis.

The t-test revealed statistically significant differences between initial and retest measurements, indicating variability in respondents' perceptions over time. Correlation analysis demonstrated strong positive relationships between variables, confirming the reliability of the questionnaire. Factor analysis identified two key dimensions - knowledge and application of ergonomic principles, and health issues and efficiency—which together explained 57% of the total variance. These findings highlight the importance of ergonomic knowledge and its practical implementation, as well as the need to address health-related challenges in maritime work environments.

Further research is needed to explore how sustained ergonomic interventions can enhance health and productivity across different working conditions and cultural contexts within the maritime industry. In conclusion, the developed questionnaire is a reliable and valid tool for assessing ergonomic satisfaction among seafarers. The results provide a foundation for targeted interventions to improve ergonomic practices, enhance crew well-being, and increase productivity in the maritime industry.

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APPENDIX 1. Questionnaire Used in the Study

How many years of experience do you have sailing on merchant navy vessels? Please circle one of the following options:

- Less than 5 years
- 5-10 years
- More than 10 years

The classification of responses in the questions is as follows:

- Response 1 – Strongly disagree,
- Response 2 – Disagree,
- Response 3 – Neither agree nor disagree,
- Response 4 – Agree,
- Response 5 – Strongly agree.

Please circle the appropriate response.

The results of the survey will be completely anonymous and will be used for scientific purposes.

Questions:

Q1. I am familiar with ergonomic principles and practices related to shipboard work.

1 2 3 4 5

Q2. I often apply ergonomic principles while performing my work tasks.

1 2 3 4 5

Q3. The employer pays sufficient attention to ergonomics in the workplace and has provided me with appropriate information on ergonomics during training or work on board.

1 2 3 4 5

Q4. I have had health problems resulting from poor ergonomics in the workplace.

1 2 3 4 5

Q5. I am familiar with the proper ergonomic setup of the work environment, including seating, tables, and other work surfaces.

1 2 3 4 5

Q6. I believe that additional training on ergonomics would be useful for improving my work efficiency and safety.

1 2 3 4 5

Q7. Poor ergonomics affects my work efficiency.

1 2 3 4 5

Q8. I often feel tired or exhausted after performing my work tasks.

1 2 3 4 5

Q9. My experience with ergonomics is satisfactory.

1 2 3 4 5

Q10. What are your recommendations for improving ergonomic practices in the maritime industry?
(Open-ended question – please write your suggestion freely)

The Influence of Piracy on the Security of Ships – an Overview of Current State

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Piracy poses a considerable threat to the international maritime fleet and subsequently global trade. It is therefore of global significance to raise awareness of the importance of thorough analysis to tackle the problem effectively. With the increase in piracy, the protection of crew members and maritime assets has become a major concern. Piracy endangers human lives and disrupts global trade, shipping safety, and economic stability. This research aims to present the risks of piracy attacks by giving an overview of the recent piracy attacks at sea especially in high-risk areas. By overviewing the patterns of pirate attacks and presenting the latest state of play this paper can be a useful tool to any stakeholder further developing the methodologies and security models tailored to different areas of attacks. Additionally, this paper provides valuable insights to help shipping companies and security authorities potentially tailor their piracy mitigation strategies. Understanding the motives and methods of pirates is critical to refining further security protocols and optimizing the security of the ship. This paper underscores the need for a robust approach to maritime security, particularly for countering pirate attacks by giving an overview of the piracy attacks' frequency and locations worldwide in the last 15 years with an emphasis on the latest data available. Targeted ships are categorized by type, maritime areas of the attacks are categorized by geographical regions and pirate activities are categorized by the nature of the attack.

KEYWORDS

Piracy attacks; High-risk areas; Security of ships; Safety of navigation; SOLAS; IMO

1. INTRODUCTION

Piracy is considered to present a serious threat to international maritime merchant fleet and subsequently global trade. Therefore, a rise in the need for thorough analysis is paramount to address the problem effectively. With the increase in piracy activities, the protection of both crew and maritime assets is being seriously considered. In addition to endangering crewmembers' lives, piracy attacks also disrupt global trade, safety of navigation, and economic stability.

A key step in the fight against piracy is to understand the patterns of pirate attacks and identify the types of ships that are most often targeted. This research aims to give an overview of the current state of piracy attacks worldwide. This overview can be a useful tool for creating further analyses and methodologies that aim to create a reliable security system improving existing security measures, and developing new approaches.

This analysis provides valuable insight that could enable shipping companies and security agencies to develop sophisticated and targeted protection strategies in the future. These protocols could not only increase the safety of crew and cargo but also significantly reduce the economic impact of piracy activities. In this paper, which is an overview of the recent years of piracy attacks, multiple elements of the piracy attack analysis are categorized. Firstly, the number of successful pirate attacks is given and categorized by the type of ship. Secondly, pirate attacks are categorized by the geographical area of the location where the attack occurred. Lastly, pirate activities are categorized by the nature of the attack itself.

2. ANALYSIS OF PIRATE INCIDENTS

One of the key aspects in the fight against piracy is understanding what types of ships are most often targeted by the pirates. The data given below shows the number of pirates embarked by different ship types and provides insight into pirate attack patterns. This overview makes it possible to identify the types of ships that are most often targeted, which can help in better allocation of resources and application of security measures. Piracy incidents are classified according to various attributes, including location, date, details of the incident, and its consequences. This data structure facilitates the statistical analysis of piracy and enables the identification of characteristics and trends in different regions (Rukavina, 2015). This data can provide information on understanding the thinking patterns of pirates and their methods.

With such an approach, maritime companies and security agencies can develop tailored protection strategies for the most vulnerable types of ships, thereby increasing the safety of crew and cargo and reducing the economic impact of piracy attacks.

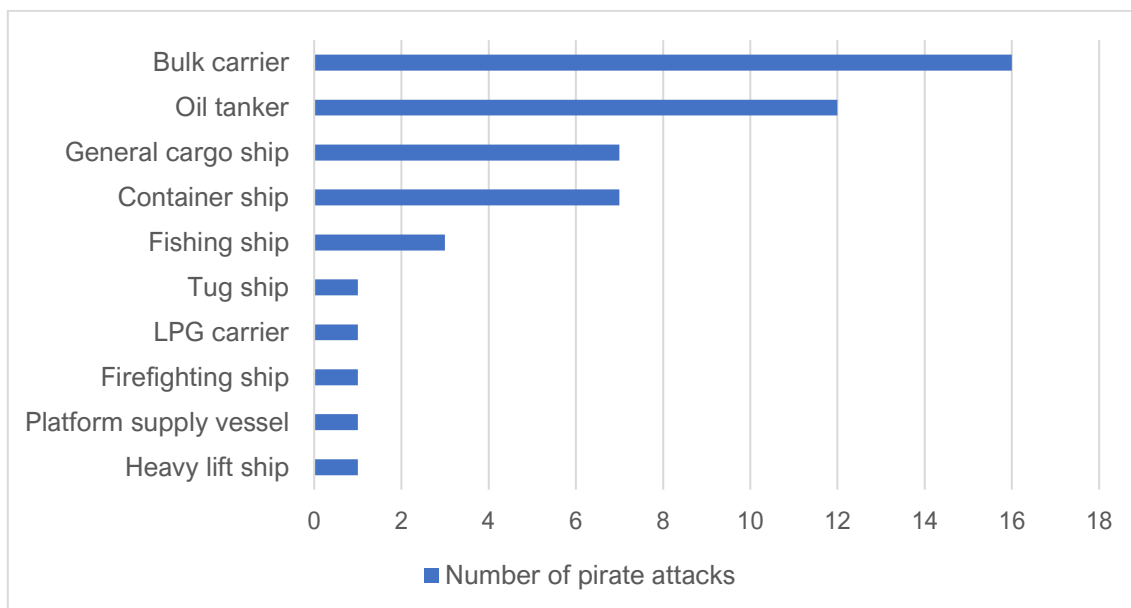


Figure 1. Analysis of successful pirate attacks in the first half of 2024

Figure 1 shows the number of successful pirate attacks on different types of ships in the first half of 2024. It can be interpreted that bulk cargo ships (bulk carriers) are most often the target of attacks, followed by oil tankers. The records show a total of 52 attacks on different types of ships. It can be seen that bulk carriers and oil tankers are the most frequent types of pirate attack targets, with 16 and 12 successful attacks respectively. Two basic factors affect the risk for the ship itself: the type of ship and its condition. The influence of the type of ship on the risk of pirate attacks is primarily manifested in the type of cargo transported and the height of the freeboard (Kothari, 2008). These ships, as well as general cargo ships and container ships, are often attacked when anchored. Pirates are attracted to this type of ship because of their valuable cargo and the availability of spare parts of the ship's machinery, which are the most common prey.

These parts are useful and can easily be resold on the black market for quick profit. In addition to parts, pirates also often steal other ship's equipment such as electronic devices and personal belongings of the crew. Bulk carriers and oil tankers are particularly vulnerable due to their large size and poor maneuverability, making them easy targets. Also, they often transport large quantities of valuable goods, such as oil, which can bring significant financial gain to pirates. This combination of enormous cargo values and ships' vulnerability while at anchor makes them ideal targets for pirate attacks. General cargo ships and container ships often carry various and expensive cargoes, making them one of the main targets of pirates. Fishing boats recorded a modest three attacks. Tugs, LPG tankers, fire-fighting vessels, platform supply vessels (PSVs), and heavy-lift vessels had one attack each. From these data, it can be concluded that larger ships carrying valuable cargo are the most frequent targets of pirate attacks according to the International Maritime Organization (IMO) (IMO, 2024). Pirates are willing to use firearms to subdue crew and kill individuals without second thought, especially when crew members show any intention of resisting (Gospić, 2019). As such, they require improved protection measures from the crew, such as greater vigilance and surveillance, especially during anchorage or near the port (IMO, 2024).

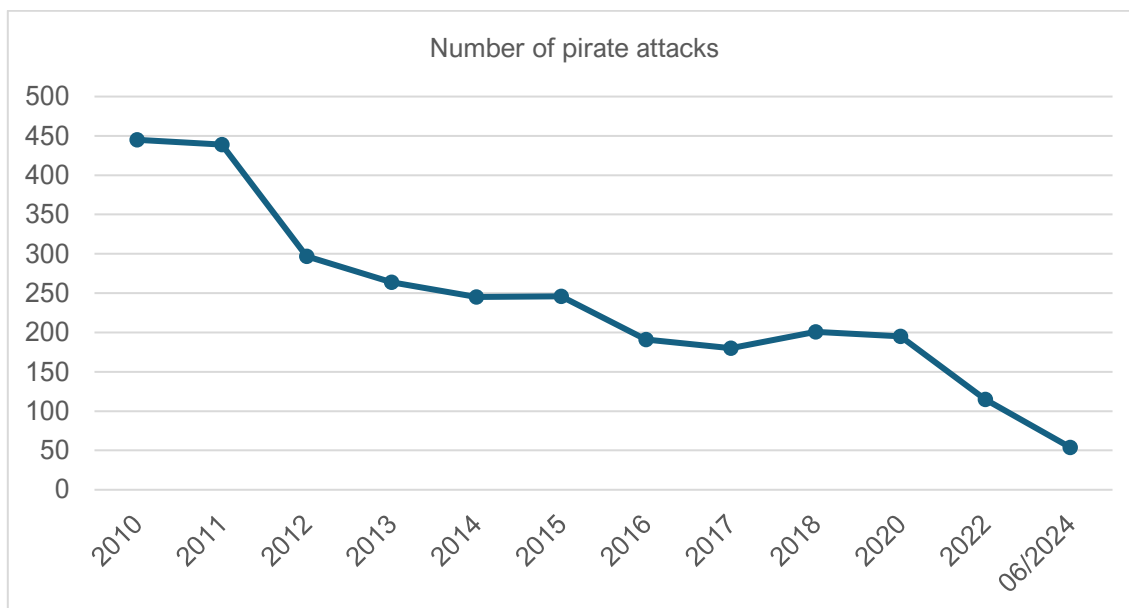


Figure 2. Analysis of pirate attacks in the period from 2010 to the first half of 2024

Figure 2 shows the number of pirate attacks in the period from 2010 to the first half of 2024. This figure provides insight into the trends and changes in the number of attacks during the mentioned years, which is useful for analysis and making strategic decisions in the context of security or preventive measures. It shows how the number of pirate attacks on the seas changed from 2010 to the first half of 2024. At the beginning of this period, in 2010 and 2011, there were a lot of piracy attacks, which peaked in 2010 with approximately 450 attacks. After that, the number of attacks began to decrease, and quite quickly. As of 2012, the number of attacks was less than 250, and this relatively low level remained for the next two years. From 2015 to 2017, the downward trend in the number of attacks continued, falling below 200 per year. Although there were minor changes, the number of attacks generally decreased. However, from 2018 to 2020, there was a slight increase in attacks, returning to around 200 per year, but the increase was not significant. The most impressive part of the graph occurs from 2021 to the first half of 2024 when the number of attacks drops to less than 150 per year. This is a significant decrease which suggests that anti-piracy efforts have yielded positive results (Mair, 2011).

Piracy at sea reached a record level in the first three months of 2011 with 142 attacks worldwide, according to the International Chamber of Commerce (ICC) and International Maritime Bureau's (IMB) global piracy report. The increase in piracy off the coast of Somalia in the first quarter of 2011 has caused great concern with 97 reported attacks compared to 35 in the same period the previous year. According to the IMB report, in 2011, 18 vessels were hijacked, 344 crew members were held hostage, and six of them were kidnapped. Of the 18 hijacked vessels worldwide, 15 were hijacked off the east coast of Somalia and around the Arabian Sea, while one was hijacked in the Gulf of Aden. Also, 45 vessels were the target of hijacking attempts, and the same number of vessels were shot at. Mukundan, director of the IMB, whose piracy reporting center has monitored piracy worldwide since 1991, points out that the figures for piracy and armed robbery at sea in the first quarter of 2011 reached their peak compared to previous years (Fredriksson, 2012). During the same quarter, pirates killed 7 crew members and injured 34 crew members, a significant increase over previous periods. Ships transporting oil and other flammable chemicals are an easy target for pirates and are very often under fire. Three ships for the transport of dangerous cargo with a carrying capacity of over 100,000 tons were hijacked off the Horn of Africa in 2011. Out of a total of 97 attacked vessels in the region, 37 were tankers, 20 of which had a tonnage greater than 100,000 tons (Progressive Policy Institute, 2024).

During the period from 2000 to 2014, the IMB documented between 300 and 500 piracy attacks annually. However, a significant turnaround was recorded in 2022, when only 115 attacks were recorded, which is the lowest number recorded in the IMB records. This significant decrease, by almost 75% compared to the 439 attacks recorded in 2012, is mainly attributed to the almost complete elimination of attacks along the coast of the Horn of Africa. The positive trend is the result of the activities of the International Maritime Committee (IMC), which successfully suppressed the Somali pirate fleet in the period from 2012 to 2015. The decline in the number of attacks in Southeast Asia and West Africa is also noticeable compared to Somalia. Of great importance is the presence of private security companies that provide various ship protection services, including armed escort, which further contributed to the reduction of the number of piracy attacks (Fredriksson, 2012). In addition to anti-piracy training and practice, crew members also need an STCW VI/6-2 ("Proficiency in designated security duties") seaman's certificate, which should be held by officers of the deck, to ensure their qualification and ability to perform the security protection of seafarers on board. This certificate confirms that the officers have received the appropriate training and have met all the necessary requirements for the safe and efficient management of the ship. Well-trained and certified officers are key to maintaining security and protecting vessels from piracy attacks and other potential threats.

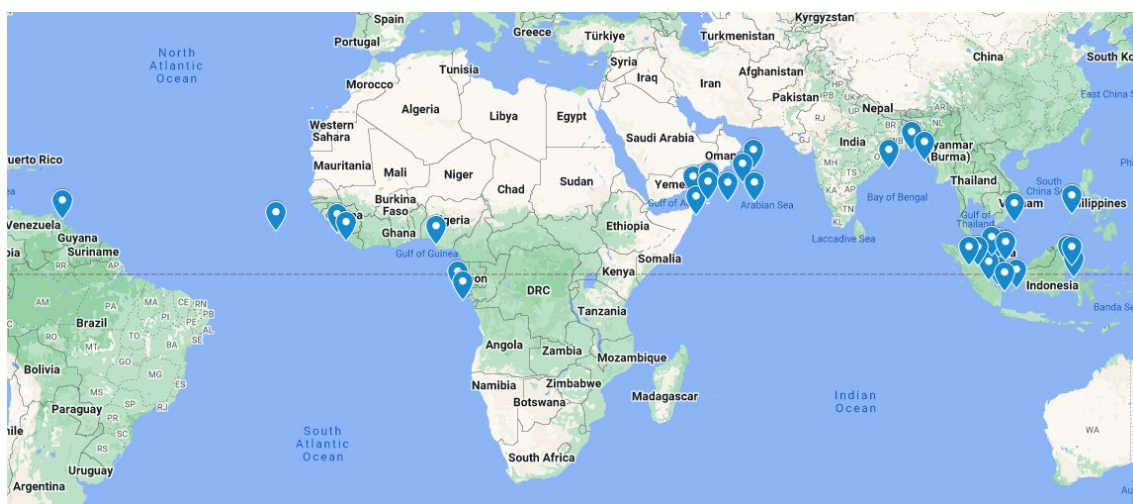


Figure 3. Locations of piracy incidents in the first half of 2024 (made by authors)

Figure 3 shows a world map of recorded piracy attacks in the first half of 2024, made by authors based on data from the official site that monitors live reports and pirate situations using a custom map. Attached are a table and a figure that results from the mentioned map.

AREA OF ATTACK	NUMBER OF ATTACKS
Malay and Singapore straits	18
Bay of Bengal	11
Gulf of Aden and Arabian Sea	9
West Africa	8
South China Sea	3
Makassar passage	2
South America	1

Table 1. Analysis of piracy incidents by location in the first half of 2024

Table 1 shows the distribution of piracy attacks by different geographical areas during 2024 with the Malay and Singapore Straits as the most threatened area. Figure 4, which represents a simplified world map and geographical visualization of the data in Table 1, shows the number and location of pirate attacks.



Figure 4. Analysis of piracy incidents by location in the first half of 2024

From Figure 4 it can be concluded that the most threatened areas are the Malay and Singapore Straits, where as many as 18 piracy incidents were recorded in the first half of 2024. This high number of attacks indicates that these two narrow and strategically important sea straits are under constant threat from pirates, which requires increased international cooperation and coordination in the fight against piracy. The Bay of Bengal with 11 incidents and the Gulf of Aden together with the Arabian Sea with 9 incidents are also high-risk zones. These regions are crucial for world trade, especially due to their proximity to important trade routes and economic centers. Therefore, it is necessary to continuously invest in security measures as well as the presence of international maritime forces in order to ensure free and safe navigation (IMO, 2024). Due to inconsistent international agreements and unclear boundaries of territorial waters, there is a reduction in control over certain areas. An example of such a situation is the South China Sea, where conflicts and disagreements occur between different states. As a consequence, more developed countries are investing in the modernization of their navies to improve defense capabilities and protect their national interests (Insurance Journal, 2024).

The Malay Strait, located between Malaysia, Singapore, and Indonesia, represents one of the world's most important international maritime routes. Each year, around 65,000 ships pass through these straits, carrying approximately one-third of global trade and half of the world's energy supplies. As well as being vital to the countries they pass through, these straits are crucial to the region's economic power. Almost 80% of Japanese and 60% of Chinese imports depend on this waterway. At the same time, the waters of Southeast Asia, especially around the Malay Strait, are traditionally known for piracy. The IMB noted that most of the incidents were committed by fishing boat crews who later disappeared among other fishing boats. They are protected by corrupt local law enforcement officials. Of course, there are also cases of systematic organized piracy by well-informed syndicates intending to take temporary or long-term control of targeted vessels. This already requires greater coordination, and financial outlay for speedboats, boats, weapons, training, and cargo information. Pirates are mostly young individuals with little formal education for whom piracy is a lucrative business with minimal risk of capture, and this is confirmed by a thesis from an Indonesian analysis showing that poor fishermen earn an average of three euros a day for legal work, while each participant in a successful attack receives award in the amount of €7,000 to €10,000. The first reason for the emergence of piracy in Indonesia is

the significant decline in income that the country suffered during the Asian financial crisis in the late 1990s. Another reason lies in the poor security situation, which is very difficult to control, and the fact that issues of state sovereignty have not always been clear. Malaysia and Singapore have somewhat maintained their authority over their territories, while Indonesia has been very unstable in this regard. For many years, piracy was neglected in this area, while other security threats, such as human trafficking, and smuggling of arms and different goods, were prioritized for countermeasures. However, at the beginning of the 2000s, this point of view began to change under the international influence of countries that use maritime routes in the region (Statista, 2024).

The development of piracy is closely related to the situation within countries. With the weakening of state institutions comes an increase in corruption, which also creates the possibility of piracy. Most often, it concerns countries with a weaker economic status, where neocolonialism, globalization, poverty, and misery prevail. In such regions, no legal issues related to the political, religious, and social aspects have been resolved, inter-tribal wars are frequent and governments are on the verge of bankruptcy (Nguyen and Le, 2019).

In these areas, the organization of state authorities is lacking, the population is uneducated, and poverty is deeply rooted. Blinded by the view of possible income, they are unable to see the damage they are doing so they interpret piracy as the most profitable and easiest way to generate income in such circumstances (Chen et al., 2024).

IMB is a non-profit organization founded in 1981, and its responsibilities are the fight against crimes related to maritime trade and transport, especially piracy and commercial fraud, and the protection of crew members of ocean-going vessels. Dissatisfied with the state of piracy in the world, the IMB encouraged the creation of the Piracy Report Center (PRC) in 1992 in Kuala Lumpur. The advantage of the PRC is that it warns seafarers 24 hours a day about the state of piracy at sea. It issues continuous updates of reported incidents by ships navigating high-risk areas which are used to further analyze trends.

IMB PRC reports various piracy incidents by category:

- a) boarding - an illegal act where the perpetrator successfully boards the ship,
- b) hijacking - an illegal act where the perpetrator successfully gains access to the ship and takes control of it and its crew members,
- c) fired upon - an illegal act where the perpetrator uses a firearm aimed at the ship, thereby trying to gain control over it,
- d) attempted attack - an illegal act where the perpetrator tries to approach the ship with the possible intention of boarding, but fails due to the timely reaction of the crew (Commercial Crime Services, 2024).

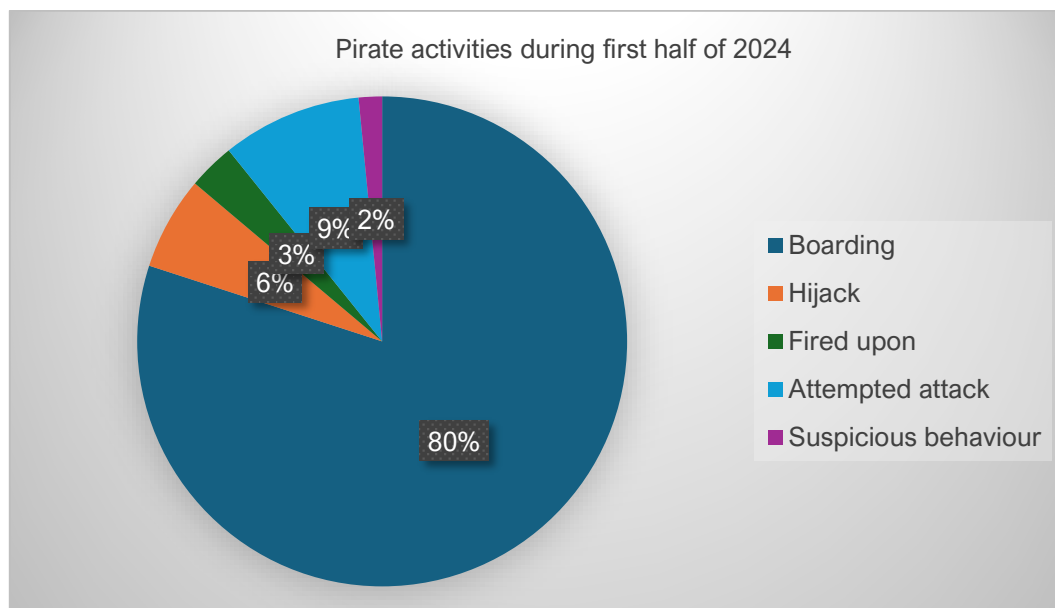


Figure 5. Pirate activities on ships in the first half of 2024

Figure 5 shows the pirate activities during the first half of 2024, in which pirates managed to board 80% of ships, and only 2% were ships where there was a suspicion of a pirate attack. Additionally, it shows the various pirate activities focused on the ships that the pirates have chosen as targets. According to PRC data, pirates boarded the ship 80% of the time which equals 52 times, attempted an attack six times, hijacked the ship four times, and behaved suspiciously once.

An example of a ship hijacking report according to the PRC looks like the following: "Between 06:00 and 07:00 in the morning, seven pirates in a boat, armed with AK-47 firearms, boarded a fishing ship which was underway and then hijacked it. After stealing food and other supplies, they freed 21 crew members and disembarked the vessel. A warship of the Indian Navy came to meet the vessel and escorted her to a safe distance" (IMO, 2024).

Security risks to the industry include various threats such as crew intimidation, ship hijacking, and attacks on ships and ports, resulting in supply chain disruptions and economic losses. The ransom for the release of hijacked merchant ships and their crews often ranges between 350,000 and 500,000 USD, while some experts estimate that the value of lost cargo per hijacked ship can reach between 8 million and 200 million USD (Chen et al., 2024).

The recent increase in pirate attacks and successful hijackings of ships and crews has led to changes in the approach of insurance companies. Insurers introduced changes to existing coverage and improved insurance offerings, such as Kidnap and Ransom (K&R) Insurance. This type of insurance is very important for ship owners since it covers specific costs related to piracy attacks that are not covered by classic comprehensive insurance (He et al., 2023).

3. CONCLUSION

The conclusion of this analysis points to the challenges of combating maritime piracy. It underlines the importance of understanding the targets of pirates and adapting the various security strategies. The data from 2024 shows that bulk carriers and oil tankers are the most frequently attacked, mainly due to the value of the cargo and their vulnerability when anchored. These findings highlight the need for enhanced security measures

and better-organized resources, especially for larger vessels. A long-term analysis for the period from 2010 to 2024 shows a significant decrease in the number of piracy attacks, which is due to successful international efforts to combat piracy, particularly in critical regions such as the Horn of Africa.

However, despite this positive trend, certain geographical areas, such as the Malay and Singapore Straits, remain hotspots of piracy, requiring additional international cooperation and coordination. The diversity of pirate tactics, from boarding to hijacking, requires constant adaptation and innovation of security protocols. It is important to emphasize that these findings are a reminder that maritime security remains a dynamic and complex challenge, where only constant vigilance and adaptation can ensure the protection of ships, crews, and valuable cargo.

Although the number of pirate attacks has declined since 2011, indicating the success of worldwide anti-piracy strategies, including the presence of international naval forces and the engagement of private security companies, challenges remain. Additional investment in crew training and the development of security procedures is required, as crew members with adequate knowledge and skills are critical to the effective protection of vessels.

In addition to physical protection measures, the increase in pirate attacks has led to a change in the approach of insurance companies. The development of special insurance policies covering, for example, hijacking and ransom payments has become important for ship owners. These policies reduce the economic burden on shipowners and enable faster recovery after an incident, ensuring business continuity.

Considering the complex causes and consequences of piracy, among which poverty, lack of education, and corruption in the affected countries stand out, this problem could be tackled "holistically". This includes not only security measures but also investing in the development of local communities and improving the economic situation, which can reduce the attractiveness of piracy as a "quick" way to make money.

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Challenges and Strategies for the Improvement of the Well-being of Seafarers: A Systematic Literature Review

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Careers in maritime industry have numerous challenges that significantly impact the mental and physical health of seafarers e.g. prolonged isolation, stressful working conditions, physical exhaustion, and limited access to healthcare. These factors often directly affect seafarers' well-being, safety, and the overall efficiency of maritime operations. The well-being of seafarers encompasses physical, mental, emotional, and social health and represents a crucial factor in safety maintenance at sea. Leading international maritime and health organizations developed guidelines to improve the working conditions of seafarers in terms of better management of working hours, rest periods, communication with family, and access to healthcare. This study employs a systematic literature review to analyze key stressors in the maritime industry, explore secondary quantitative and qualitative research findings on seafarers' mental health, and examine existing initiatives aimed at enhancing well-being. Furthermore, the study proposes specific stress management strategies to mitigate negative effects and improve the quality of seafarers' life. The implementation of the strategies is essential as it would preserve the health of seafarers, safety on board, and enhance operational efficiency, which ultimately contributes to a long-term sustainability of the maritime profession.

KEYWORDS

Well-being; Seafarer; Health; Strategy

1. INTRODUCTION

Well-being is a positive state experienced by individuals and societies and, like health, represents a resource for everyday life which is determined by social, economic, and environmental conditions. Well-being encompasses the quality of life and the ability of individuals and societies to contribute to the world with a sense of meaning and purpose (World Health Organization, 2020).

Stress can be defined as a state of worry or mental tension caused by a difficult situation. It is a natural human response that motivates people to address challenges and threats in their lives (World Health Organization, 2020).

Stress involves changes that affect nearly every system in the body and influence the ways people feel and behave. By causing alterations in both the mind and body, stress directly contributes to psychological and physiological disorders and illnesses, thus impacting mental and physical health and reducing the quality of life (American Psychological Association, 2024).

Seafarers' well-being encompasses all aspects of health and welfare, including physical, mental, emotional, and social health. Seafarers face unique challenges due to the specific nature of their work, such as extended periods at sea, isolation, stressful working conditions, and limited social interactions. Maritime well-being is not only essential for the mental and physical health of the seafarers but is also crucial for the safe and efficient operation of ships. The mental and emotional well-being of the seafarers can directly impact their work performance, decision-making ability, and overall ship safety (Senbursa & Tavacioglu, 2023).

The stigma to mental illnesses in the maritime industry makes it more difficult for seafarers to access psychological support. The improvement of the quality of life and stress reduction among the seafarers requires proper understanding of the challenges that affect the well-being at sea and the development of strategies to overcome such challenges. Although numerous studies have explored stress in the maritime industry, many areas still require attention and strategies to reduce stressors and enhance seafarers' well-being.

This paper focuses on a systematic literature review. The aim of the paper is to evaluate the current progress regarding the identification of the main challenges to the seafarers' well-being and to determine the strategies for improvement. The goal of the study is to bridge the theoretical gap that clearly exists in this emerging field in order to enhance future research and practices for human resource management in the maritime industry.

2. THE MAIN CHALLENGES TO SEAFARERS' WELL-BEING

The seafarers face numerous challenges that are specific to their profession and represent the factors that contribute to high levels of stress. Key stressors for the seafarers (Brooks & Greenberg, 2022) include: long working hours and highly demanding jobs, poor sleep and extensive fatigue, bad working conditions, and isolation and separation from families. Additionally, other stressors include poor team cohesion and interpersonal relationships, poor management perception, limited access to healthcare, uncertainty regarding working conditions and safety, financial worries, and excessive job commitment. According to Peković (2020), physical stressors include long working hours, strenuous physical tasks, extreme weather conditions, and sleep problems, while psychological stressors include prolonged isolation, loneliness, monotonous work, lack of privacy, unpredictability, and danger at sea. There are also social stressors such as separation from family and friends and issues about interpersonal relationships on board. Organizational stressors include unclear or overly demanding expectations and complicated legislative and safety regulations. Peković (2020) highlights that stressors can be acute, which last up to 6 months, or chronic, lasting longer than 6 months.

The life and work of the seafarers often involve long, night or irregular, shifts which lead to stress and physical exhaustion. Irregular working schedules, rotating watch systems, and noise on board reduce sleep quality and increase fatigue. Exposure to noise, vibrations, extreme temperatures, and unstable weather conditions negatively impact mental health. Furthermore, prolonged absence from home contributes to the feelings of loneliness and homesickness that increase the risk of depression. The lack of support from superiors and job insecurity also worsen the mental well-being of seafarers on board. The lack of medical services on board complicates timely identification and treatment of mental health issues, while changes in schedules, job insecurity, and the risk of accidents or piracy increase stress levels. Economic pressures and the uncertainty of contracts add another layer of anxiety.

A study from 2021 conducted in Portugal revealed that 30% of the seafarers show signs of depression, while 26% have serious anxiety issues (Svetina et al., 2024). The seafarers in Europe report stress reactions in 65% of cases when exposed to bad weather conditions and unsafe working environments (IMO, 2021). Data on depression show that between 25% and 35% of the seafarers exhibit signs of depression. 50% of the seafarers with depressive symptoms reported work-related injuries in the previous year, while only 15% of those without depression reported such injuries. High levels of stress are associated with job insecurity, long periods at sea, and highly demanding tasks. Additionally, over 60% of the seafarers reported chronic fatigue and lack of sleep, which increases the risk of depression and injuries.

In terms of safety and its impact on mental health, previous studies show that:

- 65% of the seafarers feel stressed due to safety concerns on board,
- 59.5% of the seafarers worry about piracy and attacks at sea, which intensifies the feeling of insecurity,
- During COVID-19 pandemic, nearly 50% of the seafarers reported increased insecurity, insomnia, and depressive symptoms (Brooks & Greenberg, 2022).

The physical consequences of stress primarily involve cardiovascular diseases, which are linked to the following issues (Sagaro et al., 2021):

- Hypertension – The percentage of reported hypertension cases among the seafarers was 20.8%, whereby older seafarers and those with longer experience at sea are at higher risk.
- Diabetes – The prevalence of diabetes was 8.5%, whereby the risk of diabetes significantly increases with age.
- Tobacco use – 32.5% of the respondents were currently using tobacco, whereby non-officers exhibit a higher smoking rate compared with officers.
- Excessive weight and obesity – 44.7% of the respondents were overweight or obese, which is a key risk factor in cardiovascular diseases.
- The seafarers working more than 71 hours per week are at a higher risk of at least two cardiovascular diseases.
- More than two-thirds of the seafarers suffered from at least one risk factor of cardiovascular diseases, whereby the combination of smoking and obesity were the most common among the respondents.
- The seafarers are more prone to physical injuries due to exhaustion and reduced concentration, which also increases the number of accidents on board.

3. SYSTEMATIC LITERATURE REVIEW

This review presents key studies on the well-being of the seafarers with a particular focus on mental health, physical aspects, and social challenges.

Author(s), Year	Title	Aim of the research	Methodology	Key finding	Recommended strategies
World Health Organization, 2011	Guide to ship sanitation, 3rd edition	The document aims to standardize sanitary measures on ships to protect the health of passengers, crew, and the broader community, and to prevent the international spread of infections.	The guide was developed through a gradual process of development and review: Expert meetings, Fundamental and existing standards, and a systematic review of disease outbreaks on ships.	Risks associated with ships and critical points.	Water Safety Plans and Food Safety Plans, Design and maintenance, Education and supervision, and Vector control.
Iversen, 2012	The Mental Health of Seafarers	A review of published information on the mental health of the seafarers.	Literature review on the mental health of the seafarers, with collected and published statistics covering the period from 1960 to 2009.	Increased suicide rates among the seafarers.	Delivering educational information to all ships worldwide about the importance of mental health for the well-being of the seafarers.
Penezić et al., 2013	Some Correlates of Life Satisfaction in Seamen	The insight into the factors that affect life satisfaction among the seafarers.	Survey research (N=176).	Personal traits and job satisfaction significantly affect overall life satisfaction.	The development of programs to improve the working environment and enhance mental health.
McVeigh et al., 2017	Positive Psychology and Well-Being at Sea	The application of positive psychology in the maritime sector with the aim of improving the psychological resilience and well-being of the seafarers.	A combination of cognitive-behavioral therapy, neuro-linguistic programming, and leadership research through a 12-module program.	The implementation of the program led to a significant increase in the psychological capital of the seafarers. Additionally, mindfulness meditation and positive reframing of experiences proved effective in improving attention, information processing speed, and verbal fluency.	Computer-supported training for the seafarers could be an effective and cost-efficient way to improve their psychological resilience and well-being. Techniques such as writing about life goals and using 'signature strengths' have shown a long-term positive impact on happiness and a reduction in depressive symptoms.
Kukobat, 2017	Quality Management in Shipping Companies	Research on the quality management system in shipping companies and its impact on the work of seafarers.	Literature review and the analysis of existing models.	An effective quality management system improves working conditions and safety for the seafarers.	Implementation of integrated quality management systems, health, safety, and environmental protection.
Slišković, Penezić, 2017	Lifestyle Factors in Croatian Seafarers as Relating to Health and	The study on the lifestyle habits of Croatian seafarers in relation to health and stress on board.	Survey research (N=530).	Unhealthy lifestyle and behavior are associated with increased stress.	The promotion of healthy habits and regular physical activity on board.

	Stress on Board				
Lefkowitz & Slade, 2019	Seafarer Mental Health Study	Research on the mental health of the seafarers.	Literature review (N=500).	The prevalence of depression and anxiety among seafarers.	Online psychological support and education on mental health.
Jones & Lee, 2019	The Impact of Work Hours on Seafarers' Well-being	The research on the effects of working hours on the physical and mental health of the seafarers.	Longitudinal study (3 years, N=300).	Seafarers with longer working hours experience higher stress and fatigue.	Reduced working hours and optimized shifts on board.
Mitrović, 2022	Free time that is not free	The analysis of the impact of continuous professional development on the mental health of the seafarers.	Qualitative analysis.	Ongoing professional development obligations during free time increase stress and reduce quality of life.	Revising training programs and ensuring adequate rest between contracts.
Miljković et al., 2023	Seafarers' health and what can be done to improve it.	A review of health risks faced by the seafarers and suggestions for improvement.	Literature review and expert recommendation	The seafarers are exposed to specific health risks such as UV radiation and stress.	Regular health check-ups, safety and health training, the improvement of working conditions on board.
Galić et al., 2023	Mixed-methodology Approach to Seafarers' Sleep on Board	The aim of the research was to expand knowledge about the seafarers' sleep on board, exploring the relationship between job satisfaction, mental health, hours of sleep on board, and somatic symptoms.	Mixed-methodology in two parts: Quantitative study (N = 286) analyzed the impact of sleep hours on job satisfaction, mental health, and somatic symptoms using a path analysis. Qualitative study (N = 205, of which 80 participants had sleep problems) was based on thematic analysis and explored, subjective sleep difficulties, consequences of poor sleep, and coping strategies.	A higher level of job satisfaction reduces somatic symptoms, which is partially caused by longer sleep on board. Better mental health directly reduces somatic symptoms.	Recommends the development of strategies to improve the working conditions of the seafarers e.g. reduced workload, improved sleep management, and the development of the mental health programs that improve the well-being and safety of the seafarers.

Table 1. A systematic review of literature on the seafarers' well-being (Source: Authors)

4. STRATEGIES FOR IMPROVING THE WELL-BEING OF SEAFARERS

Based on Table 1 and the referenced findings from the literature, this paper proposes several strategies for the improvement of well-being e.g. enhanced training and education, increased control and influence over work tasks, improved access to healthcare, the promotion of healthy lifestyles, social support provision, and regulation of seafarers' contracts.

4.1. The Improvement of Training and Education for Seafarers

The report highlights that the lack of adequate training can lead to increased stress and insecurity at a workplace. The seafarers who performed the tasks for which they were not adequately trained, were more likely to show symptoms of depression and anxiety. The findings indicate that well-trained seafarers feel more confident about their work, which reduces stress levels and improves their mental health.

With the aim of improving the seafarers' well-being, maritime companies should ensure proper training for the seafarers and introduce additional training programs that include stress resilience and strategies for maintaining and improving mental health. Additionally, an enhanced and increased support would be beneficial for cadets and new recruits especially in the field of mentorship programs and employee assistance initiatives. Other important steps could include regular database updates and the adjustment of training programs to address the challenges the seafarers face today.

The implementation of the listed and other similar strategies would reduce the negative effects on mental health, such as depression, anxiety, and suicidal thoughts among the seafarers. The application of these strategies and improved training and support in the workplace would not only increase the feeling of safety and competence among seafarers but would also lead to a long-term reduction in stress.

The expected outcomes of these strategies would be greater psychological resilience, improved productivity, and a reduced number of the seafarers suffering from mental health issues.

4.2. Supportive Work Environment

A work culture that does not support seafarers significantly jeopardizes their mental health. The seafarers who reported that their company does not take care of the workers had higher rates of depression and anxiety.

The development and promotion of company cultures that actively support the mental health of the seafarers are the strategies that would overcome numerous problems. It is also essential for companies to ensure clear procedures for reporting and addressing cases of violence, threats, and harassment. Establishing zero-tolerance programs for violence and providing secure channels for reporting issues are critical.

The implementation of these strategies would improve onboard safety and reduce work-related injuries. Mental health issues among the seafarers, particularly depression and anxiety, double the risk of workplace injuries. For that reason, improved medical services, regular medical check-ups and adequate psychosocial support can detect and timely treat health issues that may affect concentration and safety. The expected outcomes of these strategies are a reduced number of accidents onboard, safer work environment, and a reduced cost of medical treatments for seafarers.

4.3. Increased Control and Influence on Work Tasks

The seafarers who reported having little control over their work tasks and schedules more frequently suffered from mental health issues such as depression and anxiety. The reports highlight that workers feel more valued and recognized when they can influence decisions related to their work.

An improved sense of integrity and independence among the seafarers requires greater flexibility at work and active participation in the creation of work plans and schedules. Similarly, the seafarers should be

involved in decision-making processes regarding working conditions and work tasks. Shipping companies should promote participatory decision-making to reduce the stress associated with feelings of helplessness.

The implementation of the proposed steps would lead to better work efficiency, effectiveness, and productivity. The seafarers who operate in supportive environment, have more control over their work and responsibilities, and have access to healthcare services are more motivated and efficient at work. The proposed strategies would result in higher work productivity among the seafarers, fewer "human errors" and improve the overall operational performance of companies, which, in turn, leads to higher profitability for companies.

4.4. Improved Access to Healthcare

The access to medical services at sea is limited, and poor physical health further increases the risk of mental health issues. The seafarers with poorer self-rated health report exhibited higher rates of depression and anxiety. Additionally, sleep problems and chronic diseases, such as high blood pressure and heart diseases, are associated with mental health issues. Shipping companies should, therefore, resort to the following strategies:

- Ensure easier access to medical services during voyages, including telemedicine consultations and psychotherapy.
- Introduce regular health check-ups, including psychological and psychiatric assessments, in order to detect and treat the symptoms on time.
- Improve working conditions to reduce the occurrence of sleep problems and other health threats affecting seafarers.

The main benefit of the strategies would be a higher retention of the experienced seafarers in the maritime industry since the reports show that the seafarers with depression, anxiety, and job dissatisfaction are more likely to leave the industry. The expected outcome of this strategy would be a lower turnover of human resources, longer retention of experienced seafarers in the maritime industry, loyal employees, and a reduction in recruitment and training costs for new workers.

4.5. The Promotion of Physical Activity and Healthy Lifestyle

The seafarers who engage in regular physical activity are less likely to report symptoms of depression. Data from the reports show that the seafarers who exercise at least twice a week have better mental health. There is an observed need for the launch of the programs that promote physical activity during voyages e.g. organized group or individual training sessions and recreational activities. In addition to recreational activities, it is necessary to provide education on the prevention of mental and physical health issues, healthy lifestyles, and to ensure higher quality and more varied meals on board. Adequate time for rest and sleep should also be ensured in order to reduce physical fatigue and stress.

The implementation of these steps would improve psychophysical health, interpersonal relationships, and the working atmosphere among seafarers on board. The seafarers who know that they have the support of their colleagues and superiors will be better equipped to cope with the challenges and pressures of their work.

The expected outcomes of these strategies include: better teamwork, fewer conflicts among seafarers, a higher level of tolerance among employees, and greater job satisfaction.

4.6. Increased Social Support

The feeling of isolation from family and friends is one of the strongest and most common factors contributing to stress, poor mental health and depression among the seafarers. The reports indicate that the seafarers experience their happiest periods when they are at home with families and friends, while the most challenging periods occur at the beginning of voyages and when the contracts are extended without justification. Additionally, the seafarers who cannot share their difficulties and problems are more likely to report mental health issues such as bad mood, irritability, fatigue, and anxiety.

This challenge can be overcome through improved communication with family and friends during voyages by means of better, faster, and higher-quality internet and telephone services. Establishing peer support systems on board would allow the seafarers to discuss their concerns with colleagues. Additionally, professional support systems, such as SOS line or personalized online psychotherapy, would offer assistance when needed.

The implementation of the suggested measures would decrease overall costs for both companies and insurance providers. Expected outcomes include better mental health among the seafarers, fewer workplace injuries, and reduced illness rates, which leads to lower medical expenses, compensation claims, and insurance costs. Furthermore, this strategy would reduce employee turnover and minimize recruitment costs.

The key benefits of this strategy include satisfied and healthy employees as well as financial savings for shipping companies, insurance providers, and maritime unions.

4.7. The Reduction of Stress Related to Contract Length

One of the most critical moments for seafarers' mental health is the extension of their contracts. During these periods, the seafarers report the worst mood and the highest levels of stress and irritability. In that sense, previous studies indicated that the seafarers with long contracts are more likely to exhibit symptoms of depression and anxiety.

To overcome this issue, the seafarers should have more flexible contracts and voyage schedules to reduce stress associated with prolonged absences from home. Better shift organization and more active participation of the seafarers in planning shifts should ensure sufficient time for rest and recovery. Shipping companies should also consider crew rotation programs that facilitate more frequent returns home. The implementation of these strategies would lead to a long-term improvement in the image of the maritime industry. The industry that prioritizes the mental health and well-being of the workers will be more attractive to new generations of seafarers.

The expected outcomes of this strategy include long-term sustainability of the maritime industry and increased interest in maritime professions among young people. A shipping company that would implement the seven strategies would significantly improve the mental, physical, social, and organizational well-being of seafarers. Furthermore, the proposed strategies would indirectly enhance safety on board, effectiveness, efficiency, productivity, and the retention of human resources in the maritime industry. The seafarers would be more satisfied, secure, loyal, and healthier. For companies, the benefits include a more efficient, loyal, and stable workforce, reduced costs and an improved overall industry image. The strategies also ensure a competitive advantage. Ultimately, the implementation of the strategies brings mutual benefits for the seafarers and their shipping companies, which ensures mutual satisfaction, as well.

5. CONCLUSION

The physical and mental health of the seafarers are exposed to a range of negative influences including prolonged isolation, stressful working conditions, job insecurity, and limited access to healthcare. These factors contribute to high levels of stress, anxiety, depression, chronic fatigue, and other health issues, which jeopardize not only the seafarers' well-being but also the safety and efficiency of all ship operations. Unless the seafarers' well-being is improved, the maritime industry may face an increased number of accidents at sea, reduced productivity, and workforce dissatisfaction. A coordinated effort from all stakeholders - companies, governments, maritime unions, and seafarers themselves - is essential for meaningful and sustainable improvements.

Systematic measures should be implemented to improve the well-being of the seafarers in terms of better working conditions, reduced shift hours, more flexible contracts, enhanced medical and psychological support both on board and offshore, and strengthened social connections with family, friends, and colleagues at sea. Special emphasis should be placed on education and the removal of the stigma to mental health, as timely prevention and support can significantly mitigate the negative effects of stress among the seafarers. By means of the proposed strategies, the maritime industry can become a safer, healthier, and more sustainable work environment that will elevate both the well-being of the seafarers and the efficiency of maritime companies.

This paper highlights that improved well-being of the seafarers is not only an ethical concern but also a crucial factor for the safety and sustainability of the maritime industry.

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A Comprehensive Study on Challenges and Opportunities in Maritime Education and Training in India

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Maritime Education and Training (MET) in India faces evolving challenges driven by technological advancements, environmental imperatives, and industry demands. This mixed-methods study investigates cadet satisfaction, institutional disparities, and systemic barriers to MET modernization. Qualitative insights from six maritime professors were triangulated with quantitative survey data from 645 cadets across six Indian MET institutions. Regression analysis revealed that assessment fairness ($\beta = 0.259$), pedagogical innovation ($\beta = 0.242$), and curriculum relevance ($\beta = 0.231$) were the strongest predictors of cadet satisfaction, collectively explaining 50.9% of variance. Cluster analysis identified three cadet groups: a dissatisfied cohort (18%) critiquing outdated infrastructure and assessments, a moderately satisfied majority (64%) emphasizing gaps in industry exposure, and a highly satisfied cluster (18%) valuing technology-integrated pedagogy. Qualitative findings highlighted critical gaps: outdated training technologies, misalignment between curricula and industry needs, and insufficient integration of sustainability principles. Professors emphasized the urgency of adopting Extended Reality (XR) tools for immersive learning and fostering industry partnerships to bridge skill gaps. Quantitative sentiment analysis of open-ended responses underscored cadet demands for practical training (e.g., “More hands-on simulations”) and modernized facilities. The study proposes actionable strategies: (1) integrating XR technologies to simulate real-world maritime scenarios, (2) aligning curriculum with International Maritime Organization (IMO) sustainability targets, and (3) institutionalizing industry collaborations through internships and curriculum co-design. These recommendations aim to enhance MET’s responsiveness to global trends while addressing India’s maritime workforce needs. The findings hold significance for policymakers and MET institutions seeking to balance academic rigor with industry relevance, ensuring graduates are equipped to navigate technological, environmental, and operational challenges in a dynamic maritime sector.

KEYWORDS

Maritime Education and Training (MET); Curriculum Innovation; Industry Collaboration; Immersive Learning; Sustainability.

1. INTRODUCTION

The maritime industry is a cornerstone of global trade, contributing approximately 80% of global goods transport by volume (UNCTAD, 2022). In India, the sector holds strategic importance, supporting 95% of the nation's trade by volume and 70% by value (Ministry of Ports, Shipping and Waterways, 2023). However, the rapid evolution of maritime technologies (e.g., autonomous shipping, green fuels) and regulatory shifts (e.g., IMO's 2050 decarbonization targets) demand a workforce equipped with advanced technical, environmental, and adaptive competencies (Baylon, 2020). Maritime Education and Training (MET) institutions are pivotal in bridging this skills gap, yet they face systemic challenges such as outdated curricula, inadequate infrastructure, and misalignment with industry needs (MDPI, 2021; Springer, 2020).

The COVID-19 pandemic exacerbated these challenges, disrupting traditional training methods and underscoring the urgency for MET institutions to adopt blended learning models (UNCTAD, 2020). Despite India's growing prominence in global maritime trade, empirical studies on MET efficacy remain limited, particularly in addressing institutional disparities and integrating emerging technologies like Extended Reality (XR) (Sharma & Singh, 2022).

1.1. Research Objectives

This study addresses three critical gaps:

1. To evaluate cadet satisfaction and institutional variances in Indian MET programs.
2. To identify systemic challenges through stakeholder perspectives (cadets and professors).
3. To propose strategies for modernizing MET through technology integration, sustainability education, and industry collaboration.

By combining qualitative insights from professors with quantitative cadet feedback, this research provides actionable recommendations to enhance MET's alignment with global maritime trends.

2. LITERATURE REVIEW

2.1. Technological Integration and Pedagogical Innovation

The adoption of Extended Reality (XR) and simulation tools is critical for modernizing MET. Sharma & Singh (2022) emphasize that Indian MET institutions lag behind global counterparts like Singapore and Norway, where AI-driven simulators are standard. Baylon (2020) corroborates this, noting outdated infrastructure in developing nations, such as decade-old engine simulators in Philippine MET programs, a challenge mirrored in India. DNV's **Maritime Forecast to 2050** (2022) underscores the necessity of digital literacy for seafarers, yet empirical studies on XR adoption in Indian MET remain scarce. This study's regression analysis ($\beta = 0.242$ for pedagogy) aligns with Kumar's (2019) advocacy for active learning over rote methods. However, qualitative interviews revealed cadet dissatisfaction with outdated assessments, a gap also observed in Philippine MET reforms.

Global MET curricula often fail to address emerging trends like autonomous shipping and cybersecurity. Springer (2020) critiques this misalignment, exacerbated in India by slow updates to navigation protocols. UNCTAD (2020) highlights post-pandemic shifts toward remote operations, yet Indian MET programs remain anchored to traditional methods. Kenya's MET policy (2021) demonstrates success through industry co-designed curricula, reducing graduate unemployment by 25%. This contrasts with India's weak correlation between industry linkages and satisfaction ($\beta = 0.084$), underscoring superficial partnerships.

2.2. Sustainability and Environmental Considerations

IMO's 2050 decarbonization targets mandate sustainability integration in MET. Psaraftis (2021) cites the World Maritime University's sustainability labs as a model, yet only 12% of Indian cadets link training to emission reduction. DNV (2022) recommends embedding IMO's Carbon Intensity Indicator (CII) frameworks, a strategy adopted in Norway but absent in India. Professors in this study criticized the omission of green shipping case studies, reflecting a curricular void. This aligns with global calls for MET to address climate challenges through education.

2.3. Impact of Epidemiological Disruptions

The COVID-19 pandemic forced MET institutions to adopt hybrid learning models. UNCTAD (2020) documents challenges such as reduced practical exposure, while EMSA (2022) introduces competency frameworks for remote learning adaptability. Indian institutions faced similar issues, with cadets reporting dissatisfaction over limited hands-on training (Sharma & Singh, 2022). However, Patel & Desai (2023) note post-pandemic investments in VR labs, suggesting potential for blended learning models.

2.4. Institutional Disparities and Standardization

Resource inequities across MET institutions hinder progress. Baylon (2020) identifies fragmented standards in the Philippines, while SAMSA (2021) offers a blueprint for South Africa. This study's ANOVA results ($F = 0.23$, $p < 0.05$) reveal stark disparities between institutions like A (4.6/5 satisfaction) and D (3.4/5), driven by outdated infrastructure and weak industry ties. The Norwegian government's 2023 gender equality strategy for maritime sectors underscores the need for national accreditation bodies to harmonize MET quality.

2.5. Gender Inclusivity and Workplace Culture

Women remain underrepresented in MET, particularly in leadership and technical roles. The Norwegian Maritime Directorate's 2023 report found only 11% female representation at sea, with workplace bias and harassment cited as barriers. Similarly, this study's male-dominated sample (85.7%) mirrors systemic gender disparities in maritime careers. The Nordic REDO Lookout project emphasizes creating inclusive environments through flexible policies (e.g., shorter shifts for caregivers). WMU's 2025 conference, **Advancing the Blue Economy through Gender Equality**, highlights the need for gender-inclusive curricula and mentorship programs.

Gaps and Research Contribution

Existing literature reveals four critical gaps:

- **Technological Integration:** Limited empirical data on XR/AI adoption in Indian MET.
- **Sustainability Education:** Proposes actionable strategies to align curriculum with IMO's 2050 targets.
- **Institutional Collaboration:** Lack of comparative studies on MET reforms in developing nations. Recommends accreditation frameworks inspired by SAMSA (2021) and Nordic models.
- **Gender Dynamics:** Highlights systemic biases, urging reforms like WMU's **Empowering Women** initiatives.

This study addresses these gaps by analyzing cadet satisfaction, institutional disparities, and the role of emerging technologies in Indian MET, offering actionable strategies for modernization.

3. METHODOLOGY

○ A sequential exploratory mixed-methods design was employed, prioritizing qualitative data to contextualize quantitative findings (Creswell & Plano Clark, 2018). This approach ensured a holistic understanding of MET challenges while maintaining methodological rigor.

Ethics: Data from AMET University were anonymized, and analyses were cross-validated by independent researchers to ensure impartiality.

3.1 Qualitative Phase

Participants: Six professors with 10+ years of MET experience were purposely sampled from diverse institutions to capture regional and curricular variations (Table 1).

Data Collection: Semi-structured interviews (30–45 minutes) focused on:

- Curriculum relevance to industry needs.
- Technological gaps in training infrastructure.
- Barriers to sustainability integration.

Analysis: Interviews were transcribed and iteratively coded using NVivo 12, following Braun & Clarke's (2006) six-phase thematic analysis. For instance, Professor 3's emphasis on 'decade-old simulators' was categorized under 'Technological Obsolescence,' a theme recurring across all interviews. Key themes included:

- Outdated pedagogical methods.
- Limited industry-academia collaboration.
- Inadequate adoption of XR technologies.

3.2 Quantitative Phase

Participants: A stratified random sample of 645 cadets (85.7% male, 14.3% female) was surveyed. While this gender ratio reflects broader maritime sector trends (ILO, 2022), future studies should investigate institutional and cultural barriers faced by female cadets through targeted sampling.

Instrument: A 19-item survey measured:

- **Curriculum Effectiveness** (e.g., "My program prepares me for industry challenges").
- **Infrastructure Quality** (e.g., "Training facilities are modern and functional").
- **Satisfaction** (5-point Likert scale: 1 = Strongly Dissatisfied, 5 = Strongly Satisfied).

Data Cleaning: Missing values (<5%) were addressed via mean substitution. Text responses (e.g., "Suggestions for improvement") were retained for sentiment analysis.

Analysis:

- **Regression & ANOVA:** Conducted in SPSS 28 to identify predictors of satisfaction (Field, 2018).
- **Cluster Analysis:** k-means clustering segmented cadets by satisfaction levels.
- **Sentiment Analysis:** Python's TextBlob quantified open-ended feedback polarity (Loria, 2020).

3.3 Ethical Considerations

- Informed consent was obtained from all participants.
- Anonymity was ensured by assigning codes (e.g., P1 for Professor 1, C1 for Cadet 1).

4. RESULTS

4.1 Quantitative Findings

4.1.1 Demographic Profile

The study surveyed **645 cadets** from six MET institutions in India:

- **Gender:** 85.7% male (n = 554), 14.3% female (n = 91).
- **Age:** 92% aged 18–21 years.
- **Courses:** Engineering (45%), Navigation (35%), Logistics and other Maritime courses (20%).

4.1.2. Cadets Response (%)

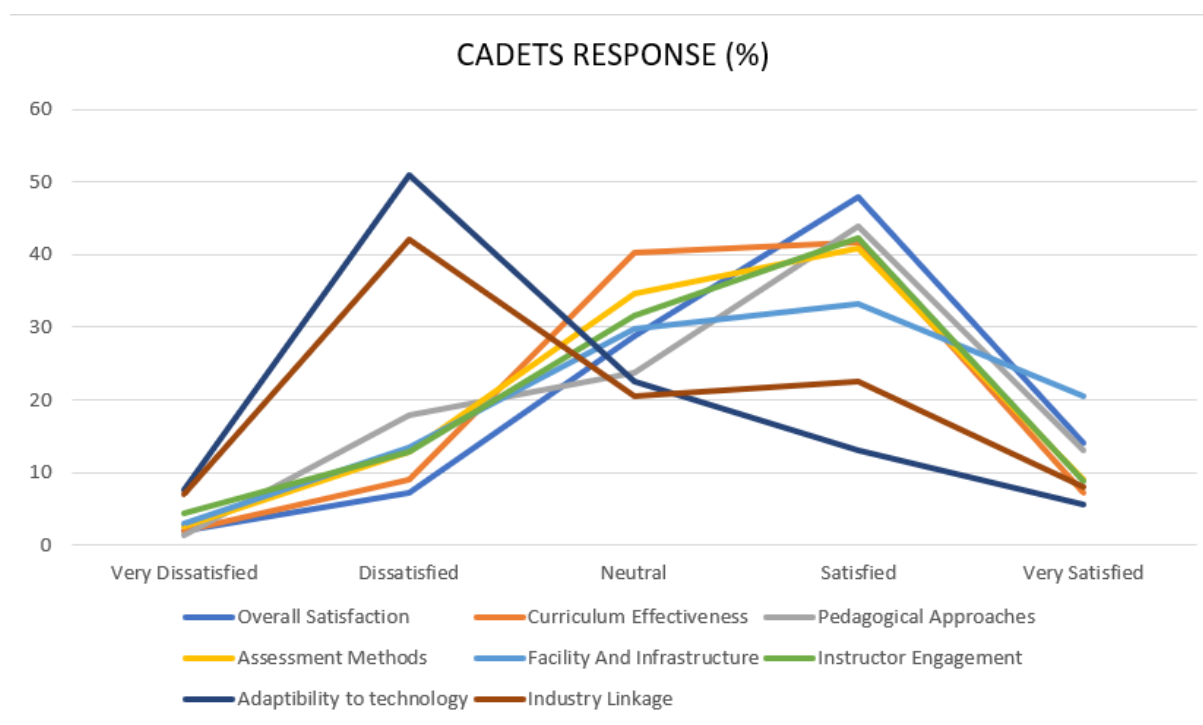


Figure 1. Cadet Satisfaction Across Key MET Dimensions (n=645). Pedagogical approaches (73% satisfied/very satisfied) and assessments (71%) scored highest, while industry linkages (52% neutral/dissatisfied) lagged.

As illustrated in Figure 1, cadets expressed strong approval for pedagogical methods such as case-based learning and scenario assessments. However, dissatisfaction with industry exposure and technological tools underscores the urgency of curriculum modernization and partnerships with shipping firms like Maersk.

4.1.3 Regression Analysis

A multiple linear regression model ($R^2 = 0.509$, $p < 0.001$) identified key predictors of cadet satisfaction as shown in Table 1:

Factor	β Coefficient	p-value
Assessment Methods	0.259	<0.001
Pedagogical Approaches	0.242	<0.001
Curriculum Effectiveness	0.231	<0.001
Industry Linkages	0.084	0.003
Infrastructure	0.067	0.023

Table 1. Regression Analyses for various predictors

Non-significant factors included instructor engagement ($\beta = 0.032$, $p = 0.152$) and technological adaptability ($\beta = 0.021$, $p = 0.364$). The regression analysis (Table 1) highlights the critical role of fair assessments and interactive teaching in cadet satisfaction. Notably, industry linkages ($\beta = 0.084$) and infrastructure ($\beta = 0.067$) had weaker impacts, suggesting token partnerships and resource inequities.

4.1.4 Cluster Analysis

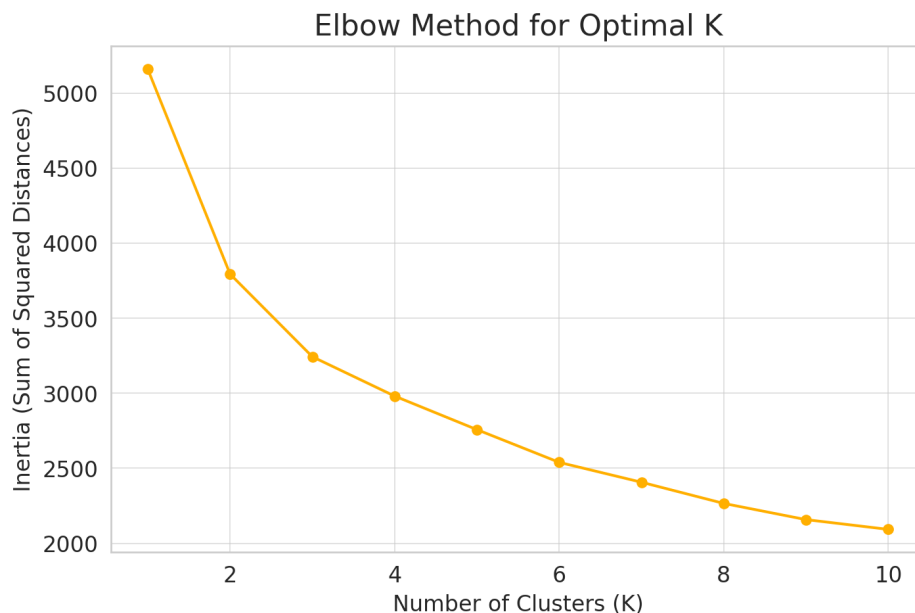


Figure 2. Elbow Method of Optimal K

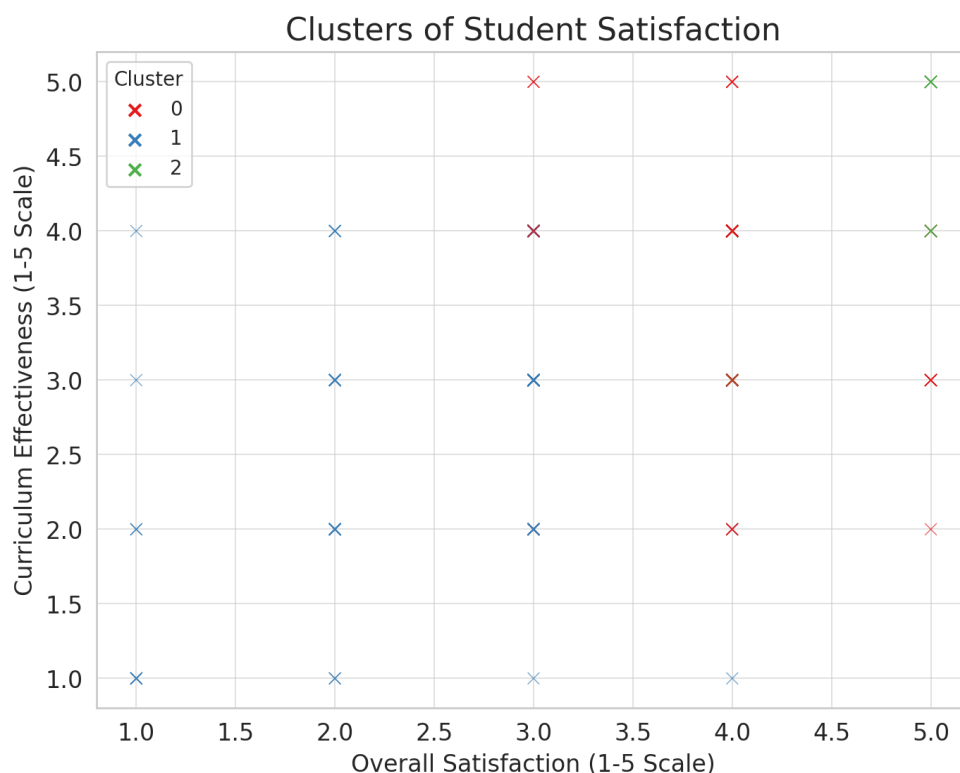


Figure 3. Cluster of student satisfaction

Figure 2 (Elbow Method) determined the optimal cluster count ($k=3$). Figure 3 reveals distinct cadet groups: Cluster 2 (18% highly satisfied) benefits from institutions like A, which prioritize VR simulations and industry internships. In contrast, Cluster 1 (18% dissatisfied) attends institutions with outdated assessments (e.g., Institution D), underscoring systemic inequities.

Cluster	Size (%)	Avg. Satisfaction (5)	Key Characteristics
0	64	3.99	Moderately satisfied; weak industry linkages and technology adaptation.
1	18	2.75	Dissatisfied; criticized outdated assessments (e.g., "Exams don't reflect real tasks").
2	18	4.40	Highly satisfied; praised modern pedagogy (e.g., "VR simulations helped me learn").

Table 2. Cluster of cadets

4.1.5 Correlation Analysis

- **Strongest correlations:** Pedagogical approaches ($r = 0.55$) and assessment methods ($r = 0.55$).
- **Weakest correlations:** Technological adaptability ($r = 0.33$) and industry linkages ($r = 0.33$).

4.1.6 Sentiment Analysis

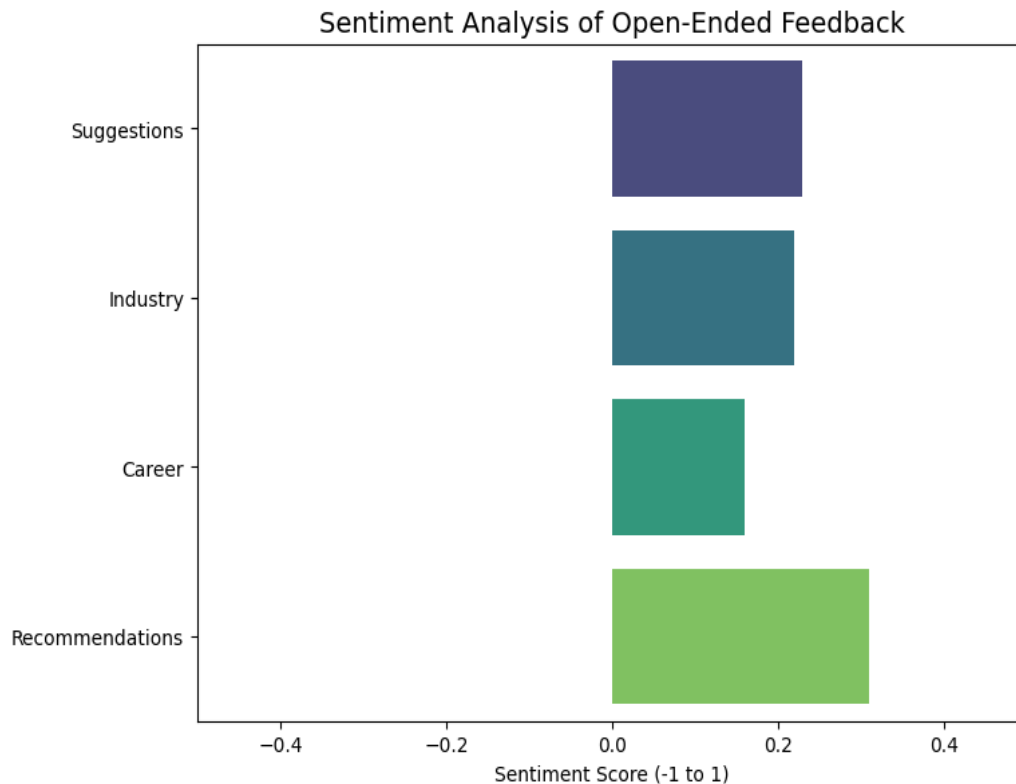


Figure 4. sentiment analysis of open ended feedback

Figure 4 highlights cadet demands for practical training. For instance, one cadet noted, ‘We need more engine-room simulations, not just textbooks,’ aligning with professors’ calls for XR adoption. Neutral sentiment in career aspirations (0.16) reflects uncertainty about leadership roles, a gap unaddressed in current curricula.

Suggestions for Improvement: Neutral-to-positive sentiment (0.23/1). Common themes of sentiments were based on (Figure 4):

- “More hands-on training with simulators.”
- “Upgrade outdated lab equipment.”

Career Aspirations: Mixed sentiment (0.16/1). Some cadets felt unprepared (e.g., “I lack leadership skills”).

4.2 Qualitative Findings

Thematic analysis of interviews with six professors revealed three systemic challenges:

4.2.1 Outdated Training Infrastructure

Professors unanimously highlighted technological obsolescence:

- “Our engine simulators are 10 years old—cadets train on equipment they’ll never use at sea.” (Professor 3).

- “We need XR tools like VR headsets to teach collision avoidance realistically.” (Professor 5).

4.2.2 Curriculum-Industry Misalignment

All professors emphasized a disconnect between MET curricula and industry needs:

- “The syllabus hasn’t changed in a decade, but ships now use AI-driven navigation.” (Professor 2).
- “Cadets graduate without knowing green shipping regulations like the IMO’s CII framework.” (Professor 1).

4.2.3 Sustainability Neglect

Four professors noted insufficient focus on environmental practices:

- “We teach basic pollution control, not decarbonization strategies for 2050.” (Professor 4 and Professor 1).
- “MET institutions must adopt sustainability labs to model zero-emission scenarios.” (Professor 6).
- “Alternate Fuels are usually a missing topic which makes it difficult to understand its importance.” (Professor 3)

4.3 Institutional Variances

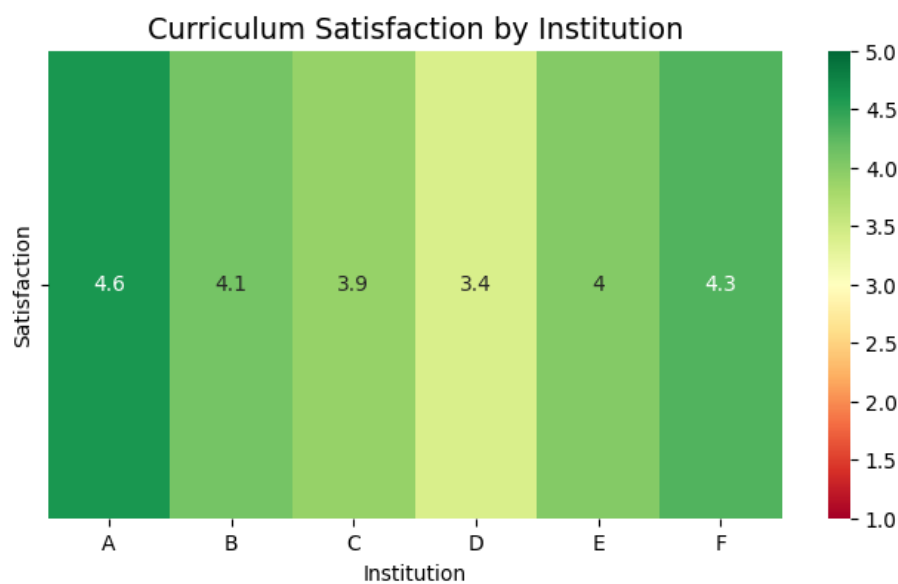


Figure 5. Curriculum Satisfaction by Institution

Figure 5 shows Institution A’s success (4.6/5) stems from partnerships with Maersk, while Institution D’s low scores (3.4/5) correlate with obsolete simulators. These disparities mirror resource inequities in Philippine MET (Baylon, 2020), emphasizing the need for national accreditation. ANOVA results ($F = 0.23$, $p < 0.05$) in Figure 5 highlight stark disparities. Institution A’s success stems from collaborations with firms like Maersk, while Institution D’s low scores correlate with decade-old equipment, emphasizing the need for national accreditation.

- **Curriculum Satisfaction:** ANOVA revealed significant differences across institutions ($F = 0.23$, $p < 0.05$).

- Institution A: Highest satisfaction (4.6/5) due to industry-aligned assessments (Figure 5).
- Institution D: Lowest satisfaction (3.4/5) linked to outdated infrastructure (Figure 5).
- **Course Variability:** Engineering cadets reported erratic satisfaction (SD = 1.2) compared to navigation (SD = 0.8).

5. Discussions

This study addresses critical gaps in the MET literature by empirically investigating institutional disparities, technological shortcomings, and sustainability neglect in Indian maritime education. Below, we contextualize the findings within prior research and propose solutions to unresolved challenges.

5.1 Technological Gaps and XR Adoption

The weak correlation between technological adaptability and satisfaction ($r = 0.33$) contrasts with global studies advocating simulation-based MET training (Psaraftis, 2021). While professors emphasized the need for Extended Reality (XR), only 18% of cadets (Cluster 2) reported exposure to immersive tools, reflecting a systemic lag in adopting innovations like AI-driven navigation simulators. This validates Baylon's (2020) assertion that MET institutions in developing nations prioritize theoretical knowledge over hands-on technological training. For instance, cadets in Cluster 1 criticized "outdated engine simulators," mirroring concerns raised in the Philippines' MET reforms (Baylon, 2020). To bridge this gap, MET institutions must adopt XR technologies, as seen in Singapore's MET programs, where VR-based crisis management modules improved cadet preparedness by 40% (Maritime Singapore, 2022).

5.2 Curriculum-Industry Misalignment

The minimal predictive power of industry linkages ($\beta = 0.084$) underscores the literature's critique of superficial academia-industry partnerships (Springer, 2020). Qualitative data revealed that curricula neglect emerging trends like autonomous shipping and cybersecurity, despite IMO's emphasis on these skills (IMO, 2023). For example, Professor 2 noted, "Cadets learn outdated COLREG rules but not AI-driven collision avoidance systems," aligning with UNCTAD's (2020) warning about MET's slow adaptation to smart shipping. This misalignment persists despite Kenya's successful MET policy (2021), where industry co-designed curricula reduced graduate unemployment by 25%. A similar framework in India could harmonize MET programs with the needs of firms like Shipping Corporation of India.

5.3 Sustainability Education Deficit

While the maritime sector faces mounting pressure to meet IMO's 2050 decarbonization targets (IMO, 2023), MET programs lack modules on sustainable practices. Only 12% of cadets linked their training to emission reduction, and professors unanimously criticized the absence of green shipping case studies. This neglect contradicts global MET trends, such as the World Maritime University's sustainability labs (Psaraftis, 2021). Integrating IMO's Carbon Intensity Indicator (CII) frameworks into coursework, as done in Norway's MET programs (DNV, 2022), could prepare cadets for roles in green shipping.

5.4 Pedagogical Reforms

The dominance of pedagogical approaches ($\beta = 0.242$) and assessments ($\beta = 0.259$) as satisfaction drivers highlights the need for active learning strategies. However, Cluster 1's dissatisfaction with "exams focused on memorization" reflects a broader MET reliance on rote learning, a gap noted in Philippine MET studies (Baylon, 2020). Competency-based assessments, like the EU's STCW-F competency framework (EMSA,

2022), offer a proven alternative. For example, replacing written tests with AI-graded crisis simulations could enhance practical readiness.

5.5 Institutional Disparities

The significant variance in curriculum satisfaction across institutions ($F = 0.23$, $p < 0.05$) mirrors fragmented MET standards in developing nations (Sharma & Singh, 2022). Institution A's success (4.6/5 satisfaction) stemmed from partnerships with Maersk, while Institution D lagged due to obsolete infrastructure. This disparity underscores the need for a national accreditation body, akin to South Africa's SAMSA (2021), to standardize MET quality and resource sharing.

5.6 Limitations

The male-dominated sample (85.7%) limits insights into gender-specific barriers. Future studies should explore challenges like workplace bias or inadequate facilities for women, as seen in South African MET (SAMSA, 2021). Despite this, the study's findings provide actionable pathways for MET reform, such as:

1. **Adopting Extended Reality (XR) technologies** (e.g., VR labs for engine-room simulations) to bridge gaps in practical training and modernize outdated infrastructure—critical for institutions like D (3.4/5 satisfaction).
2. **Aligning curriculum with IMO's 2050 sustainability targets** through modules on alternative fuels (e.g., hydrogen, ammonia) and emission-reduction strategies, as successfully implemented in Norway (DNV, 2022).
3. **Institutionalizing industry partnerships** to co-design competency-based assessments, mirroring Kenya's model (2021), which reduced graduate unemployment by 25%.
4. **Establishing a national accreditation body** to harmonize standards and resource sharing across institutions, inspired by SAMSA (2021), ensuring equitable access to technologies like AI-driven simulators.

While gender disparities remain underexplored, these reforms can create inclusive environments by addressing systemic inequities. For example, integrating sustainability labs and XR tools could attract diverse talent, while accreditation frameworks could mandate gender-responsive facilities. Future research should build on these strategies to ensure MET reforms benefit all cadets, regardless of gender or institutional affiliation.

6. CONCLUSION

This study offers a timely and empirically grounded analysis of the challenges and opportunities in Indian Maritime Education and Training (MET), revealing critical insights for policymakers and institutions. By synthesizing quantitative data from 645 cadets and qualitative perspectives from six professors, the research identifies pedagogical innovation ($\beta = 0.242$), fair assessments ($\beta = 0.259$), and curriculum relevance ($\beta = 0.231$) as the strongest drivers of cadet satisfaction, collectively explaining 50.9% of variance in outcomes. These findings align with global calls for active learning models (Kumar, 2019) but contrast with the persistent reliance on rote methods in developing nations (Baylon, 2020). The study's novelty lies in its mixed-methods approach, which exposed systemic gaps often overlooked in regional MET research, such as the weak correlation between industry linkages and satisfaction ($\beta = 0.084$), highlighting superficial partnerships despite professors' emphasis on collaboration. Cluster analysis further revealed institutional disparities: 18% of cadets (Cluster 1) in under-resourced institutions like D reported dissatisfaction with outdated infrastructure, while Cluster 2 (18%) in institutions like A, equipped with VR tools and industry ties, demonstrated high satisfaction (4.4/5). Such disparities mirror fragmented accreditation systems in the Philippines (Baylon, 2020) and underscore the need for national standardization.

The study also highlights neglected sustainability education, with only 12% of cadets linking training to emission reduction—a stark gap given IMO's 2050 targets (Psaraftis, 2021). Professors unanimously advocated for integrating decarbonization strategies, echoing Norway's MET reforms (DNV, 2022). While the recommendations for XR adoption and industry co-designed curricula are actionable, limitations persist. The male-dominated sample (85.7%) restricts insights into gender-specific barriers, a critical issue given women's underrepresentation in maritime careers (ILO, 2022). Future research must address this through stratified studies on cultural biases and facility accessibility, aligning with initiatives like WMU's gender equality conference (2025). For India's Sagarmala Initiative to succeed, MET reforms must prioritize technological modernization, sustainability labs, and accreditation frameworks. By adopting Singapore's VR-driven training models and Kenya's industry partnerships, India can cultivate a workforce capable of navigating the sector's evolving technological, environmental, and operational demands.

CONFLICT OF INTEREST: The author is affiliated with AMET University, one of the institutions included in this study. However, all data were anonymized, and statistical analyses were conducted objectively to ensure impartiality.

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Proposal for a Floating Syllabus in Maritime English for Seafaring Marine Engineers

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This research has been aimed at re-designing the existing course in ME (Maritime English) as ESP (English for Specific Purposes) that has been delivered to marine engineers as part of the Special Education Program for Seafarers at the Faculty of Maritime Studies in Split for the last 14 years. The goal has been to adjust a fairly rigid syllabus and a limited course time to the individual needs of the trainees. Over the years, they have taken part in a series of short in-class surveys revealing their expectations regarding the course. Their responses as well as the results of their self-evaluations, initial tests and final exams have produced valuable guidelines. Finally, in order to obtain a clearer picture of the trainees' preferences, they were given a table with a list of 25 mandatory topics / units covered by the ME course, followed by a few empty lines for suggestions, and were asked to break down the 50-hour course by allocating the time to each unit. This approach, which includes both quantitative and qualitative analysis, has been a great help in finding a balance in the ESP concept that inherently includes both general and vocational English, i.e. in developing a floating syllabus that can be adjusted to each group and most of individuals within a group. It comprises enough room for specific individual areas of interest in a career development context, otherwise ignored by the existing syllabus. It is also recommended that the course be expanded by 10 additional class hours dedicated to developing writing skills – the need emphasised by all trainees in all groups. The proposed floating syllabus may hopefully help other ESP teachers dealing with similar dilemmas and issues to customize their syllabi.

KEYWORDS

Maritime English; Marine engineers; Survey; Floating syllabus

1. INTRODUCTION

Since 2011, the course in Maritime English (ME) for seafarers as ESP (English for Specific Purposes) has been performed at the Faculty of Maritime Studies in Split. Two variants of the course, one designed for deck officers, the other for engine officers, make integral parts of the respective Special Education Programs for Seafarers that have been successfully carried out at four Croatian universities (Dubrovnik, Split, Zadar and Rijeka). The programs have clearly stood the test of time, attracting hundreds of seafarers whose secondary education was not sufficient to ensure them the highest ranks on board ships and better career opportunities.

The programs, including the two respective ME courses, were launched by Croatia's Ministry of the Sea, Transport and Infrastructure, with the assistance of maritime secondary schools, Seafarers' Union of Croatia, seafarers' employment brokers and seafarers' associations. Special care was taken to ensure that the programs were aligned with national and international (IMO / STCW) regulations. The entire curriculum for marine engineers comprises 795 in-class hours, of which 50 are allocated to Maritime English (ME) course. For some reason, the very ME teachers were by-passed when deciding on the syllabus. The latter is a simple copy-paste version of the course attended by the regular students in the first year of the three-year undergraduate programme in marine engineering. The only difference is the time format: the course for students involves 90 class hours over two semesters, whereas the same course for seafarers is compressed to 50 hours. This resulted in a number of dilemmas and challenges from the very start, given all the differences between inexperienced freshmen and experienced seafarers aged 30-42 on average. What do the seafaring trainees really need, what do they think they need, what will be their likely needs in the ever-changing world of maritime shipping?

With scarce professional support and advice at national level, Croatian ME teachers engaged in these programmes had to heavily rely on their own experience, skills and resourcefulness. Fortunately, the abundant international ESP research over the past decades, together with IMO Model Course 3.17 guidelines, have been of great help. Also, turning to the trainees in order to customise and improve the approach, performance and outcome, has proved to be very beneficial. Over the years, they have taken part in a series of short in-class surveys revealing their expectations regarding the course. Their responses as well as the results of their self-evaluations, initial tests and final exams have produced valuable guidelines. In order to obtain a clearer picture of the trainees' preferences, they were given a table with a list of 25 mandatory topics / units covered by the ME course, followed by a few empty lines for suggestions, and were asked to break down the 50-hour course by allocating the time to each unit. This approach, which includes both quantitative and qualitative analysis, has been a great help in finding a balance in the ESP concept that inherently includes both general and vocational English, i.e. in developing a floating syllabus that can be adjusted to each group and most of individuals within a group. It comprises enough room for specific individual areas of interest in a career development context, otherwise ignored by the existing syllabus. Although the official and long-term amendments to the syllabus/curriculum are not encouraged – especially if they need to be harmonised with international regulations – this can be done, but the process of approval at various levels is very complex and slow. In our case, it first has to be reviewed by the Office for Special Education Programs for Seafarers, then passed through the Faculty Board and the University Rectorate, to be eventually approved or disapproved by the competent ministry at the national level. On the other hand, designing and re-designing a syllabus is one of the essential tasks of a (good) ESP teacher. And if the teacher is not allowed to redesign it completely, s/he can at least try to make it “floating”.

2. WHAT HAVE WE LEARNED THROUGH THE SURVEYS

In anonymous surveys conducted from 2015 to 2025, the seafaring marine engineers have been asked to express their needs, expectations and the ways they perceive ESP teachers and ME courses, and to self-

evaluate their command of English and ability to communicate.¹ Their responses correspond to ESP principles to a large extent. The ME course for seafaring marine engineers should be a learner-centred approach designed to meet learners' specific needs and should be related in content to their particular occupation.² The education inevitably becomes a two-way street: the teacher becomes more like a language adviser and consultant, having equal status with the learners, who are experts in the subject matter. To a certain extent, a good ESP teacher is familiar with the specific subject matter, or at least shows genuine interest in it.³ S/he should not navigate under the safe flag of general English. Still, the surveys confirmed that ESP and general English were not at war. The respondents recognised the importance of grammar and general English as the infrastructure on which ESP superstructure is built. As Vidak and Didović Baranac (2012) emphasise, ESP uses "the same tenses and sentence structures as the general English" but in different ways and rates. For example, in the sentences "There is no need for a reversible engine if your vessel is fitted with a CPP" or "The amount of boil-off depends on temperature and pressure in the tanks", the ESP teacher has to be familiar with the real job situation, i.e. the propulsion drive systems and the boil-off concept (transporting liquified gases by sea), but the rest of these sentences is general English.

While it seemed rather easy to strike a balance between general and vocational English, the amount of time to be dedicated to grammar remained unclear. Just about 6% of 84 surveyed trainees stated that the ME course should focus on grammar; around 25% reported the teacher should focus on general English, while around 70% expected the teacher should be familiarised with the profession and teach professional English (out of these, 20% admitted that some grammar could be included in the syllabus as well) (Skračić 2023, pp. 64-73). Subsequently, the trainees participated in a quick survey featuring similar questions. This little survey served as a double check. The trainees were allowed to choose more than one option. Here are 160 responses of 84 trainees:

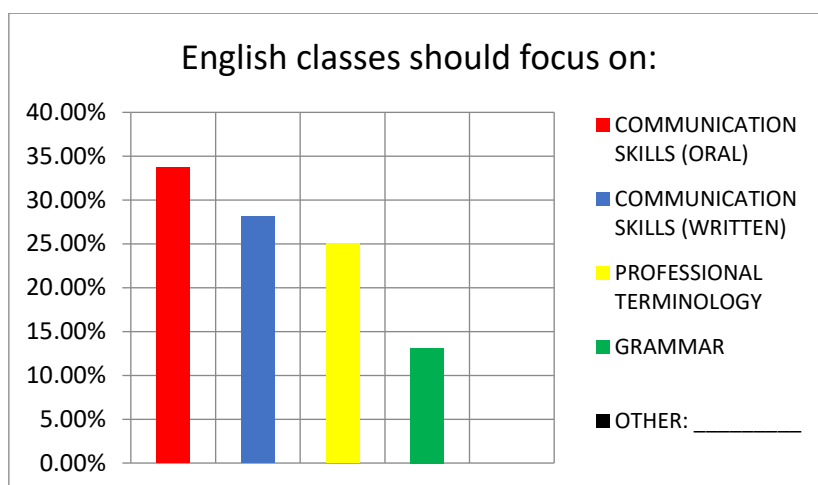


Figure 1. What should ME classes focus on, as viewed by the seafarers (source: the author)

The small grammar rates were both surprising and confusing. Besides, they did not match the actual performance of the respondents during written and oral examination. Between March 2023 and February 2025, four groups (54 seafarers in total) were given a quick initial test in order to clarify the situation. It was a basic

¹ This process revealed that three to four surveys (involving approx. 50 respondents) were enough to produce credible information. The subsequent surveys produced only slight variations in results. This applies to all types of surveys, questionnaires and initial tests conducted.

² See elaborate definitions, features and roles of ESP, teachers and students in: Cigan, 2012.

³ See more about the responsibility of teachers and students in: Fiorito 2005. See more about the seafarers' views on Maritime English teachers and programs in: Skračić 2018, pp. 329-333.

English grammar test (without 2nd and 3rd conditionals, sequence of tenses, and the like) consisting of 20 multiple-choice questions. All four groups performed similarly, with results varying 62-69.5%, providing an average group score of 66%. In Croatian education system, where learners' performance is graded 1-5, 5 being the highest grade, the 66% performance translates into grade 3 (good). Although statistics may be a very useful tool, one has to be very careful when applying these results into a real-life learning environment because the initial tests showed considerable individual deviations. In every group, there were trainees whose performance was very good or excellent (16-19 correct answers out of 20) and the ones whose performance was insufficient (below 10/20), even very poor (e.g. 4-5/20). It is easy to conclude that the ones whose performance is insufficient on the initial test and on the first interim written exam (comprising most of the grammar content) clearly require more attention, i.e. more grammar practice in order to pass the exam and, more importantly, to perform better at work. They will need extra class hours to master the basics of English grammar. This, logically, implies a legitimate question: what will the others do meanwhile?

3. THE FLOATING SECTIONS OF THE MARITIME ENGLISH SYLLABUS

Here we come to the first "floating" section of the syllabus. According to the one of the essential ESP concepts (learner-centered approach meeting individual needs), and based on additional information gathered through this research, it would be counter-productive to force the trainees having good command in grammar to spend one or two days listening to what they already know, when this valuable time can be used for the topics they find interesting / relevant for their individual profession. A number of them expressed various specific needs / topics, depending on their occupation and future on-board or shore-based career plans. The first floating section of the proposed ME syllabus would divide each group of trainees into two sub-groups: one dealing with the basics of grammar, the other dealing with individual fields of interest. Let us assume that 10 class hours would be enough to meet these needs. This increases the teacher's load by 20% as s/he has to be with two sub-groups at a different time. On the other hand, the trainees' load remains the same so far (50 hours). Logically, these parallel activities would observe the framework of the IMO Model Course 3.17 which itself is flexible and explicitly underlines that the providers should regard the course "as a guideline for assisting administrations to develop their own training" and that its intention is not "to present instructors with a rigid 'teaching package' which they are expected to 'follow blindly'".⁴

The second floating part of the syllabus should focus on written communication – a skill that almost all trainees wish to improve substantially. While all respondents claim that they manage to cope with spoken English without major misunderstandings and without accidents resulting from these misunderstandings, they would still like to improve these skills, as indicated in Figure 1 above. Oral communication is easy to practice during classes and learners do it regularly, often without noticing it. On the other hand, practicing written communication requires preparation, explanation and carefully selected material. It includes various reports, but also business letters, requests, applications, recommendations, thank notes, etc. These written exercises require a lot of time, because a number of trainees do not even know how to start a document, let alone how to compose it, end it, respond to it, and use an appropriate register. The existing syllabus does not leave much room for this exceptionally important language skill. Over the years, the ME teachers allocated a few hours to this matter (specifically: writing various reports), but this was far too little to meet the real need.

Working with written documents is a slow process, and therefore it is proposed to allocate 10 extra class hours for developing these skills. This would increase the trainees' load by 20%. The question is how to make this work. According to the STCW Convention, they have a set load for the entire Special Education Program for Seafarers, which means that it cannot be easily changed: one of the solutions is to take 10 hours from other

⁴ IMO Model Course 3.17, Introduction.

course(s) and allocate them to English, but this depends on the goodwill of the teacher(s) whose class hours would be reduced. Even if they agree, the amendments – as already mentioned – have to pass through the Office for Special Education Programs for Seafarers, the Faculty Council, the Rectorate and the competent Ministry. According to the basic principles of ESP, a teacher should be creative, resourceful, flexible; s/he has to be a good time manager and leader to be successful within a limited period of time.⁵ In our view, this is often easier said than done: a teacher may be excellent and have all the above qualities, but she or he is rarely a magician. Therefore, a good ESP teacher should always challenge the given limitations, regardless of the authorities who set it, and attempt to extend the course time, making the compressed timetable bearable.

If this is not possible, the third stage of "floating" takes place; considering the obvious importance of practicing written communication, these hours should be subtracted from the existing English syllabus, in agreement with the trainees, who would decide which of the topics could be reduced / skipped.

4. ME COURSE'S 50 HOURS BREAKDOWN AND ITS FLOATING SECTIONS

Over the period 2018-2024, a specific approach was used in order to clarify which parts of the ME syllabus should be preserved as the course "backbone" and which parts could become variable, optional or floating; in other words, to paraphrase IMO Model Course Introduction guidelines, which parts should not be "followed blindly" but followed carefully, paying close attention to the trainees' abilities and needs, and amended as the situation requires. A total of six questionnaires were conducted involving 77 respondents. They were given a table with a list of 25 compulsory topics covered by the course, followed by a few empty lines for inserting suggestions. They were asked to break down the 50-hour course by allocating the time to each item/unit, according to their preferences. This approach has resulted in a clear framework (and potential floating sections) that can be easily customised in line with the seafarers' needs and abilities.

TOPIC / UNIT	Hours allocated
GRAMMAR – English sentence structure + articles A, AN, THE	2.95
GRAMMAR – ACTIVE VOICE in various Tenses	4.68
GRAMMAR – PASSIVE VOICE in various Tenses	2.26
GRAMMAR – Modal verbs	1.35
GRAMMAR – Numbers + Basic math symbols and operations	0.95
Subtotal: GRAMMAR	12.2 h = 24,4% of the course
NAME OTHER TOPIC / AREA OF YOUR INTEREST: (Responses included IMO & MARPOL regulations, green technologies, fire prevention and fire fighting on board ship, various forms of audits and inspections, shipping company's corporate structure, tasks of the fleet manager, engine superintendent, DPA and other shore-based occupations, port infrastructure terminology, etc.)	2.49
INTRODUCTION to the Course + Short introduction to shipping	1.34
PRINCIPAL PARTS and DIMENSIONS of vessels + SHIP STRUCTURE	1.60
TYPES OF SHIPS: Ro-ro, Car carrier, Ferry, Cruise ship	1.01
TYPES OF SHIPS: General cargo ship, LASH, Container ship, Bulk carrier	1.04
TYPES OF SHIPS: Supertankers, Product and chemical tankers, LNG / LPG carriers	1.01
TYPES OF SPECIAL and MULTI-PURPOSE VESSELS: Heavy-load, OSV, Tug, Cable layer...	1.06
OTHER TYPES OF VESSELS: sail and power yachts, patrol boats, military vessels	1.04

⁵ In addition to P. Robinson (1991) and T. Dudley-Evans and M. J. St. John (1998), this chapter contains references to Hutchinson & Waters (1987) and Zhang (2007), as cited in Sierocka, 2014, pp. 3-17, and in Ahmed, 2014.

MANNING OF VESSELS – Crew tasks and responsibilities: Master, Deck dept., Catering dept., Chief Engineer, Engine room dept.	1.47
SEAMAN'S DOCUMENTS: Seaman's Book, Certificates of competence, Yellow card	1.06
MATERIALS in marine engineering: properties, types of loads/stresses	1.40
MATERIALS in marine engineering: metals, non-metals, alloys – properties and application	1.75
PROPULSION – BASIC CATEGORISATION: human power, sails, engines (inboard, outboard, paddle wheel, water jet, air fans...)	1.83
PROPULSION – TYPES OF ENGINES: internal/external combustion; steam reciprocating, steam and gas turbine, diesel and petrol engine, nuclear power	2.12
PROPULSION and DRIVES: traditional drive, diesel-electric drive; CPP, FPP, azimuth, Azipod, thrusters	1.82
DIESEL ENGINE basic PARTS: cylinder head, valve gear, piston, liner, connecting rod, crankshaft, main bearings...	2.40
DIESEL ENGINE – BASIC CATEGORISATION according to: operating cycle, cylinder arrangement, piston action, piston connection, engine speed, engine drive, reversible/unidirectional...	2.38
STEAM POWER PLANT – Basic cycle and components (boiler, drums, feed pumps, superheater, turbine, condenser...)	1.42
WATERTUBE BOILER – CLASSIFICATION according to: employment, water circulation, drums, pressure, tube inclination	1.35
ENGINE ROOM arrangement and operation: main engine, auxiliaries, control room, traditional and UMS operation	1.86
WRITTEN COMMUNICATION – REPORTS: hand-over, incident / failure / damage / injury / daily / weekly / monthly /overhaul and maintenance report...	1.88
WRITTEN COMMUNICATION – How to write a business letter (address, date, salutation, body of the letter, ending phrases...)	1.96
WRITTEN COMMUNICATION – TYPES: E-mail, Memo, Circular letter, Service letter, Repair request, Requisition of spares and consumables, Statements, CV, Letter of application, etc.	2.52 ⁶
Subtotal: PROFESSIONAL ENGLISH (in cohabitation with general English)	37.8 h = 75.6% of the course
Total: GRAMMAR + PROFESSIONAL ENGLISH + GENERAL ENGLISH	= 100% of the course
FLOATING SECTION: 10 h grammar / 10 h specific needs	= 100%
FLOATING SECTION: extended focus on specific topics / units at the expense of other topics, in agreement with the trainees	= 100%
FLOATING / AMENDED SECTION: extra 10 h of WRITTEN COMMUNICATION exercises (the need explicitly highlighted by the trainees)	= 120%
FLOATING SECTION: While waiting for the official approval of the amendments to the existing syllabus, the WRITTEN COMMUNICATION SECTION is performed at the expense of other topics, shortened or skipped in agreement with the trainees.	= 100%

Table 1. Trainees' allocation of 50 ME course class hours per learning topic / unit

As highlighted before, one should be careful with statistics. The indicated values present an average which may or may not correspond to the true abilities and needs of a particular group / individual. In our surveys, there were respondents who allocated zero hours to ship types or grammar. Other allocated up to 10 hours to

⁶ This value does not match the true needs; it results from the respondents not wanting to exceed the set 50-hour frame, but these needs cannot be covered in 2.5 hours as they constantly pointed out after completing the table.

external combustion engines, obviously because they serve on board such ships. Again, close follow-ups and appropriate (floating) adjustments are necessary in order to obtain the best results.

The white parts of the table contain the topics set by the official syllabus which remain constant; the grey parts represent the topics that are also defined by the official syllabus but are likely to change (float) from group to group and among individual members of a group; one of the grey rows refers to the “specific area of an individual’s interest”. The latter was allocated 2.5 class hours on average, but this value would be much higher if the programme was not congested with a number of other compulsory topics. As suggested above, the trainees with good command in grammar would be in a position to “skip” grammar classes and attend the ones specifically tailored for them. Given the stated interest and variety of topics, it can be assumed that 10 class hours might be enough to cover 3-5 areas of interest effectively.

The considerable extension of the written communication part of the syllabus has become non-negotiable. While waiting for the official approval of the amendments to the existing syllabus, this section is to be performed at the expense of other topics, shortened or skipped altogether, in agreement with the trainees.

The fourth “floating” aspect (not indicated in the above Table) is a theoretical but not unlikely option. Let us assume there is a small group of 10 students: all of them are excellent at grammar, all of them know the appropriate professional terminology, and all of them proved it through the initial stage of the course, performing well during oral communication and scoring at least 66% on all tests: initial, first interim and (early) second interim tests. In this case, the teacher and trainees could agree on what to do with the remaining 50% of the class work.

CONCLUSION

This research suggests a changeable or “floating” syllabus in Maritime English (ME) course that makes part of the Special Education Program for Seafarers at the Faculty of Maritime Studies in Split. The Program and the existing English syllabus have been designed in compliance with national and international regulations, leaving little room for changes. However, the in-class surveys conducted over the past ten years, followed by the results of short questionnaires, self-evaluations, initial tests and final exams, have revealed that a fairly rigid ME syllabus should be amended and made more flexible given the individual needs of the trainees and their diversity in terms of age, English proficiency, motivation, current jobs and career plans.

The floating ME syllabus suggests that the backbone of the programme can be preserved, while some sections can be amended, i.e. extended, reduced, added or omitted. The first floating section is grammar. Based on the results of the initial test and the first interim test, each group can be divided into two sub-groups: the ones whose command in grammar is poor would have extra 10 hours of grammar, while the others would attend 10 hours covering the specific fields of interest they have expressed. Furthermore, there could be minor floating adjustments to the syllabus, with reference to the 50-hour-breakdown table that was inserted above as a guideline tool: when a number of trainees allocate zero hours to one topic, or many hours to another topic, this must be regarded as a call for adjustment. Another floating section of the syllabus ideally extends everyone’s in-class work by 10 hours or 20%, to be dedicated to developing writing communication skills of the trainees. This need has been noticed by the teacher, but also repeatedly emphasised by the trainees themselves who feel that better writing skills would make them much more efficient and competitive in the complex and ever-changing world of seaborne shipping. In case the extended workload is not officially feasible, the written communication section is performed at the expense of other topics / units, shortened or skipped in agreement with the trainees. The last “floating” aspect of this ME syllabus is a theoretical option, which does not make it unlikely to happen: in the event that the trainees’ command in English is either excellent or exceptionally poor,

the syllabus may change by 50% or more, depending on the abilities and the needs of the seafaring marine engineers.

Some of these proposals may seem heretic but one has to be reminded that designing and re-designing a syllabus is one of the essential tasks of a (good) ESP teacher and that the IMO / STCW conventions strongly encourage this learner-centred approach underlining that their guidelines are not commandments carved in stone and are not supposed to be followed blindly.

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Vertical Flight (in)Efficiency: A Systematic Review of Benefits, Challenges, and Implementation Considerations

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Vertical Flight Efficiency (VFE) has emerged as a promising avenue in the Air Traffic Management (ATM) domain due to its potential to optimise fuel consumption, mitigate environmental impacts, and improve airline cost efficiency. This review article critically evaluates the benefits and limitations of VFE, with a particular emphasis on Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO). The study aims to present outcomes of a systematic synthesis of literature in the field of study, thus detailing the benefits and challenges associated with VFE. The methodology relies on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, ensuring a methodologically transparent approach to literature selection and data extraction. Accordingly, the review categorises studies according to their insights into the benefits of VFE, while also identifying key constraints, including those arising from atmospheric conditions, aircraft performance models, and operational complexities. The analysis indicates that significant advancements in fuel efficiency, reduced trip durations, lower Air Traffic Controller workload, decreased fuel costs, and emissions reductions are achievable. However, external factors often constrain these potential gains, including meteorological instability, vast technical and exploitation specifications of aircraft, and the operational limitations imposed by existing Air Traffic Control (ATC) practices. Additionally, the increased procedural complexity of implementing VFE strategies, i.e. CDO and CCO procedures, may elevate operational risks and pose difficulties in ensuring compliance with vertical profiles. In conclusion, the review paper emphasizes the necessity of balancing VFE's environmental and operational benefits with its inherent limitations. Although VFE presents a promising pathway for enhancing the sustainability and efficiency of ATM system, its effective implementation requires addressing considerable technical and procedural challenges. Therefore, this review paper outlines the relevancy and necessity of future research which should be oriented towards developing comprehensive models and strategies that integrate VFE within broader ATM systems.

KEYWORDS

Vertical flight efficiency; Continuous descent operations; Continuous climb operations; Air traffic management

1. INTRODUCTION

Vertical flight efficiency (VFE) has become one of key focuses in Air Traffic Management (ATM). EUROCONTROL's ECAC-wide study (European CCO/CDO Task Force, 2020) highlights potential annual savings of up to €150 million, 350,000 tons of fuel, and 1 million tonnes of CO₂ emissions. However, the study also notes that 100% optimization in European airspace is unattainable due to constraints such as safety requirements, maintaining separation distances, weather, airspace capacity, and Air Traffic Control Officer (ATCO) workload. These factors, integral to the ATM system, necessitate minor inefficiencies to maintain flexibility and operational stability. To address vertical flight inefficiencies, techniques like Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) have been developed, as outlined in ICAO Documents 9993 (International Civil Aviation Organization, 2013) and 9931 (International Civil Aviation Organization, 2010) respectively. Improving VFE remains central to global aviation efforts to enhance operational efficiency and sustainability. ICAO's Global Air Navigation Plan (International Civil Aviation Organization, 2025) introduces Key Performance Indicators (KPIs) targeting level-off reductions during climb and descent phases, as these deviations increase fuel use, greenhouse gas emissions, and operational costs. By minimizing these inefficiencies, ICAO aims to reduce environmental impacts and financial burdens for airspace users. Regarding CDO, a 2017 study by Howell and Dean (2017) demonstrated over 30% savings in fuel and time at airports utilizing optimized profile descents and metering. Additionally, CDO compliance reduces noise impact by keeping aircraft at higher altitudes on approach and reducing power during descent, mitigating noise in residential areas (Clarke et al., 2004; Williams et al., 2004). Despite these benefits, VFE implementation faces challenges, including technological limitations, ATM complexities, and differing stakeholder priorities. For instance, Weitz et al. (2006) emphasize the importance of accurate trajectory modelling for successful CDO adoption. Furthermore, diverse operating environments and infrastructure disparities exacerbate implementation challenges. A literature review reveals a gap in comprehensive studies addressing the benefits, challenges, and practical considerations of VFE. While many research efforts focus on specific aspects, a unified framework encapsulating these elements is lacking. The main goal of this study is to fill that gap by offering a holistic overview of VFE's benefits, challenges, and implementation considerations. The findings aim to support informed decision-making, improve prioritization of VFE initiatives, and promote harmonized strategies, ultimately advancing environmental sustainability, operational efficiency, and collaboration of stakeholders within the aviation industry.

2. METHODOLOGICAL FRAMEWORK

Systematic reviews and meta-analyses have become increasingly important in all research areas (Sharif et al., 2018; Oláh et al., 2020; Liu et al., 2022). A systematic review consolidates all relevant evidence that meets pre-defined eligibility criteria to address a specific research question. This study adopts the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, an approach originally developed in healthcare research to establish clinical practice guidelines and support clinical decision-making through a structured methodological process (Moher et al., 2015; Cooper et al., 2018). However, in a 2010 study, Moher et al. (2010), concluded that the general concepts and topics covered by PRISMA are all relevant to any systematic review. Accordingly, the study noted that some modifications of the checklist items or flow diagram will be necessary in particular circumstances.

The PRISMA flow diagram employed in this research paper adheres to a four-step process—Identification, Screening, Eligibility, and Inclusion—to ensure a systematic and rigorous approach to literature review. The study focused on two prominent scientific databases, Web of Science (WoS) and Scopus. The primary selection criteria were peer-reviewed scientific articles and book chapters written in English that addressed VFE. The systematic review process was conducted in three main phases: identification, screening,

and eligibility. The selection of appropriate keywords played a critical role in identifying relevant literature. Searches were conducted on WoS and Scopus using predefined search strings until 10 December 2024. The search strategy for the WoS database involved using the search string: records containing the terms “vertical flight efficiency”, “continuous climb operations”, or “continuous descent operations” within their topic fields. For the Scopus database, the search string targeted records with these terms appearing in their title, abstract, or keywords. The identification phase yielded a total of 2346 records (Figure 1), comprising 1029 records from WoS and 1317 records from Scopus. The screening phase began with the removal of 216 duplicate records, leaving 2130 unique records. These were further filtered using predefined inclusion and exclusion criteria. Only journal articles, conference proceedings, and book chapters published in English after the year 2000 were considered. Records irrelevant to the topic were excluded. This screening process narrowed the selection to 84 records for in-depth analysis. Finally, 23 records were deemed relevant for inclusion.

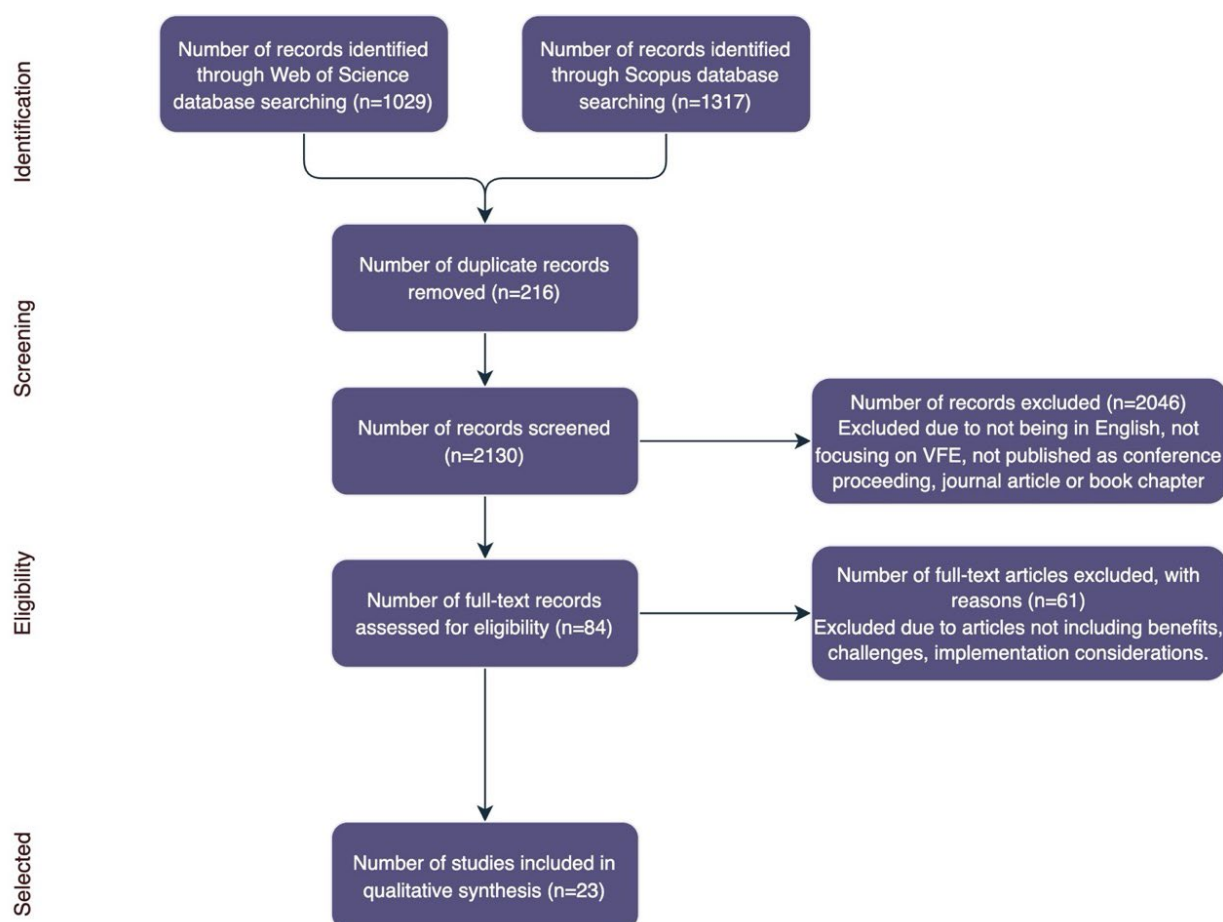


Figure 1. Methodological framework

3. MAIN RESEARCH FINDINGS

The synthesis findings indicate that the benefits, challenges, and implementation considerations in the VFE research avenue have been explored across a range of flight phases and publication types, highlighting the diversity of scholarly contributions in this domain. As outlined in Table 1, the dataset comprises 12 Journal Articles (JA), nine Conference Proceedings (CP), and two Book Chapters (BC). Specifically, all the studies included in the review were published between 2006 and 2023.

Regarding flight phases, 15 records focused on the descent (DES) phase, three on the climb and descent (CLB + DES) phase, and five on the climb (CLB) phase. The methodologies employed in the reviewed literature encompass a diverse range of approaches, reflecting the complexity and multifaceted nature of VFE research. These include simulation-based studies (10), analytical modelling (7), empirical analysis (2), qualitative research methods (2), case studies (1), and mixed-method approaches (1). Each methodology contributes unique insights, with simulation and analytical modelling being the most prevalent, primarily due to their ability to analyze and predict flight performance under varying conditions. Notably, all records identified both the benefits and challenges associated with VFE; however, 95.65% of the analyzed studies contained implementation considerations, indicating a gap in addressing practical application.

Authors	Type	Phase	Methodology	Benefits	Challenges	Implementation considerations
Turgut et al., 2010	JA	DES	Simulation	fuel; emissions; time	traffic density limitations; technological barriers	technology integration; ATM strategies
Wilson and Hafner, 2006	CP	DES	Simulation	fuel; emissions	procedure changes; ATCO decision support	technology integration; stakeholder engagement
Dimitriu et al., 2010	CP	DES	Case study	noise footprint; fuel; sustainability	lack of assessment methodology; technological barriers; Traffic density limitation	collaborative action plan; training
Vempati, 2015	CP	CLB + DES	Empirical Analysis	Procedure Flexibility	weather; traffic congestion	-
Lemetti et al., 2021	BC	DES	Empirical Analysis	fuel;	weather;	optimization of CDOs; ATM automation impact
Rosenow et al., 2022	JA	CLB + DES	Analytical modeling	fuel; incremental optimization	operational constraints; incomplete data; dependence on accurate weather data	gradual implementation; implementation complexity
Del Pozo Domínguez et al., 2023	CP	DES	Mixed method	classification of inefficiencies; operational insights	limitations of current metrics; data availability	fuel penalty metric
Alexandrov et al., 2022	JA	CLB	Analytical modeling	fuel; applicability to medium-haul aircraft	data requirements; complexity of modeling; limited savings	gradual implementation; data preparation; integration
Pasutto et al., 2020	CP	DES	Analytical modeling	actionable recommendations	complex interdependencies; operational constraints	local practices; CDO facilitation
Efthymiou et al., 2019	JA	DES	Qualitative	environmental benefits	increased ATCO Workload; training; lack of predictability	ATCO training; phraseology; communication; procedures harmonization
Pérez-Castán et al., 2018a	JA	CLB	Simulation	fuel; emissions; time	uncertainty in mass estimation; limited scope	separation minima; algorithm integration
Pérez-Castán et al., 2018b	JA	CLB	Simulation	Reduced ATC Interventions; Zero Delay Scenarios	capacity reduction; delays; ATCO workload	optimized scheduling; dynamic separation standards
Pérez-Castán et al., 2020	JA	CLB	Simulation	workload redistribution; scenario-based evaluation	increased TWR workload; conflict management complexity	workload calibration; training
Levy and Bassett, 2017	CP	CLB + DES	Simulation	fuel; time	data limitations;	prioritize high-benefit Airports; standardize models
Turgut and Usanmaz, 2012	JA	DES	Analytical modeling	fuel; emissions; noise	complex trade-offs; the impact of aircraft mass	dynamic FPA optimization; emission monitoring
Díaz et al., 2019	JA	CLB	Simulation	fuel; noise; workload (TMA)	local operational preferences; compliance	localized adaptation; compliance monitoring
Errico and Di Vito, 2019	CP	DES	Analytical modeling	fuel; operational costs; environmental benefits	technical implementation; training	simulation and testing;

Toratani et al., 2020	JA	DES	Simulation	predictability; compatibility with existing systems	simulation conditions; complexity in congested airspace	procedure integration into congested airspace
Robinson and Kamgarpour, 2010	CP	DES	Simulation	fuel; environmental	variability in fuel savings; traffic and conditions sensitivity	context-sensitive prioritization; detailed modeling
Hirabayashi et al., 2021	BC	DES	Qualitative	enhanced ATCO decision-making; CDO Success Rate	trajectory prediction; conflict prioritization	trajectory prediction technology; support displays integration
Thoma et al., 2022	CP	DES	Analytical modeling	noise;	trade-offs - noise and emissions; external factors	scenario-specific optimization; comprehensive modeling; weather
Jin et al., 2013	JA	DES	Analytical modeling	fuel; environmental impact	the complex relationship between variables; operational limitations	simulation and evaluation
Hoffmann and Walton, 2018	JA	DES	Simulation	increased runway throughput; Congestion	technology integration; testing and validation	incremental testing; phased deployment

Table 1. Overview of reviewed studies

4. DISCUSSION

Regarding benefits, 13 studies identified fuel savings as a significant advantage. For instance, Turgut et al. (2010) demonstrated that transitioning from conventional procedures to CDO could yield fuel savings of 44.3 kg per flight for a single airliner. Expanding the analysis to an airport-level perspective, Wilson and Hafner (2006) estimated that VFE improvement during the descent phase could result in fuel savings exceeding \$29 million annually at a single hub airport. Similarly, Errico and Di Vito (2019) reported fuel savings of up to 30% when compared to standard arrival routes, with simulation results indicating a corresponding reduction in environmental impact, particularly in chemical emissions due to decreased fuel consumption. Time savings were also identified as a notable benefit. Pérez-Castán et al. (2018a) emphasized the potential for operational time efficiencies. Further supporting this, Diaz et al. (2019) quantified the benefits as a 10-28% reduction in noise levels and a 7-23% decrease in fuel consumption. The study also highlighted a potential reduction in ATCO workload within Terminal Maneuvering Areas (TMAs). Pérez-Castán et al. (2018b) elaborated on this aspect, reporting a potential decrease in the need for ATC interventions. This finding was extended in a subsequent study (2020), which noted a redistribution of ATCO workload, further supporting the operational and environmental advantages of improved VFE.

Several challenges in VFE research have been identified in the reviewed studies. Robinson and Kamgarpour (2010) highlighted variability in fuel savings as a significant issue, emphasizing that variations across flights and days complicate cross-study comparisons. Additionally, the study concluded that the anticipated fuel savings per flight may not translate into reduced travel costs for passengers. Data-related limitations have also been noted. Studies by Del Pozo Domínguez et al. (2022) and Alexandrov et al. (2022) identified challenges associated with data availability, the complexity of data requirements, and the intricacy of modelling. These challenges underscore the need for robust data collection and processing frameworks to enhance the reliability of VFE studies. Similarly, Pasutto et al. (2020) revealed complex interdependencies in VFE systems, which further complicate modelling and implementation efforts. Technological and operational constraints have also been widely discussed. Studies by Dimitriu et al. (2010), Turgut et al. (2010), Errico and Di Vito (2019), and Hoffmann and Walton (2018) highlighted barriers related to technology adoption, operational limitations, and system constraints. These findings suggest that effective VFE implementation requires addressing technological gaps and reconciling operational challenges to ensure feasibility and efficiency. Challenges specific to airports and operative ATM were also reported. Pérez-Castán et al. (2018b) identified a potential reduction in airport capacity because of implementing CCO. Furthermore, Efthymiou et al. (2019) noted an increase in ATCO workload when implementing CDO. However, their study concluded that while ATCO

workload increases, it should not impede CDO implementation if managed effectively. Lastly, Hirabayashi et al. (2021) highlighted challenges in trajectory prediction, emphasizing the need for high-accuracy prediction technologies to support VFE operations. The study pointed out that improving trajectory prediction accuracy is essential for enhancing the effectiveness and reliability of VFE procedures.

The complexity of implementation and the necessity for a phased approach have been identified as critical implementation considerations in a study by Rosenow et al. (2022). These findings underscore the challenges of integrating VFE procedures into the ATM system. Additionally, Levy and Bassett (2017) examined the economic implications of level-altitude flight segments, concluding that implementation efforts should prioritize high-benefit airports. Their study highlighted that the economic impact is particularly pronounced in airports within the New York City area, suggesting a targeted approach to maximize benefits. Local geographical and operational conditions also play a significant role in shaping implementation strategies. Jin et al. (2013) emphasized that feasible procedures must be tailored to the specific geographical environment and traffic patterns of each region. They recommended conducting simulations and evaluations of these procedures before implementation to ensure their practical applicability and effectiveness. Scenario-specific optimization was also highlighted as an essential factor. Thoma et al. (2022) found that the outcomes of VFE procedures are highly sensitive to flight parameters, necessitating tailored optimization strategies. Their study stressed the importance of accounting for a range of factors, including noise impact, fuel efficiency, and pilot workload, to achieve a balanced and effective implementation. Lastly, Toratani et al. (2020) investigated the feasibility of applying continuous descent operations (CDO) in congested airspace with speed control functionality. Their findings revealed that a fixed Flight Path Angle (FPA) descent, an enhancement of CDO, possesses the necessary capabilities for integration into congested airspace. This suggests that procedure modifications and augmentations may be required to address the specific demands of high-density traffic environments. Figure 2 displays a consolidated overview of the distribution of the main research findings.

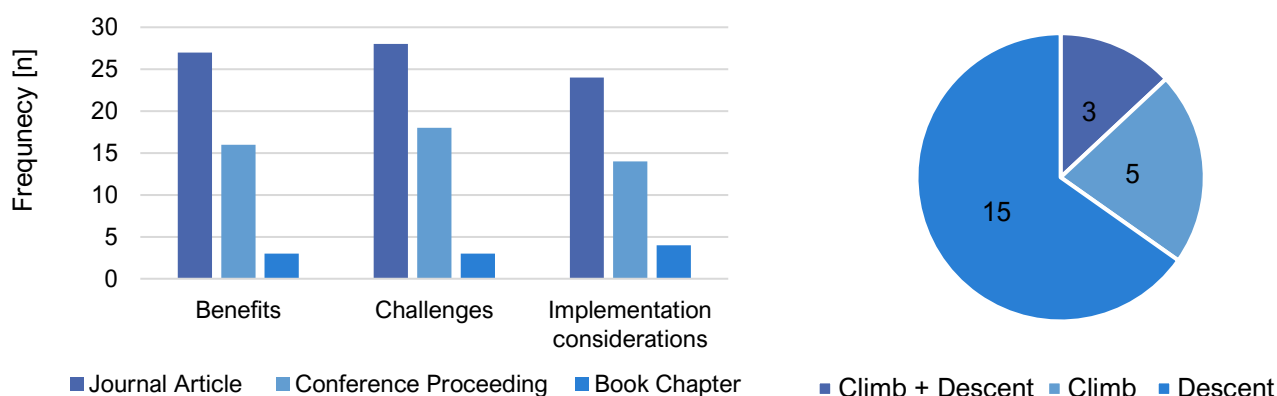


Figure 2. Frequency of research considerations (left) and share of flight phases (right)

5. CONCLUSION

The present review encompassed key insights from 23 studies examining the benefits, challenges, and implementation considerations associated with VFE, with a specific focus on CCO and CDO. The findings highlight significant potential benefits, including fuel savings, reduced emissions, time savings, and, in some instances decreased TMA ATCO' workload. Notable examples include reported fuel savings of up to 30% when compared to standard arrival routes, and noise reductions of up to 28% in certain cases. However, the review also identifies substantial challenges, such as variability in fuel savings, data limitations, modelling complexity,

and operational constraints. Interdependencies between various factors, such as airport capacity and ATCO's workload, further complicate the adoption of VFE procedures. Implementation considerations emphasize the need for gradual, context-specific approaches, as well as the importance of addressing technical and operational limitations to ensure successful integration into existing ATM systems. While the potential of VFE to enhance sustainability and efficiency in air traffic operations is clear, its successful implementation requires a holistic approach that balances environmental, economic, and operational factors. Future research should prioritize scenario-specific VFE optimization and the assessment of VFE compliance. Additionally, the reviewed literature highlights the need for studies exploring the impact of weather on VFE and the influence of airline business models.

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ADS-B Technology as a Support to the Air Traffic Management System

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Automatic Dependent Surveillance – Broadcast (ADS-B) is a surveillance system developed to allow for a wide exchange of flight and navigational information via data-link network between Air Navigation Service Providers (ANSPs) and the airspace users, as well as between airspace users themselves. The system relies on installation of an on-board transceiver, usually coupled with aircraft S-mode transponder equipment, and a ground radio equipment that feeds the Air Traffic Services' data transmission channels. Data exchange is performed via two principal modes: ADS-B *In* and ADS-B *Out*, providing both sides with a complete air picture. The future Air Traffic Management (ATM) system heavily depends on the wide and safe use of ADS-B technology in support of increase and optimization of airspace capacity, situational awareness, efficiency and safety of air transport operations. In order to establish itself as a primary surveillance mechanism, and besides of adoption of wider implementation strategy, ADS-B needs to conform to all of requirements that allow for a safe aircraft separation in a cooperative environment. This research paper provides a review of a current implementation of ADS-B status as a support to ATM system with an outlook of key areas of scientific research on perceived deficiencies of the system. In that regard, the paper focuses on the transmission range and interference aspects, accuracy of transmitted data and vulnerability of ADS-B systems to malicious attacks.

KEYWORDS

Air traffic management; ADS-B; Data-link; Situational awareness

1. INTRODUCTION

ADS-B corresponds to a set of specifically designed avionics used for the transmission of a set of flight and navigation related information in real time, by the modality of data-link exchange. The system itself is dependent in a sense that needs to be coupled with a Global Positioning System (GPS) to retrieve precise data sets for further broadcast via S-mode transponder on 1090MHz frequency - ES (Extended Squitter) for the data protocol. The automatic nature of the system indicates that it is activated without control or any other input from the pilot. The broadcast of relevant information is distributed among key stakeholders in the air transportation system, with airspace users and Air Navigational Services being the most important. By transmission of the identification and flight data, heightened situational awareness is sought among airspace users further allowing for the optimization of airspace capacity, efficiency and safety of flight operations. The main advantages of the system are its accuracy and shared availability. As such, ADS-B has established itself as a cornerstone of few important global aviation-related initiatives, most notably the NextGen Air Transportation in United States (Federal Aviation Administration - FAA, 2020) and Single European Sky ATM Research - SESAR in Europe (SESAR, 2020). In parallel, the use of airborne ADS-B equipment is steadily trending upwards, following the same trend in the development of the ground-based infrastructure, with estimated more than 1,000 ground stations in 25 European states. Further saturation of ground-based network is mandated through regulatory guidance (International Civil Aviation Organization - ICAO, 2022). Offering enhanced capabilities over existing surveillance systems, ADS-B will continue to increase its functionalities and global usage, while requiring multilayered implementation strategies to maintain high safety and operational standards. The objective of the paper is to review modalities of ADS-B technology as a support to ATM system with an insight on potential weaknesses that warrant further research in order to reach desired safety standards.

2. ADS-B AS AN ENABLER OF ADVANCED SURVEILLANCE MODALITY

ADS-B has emerged as one of redundant modalities within the Communications, Navigation and Surveillance (CNS) service of the ATM system. After its conceptual inception in 1990's, first comprehensive set of procedural requirements was laid in ICAO's ATM procedural document (ICAO, 2007). Afterwards, ADS-B has introduced a number of important features that have solidified this modality to become a focus point among means of surveillance of the future ATM system. Among others, these are primarily related to a capacity of full network coverage, air-to air surveillance, improved safety, increased capacity and cost-efficiency and compatibility with envisaged requirements in spacing and separation (Skybrary, 2025). In order to reach its maximum applicability, ADS-B can operate in two distinct sub-modalities. As such it is possible to differentiate ADS-B In and ADS-B Out. Both "In" and "Out" functions refer to the direction in which data travels and is further processed. In case of "Out", the aircraft broadcasts the flight data to the network of users which is constituted by ground stations (and Air Traffic Control (ATC) in extension) or other aircraft. Similarly, "In" function refers to capacity to receive broadcasted messages from other aircraft and in contrast to "Out" – it is not fully mandatory. By provisions of several global regulators, ADS-B Out is mandatory within specific classes of airspace as well as specific airframes categories (FAA, 2025, European Commission, 2011). Figure 1 illustrates the fundamental concept of ADS-B In and Out functions among airspace users, including their interaction with Air Traffic Control.

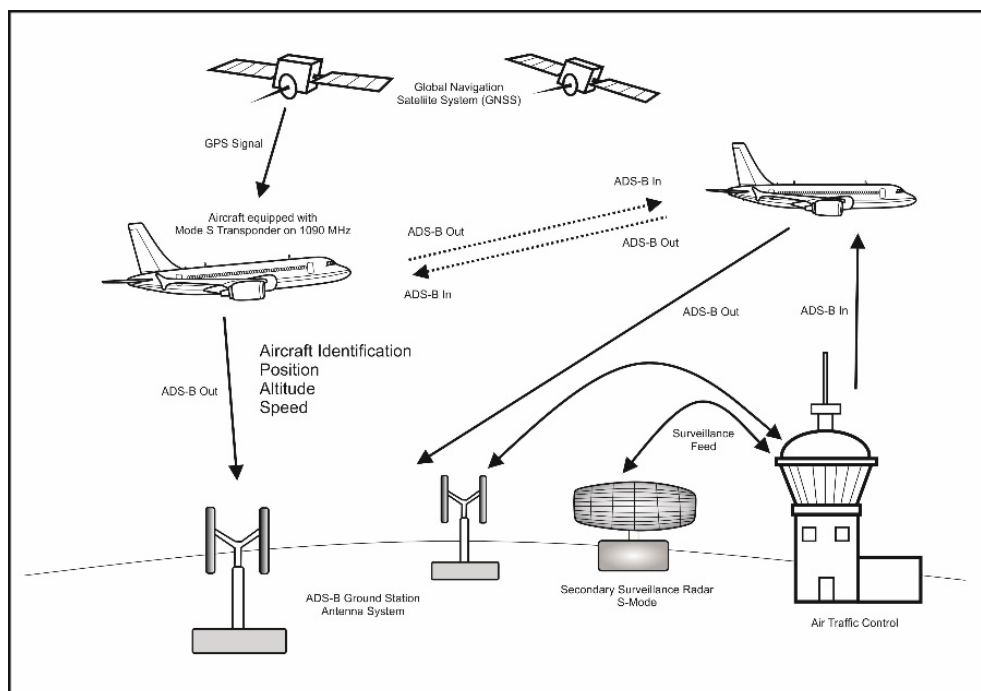


Figure 1. Basic concept of ADS-B *In* and *Out* functions

The networking of highly accurate position and navigational data via ADS-B equipment is what constitutes the principal advantage over Primary and Secondary Surveillance Radar (PSR/SSR). Mainly as it has significantly enhanced the situational awareness and flight safety. In the context of performance in non-failure analysis, ADS-B demonstrates a significant enhancement in positioning accuracy over the other surveillance sensors, such as WAM (Wide area Multilateration) or SSR (Septiavan et al., 2020; Zhang et al., 2011). Even though reliability of ADS-B may be influenced by externally or internally caused errors, cross track analysis demonstrates 95% accuracy of aircraft better than 51 meters from real position (Verbraak et al., 2017). Although ADS-B has certain vulnerabilities, which are addressed later, another key advantage of ADS-B is its capacity to maintain functionality in non-radar areas. Presently, the system is reliant upon a network of ground stations over landmass while space-based ADS-B is gaining momentum as a solution for the coverage over large water areas.

2.1. ADS-B and its current implementation status

The implementation of ADS-B technology within the CNS/ATM framework demands a coordinated effort of multiple stakeholders including airspace users, ANSPs, airports and Network Manager. This process is developing simultaneously with other facets of CNS/ATM modernization, such as Performance Based Navigation and Data-link enhancements, as well as other evolutions of airborne and ground surveillance infrastructure. Prior the separate implementation processes commence globally, ICAO has established initial requirements based on the prerequisite of standard harmonization. Mainly to prevent potential incompatibilities between states or regions (ICAO, 2014).

In Europe, the main regulatory framework is exercised by the European Commission through its agency – European Union Aviation Safety Agency (EASA) which is mandated to regulate safety and environmental sustainability in civil aviation along with technical support in certification. Existing regulatory framework lays the requirement that all aircraft are equipped with serviceable SSR transponders having the capabilities set out in Part A of Annex II of Regulation (EU) No 1207/2011, requiring these aircraft to be compliant with Mode S Elementary Surveillance. In addition, aircraft with a maximum certified take-off mass exceeding 5,700 kg or having a maximum cruising true airspeed capability greater than 250 knots, for which the individual certificate

of airworthiness was first issued on or after 7 June 1995, are required to be equipped with serviceable SSR transponders, compatible with ADS-B Out function, among others (European Commission, 2020). The oversight of the implementation of ADS-B, both in terms of ground infrastructure and airborne equipment, falls within the remits of SESAR Joint Undertaking, i.e., SESAR Deployment Manager. It reports about the progress through the Implementation Plan (SESAR, 2020) in close cooperation with EUROCONTROL. Figure 2 shows a progress of the instalments of airborne ADS-B equipment, displayed in combination with a projection of final phase-out of state-owned non-compliant aircraft by the end of October 2025. The instalments are seen as either retrofits, which refer to the installation of ADS-B equipment on the existing aircraft that were not initially equipped, or forward fits, which refer to new aircraft. As reported by the EUROCONTROL, the equipage by January 2025 has reached 96.9% for the aircraft, and 98.7% for the flights within the European airspace (EUROCONTROL, 2025). Thereby, the ground component of the ADS-B implementation heavily depends on national ANSPs and airports. In this context, SESAR estimates that approximately 64% of the European airspace, managed by European ANSPs, is covered.

The implementation of ADS-B under the jurisdiction of the Federal Aviation Administration (FAA) in the United States follows a similar trend, mandating the use of ADS-B Out equipment. This requirement primarily applies to specific classes of airspace rather than particular categories of aircraft. For instance, since Jan 2020, federal regulations mandate the use of ADS-B in airspace Class B and Class C (upward to 10,000 feet), Class E above 10,000 feet (and above 3,000 feet over Gulf of Mexico) and Class A up to FL600 (FAA, 2020). As of 2021, the FAA has deployed a network of approximately 630 ground-based ADS-B stations (Post, 2021) and as 2022, more than 178,000 aircraft registered in the United States are equipped with ADS-B Out (FAA, 2022).

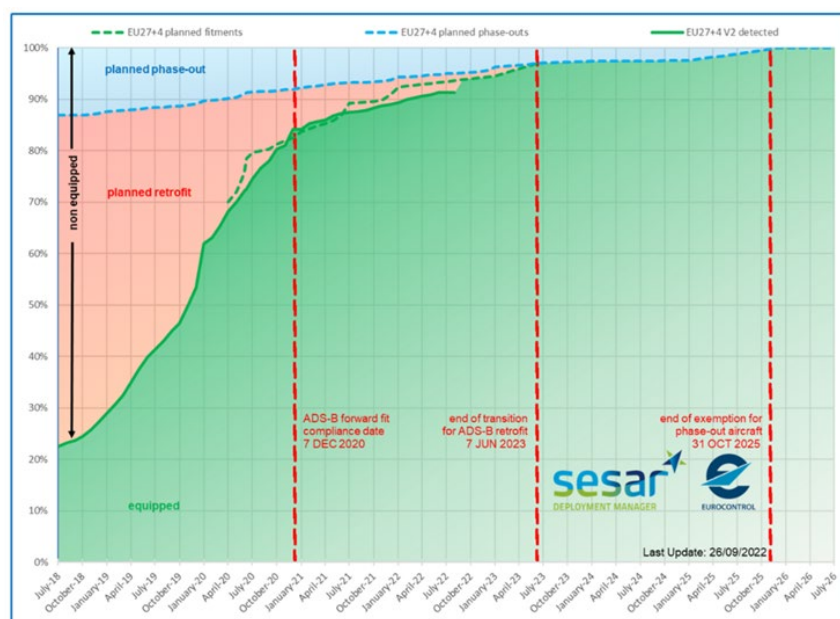


Figure 2. Status of airborne equipment implementation in EU27+4 (Source: SESAR, 2022)

2.2. Technological aspects of ADS-B in support of ATM system

From a viewpoint of air transport technology, any surveillance system is primarily designed to exchange data which provides an accurate position of an aircraft, insight required to maintain safe vertical and horizontal separation of airspace users. In extension, ATM procedures will favor those which achieve most capacity and efficiency of flight operations. In order to achieve maximum efficiency, the ATM system will gravitate towards the most capable system in terms of accuracy, availability, update rate (interrogation frequency) and coverage. As a system, ADS-B demonstrates applicability and superior performance across all these categories.

The navigational data provided by ADS-B is provided through the use of extended squitter mode of MODE-S transponder and the transmission on a basis of Pulse Position Modulation (PPM). The extended function refers to additional message capacity in relation to standard, short squitter sequence used by traditional Mode-S interrogation process via SSR. The ADS-B message structure therefore constitutes of 56 bits message of basic ICAO structure and additional 56 bits (total of 112 bits) of ADS-B message in Download Format 17 (DF-17), a format reserved for ADS-B data traffic. The ADS-B frame consists of five parts as shown in Table 1.

Downlink Format (5 bits) *Type of message transmitted	Transponder Capability (3 bits) *Transponder Mode S capacity	ICAO aircraft address (24 bits) *Unique code of 24 bits that identifies each aircraft.	ADS-B message - Extended Squitter (56 bits) *ADS-B message data	Parity/ Interrogator ID (24 bits) *Error detection code

Table 1. The structure of Extended Squitter message which includes the ADS-B data

When transmitted in its entirety, ES message format provides a host of valuable information which is not only limited to ADS-B data. In that regard, the ATM system has a spectrum of operational data at its disposal which allows for more granular approach in separation of aircraft in the (un)controlled airspace volume, but also during ground movements. Inherent in its structure, ES message provides a safety mechanism to avoid transmission errors. The ADS-B part of ES message is comprised of various navigational information that are derived mostly from GNSS data, but also from on-board equipment. The type of an ADS-B data frame content is determined on a Type code preceding the frame itself, and the content is further described in Table 2.

Type Code	Data Frame Content
1-4	Aircraft identification
5-8	Surface Position
9-18	Airborne position (with barometric Altitude)
19	Airborne velocities
20-22	Airborne position (with GNSS Height)
23-27	Reserved
28	Aircraft status
29	Target state and status information
31	Aircraft operational status

Table 2. ADS-B Data Frame Content on a basis of different type codes (Source: ICAO, 2022)

The timely and frequent provision of aforementioned navigational data is a cornerstone of the enhanced situational awareness for both airborne users and the Air Traffic Control Officers (ATCOs). The next step in this process is a visualization of received data via ADS-B in function which is regularly performed in the cockpit environment of appropriately equipped aircraft by populating navigational displays with relevant information. This serves the situational awareness of relative position versus other airborne users, supports the avoidance of traffic and, in extension, allows for more efficient traffic separation and safety of flight operations. In that regard, Figure 3 displays Airborne Traffic Situational Awareness (ATSAW) on Cockpit Display of Traffic Information (CDTI), depicted in two configurations. The left-hand side visualization displays airspace situation based on Airborne Collision Avoidance System (ACAS) input, while the right-hand side visualization shows enhanced situation with aircraft identification and heading enabled by ADS-B in function.

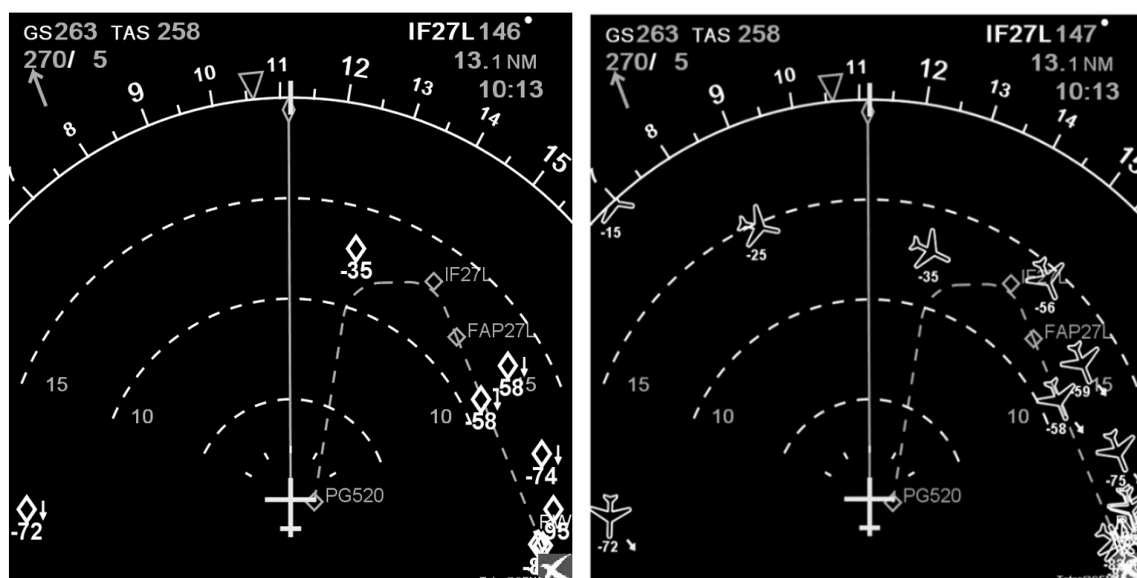


Figure 3. Air traffic situation displayed on CDTI with basic ACS input (left) and enhanced situation enabled by ADS-B (right) (Source: ICAO, 2020)

3. ADS-B SIGNAL PROPAGATION AND INTERFERENCE

The range of ADS-B transmission varies upon several parameters closely related to optical properties of radio waves. The interference of radio transmission within the 1090 MHz is one of the most prominent parameters when accounted for the congestion of the said band, which is universally used for transponder MODE-S service. In contrast, refraction may exhibit a positive effect on the range, which may be further influenced by the placement of the ground antenna in relation to its altitude and properties of the surrounding terrain. In average, range between two aircraft may extend up to 172 NM, while the range between an aircraft and a ground receiver extends up to 150 NM (Crnicki, 2016.) However, in permissive conditions, the range may extend beyond 200 NM and it will be defined as a maximum distance where the probability of received signal without interference will be set above a certain threshold. The propagation of ADS-B carrying signals is dictated by optical properties of the radio waves within the Ultra High Frequency (UHF) band. In this case, the propagation of ADS-B signaling occurs on the Line-of-Sight principle, with some minor effects of scattering within the tropospheric altitudes. Lower values of effective average range between a ground station and an aircraft are a direct consequence of negative effects imposed by absorption and diffraction, mostly caused by the terrain and other obstacles surrounding the ground station infrastructure. In addition, weather conditions exert another attenuation effects on the UHF signals, with outdoor air temperature, humidity and pressure having the most prominent and inversely proportional effect (Amajama, 2016).

When designing a ground station network with respect to its spatial distribution, there are no specific regulatory guidelines, except for a preference toward ensuring coverage in areas where Flight Information Regions (FIRs) overlap. This leaves the decision to be made primarily on the basis of coverage potential, for which the most important variables are the station altitude and surrounding terrain configuration and topography which would represent the obstacle to radio transmissions. In areas with no radar coverage, i.e. large water surfaces, ADS-B Out signal may be received via satellite platforms orbiting in Low Earth Orbit. After European Space Agency's funded research that proved the concept with above 50% probability of intercepting ADS-B signals from PROBA-V satellite system (Werner et al. 2014), many studies have addressed different aspects of potential deficiencies of space-based ADS-B signal reception (Nguyen et al., 2015; Schmitt et al., 2019) until a commercial project named Aireon has equipped eight Iridium satellites with ADS-B receivers. Similarly, potential

range amelioration was studied via use of stratospheric balloons equipped with ADS-B receiver (Francis, 2011), although this approach wasn't investigated elsewhere to equal extent.

In principle, the interference range may be derived as a function of transmitter and receiver antenna power, cable loss and standard free space loss (Barhydt et al. 2004). The interference may be significant to the point that it degrades signal to the level at which services that rely on ADS-B data become suboptimal. The primary source of unintentional interference arises from SSR interrogation replies operating within the same 1090 MHz bandwidth, leading to false replies. Thereby, considering projections of future increase of air traffic volume, there is a need for enhancement of receiving methods which will eliminate occurrence of false replies (Chiocchio et al. 2020). Another aspect refers to interference in case of overlapping of ADS-B signals which is proportional to increase of distance. This increase is a consequence of proportional increase in air traffic volume equipped with ADS-B Out with distance from ADS-B equipped aircraft (Langejan et al. 2016). Therefore, it may be outlined that potential of extending the signal range without the detrimental effect of interference may not be viable without advancements in the field of reception technology which should be able to decode overlapping frames. Beyond technical approaches, there are evidences which have demonstrated the potential of advanced algorithms applied at multiple stages of reception using Software Defined Radio (SDR) (Habibi et al., 2022).

4. VULNERABILITY OF ADS-B TOWARDS INTENTIONAL AND MALICIOUS ACTIONS

The interference as a physical property of radio waves is by its very nature unintentional. However, during last few years there is a progressive increase in number of an intentional interference which manifest in form of jamming or spoofing of Global Navigation Satellite System (GNSS) signals. The former (jamming) refers to the intentional overpowering of GNSS signals, typically GPS, preventing the receiver from determining the aircraft's position and other relevant information. The latter (spoofing) is similar in terms of overpowering the original signal but with a bit more complex process. Due to its inherent non-encrypted configuration, ADS-B messages are prone to manipulations. Within spoofing process, the originator of the signal generally broadcasts a precise encoded signal in an attempt to deceive the end-user with false position. Depending on the background motivation, the attacker may also inject a ghost message, delete it entirely, or as in previous case - modify it (Wagas et al., 2024). Both of these interference actions are relatively easy to achieve. Primarily as GNSS signals are relatively weak in lower layers of atmosphere. As specified earlier, ADS-B data, among other, feeds the ACAS system which is indispensable for tactical situational awareness. Hence, any potential disruptions negatively impact the crew's ability to avoid airborne conflicts.

When discussing mitigation strategies, the literature primarily addresses two distinct approaches to secure ADS-B signal propagation: secure broadcast authentication and secure location verification. With broadcast authentication various encryption and non-encryption modalities are considered, while location verification generally attempts to verify the location through the use of redundancy (Strohmeier et al., 2014). Also, in the context of ADS-B propagation, it is necessary to differentiate two spoofing modalities. One modality concerns the spoofing of GNSS signals, on which ADS-B relies. The other modality is spoofing of the ADS-B signal, which in practice occurs less frequent. Some mitigation techniques exist in the latter case, which rely on calculation of the Time Difference of Arrival (TDOA). Primarily to discriminate the real ADS-B signal from ghost signaling through comparison of expected and actual position of aircraft. However, this technique involves the use of at least four ground nodes and suffers from accuracy issues characteristic for multilateration location techniques. Promising research on augmentation of actual/expected TDOA relies on training algorithms that draw comparison values from historical data such derived from e.g., crowd-funded OpenSky (Elmerady and Rahouma, 2020; Strohmeier et al., 2016). In this context, literature review emphasizes various proposals for message encryption while simultaneously developing redundant authentication protocols (Khan et al, 2023; Wu et al., 2020).

5. CONCLUSION

In the context of the future development of ATM system on a global scale, ADS-B technology may be perceived as an indispensable asset complementing existing Communications, Navigation and Surveillance (CNS) framework, particularly amid growing demands for safety, capacity, environmental sustainability and cost-efficiency. Undoubtedly, the technological benefits of ADS-B are substantial, despite its reliance on a derivative of SSR interrogation technology. Although ADS-B technology is essential in regions with limited or no radar coverage, redundancy remains equally important in areas with high traffic density. For this reason, SSR and multilateration continue to be indispensable components of CNS ground networks. At the procedural level, the communication link between ATC and pilots serves as a crucial safeguard in the surveillance process and position verification. This becomes particularly important during periods of compromised situational awareness caused by interferences, malicious actions, or network disruptions. While further studies need to explore technical and technological methods for extending and improving ADS-B signal range and coverage, research on enhancing the safety and security of ADS-B remains a critical priority. In this context, mitigating the effects of jamming and spoofing emerges as a primary issue needed to be addressed more in detail within future research and development in the field of study.

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Diversifying Aerodrome' Non-Aeronautical Revenues Through Renewable Energy Investments

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The agenda of the aviation industry in Europe is to strive towards sustainable development, and ultimately to achieve net-zero carbon emissions from flight operations by 2050. To do so many aviation stakeholders are turning to business diversification and trying to maximise the efficiency of their peripheral business activities. Aerodrome operators represent no exception in that regard. Simultaneously with the increase in market share of low-cost carriers over the last two decades, aerodrome operators were trying to maximise their profit margins, primarily through non-aeronautical revenues. However, in contrast to previous years, nowadays due to geopolitical reasons and the strategic determinants of the European Commission, aerodrome operators have become one of the prominent representatives of sustainable development within the aviation industry. Foremost due to investments in renewable energy, a decision which brings multiple benefits, where the opportunity to generate a new type of non-aeronautical revenue, while simultaneously making cost-savings, stands out. In that respect, this research paper provides insights on how to exploit aeronautical data, periodically published by Air Navigation Service Providers (ANSPs), to obtain preliminary insights on the feasibility of renewable energy investments. The paper also details the findings of a case study addressing investment feasibility into solar and wind power plants at several aerodromes located across the Republic of Croatia.

KEYWORDS

Aviation industry; Sustainable development; Renewable energy; Non-aeronautical revenues

1. INTRODUCTION

Climate change and greenhouse gas emissions are nowadays perceived as one of the biggest threats faced by the world population (Shukla et al., 2018). Hence in Europe there is a strong agenda to strive towards sustainable development. Since the aviation industry accounts for 2.1% of global CO₂ emissions (ATAG, 2020), the aviation industry in Europe is mandated to achieve net-zero carbon emissions from flight operations by 2050 (EC, 2019). This agenda is profound by global, regional and national institutions supporting its “green transition” (ICAO, 2021). Regardless of ownership type or scale of financial self-sufficiency, aerodromes are nowadays exploring vast non-aeronautical revenue sources and cost-saving measures. Simultaneously, utility service providers are looking to purchase energy generated from renewable sources to meet national and regional environmental and energy goals. Since aerodromes often have available property to host and generate renewable energy, investments in renewable energy provide an opportunity to generate revenue for both parties.

Aerodrome operators must consider various factors when diversifying non-aeronautical revenues through renewable energy investments. This encompasses factors such as the kind of renewable energy technology, its placement within the aerodrome, the size of the facility, and the most appropriate ownership structure. To obtain insights into the diversification potential of aerodrome non-aeronautical revenues through renewable energy investments, this paper presents a brief review of investment options and details to be considered within investment evaluation. It also presents preliminary findings addressing investment feasibility into solar and wind power plants at several aerodromes located across the Republic of Croatia. Unlike existing literature in the field of study and existing practices, the insights presented are derived by processing aviation-specific meteorological bulletins. Primarily as they are of high accuracy (confidence level) and are periodically reported - enabling a high granularity level.

From a conceptual aspect, the paper consists of five major parts. After the introductory part, the second part presents the research background which details the research motivation, objectives, methods, materials and tools used within the study. The third part provides a review of options available to diversify the aerodrome’ non-aeronautical revenues through renewable energy investments. The fourth part introduces a case study. It details research determinants considered within a study, articulated in terms of reference locations, reference period and methodological assumptions applied within a study. The fourth part also presents the main research findings. Lastly, the paper is concluded with a summary of the main research findings.

2. RESEARCH BACKGROUND

Aerodromes occupy large spatial areas. In order not to keep land unutilized, aerodromes worldwide have recognized renewable energy investments as a source of non-aeronautical income which enables cost savings (Sreenath et al., 2020). Particularly after the maturity and expansion of the solar photovoltaic (PV) market, electricity price instability and spreading practice to generate revenues from lease payments. Apart from these, there are several endogenous factors, more aviation-specific. Among others, one of them is a market shift between flag and low-cost carriers which also affects the role of aerodromes (Figure 1). As low-cost carriers do not utilize aerodrome and ground handling services like flag carriers (Ahn & Lee, 2011), aerodrome operators are trying to maximise their profit margins through non-aeronautical revenues. There are multiple evidences of achieving that through renewable energy investments. For instance, a 24-hectare plant with 55,000 solar panels at the Vienna International Airport is the largest PV power plant in Austria (ICAO, 2022). For instance, in 2023 it had generated around 32,600 MWh, covering around 50% of the aerodrome’s electricity requirements, which makes it one of the first “green airports” in Europe (FWAG, 2024). There are more examples like in Dubai International Airport where it had been installed 15,000 solar panels able to generate around 7,480 MWh (Airport

Technology, 2019), while in Kansai International Airport in Japan it had been installed solar power generation systems with an annual power generation capability of 27,800 MWh (KAG, 2025). Moreover, there are examples of aerodromes entirely powered by solar energy. Back in 2015, Cochin International Airport located in India with 46,150 solar panels became the world's first airport to be powered entirely by solar energy (ICAO, 2016). Four years later, the Chattanooga Metropolitan Airport became the first completely solar-powered airport in the USA (NBAA, 2020). Accordingly, the trend of aerodromes investing in renewable energy and incorporating solar panels into their energy systems is gradually gaining momentum on a global scale.

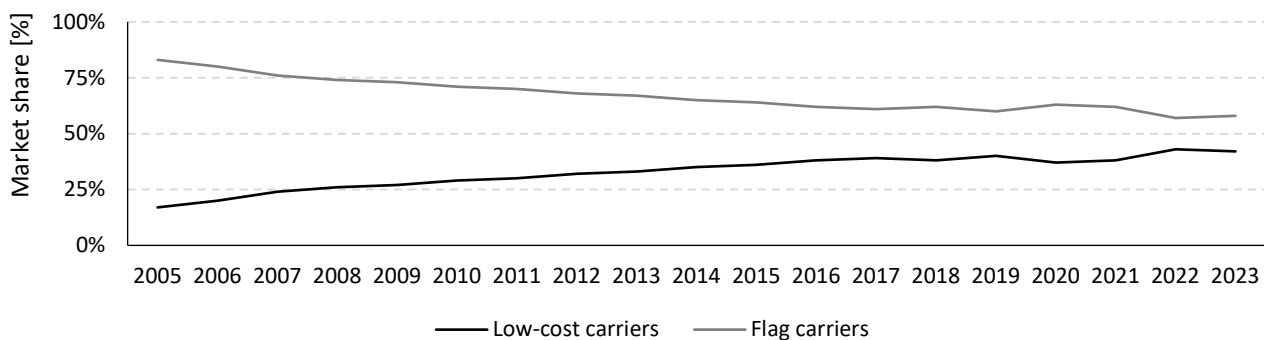


Figure 1. Categorization and development of the air transport market in Europe per airline's business type

2.1. Research motivation and objective

The literature review shows that there is a lack of sufficient guidance to assist aerodrome operators in identifying, assessing, choosing, and effectively executing renewable energy projects for financial gain. Nowadays, in most cases, aerodrome operators use consultants to learn about the business and identify the cost-benefit ratio through the prism of whether energy prices are high enough to justify investments based on revenue potential. In that respect, the research motivation behind this study is to address best practices on how aerodrome operators may diversify their non-aeronautical revenues through renewable energy investments. Ultimately, this research paper provides a dual benefit. Primarily due to its two objectives, where one is to provide a review of how to achieve diversification of non-aeronautical revenues, while the other is to present approximations on potential power output available through renewable energy investments for several aerodromes located across Croatia.

2.2. Methods, materials and tools used

The research introduces a case study that builds its findings on the application of inferential statistics. Thereby, within a case study, to assist with the estimation of the potential viability of renewable energy investments for every particular aerodrome, it had been used web application named Airport Weather Information Service (AWIS) (AWIS, 2024). Nowadays, there are many generic renewable energy modelling tools on the market. However, compared to its counterparts, AWIS incorporates location-specific data on anticipated renewable energy production capacity, taking into account the geographic and meteorological conditions at aerodromes around the globe. It exploits aeronautical data periodically published by ANSPs, to provide insights on the feasibility of renewable energy investments. For the purpose of a case study, it processed several meteorological datasets which were originated by Croatia Control Ltd (CCL). More precisely, it utilized Aviation Routine Weather Reports (METARs) which were provided in coded form at 30-minute intervals (ICAO, 2017), processed 788,400 METARs and extracted reference data spanning the period from Jan 2020 to Jan 2025. Lastly, since METAR covers an area in a radius of eight kilometres from the Aerodrome Reference Point (ARP), findings provided within a case study correspond to the given reference area, whereby data on ARP were obtained from CCL' AIP (CCL, 2025).

2.2.1. Assumptions applied for solar energy potential estimation

To obtain approximations of power generation by converting sunlight into renewable energy, several assumptions have been applied within AWIS. Apart from considering data denoting Sun movement (sunrise time, zenith angle, angle of incidence, air mass, etc.) and meteorological conditions at aerodromes, several technical settings regarding solar panels have been introduced to facilitate the estimation process. This refers to assumptions of a panel length of 1.625 meters, a width of 1.019 meters, a tilt angle of 25%, a normal operating cell temperature of 45.7°C and a maximum power of 260 W at Standard Test Conditions. Based on a combination of these assumptions, in conjunction with data on weather solar irradiance and radiation, AWIS has produced weather-corrected PV panel power output potential. Lastly, it was applied an assumption that aerodromes are interested in diversification of non-aeronautical revenues by investing into plant with 25,000 fixed solar panels.

2.2.2. Assumptions applied for wind energy potential estimation

AWIS provides approximative figures of the maximum output power that can be produced within the Betz limits for two types of wind turbines; Horizontal-Axis Wind Turbines (HAWTs) and Vertical-Axis Wind Turbines (VAWTs). Considering the assumptions applied, the initial setting of power output for a single HAWT is derived from an assumption that the modern three-bladed wind turbine has a diameter of 80 meters and a swept rotor area of 4,978 m². The initial setting of power output for a single VAWT is based on an assumption of a diameter of the rotor of 3.19 meters that sweeps 16.6 m² of the wind stream.

In addition, AWIS provides approximations of the operational capability of HAWT and VAWT types concerning wind speed captured during the reference period. These approximations rely on several assumptions. The initial setting of the cut-in wind speed for VAWT corresponds to 6 and 8 knots for HAWT. The initial setting of the cut-out wind speed equals 39 and 49 knots for VAWT and HAWT respectively. In events when the wind stream is affected by wind gusts, data on wind speed is replaced by data denoting the speed of wind gusts. Thereby, due to vast factors, as well as due to efficiency differences between wind turbines, it should be emphasized that the maximum output power reported is always greater than actual power output which may be produced onsite. Lastly, a case study relies on the assumption that aerodromes are interested in diversification of their non-aeronautical revenues by investing in 15 VAWTs and 5 HAWTs.

3. RENEWABLE ENERGY INVESTMENTS

Aerodrome operators regularly assess opportunities to broaden their revenue streams through non-aeronautical means, commonly through concessions, parking fees, advertising, and leases. In contrast, the following content outlines the reasons and methods for expanding the revenue base by exploring various renewable energy investment opportunities.

3.1. Renewable energy investment options

There are several options by which aerodromes can make cost savings through renewable energy investments. One option is to lease land for a renewable energy facility on aerodrome property to a private developer, a decision that is similar to other land lease agreements. Generally, lease values for renewable energy projects are comparable to those from agricultural leases. However, these leases tend to be considerably lower than those for other types of developments, like commercial or industrial properties. In the case of wind farms, the most suitable locations for leasing and establishing wind farms are areas with limited alternative development potential, such as land affected by noise restrictions. These sites may be perceived as optimal as nowadays there are solutions allowing mitigation of the effects of wind turbines on Air Traffic Control's radars. As such, nowadays there are HAWTs and VAWTs implemented in the vicinity of La Palma Airport, Liverpool John Lennon

Airport, East Midlands Airport, Edinburgh Airport, Amsterdam Airport Schiphol, Logan International Airport, etc. In the case of solar farms, the best siting locations are those locations with height restrictions due to proximity to the airfield. Figure 2 shows a spatial overview of land leased to a private developer for the installation of solar panels at Barnstable Airport (KHYA) and Indianapolis International Airport (KIND) in the United States of America. Thereby, although the general public might overlook this issue, aerodromes leasing land for renewable projects and receiving only lease payments in return should not be perceived as “green” aerodromes.



Figure 2. Siting locations of solar farms at KHYA (left) and KIND (right) (NASEM, 2015)

Land leases can be paired with another cost-saving strategy: financing the purchase of a specified output from a renewable energy project over a period of years using the proceeds from tax-exempt bonds. In this scenario, the aerodrome can enter into an agreement to secure a guaranteed supply of energy (e.g., 80% of the expected output of a rated facility) for a set duration (e.g., 20 years), prepay for the energy using funds from tax-exempt debt, and resell the electricity to retail customers within its service area. Meanwhile, a private developer can use these funds to cover the costs involved in developing the project. There is an option for aerodromes to capitalize, own and construct the facilities themselves, relying on low-interest bonds or government grants. Consequently, business risk is held entirely by the aerodrome. The savings accumulate over the payback period and once the system is paid off, the energy that is produced on-site is nearly free, except for operational and maintenance costs. There is also an option of net metering, which refers to a purchase of surplus electricity generated by the renewable energy system. For the majority of aerodromes, this option is not feasible due to their large-scale energy consumption.

3.2. Evaluating renewable energy investments

Evaluating renewable energy investments can be challenging. Primarily given the strong emphasis on demonstrating that the benefits directly accrue to the aviation stakeholders. The amount of energy consumed by aerodromes in most events is a fundamental factor in evaluating renewable energy investments. The practice shows that the majority of financial benefits are accrued through cost savings rather than revenue generation, where investments in renewable energy typically result in an offset to energy operating costs.

Renewable energy investments may be also evaluated through a prism of national requirements to enhance aerodrome resilience, national energy security and grid reliability by decentralizing power generation. Also, these types of investments may be undertaken as joint ventures, further enhancing cost-efficiency. For instance, by sharing investment, operating and maintenance costs between the aerodrome and ANSP, such ANSP can enhance their cost-efficiency, e.g. by introducing self-sustainable Remote Tower Services. Besides saving on personnel and infrastructure at aerodromes with low-traffic intensity, ANSPs may additionally reduce their

operational costs. Lastly, it is important to highlight that aerodromes are predominantly state or local government entities, which have the ability to issue debt on a tax-exempt basis, thereby lowering their financing expenses.

Apart from investment costs, capital and maintenance costs must be also considered within the investment evaluation. Table 1 displays the cost breakdown per electric generating technology, where α_i denotes average installation cost [\$/kW], $\alpha_{i\sigma}$ marks standard deviation of installation cost [\$/kW], $\alpha_{i,O\&M}$ indicates operational and maintenance (O&M) cost [\$/kW-yr], while $\alpha_{i,O\&M\sigma}$ signifies standard deviation of O&M [\$/kW-yr]. It also provides insights into useful life (λ_α) and its standard deviation $\lambda_{\alpha,\sigma}$ [years] for electric generating technologies.

Technology	α_i	$\alpha_{i\sigma}$	$\alpha_{i,O\&M}$	$\alpha_{i,O\&M\sigma}$	λ_α	$\lambda_{\alpha,\sigma}$
PV < 10 kW	3,910	921	21	20	33	11
PV 10 - 100 kW	3,819	888	19	18	33	11
PV 100 – 1,000 kW	3,344	697	19	15	33	11
PV 1 - 10 MW	2,667	763	20	10	33	9
Wind < 10 kW	7,859	2,649	28	18	14	9
Wind 10 - 100 kW	6,389	2,336	38	12	19	5
Wind 100 – 1,000 kW	4,019	803	33	13	16	0
Wind 1 - 10 MW	2,644	900	36	16	20	7

Table 1. The cost breakdown of electric generating technologies (NASEM, 2015)

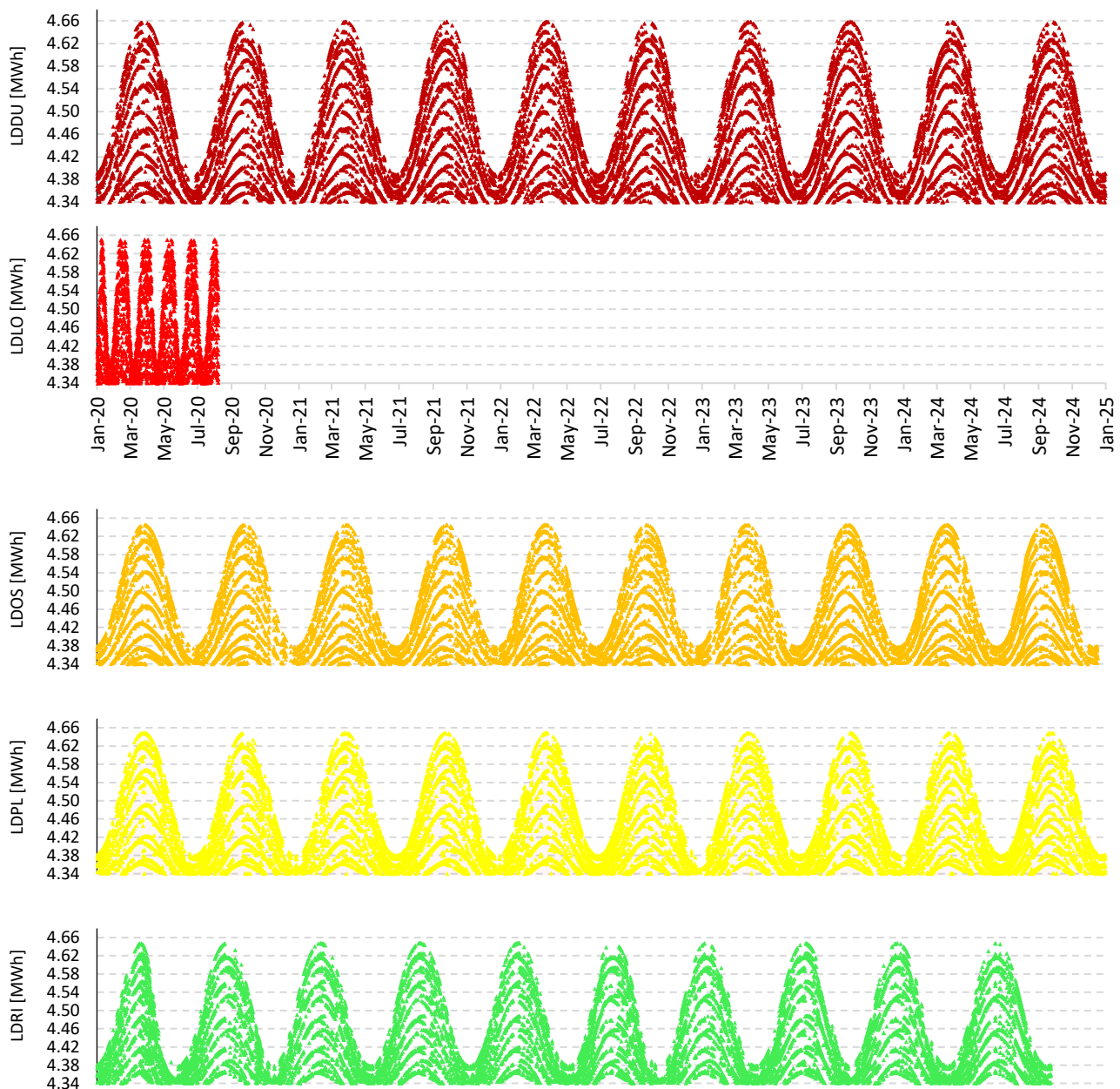
When comparing solar energy to wind farms, it's important to note that solar PV investments are generally more cost-effective than smaller-scale wind investments. A key advantage of solar over wind is that larger-scale solar projects can generate significantly more electricity, which can be directly used by aerodromes, while small-scale wind investments have limited capacity for electricity production. Additionally, solar farms have lower annual operations and maintenance (O&M) costs, typically 20-40% lower than those for wind farms, amounting to approximately USD 0.02 per kW for fixed panels. The levelized cost of energy, which includes the cost of owning, installing, and operating the system over its 25-year lifespan, is roughly USD 0.12/kWh for solar and USD 0.25/kWh for wind. Furthermore, solar panels have an expected lifespan of over 30 years, while small-scale wind turbines typically last between 15 and 20 years.

4. CASE STUDY & PRELIMINARY FINDINGS REVIEW

Renewable energy investments are very site-specific. Hence, a case study in continuation provides findings on energy generation potential via solar and wind power plants at several aerodromes within the Republic of Croatia, including Rudjer Boskovic Airport (LDDU), Losinj Airport (LDLO), Osijek Airport (LDOS), Pula Airport (LDPL), Rijeka Airport (LDRI), Brac Airport (LDSB), Saint Jerome Airport (LDSP), Franjo Tudman Airport (LDZA) and Zadar Airport (LDZD). Thereby, the paper presents preliminary findings derived for purpose of knowledge discovery and benchmarking purposes. A more detailed understanding of the field of study can be gained by taking into account several factors, including the aerodrome's geographic location and surrounding terrain, local infrastructure, energy costs, national renewable energy policies, environmental and regulatory compliance requirements, tax incentives, government and sponsor guarantees, as well as the impacts on air navigation, safety, and security. Additionally, staffing considerations and other relevant factors should also be factored in. However, these aspects have not been thoroughly explored in the case study.

4.1. Solar energy potential

Expanding the aerodrome revenue base by investing in solar farms is a sensible choice, considering the open landscapes typically found at aerodromes, the availability of vast rooftop spaces on buildings, open land for installing equipment, and the proximity to high-capacity electricity transmission infrastructure that aerodromes offer. However, the amount of power output varies based on many factors that occur in a particular location. In the case of aerodromes considered within a study, the main research findings on solar energy potential are summarized in Figure 3 and Figure 4. Considering the given assumptions, Figure 3 displays the timeline distribution of solar-powered energy potential, while Figure 4 provides a cumulative overview of power output potential per aerodrome during the reference period.



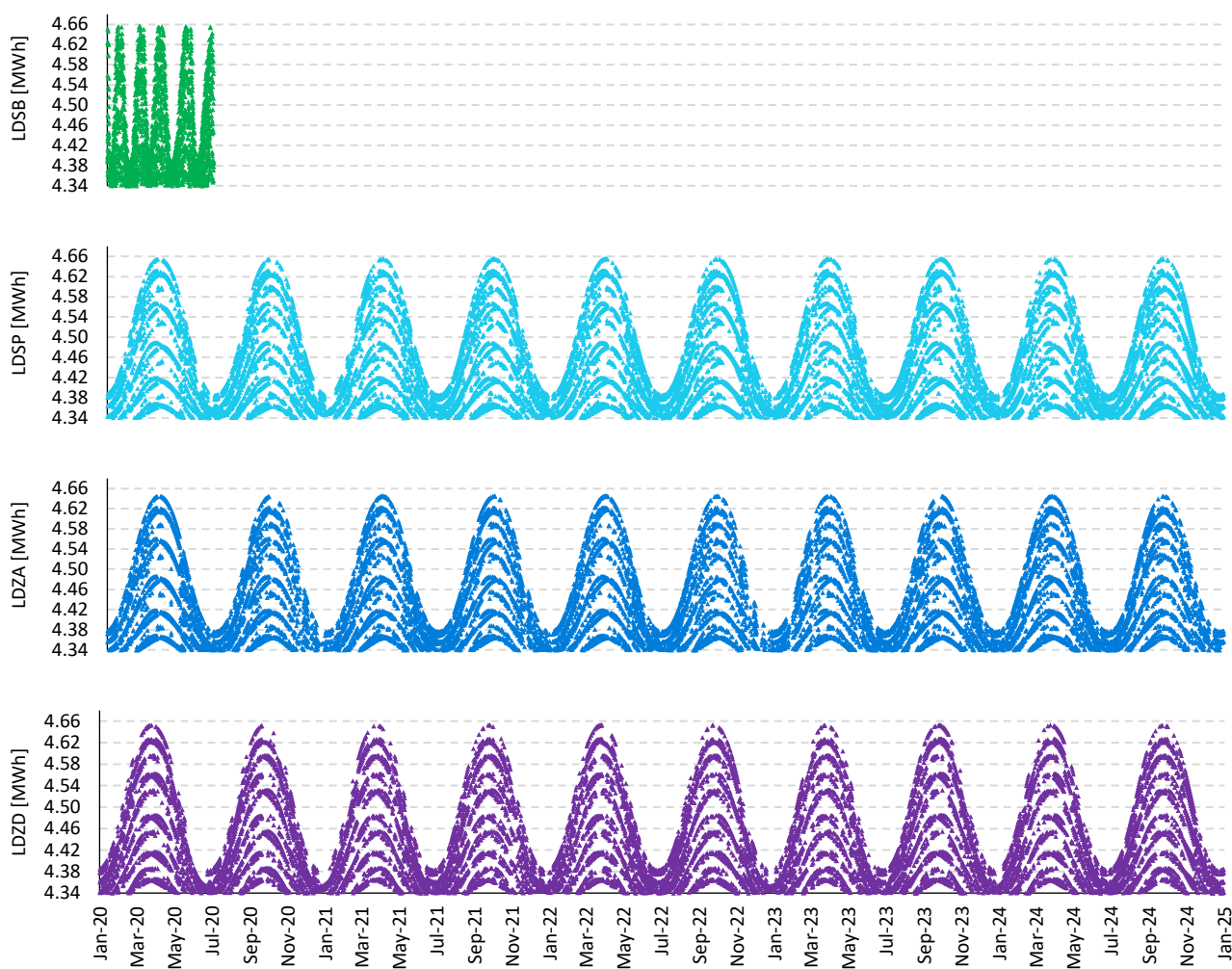


Figure 3. Power output potential per aerodrome (2020-2025)

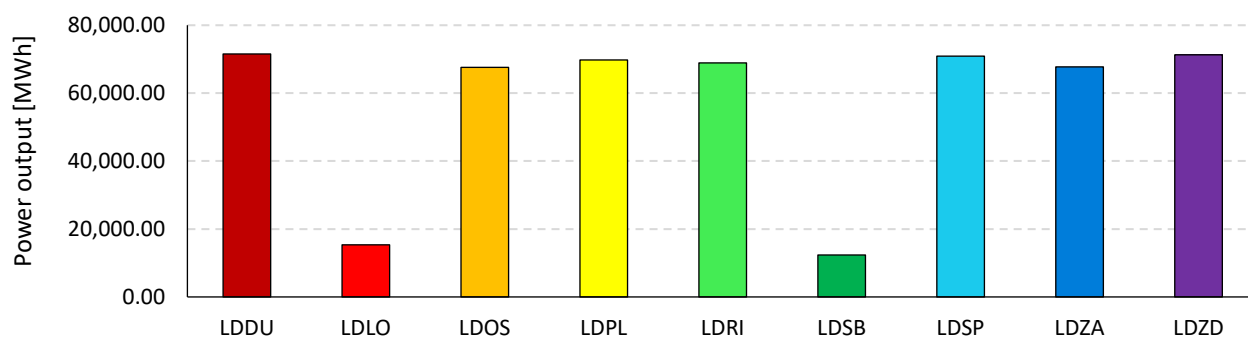


Figure 4. Cumulative overview of power output potential per aerodrome (2020-2025)

4.2. Wind energy potential

Similarly to solar, wind power generation is very site-specific. In contrast to VAWT, when HAWT is operative, no other renewable energy power generation technology can match its power output capacity. For the aerodromes analyzed within a case study, the main research findings on wind energy potential are summarized in Figures 5

and 6. Figure 5 illustrates the temporal distribution of wind energy potential, while Figure 6 presents the cumulative power output potential for each aerodrome over the reference period, indicated per turbine type.

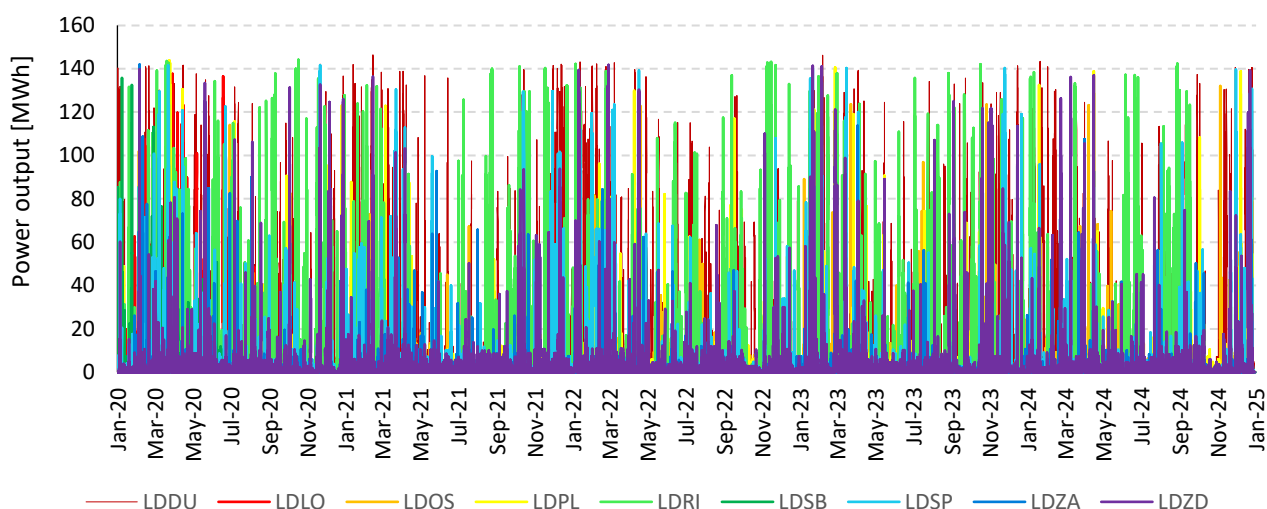


Figure 5. Maximum power output potential per aerodrome (2020-2025)

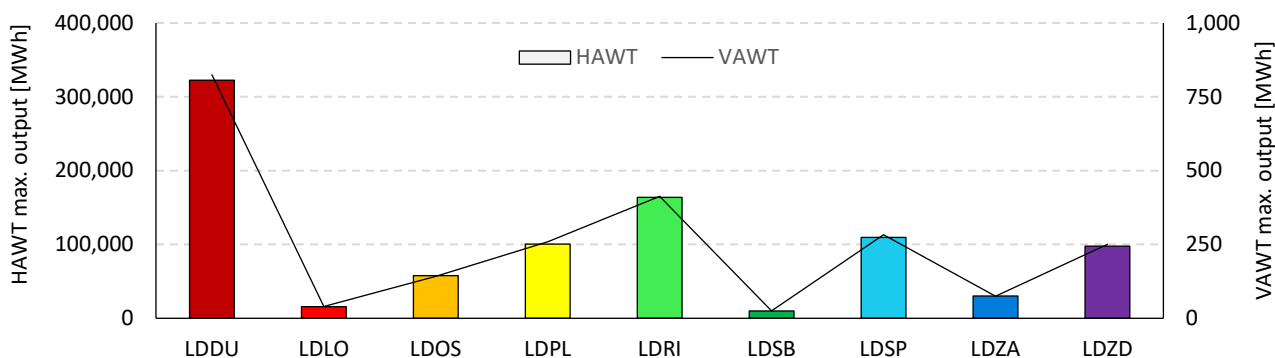
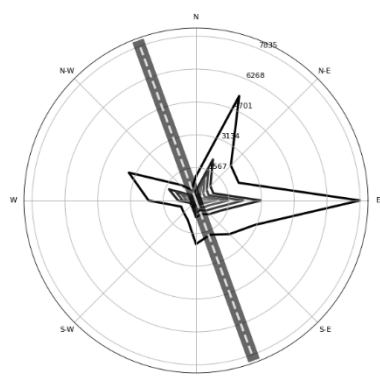
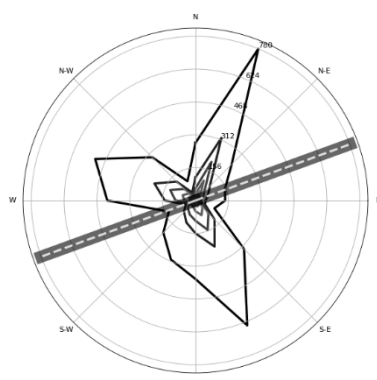


Figure 6. Cumulative five-year overview of maximum power output potential per aerodrome (2020-2025)

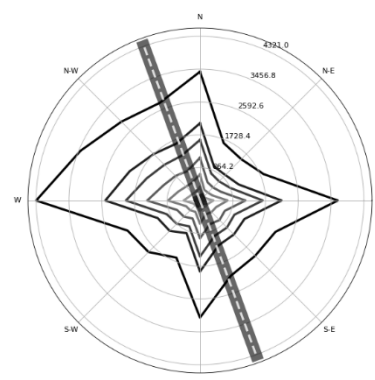
Figure 7 and Figure 8 display wind roses for aerodromes considered within a case study. Figure 7 displays the distribution frequency of wind speed, while Figure 8 displays wind gusts with respect to wind direction. Both figures also integrate aerodrome runway(s) orientation, detailing insights on crosswind and tailwind components.



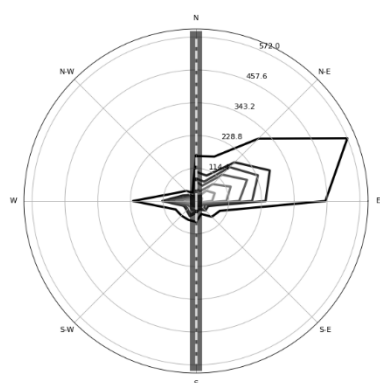
LDDU



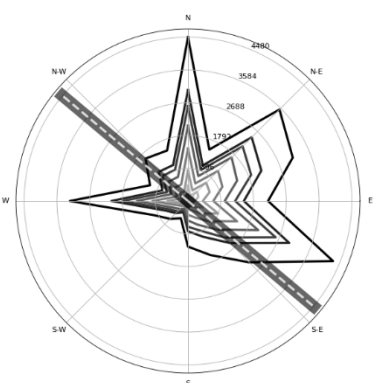
LDLO



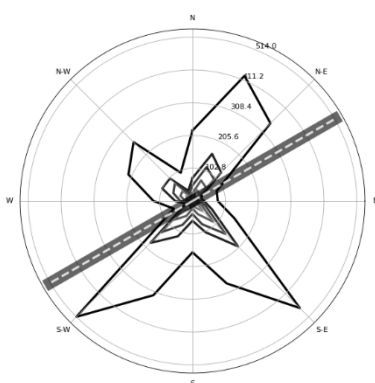
LDOS



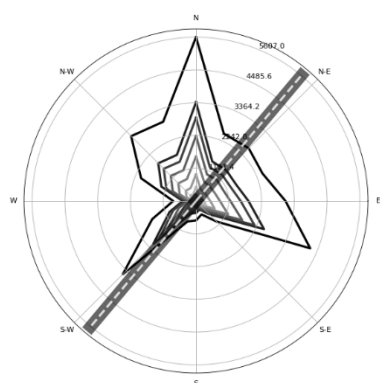
LDPL



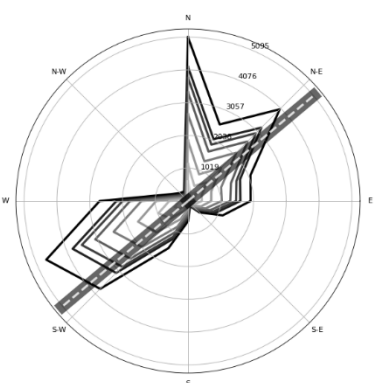
LDRI



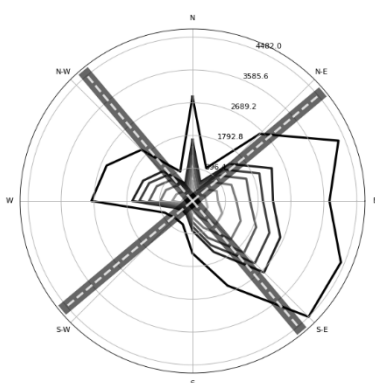
LDSB



LDSP



LDZA



LDZD

Figure 7. Frequency distribution of wind speed by wind direction

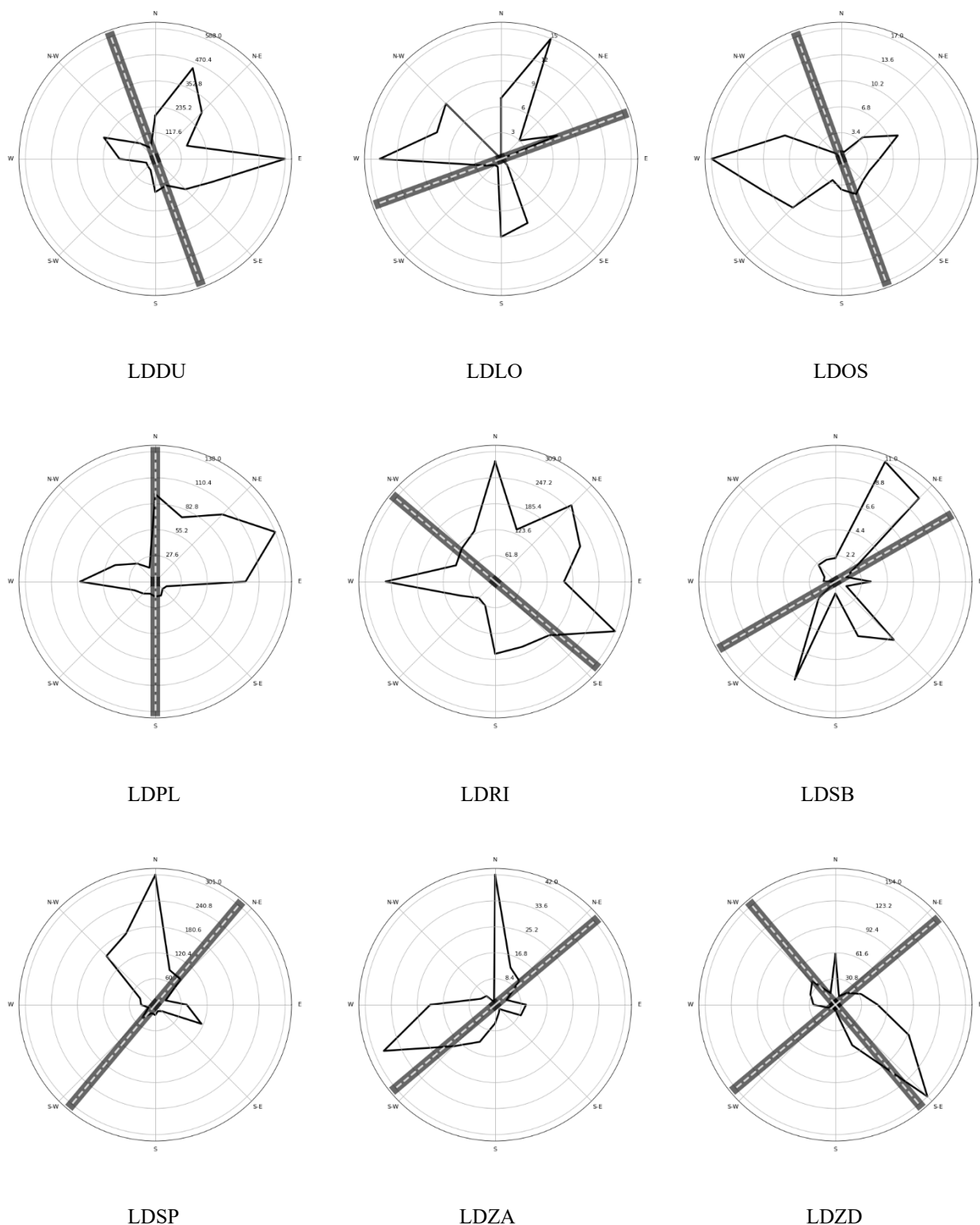


Figure 8. Frequency distribution of wind gusts by wind direction

In both cases, within Figure 7 and Figure 8, wind roses indicate wind distribution and not wind velocity. Primarily as insights on wind velocity are integrated into wind energy potential estimation, while distribution frequency provides insights on optimal HAWTs and VAWTs siting with respect to aerodrome runway(s) and traffic patterns.

5. CONCLUSION

Advancements made in science and technology over the last two decades have enabled the aviation industry to modernize its traditionally run aspects of business. Digitalized and automated sampling and reporting of vast performance and meteorological data is just one of many achievements in that regard. The next milestone is to maximize the utilization of data, technology and knowledge available to further modernize the way of business. In that regard, this paper provides insights into the diversification of aerodrome non-aeronautical revenues through renewable energy investments.

Apart from a brief overview of renewable energy investment options relative to aerodrome operators and details regarding investment evaluation, the paper introduces a case study. On the example of several aerodromes located across the Republic of Croatia, research demonstrates that, on the one hand, the greatest potential for diversifying aerodrome' non-aeronautical revenues through solar energy investment have, sequentially, LDDU, LDZD, LDSP, LDPL, LDRI, LDZA, LDOS, LDLO and LDSB. On the other hand, the greatest potential for diversifying the aerodrome' non-aeronautical revenues through wind energy investment has, sequentially, LDDU, LDRI, LDSP, LDPL, LDZD, LDOS, LDZA, LDLO and LDSB. In terms of solar energy, the five-year potential during the period from 2020 to 2025 has ranged from 12,353.66 to 71,538.64 MWh, i.e., from 1,580,650.94 to 9,153,369.41 EUR. In terms of wind energy, during the same period, the five-year potential has ranged from 9,948.06 to 323,362.94 MWh, i.e., from 1,272,855.16 to 41,374,287.62 EUR. Thereby, the findings related to LDLO and LDSB presented in this study are partial due to limited data availability. As these sites require additional site-specific measurements, their results should be viewed as complementary insights rather than definitive estimates. Considering all the above, aerodrome operators should consider the presented findings in more detail, select the optimal business model for them and exploit natural resources. As such, aerodrome operators can diversify their non-aeronautical revenues, the process of which starts with the determination of future investment locations within their master plans.

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1 Year of Crisis in the Red Sea: What Impact for the Adriatic Ports?

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Geopolitical events in the Gulf of Aden have targeted merchant ships using the Suez Canal, particularly container ships. Since the first Houthi attacks, liner shipping companies have been bypassing the African continent via the Cape of Good Hope to secure trade between Asia, the Mediterranean and Europe. This major operational adjustment is having an impact on Mediterranean port connectivity and on the ports of the Adriatic Sea. The purpose of this presentation is to analyse the impact of this crisis on containerised traffic in Adriatic ports and on the strategies of shipping lines set up to serve this region. We will use the AIS signals emitted by ships over a period of one year before and after the first attack to assess the consequences of this political and maritime crisis. The Mediterranean Sea, by virtue of its geography and as a consequence of the crisis, has become a cul de sac. Companies are deploying new strategies to serve Mediterranean ports, and the Adriatic in particular. This reorganisation has had numerous consequences for the ports and their customers. Shipowners are relying mainly on the main hubs in the western Mediterranean, and even on other European hubs.

KEYWORDS

Maritime transport; Adriatic Sea Ports; Crisis; Container; AIS.

1. INTRODUCTION

Since 2020, global maritime trade has been grappling with increasing uncertainties driven by geopolitical and pandemic-related crises, making the global transport system more unpredictable and adaptable (Cullinane, Haralambides, and Notteboom 2023; Cariou and Notteboom 2022; Barleta and Sánchez 2021). From the war in Ukraine to the ongoing conflicts in Palestine and Syria, and escalating tensions in the Red Sea and the Gulf of Aden, international logistics networks are experiencing severe disruptions—particularly when they involve key geostrategic chokepoints such as the Suez Canal (Qu and al. 2024; ITF 2024; Biaggi and Carroué 2024).

In recent years, the Suez Canal has handled around 10% of global maritime trade annually, amounting to approximately 19,000 transiting vessels. However, in just January and February 2024, maritime transits through the canal dropped by 42% (United Nations 2024), with cargo volumes down by 50% compared to 2023 (Kamali et al. 2024). All vessel categories have been affected, but container ships and large tankers have been the most likely to reroute in order to avoid Suez (Journal de la Marine Marchande 2024). In 2024, the Egyptian government estimates losses of nearly 6 billion dollars.

Overall, container traffic in the Mediterranean basin was affected in the short term. Strategic rerouting by shipping lines via the Cape of Good Hope has favoured northern European ports, which have themselves found themselves saturated with capacity, particularly with units larger than 18,000 TEUs. Over the first 120 days after the start of the crisis, the ports of the Eastern Mediterranean zone were the most affected both in terms of number of calls (-22%) and total capacity deployed (-39%). On the other hand, the port of Tanger-Med was able to take advantage of its strategic geographical position by gaining market share from the other Mediterranean hub ports (Alix and Kerbiriou 2024).

The decision to bypass Africa as an alternative route highlights the adaptability of shipping lines (Arvis, Rastogi and Ulybina 2024), which is driven by four main strategic levers:

- Speed adjustments, increasing sailing speeds from 14 to 16 knots.
- Additional capacity deployment to compensate for the extended distances.
- Selective use of the Suez Canal, depending on security conditions. Smaller container ships do not always divert via the Cape of Good Hope, while larger vessels benefit from economies of scale that help absorb the additional 3,000 nautical miles on a China–West Med route (Alix and Kerbiriou 2024).
- Economic and financial adjustments, including rising spot freight rates on China–Europe routes, particularly those connecting China to the Mediterranean.

With the ongoing Red Sea crisis and operational shifts by shipping lines, the Mediterranean's maritime and port centrality is becoming increasingly peripheral, turning certain port ecosystems into logistical dead ends (Kerbiriou and Daudet 2024). Maritime connectivity is deteriorating, with transit times extended by several weeks—especially for shipments to and from the Far East.

This leads us to hypothesize that Mediterranean ports, particularly those in the Adriatic Sea, have been significantly impacted in terms of traffic. Our research question is therefore: what is the impact of the crisis in the Red Sea and the bypass of the African continent on traffic in container ports on the Adriatic Sea?

In this paper, we examine the effects of the African bypass on container traffic in Adriatic ports. The first section outlines the study framework, methodology, and data sources. The second section presents and

analyzes the key results in the context of the Red Sea crisis. Using AIS data, we conduct a diachronic analysis by comparing container traffic trends one year before and one year after the crisis.

2. STUDY FRAMEWORK, DATA AND METHOD

In this article, we will analyze container ship calls at the main ports of the Adriatic Sea to assess the evolution of maritime traffic and the impact of the Red Sea crisis (Figure 1). The first recorded attack in the Red Sea took place on November 17, 2023. We will use this date as a reference point for our analysis, comparing data from one year before and one year after this event. This comparison will highlight both overall trends and port-specific dynamics.

Additionally, we will examine the evolution of inter-port relationships between Adriatic ports and major Mediterranean hubs, as well as the shipping strategies implemented to serve this maritime space. These connectivity analyses should shed light on the organizational agility of the world's leading shipping companies.

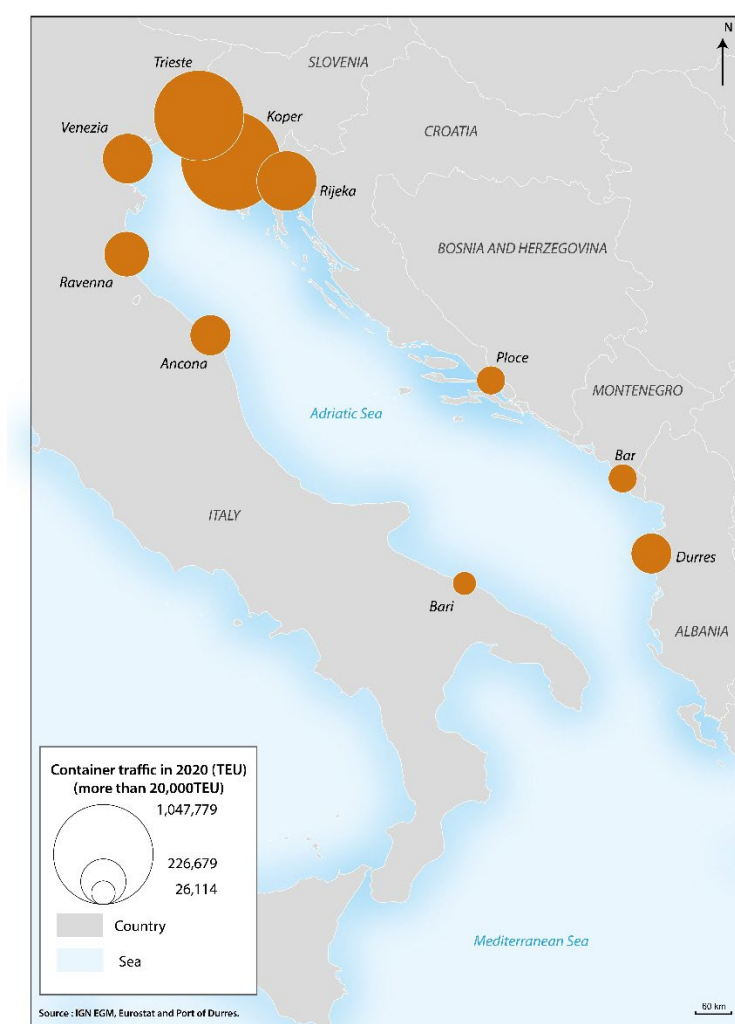


Figure 1. Container traffic in 2023 (TEU) (Source: Ronan Kerbiriou, 2025).

AIS data, introduced by the IMO in 2004 to enhance maritime safety, provide real-time information on the position and identification of vessels. Used in scientific research, they offer global coverage, high temporal

precision, and enable detailed analyses, paving the way for an in-depth exploration of maritime dynamics at various scales (Kerbiriou and Serry 2024; Faury and al. 2019) along three main dimensions:

- The global coverage and accessibility of AIS data extend the study scope from an individual vessel or a specific region to global or continental territories;
- The unparalleled high-resolution and real-time features of AIS data enhance the accuracy of vessel behavior analysis; and,
- The discretization and abundance of individual vessel data allow researchers to examine issues from a bottom-up rather than top-down perspective (Figure 2).



Figure 2. Main data from AIS (Source: Ronan Kerbiriou, 2020).

The use of AIS relies on its multiscalar nature, operating at different spatial scales (global, regional, local) and temporal scales, often combined with other databases to enable effective applications for economic intelligence and policy support (Serry, Kerbiriou, and Alix 2018). In this study, AIS data are essential, as they provide near real-time information, offering flexibility and responsiveness to analyze major events such as the Houthi rebel attacks.

We adopted a diachronic approach to assess the impact of these events:

- Analysis of container ship calls one year before and one year after the first recorded attack on November 19, 2023, using all AIS vessel position data. Temporal segmentation was conducted on a quarterly basis for each study period.
- Calculation of the number of port calls and total deployed container capacity for each port, categorized into five container ship size classes:
 - Less than 1,000 TEU
 - 1,001 – 2,500 TEU
 - 2,501 – 5,000 TEU
 - 5,001 – 10,000 TEU
 - More than 10,001 TEU
- Examination of the evolution of inter-port relationships between Adriatic ports and major Mediterranean hub ports.

To carry out this study, we used data from the supplier S&P Global. S&P Global offers a platform that allows you to run queries based on different criteria (date, type of ship, port, etc.) and download them. In this way, we have built up a table of data on ship calls according to the criteria defined. This file requires a series of operations to cleanse it of erroneous or duplicate data. By cross-referencing data on vessel movements, nominal capacity, and port calls over the two-year study period, this analysis provides an immediate overview of the port reorganization in our study area. The chosen approach allows us to capture both operational and strategic adjustments.

For this paper, we will primarily employ empirical analysis methods based on descriptive statistics.

3. RESULTS AND ANALYSES

In this section, we will begin with a general analysis before examining container ship calls at various ports in greater detail.

Contrary to our initial working hypothesis, the number of container ship calls increased in the year following the first crisis, rising from 3,208 to 3,352—a 4% increase. The total capacity deployed at ports of call also grew, from 8.1 million TEUs in the year before the crisis to 8.5 million TEUs after, representing a 5% increase. To explore these initial findings in greater depth, it is useful to analyze the results on a quarterly basis (Figure 3). We have divided the data into six periods (two sets of three periods per year of study).

Focusing on the comparison between the quarter preceding the crisis and the one that followed, we observe a 11% drop in total capacity offered at ports, equivalent to more than 300,000 TEUs. In the early months, shipping lines were caught off guard by these attacks on their operations. Passage through the Red Sea—and, more critically, the Suez Canal—became too dangerous, forcing vessels to reroute via the Cape of Good Hope. This strategic shift had an immediate impact on container traffic at Adriatic ports.

In the final two quarters, however, port call capacity rebounded, approaching pre-crisis levels. Notably, the first quarter recorded a relatively low level of call capacity compared to the others. This period, spanning late 2022 to early 2023, may have been affected by lingering post-COVID economic impacts on port activity.

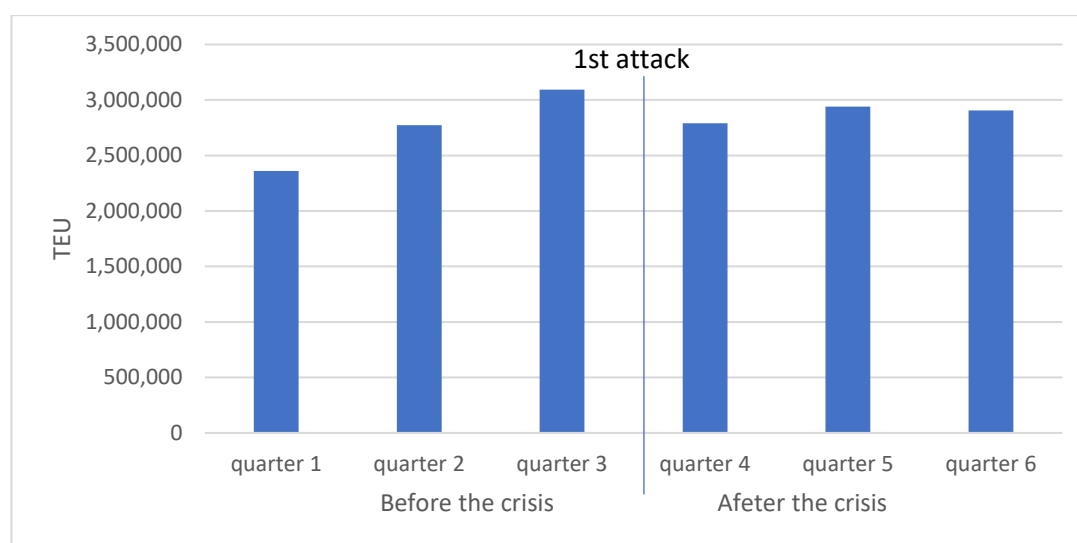


Figure 3. Total capacity offered in calls per quarter before and after the first attack (Source: AIS data from S&P Global, 2025).

In Table 1, we can observe the total port call capacities by port and by quarter. This table allows for a detailed analysis of the trends and impacts at the level of the various port hubs included in our study.

First, when comparing the third and fourth quarters, we can see that all ports were affected by a decline in total capacity, albeit to varying degrees. The ports of Bar, Bari, and Durres experienced the most significant reductions, with decreases of -35%, -27%, and -25%, respectively. These three ports are the smallest in our sample. The port of Ploce, which is one of the smallest, suffered a lesser impact than the other 3 (-10%). Trieste

and Koper were also impacted beyond the average, with declines of -13% and -12%, respectively. These two ports are the largest in our sample.

From this table, we can observe that mid-sized ports were the least affected by the crisis in the Red Sea, whereas both the largest and, even more so, the smallest ports experienced major disruptions to their traffic. One possible explanation is that major ports are directly impacted by transcontinental vessels, which had to be rerouted. Meanwhile, small ports rely exclusively on feeder services, which are highly dependent on connections with large container ships. A reduction in port calls by these larger vessels subsequently leads to disruptions in feeder services.

Secondly, when comparing the fourth and fifth quarters, we see a strong recovery in the ports that were most affected (+21% in Bar, +47% in Durres, +16% in Koper, etc.). The only exception is the port of Trieste, where available port call capacity declined once again (-2%).

Overall, Adriatic ports were all affected in the initial months following the onset of the crisis, though to varying extents.

Ports	Before the crisis			After the crisis		
	quarter 1	quarter 2	quarter 3	quarter 4	quarter 5	quarter 6
Ancona	163 963	186 336	212 719	203 812	213 318	204 558
Bar	11 064	51 457	57 357	37 281	45 214	48 965
Bari	30 380	31 076	35 179	25 750	34 274	32 935
Durres	30 777	66 470	54 748	41 174	60 420	49 047
Koper	620 815	694 633	774 976	683 277	792 226	791 042
Ploce	6 980	27 852	35 922	32 252	31 544	23 814
Ravenna	199 273	217 631	232 018	218 361	229 898	221 973
Rijeka	420 695	475 587	476 464	456 164	453 407	483 185
Trieste	539 043	670 078	862 586	747 197	729 878	722 267
Venice	336 313	350 931	352 627	344 586	349 862	328 062
TOTAL	2 359 303	2 772 051	3 094 596	2 789 854	2 940 041	2 905 848

Table 1. Total capacity offered in calls by port and by quarter (Source: AIS data from S&P Global, 2025.)

Following the previous analysis, we highlighted that major ports were significantly affected in the initial months following the onset of the crisis. We will now examine the evolution of port calls by container ship size category and by quarter (Table 2). We categorized the number of port calls into five size ranges to better illustrate the structural changes in port calls over time.

Between the third and fourth quarters, the two largest size categories were the most affected. In the 5,001–10,000 TEU category, the number of calls dropped from 42 to 29, a 45% decline. However, it is important to note that the third quarter appears to represent a peak in activity for this category, as it saw a significant increase in port calls compared to previous quarters. As a result, the 45% decline should be interpreted with caution, as it may not be solely attributable to the crisis—particularly since the number of calls does not increase in the fifth and sixth quarters.

Conversely, for container ships exceeding 10,000 TEUs, we observe a significant decrease between the third and fourth quarters, from 72 to 61 calls (-18%). However, in the following quarters, this segment experienced continuous growth, reaching a peak of 86 calls in the sixth quarter—surpassing pre-crisis levels.

At the opposite end of the spectrum, we note a significant and continuous decline in the number of calls for the smallest vessels (under 1,000 TEUs).

It is particularly relevant to examine the smallest ports—Bar, Bari, and Durres—which were among the most affected in terms of traffic. At first glance, the decrease in calls for sub-1,000 TEU vessels appears to be linked to the downturn in these ports. However, a more detailed analysis of our dataset nuances this interpretation.

In Durres, there was a sharp and sustained decline in port calls within this category (-81%), but this was offset by an increase in calls for vessels in the 1,000–2,500 TEU range during the fifth and sixth quarters. In Bar, the number of calls in the 1,000–2,500 TEU category dropped significantly between the third and fourth quarters (-67%) before returning to normal levels thereafter. In Bari, the 2,500–5,000 TEU category was the most affected, with the number of calls dropping from four in the third quarter to none in the fourth.

These AIS-based data provide valuable insights into the differentiated impacts of the crisis on container traffic across Adriatic ports.

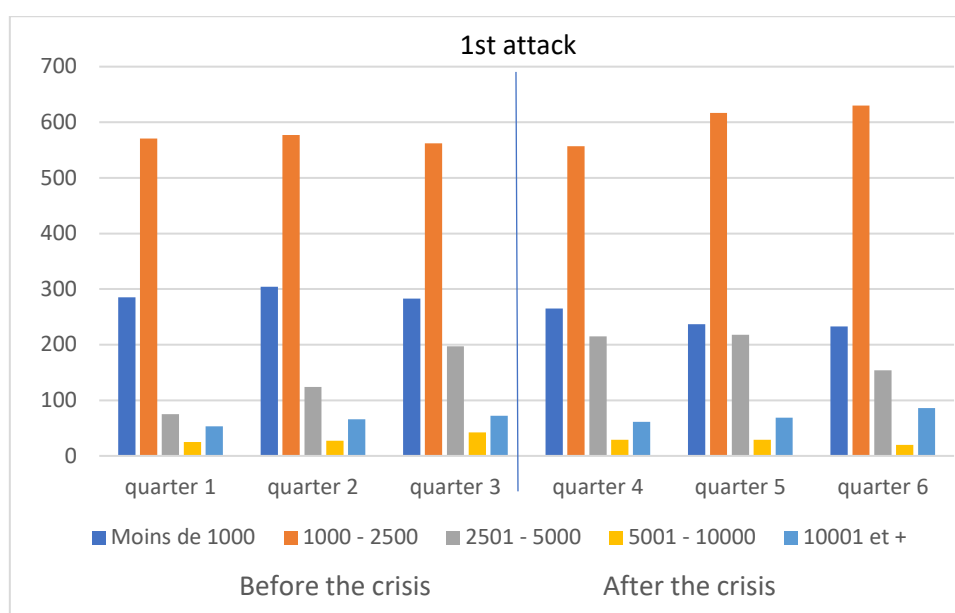


Figure 3. Number of calls by size of container ship and by quarter (Source: AIS data from S&P Global, 2025.)

We will now focus on the strategies adopted by shipping companies for servicing the region with container ships exceeding 10,000 TEUs. Maersk positions itself as the dominant player, with a significant number of port calls at the three main ports: Rijeka, Koper, and Trieste.

As shown in Table 3, Maersk initially maintained a stable number of port calls between the third and fourth quarters, but its calls almost halved in the following period. In contrast, the French company CMA CGM has emerged as a growing competitor in the region, positioning itself as a key player in recent quarters. The company serves the three aforementioned ports evenly, with 8 to 9 calls in the last quarter.

These empirical data highlight the strategic shifts in the maritime network organization of the world's leading shipping companies. With restrictions on passage through the Red Sea, companies have had to reorganize their routes, adjusting their maritime services and commercial offerings to continue serving the Mediterranean market.

The decline in port calls for container ships over 10,000 TEUs between the third and fourth quarters can largely be attributed to Zodiac. The company's number of calls dropped from 13 to zero before returning to pre-crisis levels in the following quarters.

Operator	Before the crisis			After the crisis		
	quarter 1	quarter 2	quarter 3	quarter 4	quarter 5	quarter 6
APL LLC	5	3			3	3
CMA CGM	4	9	6	7	15	26
Danaos Shipping						4
Maersk	41	49	52	50	28	34
MSC			1			
Seaspan Corp				4	7	6
Zodiac Maritime Ltd	3	5	13		16	13

Table 2. Number of calls by operator and by quarter for container ships over 10,000 TEU (Source: AIS data from S&P Global, 2025.)

In the previous analyses, we highlighted the main impacts of the Red Sea crisis on container traffic in the Adriatic Sea, focusing on port calls, their structural changes, and the strategies of major operators. Moving forward, we will examine the evolution of connections with the main Mediterranean hub ports (Table 4).

Overall, the observed changes remain relatively minor, with no significant shifts in the origin ports of container ships. The only notable developments are a substantial increase in connections with Port Said and a decline in vessels arriving from Haifa. The latter, an Israeli port, is directly affected by the ongoing conflict, which may explain this decrease.

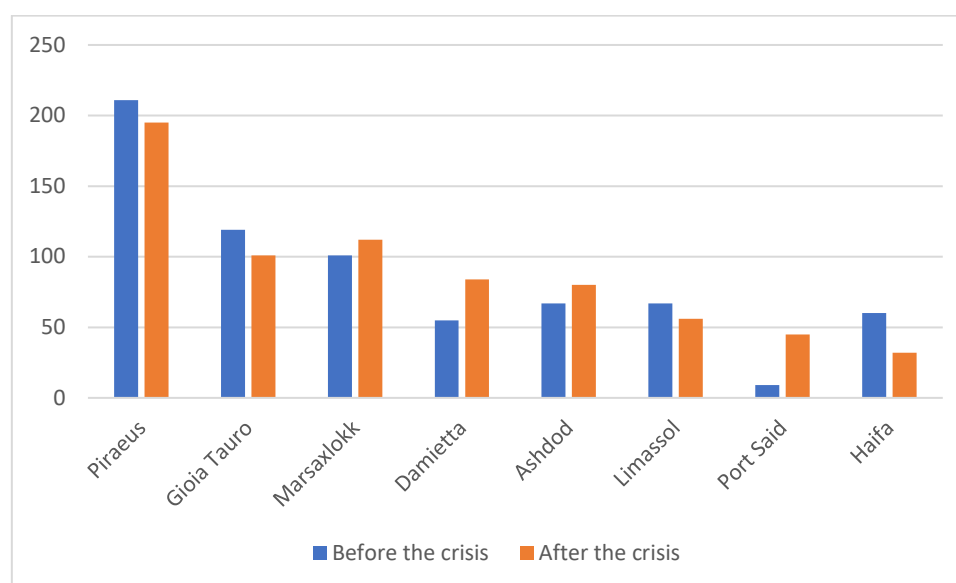


Figure 4. Number of container ship connections from the main Mediterranean ports (Source: AIS data from S&P Global, 2025.)

4. CONCLUSION

For this paper, we hypothesized that the Red Sea crisis and its consequences on the movement of container ships would impact Adriatic ports. Based on our empirical analyses, we can conclude that the actual impact is less significant than initially anticipated. The ports in our study were affected during the first few months following the crisis but largely returned to their pre-crisis levels thereafter. The main conclusions of our study are as follows:

- **A 11% decrease in the number of container ship calls between the quarter preceding the first attack and the following one.** In the subsequent quarters, traffic returned to previous levels as shipping companies adapted their services to the situation.
- **The smallest and largest ports were the most affected by the crisis.** Except the port of Ploče, the smallest ports—Bar, Bari, and Durres—saw their offered capacity for port calls drastically reduced. The larger ports of Koper, Rijeka, and Trieste also experienced a decline, albeit to a lesser extent. For these latter ports, part of their traffic is directly tied to transcontinental links, particularly with Asia. The reduction in calls by large vessels consequently affected feeding traffic, on which the smaller ports rely for their maritime services.
- **Traffic from very large container ships decreased significantly between the two quarters before and after the crisis.** Large container ships structure intercontinental maritime routes, so it is logical to observe a notable decline in their port calls in the Adriatic Sea.
- **In terms of shipping company strategies, we observed shifts in the market. Maersk, which had been the dominant player in the region, reduced its number of calls with large container ships.** In contrast, CMA CGM increased its presence, significantly boosting its offering of calls with very large container ships.
- **Connections with the main Mediterranean hubs showed only minor changes.**

Containerized transport in the Adriatic Sea is a regionalized traffic system, primarily relying on intra-Adriatic connections or links with the broader Mediterranean basin. Each year, over 3,000 container ships call at an Adriatic port, and two-thirds of them continue to another port within the Adriatic. The limited impact observed on the traffic of the ports in our study is likely related to the regional nature of this traffic.

For this study, we mainly employed an empirical method. To further explore the topic, it would be valuable to incorporate additional statistical methods, such as those from graph theory, and complement our findings with qualitative data, such as potential investments in terminals by certain operators or the strategies deployed within the ports.

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Sustainable Development in Croatian Maritime Journals – Literature Review and Thematic Analysis

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The aim of this paper is to review and analyse scientific papers in which sustainable development is mentioned in Croatian maritime journals and to identify and describe the themes represented in these selected scientific papers. Based on the methodology of a semi-systematic review of the literature and using the method of thematic analysis of the collected scientific papers, this paper analyses scientific papers that mention the term “sustainable development” (“sustainability”, “sustainable”, „sustainably“ etc.) in the title, abstract or keywords and were published in the period from 2014 to 2024 in the following four Croatian maritime journals: “Naše more”, “Pomorski zbornik”, “Pomorstvo” and “Transactions on maritime science” (ToMS). The application of the aforementioned methodology and method enables the collection, analysis and synthesis of relevant scientific findings on different maritime aspects of sustainable development published in renowned Croatian maritime research journals in the last ten years, as well as the identification and description of established themes. The results of the thematic analysis will help to clarify and better understand the links between the diversity of issues related to different aspects of sustainable development and the relationship between the sea and society, as well as to contribute to the synthesis of current knowledge on environmental and other aspects of maritime sociology.

KEYWORDS

Sustainable development; Croatian scientific maritime journals; Semi-systematic literature review; Thematic analysis; Maritime sociology.

1. INTRODUCTION

The term “sustainable development” (SD) “has been in use for fifty years, and by the mid-1990s of the last century, “more than sixty definitions, interpretations and visions” could be found in the literature (Cifrić, 2012). One of the most famous definitions of SD is given by the WCED in its 1987 report “Our Common Future”: “SD is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, and “it contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given”, as well as “idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs” (WCED, 1987). The above-mentioned concept of SD was later adopted at the UN “Conference on Environment and SD” in Rio de Janeiro in 1992, and since “Agenda 21” as a action programme for the 21st century, we can speak about the basis of action, goals and measures that need to be taken so that sustainability does not become just an “empty formula” or a “political slogan” (Cifrić, 2012). After that, “Sustainable Development Goals” (the 17 SDGs) of “The 2030 Agenda for Sustainable Development” were adopted by all members of UN in 2015 (UN, 2015). Today, the EU’s commitment toward SD is especially noticeable in the “European Green Deal”, adopted in 2019, and according to which “all 27 EU Member States committed to turning the EU into the first climate neutral continent by 2050” (European Commission, 2019). That includes different actions and changes in order to transform our economies and societies, making transport and mobility greener and sustainable for all, reducing gas emissions, using cleaner fuels, creating new jobs etc. (European Commission, 2019). Then, in 2021, the European Commission suggested the “new approach for a sustainable blue economy in the EU”(European Commission, 2021). Europe’s blue economy approach connects and “encompasses all industries and sectors related to oceans, seas and coasts” with the Green Deal's goals, regardless of “whether they are based in the marine environment” (e.g. green shipping, maritime transport, “fisheries, energy generation) or on land (e.g. ports, shipyards, land-based aquaculture and algae production, coastal tourism” (European Commission, 2021).

In this regard, the Republic of Croatia has opted for SD as early as 1992, when the “Declaration on Environmental Protection” was adopted (Cifrić, 2012). Currently, the most important, basic strategic document for Croatia's orientation towards SD is the “National Development Strategy of the Republic of Croatia until 2030”, which defines priorities and goals that are in line with the “2030 Agenda for Sustainable Development” and the “European Green Deal”. In order to implement the mentioned priorities and goals, it is necessary to continuously develop and monitor new scientific knowledge on different but interrelated “green” and “blue” aspects and dimensions of sustainability (economic, social, environmental, technological, digital, cultural etc.). The aim of this paper is therefore to review and analyze scientific papers (original scientific papers, preliminary communications and review papers) in which SD is mentioned in selected maritime journals and to identify and describe the themes represented in these collected scientific papers. Based on the methodology of a semi-systematic review of the literature and using the method of thematic analysis of the collected scientific papers (Snyder, 2019), this paper analyses scientific papers that mention the term “sustainable development” (“sustainability”, “sustainable”, “sustainably” etc.) in the title, abstract or keywords and were published in the period from 2014 to 2024 in the following four Croatian maritime journals: “Naše more”, “Pomorski zbornik”, “Pomorstvo” and “Transactions on maritime science” (ToMS). The main purpose of this semi-systematic review of the literature and thematic analysis is identification and description of established themes, as a prerequisite for further synthesizing research findings and conclusions (Braun and Clarke, 2006). Besides that, the second purpose is deeper understanding of the connections between the diversity of issues and themes related to SD, with emphasis on the relationship between the sea and society. This part of the paper aims to highlight and contribute to the current knowledge on environmental, but also other aspects of maritime sociology as a sociological sub-discipline.

2. MAPPING SUSTAINABLE DEVELOPMENT RESEARCH IN CROATIAN MARITIME JOURNALS

By means of a semi-systematic literature review and thematic analysis of the collected papers, a total of 94 scientific papers published in the following four Croatian maritime journals in the period from 2014 to 2024 were analysed: "Naše more" (15), "Pomorski zbornik" (23), "Pomorstvo" (38) and "ToMS" (18) (Table 1).

Year	"Naše more"	"Pomorski zbornik"	"Pomorstvo"	"ToMS"	Total
2014	0	–*	4	0	4
2015	1	1	4	0	6
2016	3	3	3	0	9
2017	2	1	0	0	3
2018	3	2	2	3	10
2019	0	3	6	0	9
2020	3	2	1	3	9
2021	1	1	7	1	10
2022	0	1	6	1	8
2023	1	3	3	5	12
2024	1	6	2	5	14
Total	15	23	38	18	94

* In 2015, a double issue was published (Vol. 49-59), as in 2013 (Vol. 47-48);

Table 1. The number of published scientific papers used in thematic analysis

With regard to the number of scientific papers published in the selected journals during the period under review that mention the term SD ("sustainability", "sustainable", "sustainably", etc.) in the title, abstract or keywords, an increase in the total number of scientific papers can be observed, as expected (Figure 1).

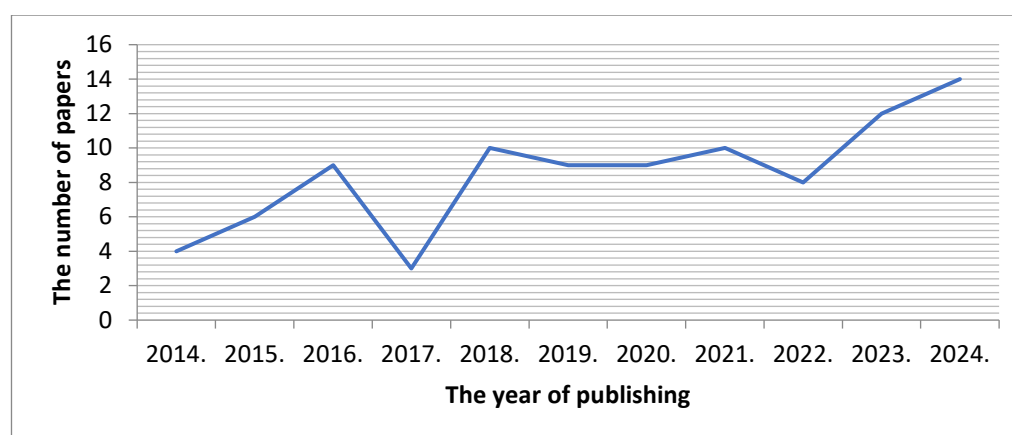


Figure 1. The increase in the total number of selected scientific papers published during the period under review

The thematic analysis of the collected scientific papers resulted in five thematic units: the social component of SD (Table 2), the ecological component of SD (Table 3), sustainable logistics and mobility (Table 4), economy, tourism and digitalization (Table 5).

Theme	Description of theme	Articles
Maritime education, training, profession	utilising mathematical methods for SD and growth	(Zelenika, 2016);
	new competencies of green logistics operators	(Poletan Jugović, Vukić, 2016);
	education about environment in the maritime sector	(Čulin, Bijelić and Jakšić, 2019);
	new port operation managers competencies in the area of sustainability	(Tezcan and Kuleyin, 2021);
	education and training for resilience, coastal risks and sustainability	(Runko Luttenberger and Mandić, 2022);
	maritime English; the role of maritime English lecturers	(Čulić-Viskotsa, 2024);
	sustainability of maritime profession	(Kan, 2024);
Legal regulations and laws, strategic documents	analysis of the strategic development documents of the local self-government units on the island of Krk (Croatia)	(Kristinić Nižić and Fugošić, 2019);
	analysis of the Croatian legal system for the protection and sustainable use of submarine cables	(Jurdana, Rukavina and Tominac Coslovich, 2021);
	international law and national laws as key to the sustainable use of natural resources	(Tismananda Kumala et al., 2023);
	regulations on maritime cultural heritage and maritime nature conservation law	(Puluhulawa, et al., 2024);
The attitudes of the citizens	the attitudes of the citizens in Croatia towards various impacts of cruise tourism	(Lučić, Sindik and Manojlović, 2017); (Vukić, Peronja and Mihanović, 2021);
	the attitudes of participants in coastal maritime transport towards electric ships in Croatia	(Mišura, Stanivuk and Čišić, 2019);
	citizens' attitudes towards the smart city concept for the SD of a tourist destination (Croatia)	(Krstinić Nižić, Vodeb and Šverko Grdić, 2020);
	the attitudes of the local population of the Elafiti Islands towards their quality of life and the development of a tourist destination (Croatia)	(Gračan and Lučić, 2022);
Socially responsible behavior	socially responsible behavior and management of the marina and the local community (Croatia)	(Luković, Gračan and Agbaba, 2024);

Table 2. Description of themes identified by the thematic analysis - the social component of SD

Theme	Description of theme	Articles
Environmental pollution	noise as a source of marine pollution – the example of the Adriatic Sea	(Sarić and Radonja, 2014);
	pollution from ships	(Čulin and Bielić, 2015);
	reduction of exhaust gasses from ships (the example of short sea ferries in the Suez Canal)	(Yehia, et al., 2020);
Sustainable energy sources	natural gas as a sustainable energy source - the cleanest fossil fuel	(Jovanović, et al., 2019);
	increasing energy and economic efficiency while at the same time reducing pollutant emissions	(Pelić, et al., 2024);
	reducing the environmental footprint and operating costs as part of slow steaming	(Balas, Dejhalla and Prpić-Oršić, 2024);
Biodiversity	sustainability of Croatian fisheries	(Runko Luttenberger, Ančić and Luttenberger, 2021);
	SD of marine aquaculture in Croatia	(Milošević, et al., 2024);
Marine environment	marine spatial planning for the protection of the marine environment in Croatia	(Zekić and Luttenberger, 2016);
	environmental and other charges for environmental protection (North Port of Split, Croatia)	(Vukić, Peronja, Slišković, 2018);
	impact of passenger terminal development on the environment (Zadar County, Croatia)	(Jugović, Gračan and Barkidžija Sotošek, 2023);
Waste management	collecting waste on the Croatian islands - example of the waste sorting ship (Croatia)	(Smilović and Dejhalla, 2022);

Table 3. Description of themes identified by the thematic analysis - the environmental component of SD

Theme	Description of theme	Articles
Sustainable maritime transport and logistics	sustainability of a transport route	(Poletan Jugović, Šimić Hlača and Žgaljić, 2014);
	intermodal maritime logistics chains	(Jugović, Žanić Mikuličić and Maglić, 2014);
	sustainability of transport and shipping companies	(Vochozka, Strakova, Vaschal, 2015);
	principles, methods and instruments of green logistic	(Rahmangulov, et al., 2017); Rahmangulov, et al., 2018);
	modern transport chains (ports on the eastern Adriatic, Croatia)	(Beškovnik, et al., 2020);
	environmental suitability of overseas transport chains	(Beškovnik, 2021);
	efficiency of empty container management and transport	(Blažina, et al., 2022);
	intermodal container transportation	(Golnar, Beškovnik, 2023);
	transport management of the container traffic (Croatia)	(Grubišić, Krljan and Sesar, 2023);
Sustainable port development	sustainable shipping (propeller and rudder performance)	(Sunarsih, Ndraha and Baidowi, 2024);
	SD of the port of Ploče (Croatia)	(Rathamn, Kružić and Poletan Jugović, 2015);
	SD of the North Adriatic container ports (Croatia)	(Oblak, Hess and Jugović, 2016);
	sustainable port planning	(Ignaccolo, Inturri and Pira, 2018);
	model of port development based on a public-private partnership (Croatian seaports)	(Perić Hadžić, 2022);
	the concept of the green port in Croatian marinas	(Poletan Jugović, et. al., 2022);
	port service quality (port of Rijeka, Croatia)	(Bortas, Kolanović and Vilke, 2022);
Sustainable mobility	the criteria for assessing the performance of a green port	(Tezcan and Kan, 2023);
	“motorways of the sea“	(Kegalj and Traven, 2017); (Žgaljić, Oblak and Schiozzi, 2019);
	traffic data and information	(Budimir, Jelušić and Perić, 2019);
	sustainability and new technologies in urban transport and mobility (Croatia)	(Vilke and Ostović, 2019);
	hydrogen technology and fuel in urban transport	(Vilke, et al., 2020);
	urban mobility examples of good traffic management practice	(Vilke and Tadić, 2020);
	liner passenger shipping for connecting the Croatian islands with the mainland (Croatia)	(Mišura, Sopta and Perić Hadžić, 2020); (Sušić, et al., 2021);
	sustainable urban public transport system in Istanbul	(Soy, Tavacioglu, 2023);
Sustainable urban logistics	sustainable mobility in the context of passenger maritime transport (Italy and Greece)	(Campisi, et al., 2024);
	the impact of logistics on the perception of the sustainability of the urban space (Croatia)	(Kovačić, et al., 2023);
	analysis and bibliometric review of the sustainable urban logistic	(Mutavdžija, Kovačić and Cvitković, 2023);
Road transport	using drones in urban logistics to reduce gaseous emissions footprint (Croatia)	(Aksentijević et al., 2023);
	electro mobility - electric buses instead of diesel and hybrid buses	(Potkany, et al., 2018);
	sustainable competitive railway transport	(Dedik, et al., 2018);
	SD of railroads and transport (Central Dalmatian Ports, Croatia)	(Stričević, Vukić, 2024);

Table 4. Description of themes identified by the thematic analysis – sustainable logistics and mobility

Theme	Description of theme	Articles
Sustainable maritime business development	stable cash flows and stakeholder “value in the ‘value in use’ concept”	(Brlčić Valčić, Katunar J. and Katunar H., 2015);
	reduction of risk caused by uncertainty to achieve sustainable growth (China’s trade)	(Efes, Baser and Acik, 2019);
	impact of cost structure on SD and company survival (five maritime Croatian companies)	(Brlčić Valčić, 2021);
	sustainable business management in the maritime sector	(Debelić, 2024a);
Sustainable maritime trade and management	integral management of coastal and marine areas (Croatia)	(Kovačić, Zekić and Rukavina, 2016);
	coastal zone and their development in local communities	(Ivanić, et al., 2018);
	sustainable management of the coastal area	(Kovačić, Mrvica and Šimić Hlača, 2020);
	port-city relationship and development (Spanish port system)	(Lopez-Bermudez, et al., 2020);
	sustainable port city development	(Jugović, Sirotić and Peronja, 2021);
	sustainable initiatives in the port cities	(Gonzales Laxe, Bermudez and Palmero, 2022);
	SD of dry ports in Malaysia	(Jeevan et al., 2023);
	coastal zones and maritime common good	(Debelić, 2024b);
The blue economy	the blue economy development (nautical tourism and small shipbuilding, Croatia)	(Alempijević and Kovačić, 2019);
	greening the blue economy (Primorje-Gorski Kotar County, Croatia)	(Kovačić, Perinić and Kerčević, 2021);
	systematic quantitative literature review on the blue economy	(Pilko, 2024);
Digitalization and informatization in the maritime sector	economically sustainable information security management in seaport clusters	(Aksentijević, Tijan and Čišić, 2014);
	the impact of information and telecommunication technologies on supply chain efficiency (City of Rijeka, Croatia)	(Jardas, Dundović and Badurina-Tomić, 2016);
	digitalization in the maritime economy (national and international level)	(Pavlinović, Račić, Mišura, 2023); (Kaštelan, et al., 2024);
Sustainable coastal and marine tourism	SD of mass tourism (Dubrovnik, Croatia)	(Ljubičić, 2016);
	SD of transport and tourism (Dubrovnik-Neretva County, Croatia)	(Vidučić, Marušić, Plazibat, 2016);
	the role of transport in the SD of tourism	(Kovačić and Milošević, 2016);
	connecting maritime and continental tourism from the sustainable tourist destination management perspective (Croatia)	(Gračan, Coner and Štros, 2018);
	dark tourism products as the example of unsustainable approach to tourism	(Šerić, Mihanović and Tolj, 2020);
	sustainable international marine tourism	(Troian, et al., 2023);
Nautical tourism	the development of nautical tourism in Croatia	(Kovačić, Gračan and Jugović, 2015); (Alkier, Miložica and Drpić, 2015);
	crisis situation in nautical tourism	(Gračan and Agbaba, 2021);
Beach tourism	sustainable beach management (Croatia)	(Kovačić and Zekić, 2018); (Zadel, Gračan and Miložica, 2018);
	SD of the coastal zone and beach tourism	(Magaš, Debelić and Vilke, 2018);

Table 5. Description of themes identified by the thematic analysis – economy, tourism and digitalization

3. SEA AND SOCIETY – THE PROCESS OF “MARINIZATION“

Maritime sociology is influenced by the following “two key paradigms”: one relates to topics close to the sociology of work, occupations and organisations and emphasises “work at sea”, the second relates to topics close to environmental sociology and focuses on “how human activities affect reality at sea” (Kolodziej-Durnas, Sowa and Grasmeier, 2022). Although the SD is more a topic of environmental sociology, it encompasses both perspectives: “the influence of the sea” as well as the human “influence on the sea”

(Kolodziej-Durnas, Sowa and Grasmeyer, 2022). To include both perspectives in this paper, the concept and social process of “marinization”, as described by Ludwik Janiszewski, is highlighted (Kolodziej, 2020). This concept emphasizes that social reality is “shaped by the influence of the sea and the various human activities associated with the sea” (Kolodziej, 2020). The basic concepts of this theory include “human activity related to the sea” (an economic, political, scientific and cultural one), with economic activity (maritime economy) having the greatest influence on social reality as well as on the sea (Kolodziej, 2020). This concept also includes “maritime institutions” (ports, maritime schools, maritime transport companies, etc.), which are “both an influencing factor and an effect of the marinization process” (Kolodziej, 2020). Furthermore, the process of “marinization” encompasses and shapes different levels of social life (local, social, regional, national, global) (Kolodziej, 2020). In order to connect and combine the basic concepts and process types that constitute the “the process of marinization” with the themes identified through the thematic analysis, the following Table 6. is presented.

Component processes	Themes identified by the thematic analysis	Aspects of the analysis of the “marinization process” identified by the thematic analysis
Social processes	Maritime education and training	Education on environmental and other dimensions of sustainability in the maritime sector
	New competences in the field of sustainability	New competencies of green logistics operators; new port operation managers competencies; competent seafarers and officers
	Legal protection, regulations and laws	International law and national laws and regulations as prerequisite for achieving SD
Cultural processes	Citizens' attitudes, values and norms	New system of values and norms regarding sustainability (e.g. socially responsible behavior)
		Citizens' attitudes towards the various impacts of cruise tourism
		Citizens' attitudes towards electric ships in Croatia, the concept of the smart city, etc.
Economic processes	Sustainable maritime business development	Achieving sustainable growth; sustainable economic governance
	Sustainable maritime trade and management	Sustainable management on coastal and maritime areas; port-city development; digitalization and information security in maritime economy
	Sustainable tourism	SD of mass tourism; nautical tourism; cruise tourism; sustainable beach managing and beach tourism
Tecnological processes	Sustainable maritime transport and logistics	Green logistics; green ports; sustainable port development and planning; sustainable shipping; “motorways of the sea”
	Sustainable mobility	Sustainable maritime mobility of goods and data; sustainable maritime passenger transport; sustainable road transport - electromobility
	Sustainable energy sources	Reduction of exhaust gasses from ships; reduction of pollution from ships and harbours; protection of the marine environment
Political processes	“European Green Deal”	Implementation of the priorities and goals stated in the “European Green Deal”

Table 6. Selected themes and processes that create the process of “marinization”

4. CONCLUSION AND DISCUSSION

Based on the thematic analysis of the reviewed scientific papers, some conclusions can be drawn. Firstly, it can be concluded that according to the dominant level of analysis, of the total number of analyzed scientific papers (94 papers), 54 relate to the international level or cross-national analysis (Europe and worldwide), while 40 of them relate to the national level or analysis within one country (Croatia). Specifically, among 17 papers related to the social component of SD (9 relates to the international and 8 to national level);

among 12 papers related to the environmental component of SD (6 relates to international and 6 to national level); among the 34 papers on sustainable logistics and mobility (21 relates to international and 13 to national level), and among 31 papers on economy, tourism and digitalisation (18 relates to international and 13 to national level). Secondly, based on Europe's blue economy approach, according to which all topics related to "all industries and sectors related to oceans, seas and coasts", including sustainable maritime transport, sustainable port development, sustainable mobility etc. can be analysed as topics related to the "sustainable blue economy" (European Commission, 2021), it can be concluded that these "blue economy" topics dominate with 65 out of a total of 94 scientific papers, including papers on sustainable logistics and mobility (Table 4) as well as on economy, tourism and digitalisation (Table 5). Thirdly, with regard to the analyzed papers related to Croatia and by comparing them with the "National Development Strategy of the Republic of Croatia until 2030", which aims to achieve sustainable economic and social development within the framework of the four development directions ("sustainable economy and society", "green and digital transformation", "strengthening crisis resilience" and "balanced regional development") (National Development Strategy, 2021), the following conclusions can be drawn. Although there is some overlap between the above-mentioned themes and development directions, overall it can be stated that of the 40 papers related to Croatia, 18 papers refer to the "sustainable economy and society" (including the social component of SD as well as sustainable maritime business development, sustainable maritime trade and management, blue economy development, sustainable coastal and marine tourism, nautical tourism and beach tourism); 14 papers refer to the "green and digital transformation" (including the environmental component of SD, sustainable logistics and mobility and digitalization in the maritime sector); while 8 papers refer to "balanced regional development" (including 5 papers on SD of Croatian seaports and marinas) and "strengthening crisis resilience" (both development directions are including topics of 3 papers related to improving the quality of life on the Croatian islands and the importance of liner shipping for connecting the Croatian islands with the mainland) (National Development Strategy, 2021). In this regard, conducted analysis can provide useful synthesis of existing scientific knowledge that contributes to achieving goals that are in line with aforementioned Strategy, and could also be useful for monitoring the application of the specified policy document.

The main limitation of this literature review and thematic analysis is the fact that it is possible that in the journals analysed and within the selected time period, scientific papers have been published that also deal with the topic of SD and represent a valuable contribution to the scientific analysis of this topic, but do not mention the term "sustainable development" ("sustainability", "sustainable", "sustainably" etc.) in the title, abstract or keywords. During the process of literature review this was especially noticeable while reading the abstract and papers related to the environmental component of SD, more specifically, papers dealing with biodiversity and aquaculture topics, as well as greenhouse gas emissions, which undoubtedly refer to topic of this paper, but were not included in the analysis because of the above specified research criteria. For this reason, some papers have not been included in the analysis, and therefore, the results of this analysis provide a good insight, but not a complete one, into the representation of the topics mentioned in the selected journals. Nevertheless, the results of a semi-systematic review of the literature and thematic analysis presented in this paper can be interesting and useful in an applied sense for further summarising conclusions and planning the future research, and in a theoretical sense they can contribute to the confirmation of interdisciplinary knowledge on SD as well as providing insight into the current knowledge on maritime and other aspects of SD. In this regard, special attention in paper is given to emphasizing the relationship between the sea and society. Therefore, the social process of "marinization" as described by Ludwik Janiszewski is highlighted and connected to the themes identified through the thematic analysis.

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A Case Study on Direct Connection of Shore Power for Domestic Vessels

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The shore power facilities cost is expensive. If onboard electric system can connect to the shore side electric system directly, several of equipment can be omitted, which may suppress those cost. This study approached the technical issues for the low-cost installation of shore power equipment for 499GT domestic cargo vessels. Power demand and actual pump head were measured in a general cargo vessel. Based on these data, the degradation of onboard equipment performance was estimated in shore connection condition. The results revealed that above concerns may not cause problems for 499 GT general cargo vessels. The cost of shore power equipment can be reduced because power can be supplied directly from the shore-side electric grid to the ship without frequency converter.

KEYWORDS

Shore power; Domestic cargo vessels; Voltage drop; Frequency drop

1. SHORE POWER CONNECTION TARGETS AND CONCERNS.

There are many advantages to shutting off vessel's onboard generators and connecting to a shore power source when the vessel is moored (Sun, Ding, Xiong, Liu, Hu, 2022)(Mahdi, Student Member, IEEE, Hoff, Senior Member, IEEE, and Trond Østrem, Member, IEEE, 2023). It used to be called “cold ironing” and recently “shore connection”. The shore connection has long been noted for its ability to reduce harmful emissions like NO_x, SO_x, and PM in ports, and to reduce noise caused from onboard diesel generators (The Institute of Marine Engineering, Science and Technology (IMarEST), 2006)(Parth Vaishnav, Paul S. Fischbeck, M. Granger Morgan, James J. Corbett, 2015)(Wu, Wang, 2020). In addition, the use of the shore power contributes to reduce energy consumption and operating costs for whole society including not only marine environment but land residential area (Ghanatghehstani, Jahandari, 2023). IEC TC18 has already published their standard IEC80005-1 for high voltage shore connection and low to middle voltage one (IEC 80005-3) will be coming soon on later (IEEE/IEC 80005-1:2019).

The shore connection service started in 2004 in US. The shore power facilities have been installed in the ports of Los Angeles and San Francisco (Daniel, Trovão, Williams, 2022). The ports of Hamburg, Antwerp, Bremerhaven, Haropa, and Rotterdam plan to install the shore power facilities at large container ports by 2028 (Public Statement,2021). Like these examples, the shore power facilities are increasing in public quays especially for international large vessels, however, only a few ports have the facilities for domestic vessels.

In Japan several private berths have installed the shore power facilities for domestic cargo vessels. Although some port authorities are interested in installing the facilities of shore connection, the number of them in public berths for coastal shipping has not increased as much as expected. Cost and technical challenges are the main factors hindering the installation of shore power facilities (Tseng, Pilcher, 2015). Technical challenges are caused by the differences in voltage and frequency.

Generally speaking, ocean-going vessels used to employ 450 V or 690 V generator, although parts of large cargo vessels like LNG carrier, over 20,000 TEU container liner have started to use high voltage (6.6 kV/11 kV) electric system in these days. On the other hand, many domestic cargo ships equip with 225 V generator for onboard electric system in Japan. When they connect to the shore power, it is desirable to receive the same voltage as their onboard generators. On the contract of electric power receiving in Japan, user needs to choose voltage level from 200 V, 6.6 kV, or higher voltage. If the received voltage is 6.6 kV or higher level, dedicated equipment have to be installed on shore side. These facilities need to be checked periodically and maintained by dedicated technicians. Therefore, port authorities must bear the high initial and operational costs of the shore power facilities. On the other hand, electric power receiving contracts of 200 V or less require a simple power-receiving facility (this is called low-voltage power receiving in Japan). With low-voltage shore power, it allows port authorities to save the initial and maintenance costs, which motivates the port authorities to install the shore power facilities, if onboard electric machines work properly.

Japan is very unique because there are two areas in terms of electric frequency. In eastern Japan, the frequency is 50 Hz, whereas it is 60 Hz in western Japan. In general, the ship equips with 60 Hz generators and all of electric machines are designed to operate in 60Hz. Therefore, it is a common sense to use a frequency converter for supplying electric power from shore grid to ship in 50 Hz region. However, the frequency converters are expensive and not affordable for organizations or local government which manage their ports for domestic coastal ships. If the onboard equipment works properly when connected to 50 Hz shore grid, a frequency converter is not necessary. This simplifies the components of facilities on the port-side. Therefore, this study assesses whether the onboard electrical equipment works properly when receiving 200 V/50 Hz shore power.

The technical concerns are listed below.

1. Electric motor torque: Low voltage than designated level results in lower torque.
2. Pump capacity: Frequency difference causes low speed of the electric motor, which reduces the pump capacity.
3. Excessive heat in transformer: Low frequency may cause magnetic saturation in transformer core, which may raise temperature of transformer.
4. Upper limit of received power: Electricity demand may reach to limitation of the power.

This study assesses the technical issues associated with these performance degradations due to 200 V/50 Hz shore power.

2. TECHNICAL ISSUES OF SHORE CONNECTION

This study focused on ship_A (The second Kiyu Maru), which is a 499 GT typical general cargo ship (Table 1); 499 GT ships are the most numerous domestic vessels in Japan. The generator output power and consumed power by several large electric machines were measured on the ship_A for several months. In general, cargo ships open their hatch covers before loading / unloading, and close them after unloading / loading. There is no special cargo handling equipment and large electric machines to be operated during cargo handling. Therefore, onboard electricity demand is limited while being moored.

LOA	72.7 m	
GT	499 ton	
DWT	1750 ton	
Main engine	Power	1471kW
	Speed	300 rpm
Diesel generators	Power	160 kW×2set
	Engine speed	1200 rpm
	Voltage	225V
	Frequency	60Hz

Table 1. Specification of ship_A

2.1. Pump Head

2.1.1. The major equipment of ship_A

The major equipment used in ship_A are listed in Table 2. The equipment highlighted with light blue are in automatic intermittent operation. The low-temperature cooling-freshwater pump and the cooling-seawater pump can be stopped during shore connection condition, because they do not need to cool the generator engine when the ship connects shore power. All of these pumps are driven by induction motors which could be affected by voltage and frequency drops if onboard electric system uses shore grid power.

Name		Rated power
Low temp cooling fresh water pump		11 kW
Cooling sea water pump		11 kW
Air compressor		5.5 kW
Air conditioner	Compressor	5.5 kW
	fan	1.5 kW
Boiler oil burner		0.15 kW
General service fresh water pump		0.4 kW
Purifier	Heater	8 kW
	Pump	0.75 kW
	Separator	1.5 kW
Air conditioner fresh water pump		1.5 kW
Hot water circulation pump		2.2 kW
Engine room fan		3.7 kW
Purifier LO service pump		0.75 kW
Balast pump×2		15 kW

Table 2. Major equipment in machinery space.

2.1.2. Calculating method of discharge amount and pump head

Centrifugal pumps may lose sufficient capacity owing to the decrease in voltage and frequency. To assess the pump capacity, it is desirable to estimate the discharge amount and the pump head.

Generally, the discharge amount Q is proportional to the electric motor speed N (Matsushita, Furukawa, Watanabe, Okuma, 2009):

$$Q \propto N \dots \dots \dots (1)$$

The discharge amount decreases by a factor of 50/60 when the frequency becomes low from 60 Hz to 50 Hz:

$$Q \propto \frac{50}{60} \dots \dots \dots (2)$$

The pump head is proportional to the square of voltage:

$$H \propto E^2 \dots \dots \dots (3)$$

Therefore, when the voltage drops from 220 V to 200 V, the pump head drops by a factor of $(200/220)^2$:

$$H \propto \left(\frac{200}{220}\right)^2 \dots \dots \dots (4)$$

Furthermore, the pump head is proportional to the square of the electric motor speed.

$$H \propto N^2 \dots \dots \dots (5)$$

Therefore, when the frequency becomes low from 60 Hz to 50 Hz, the pump head is reduced by a factor of $(50/60)^2$:

$$H \propto \left(\frac{50}{60}\right)^2 \dots \dots \dots (6)$$

2.1.3. Degradation on pump capacity.

Degradation of pump capacity can be estimated by using equations mentioned above with shop trial data. Figure 1 shows the pump head curves of the general service freshwater pump which requires the highest head among the pumps on ship_A. Its actual head is approximately 10 m. When the ship is connects to the shore grid, the head and discharge amounts of the pump are lower than the state that the main generators are ON. However, it can be confirmed that the resistance curve intersects the pump head curves even if onboard electric system uses 200 V/50 Hz shore power, which means the pumping capacity can be maintained. The head curves of other pumps were also checked, and similar results were found. Therefore, although the performance of the pump is reduced, its function can be maintained.

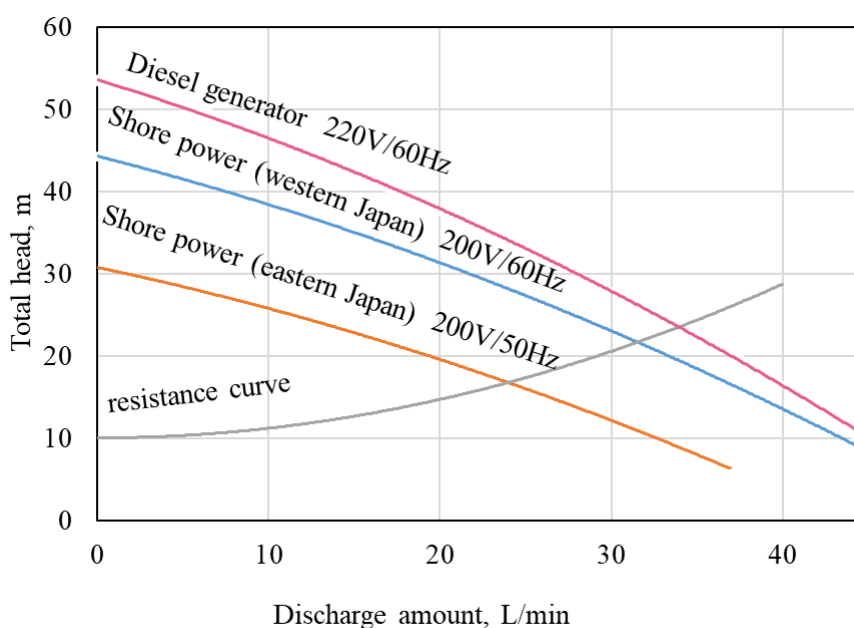


Figure 1. The pump head curves of the general service freshwater pump.

2.2. Power loss in Transformers

Transformers are installed to step down the main bus system voltage from 220 V to 100 V for supplying electricity to lighting and other consumer devices. Generally, efficiency of transformers is high around 99%. Around 1% of input power is dissipated and converted to heat energy. Therefore, those transformers are self-cooled by ambient temperature air. The power losses in transformers are classified into copper loss caused by load current and iron loss occurred in the transformer core. These phenomena are influenced by the primary

side voltage condition. If the power dissipation becomes larger than its initial designed level, transformer's temperature may rise unexpectedly. It makes root cause of deterioration in the worst scenario of onboard transformers because it doesn't have a force cooling system. Therefore, it is necessary to assess how power losses are influenced in the shore connection condition.

One of the components of iron loss P_c which is occurred in the transformer's core is hysteresis loss P_h .

$$P_h = K_h f B_m^n \dots \dots \dots (7)$$

where :

K_h : constant depending on core volume and steel quality

B_m : maximum core flux density [Wb/m²]

The constant n in equation (7) is typically in the range of 1.5 to 2.5, and 1.6 is often used for estimation (E. Fitzgerald, C. Kingsley and D. S. Umans, 2003), (S. B. Guru and R. H. Hiziroglu, 2001).

The primary voltage V_p of the transformer is defined as follows,

$$V_p = 4.44 f N_p \phi_m \dots \dots \dots (8)$$

where:

f : frequency [Hz]

N_p : number of turns in the primary winding

ϕ_m : maximum magnetic flux [Wb]

Hence, B_m is rewritten as follows,

$$B_m = \frac{V_p}{4.44 f N_p A_c} \dots \dots \dots (9)$$

where :

A_c : cross-section area of the transformer core [m²]

Substituting equation (9) for (7), the influence of shore connection to the hysteresis loss is obtained.

$$\frac{P_{h_{200,50}}}{P_{h_{220,60}}} \cong 0.958 \dots \dots \dots (10)$$

where :

$P_{h_{200,50}}$: hysteresis loss in 200 V/50 Hz condition [W]

$P_{h_{220,60}}$: hysteresis loss in 220 V/60 Hz condition [W]

Eddy current loss P_e is also one of main factors of the iron loss.

$$P_e = K_e f^2 B_m^2 t^2 \dots\dots\dots (11)$$

where:

K_e : constant depending on core volume and resistivity of the iron

t : thickness of core laminations[m]

Substituting (9) for (11), the influence of shore connection to the eddy current loss is obtained.

$$\frac{P_{e\_200,50}}{P_{e\_220,60}} \cong 0.826 \dots\dots\dots (12)$$

where :

$P_{e\_200,50}$: eddy current loss in 200V 50Hz condition [W]

$P_{e\_220,60}$: eddy current loss in 220V 60Hz condition [W]

Consequently, the iron loss is mitigated when the shore power is used.

Additionally, copper loss P_w occurred in the windings needs to be assessed.

$$P_w = I^2 R \text{ [W]} \dots\dots\dots (13)$$

where:

R : representative resistance of the windings [Ω]

In many cases, loads connected to the secondary side of transformer are home appliances. Recently, those home appliances have a built-in power converter to control their power properly. They maintain the requested power P for their load even if input voltage drops. The current absorbed by home appliances increases in the shore power condition. If turn ratio is 2.143, the secondary voltage V_s is around 93.3 V in the shore power condition. As the result, the secondary current I_s increases.

$$\frac{I_{s\_200}}{I_{s\_220}} = \frac{\frac{P}{V_{s\_200} \cos \theta}}{\frac{P}{V_{s\_220} \cos \theta}} \cong 1.072 \dots\dots\dots (14)$$

As shown in equation (13), the copper loss is proportional to the square of current I . Therefore, P_w increases 1.149 times in the shore power condition at the maximum. In order to address this issue, the current value flowing in the secondary side of the transformer had been observed for one month. Figure 2 shows a histogram of the observed current for one month. The horizontal axis shows the current value and the vertical axis shows the ratio of that current value to the total. The rated apparent power of transformer installed in ship_A is 25 kVA. Therefore, the maximum current of the primary side is around 64 A. Since the turn ratio of the transformer is 2.143, the secondary side current I_s is limited to 137 A. Figure 2 shows that the secondary current of the transformer is sufficiently small. As is clear from these discussions, there is no concerns about the power dissipation which raises the transformer temperature.

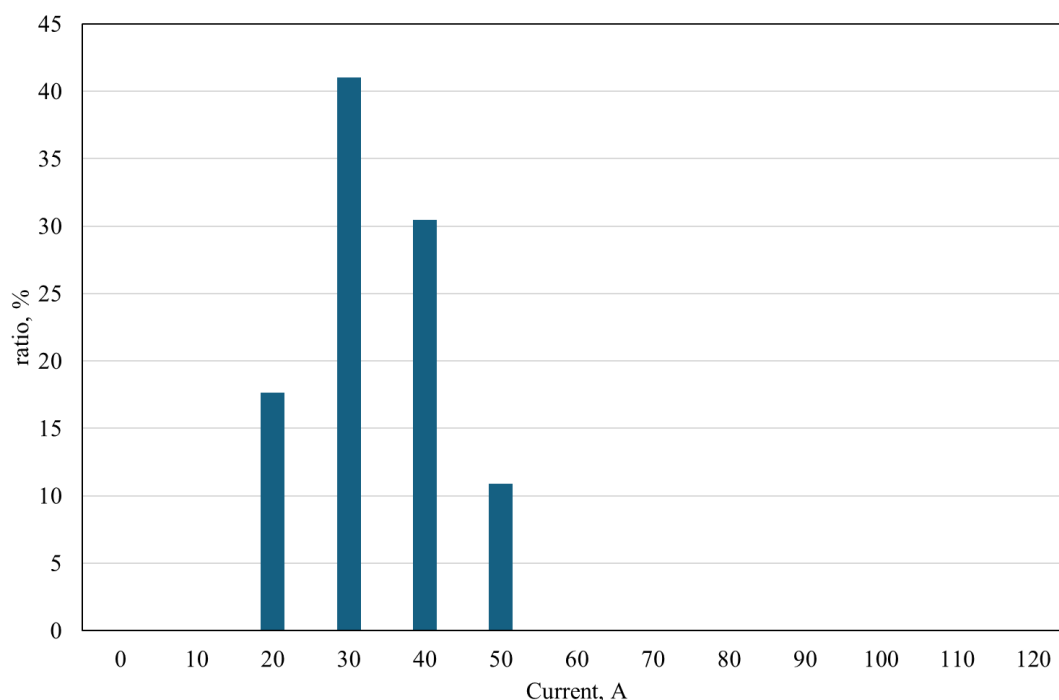


Figure 2. The histogram of secondary current in transformer.

When it uses low voltage connection, the secondary voltage of the transformer is also decreased by 10 %. However, it was confirmed that home appliances like refrigerators, microwave ovens and other electric devices can work well under 90 V condition.

2.3. Limitations on receiving power

2.3.1. Limitation of the total current

On the contract of the low-voltage power, it is allowed to use electricity up to 50 kW in Japan. Therefore, onboard electric machines can work within 50 kW if ship connects to the shore power. In general, the power factor ($\cos\theta$) of onboard electric system is around 0.8 because there are many induction motors in the machinery space. Hence the current flowing in three phase AC bus may reach to around 180 A ($=P/(\sqrt{3}V\cos\theta)$) at the maximum.

On the other hand, the main breaker in a power receiving terminal on shore side is often set to 150 A at the maximum, because the power factor is assumed as unity (1.0) on the shore grid. Therefore, during the shore connection, onboard three phase AC current is not allowed to exceed 150 A. Consequently, onboard electric machines may have a power limitation (P_{limit}) as follow;

$$P_{limit} \leq \sqrt{3}VI\cos\theta = \sqrt{3} \cdot 200 \cdot 150 \cdot 0.8 \approx 41.6 \text{ [kW]} \dots\dots\dots(14)$$

Therefore, it is necessary to know whether the total current exceeds 150 A when the voltage and frequency are reduced.

2.3.2. The method of calculating the current and power.

To approach this issue, it is necessary to assess and calculate load current of each electric equipment. This study classifies the onboard electric machines into two categories: major equipment and miscellaneous loads, so that the current is estimated properly in the shore connection condition. The major equipment in the engine room is shown in Table 2. The lighting, home appliances, and other electric equipment which do not consume large power are categorized as miscellaneous loads.

Since the major equipment is driven by electric motors, its power and current are influenced by dropping voltage and frequency.

The torque of an induction motor is proportional to the square of the voltage.

$$T = k \times V^2 \times \frac{sr}{r^2 + (sx_1)^2} \dots \dots \dots (15)$$

where:

s : slip

r : Rotor circuit resistance [Ω]

x : Leakage reactance of the rotor circuit, $x = 2\pi fL$

k : constant

The mechanical power of an induction motor is proportional to the product of torque and speed.

$$P_{out} = 2\pi \times T \times N \text{ [W]} \dots \dots \dots (16)$$

The electric power of the induction motor P_{in} is calculated as

$$P_{in} = 2\pi \times k \times V^2 \times \frac{sr}{r^2 + (sx)^2} \times N \dots \dots \dots (17)$$

Voltage and frequency conditions are written as subscripts.

The electric power of the motor at 220 V 60 Hz is calculated as

$$P_{in220,60} = 2\pi \times k \times V_{220,60}^2 \times \frac{S_{220,60}r}{r^2 + (S_{220,60}x_{60})^2} \times N_{220,60} \dots \dots \dots (18)$$

On the other hand, the electric power of the motor at 200V 60Hz is calculated as

$$P_{in200,60} = 2\pi \times k \times V_{200,60}^2 \times \frac{S_{200,60}r}{r^2 + (S_{200,60}x_{60})^2} \times N_{200,60} \dots \dots \dots (19)$$

The speed of the motor is expressed by the following equation.

$$N = \frac{120f}{p}(1 - s) \dots \dots \dots (20)$$

where :

p : number of poles

If the slip does not change when changing from 220V60Hz to 200V60Hz, the rotation speed will not change either.

$$s_{200,60} = s_{220,60} \dots \dots \dots (21)$$

$$N_{200,60} = N_{220,60} \dots \dots \dots (22)$$

From the equation (18), (19), and (21), the electric power of the induction motor at 200 V/60 Hz is expressed by the following formula, approximately.

$$P_{in200,60} = P_{in220,60} \times \left(\frac{V_{200,60}}{V_{220,60}}\right)^2 \dots \dots \dots (23)$$

Hence, the output power decreases when the voltage drops to 200 V. For this reason, the current declines when the voltage decreases. The estimated load current of the induction motor at 200 V/60 Hz is as follows:

$$I_{ld200,60} = P_{in220,60} \times \left(\frac{V_{200,60}}{V_{220,60}}\right)^2 \times \frac{1}{\sqrt{3}V_{200,60}\cos\theta_{200,60}} \dots \dots \dots (24)$$

where:

V : Applied voltage to the induction motor [V]

I_{ld} : Load current [A]

$\cos\theta$: Power factor

The electric power of the motor at 200V 50Hz is calculated as:

$$P_{in200,50} = 2\pi \times k \times V_{200,50}^2 \times \frac{s_{200,50}r}{r^2 + (s_{200,50}x_{50})^2} \times N_{200,50} \dots \dots \dots (25)$$

Since the slip is very small during steady operation, equation (25) can be omitted as follows.

$$P_{in200,50} = 2\pi \times k \times V_{200,50}^2 \times \frac{s_{200,50}}{r} \times N_{200,50} \dots \dots \dots (26)$$

Assuming that the slip does not change with declining voltage and frequency. From the equation (18), (20), and (26), In the condition of 200V/50Hz, the power of the motor can be expressed by the following equation.

$$P_{in200,50} = P_{in220,60} \times \left(\frac{V_{200,50}}{V_{220,60}}\right)^2 \times \frac{f_{200,50}}{f_{220,60}} \dots \dots \dots (27)$$

The estimated load current of the induction motor at 200 V/50 Hz is as follows:

$$I_{ld200,50} = P_{in220,60} \times \left(\frac{V_{200,50}}{V_{220,60}}\right)^2 \times \frac{f_{200,50}}{f_{220,60}} \times \frac{1}{\sqrt{3}V_{200,50}\cos\theta_{200,50}} \dots \dots \dots (28)$$

The miscellaneous loads current I_{mis} is obtained by following,

$$I_{mis} = I_{220,60} - I_{ld,total,220,60} \dots \dots \dots (29)$$

$I_{220,60}$ is an observed generator current. $I_{ld,total,220,60}$ is sum of all induction motor's current in operation. In this study, the power factor of all induction motors is considered to calculate $I_{ld,total,220,60}$. The total power factor of the miscellaneous loads is around 0.9 on average. The miscellaneous loads do not account for a large proportion of total onboard power consumption. Therefore, in this study, it was assumed that I_{mis} doesn't change even if the onboard electric system receives 200V/50Hz shore power. On the other hand, the induction motor current $I_{ld,200,50}$ is influenced and calculated with equation (28). All of $I_{ld,200,50}$ is summed up to $I_{ld,total,200,50}$. Hence, the total current $I_{200,50}$ in the onboard electric system is estimated by adding the current supplying to the major equipment and the current flowing to the miscellaneous loads.

$$I_{200,50} = I_{ld,total,200,50} + I_{mis} \dots \dots \dots (30)$$

In same manner, the total current $I_{200,60}$ in the onboard electric system during the shore connection at 200V/60Hz is expressed by the following formula, approximately.

$$I_{200,60} = I_{ld,total,200,60} + I_{mis} \dots \dots \dots (31)$$

2.3.3. The scenario of calculation

More realistic results can be obtained by using actual observed data to determine the current value and power when the ship connects to the shore power. The power consumption and current values during berthing were calculated based on the above calculation method. The calculations were implemented by using observed current data on ship_A (shown in Figure 3). It shows an example of the observed current value supplied by onboard diesel generator from arrival to departure of the vessel. Just after berthing at a quay, the hatch covers are opened. The hatch cover consumes a large amount of the power, and the current value rises to nearly 400 A. Simultaneously, marine engineers conduct the cool down operations. When the ballast pumps are started, the current value increases to approximately 200 A. Those pumps are operated to adjust the trim of the vessel during loading and unloading operations. They run from time to time because seafarers change the amount of ballast water according to cargo handling conditions. Before finishing the loading operation, the main engine starts to be warmed up. After closing the hatch covers, the ship is ready to depart the port.

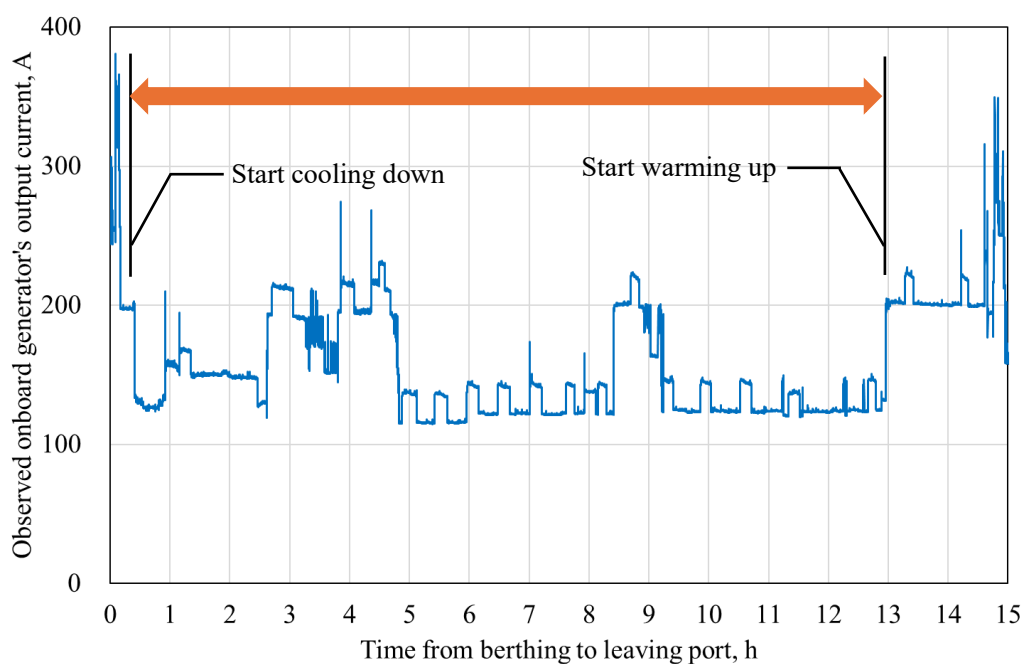


Figure 3. An example of observed current value during berthing at port.

Using the observed current values described above as a scenario, the total power consumption and the current flowing through the breaker were calculated while the diesel generator is stopped, and onboard electric system connects to a 200 V/60 Hz or 200 V/50 Hz shore power supply. Switching between shore power and generator power is considered to be conducted after cooling down and before warming up (Figure 3). Therefore, the shore power can be applied to a period indicating with arrow.

2.3.4. The estimated power consumption.

Figure 4 shows the observed onboard demand with the diesel generator and estimated demand with shore connections. The power consumption of the conditions using the shore connection is reduced to half of the state with diesel generator. Peak power when using diesel generator exceeds 70 kW, while that in western Japan is less than 50 kW and that in eastern Japan is less than 40 kW. This is because the cooling freshwater pump and cooling seawater pump are stopped in the case of the shore connection. In terms of the shore connection, the power consumption in eastern Japan is slightly low because the induction motor's speed is lower than western Japan. On the other hand, the pump discharge amount less, so the pumps run longer. This makes a difference in the operation timing of intermittent operation equipment.

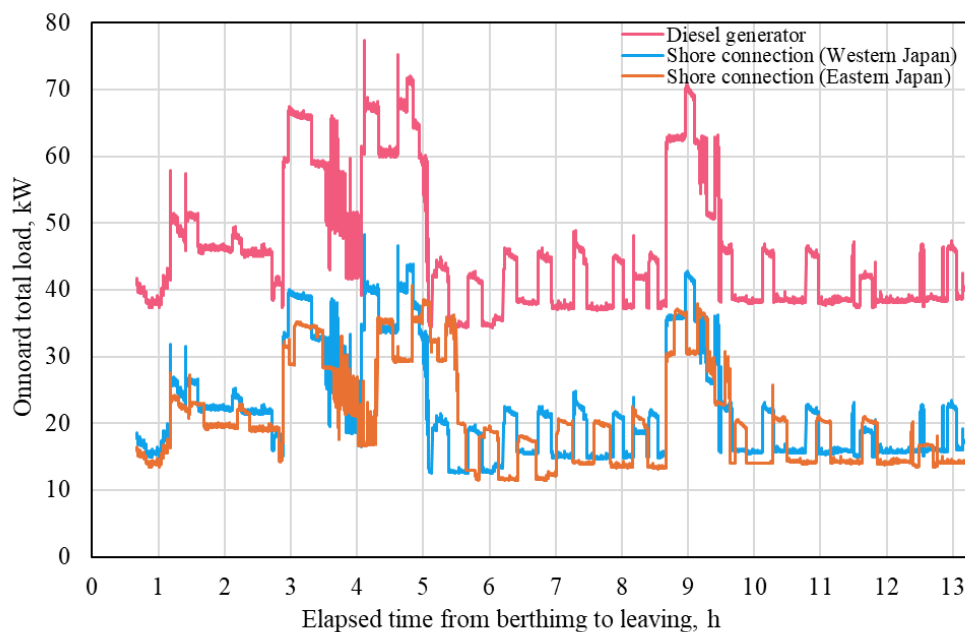


Figure 4. Observed onboard demand with generators and simulation results of onboard demand with shore connection.

2.3.5. The estimated current

This study uses equations (24), (28), (29), (30), and (31) to estimate onboard total load current. Figure 5 shows the observed current of diesel generator and estimated values in the shore connection conditions. The ballast pumps and intermittent operation equipment have 6/5 of the operating time in case of 50 Hz compared to 60 Hz. Since these pumps and equipment discharge the necessary amount of water/oil. Therefore, the timings of start and stop are also different. Similar to the aforementioned power trend, the overall load current of the electric system with shore power is small. Unlike electric power, however, in eastern Japan, the current tends to be larger than western area because the power factor of the induction motor becomes low due to low frequency. The breaker is not supposed to trip when the starting current of induction motor flows. As is clear from the figure, the current value does not exceed 150 A except for starting current when the ship connects to the shore power.

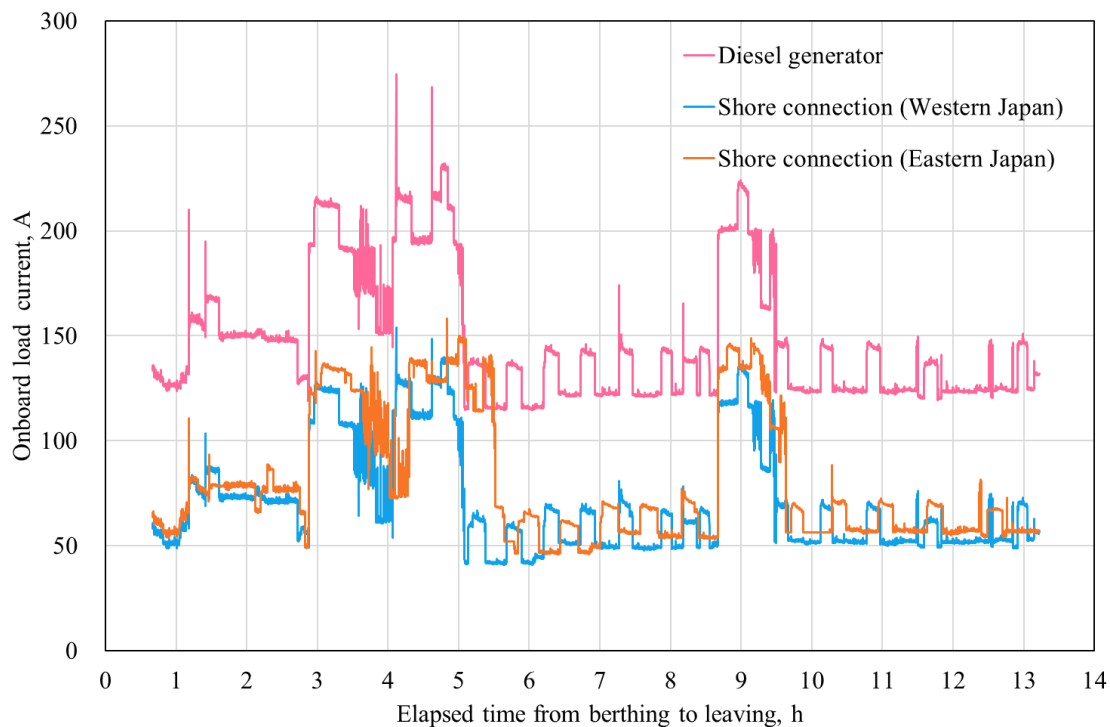


Figure 5. The current value (shore connection and diesel generator).

The above results indicate that a 499 GT general cargo ship can connect 10 % low voltage shore power without using a frequency converter, which means the general cargo ship does not require expensive facilities to use the shore connection.

3. CONCLUSION

This paper discussed the concerns associated with the 200 V/60 Hz or 200 V/50 Hz shore connection to a 499 GT domestic cargo vessel. The torque and speed of the induction motors drop during shore connection, which makes the pump's performance low. However, their onboard operation is covered. In terms of the transformer, it does not have concerns that its temperature rises unexpectedly. Since onboard total demand is suppressed less than 50 kW in the shore connection condition, port authority can choose the low voltage power contract.

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The Socio-Economic and Environmental Effects of the Marina Industry and Nautical Tourism on Local Communities

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This paper investigates the multifaceted economic, social, and environmental impacts of the marina industry on local communities and the natural environment, emphasizing the crucial role of locals in marina development plans. Marinas and nautical tourism are recognized for their socio-economic contributions to local communities worldwide through creating income, new jobs, and employment opportunities. However, the marina industry also generates undesirable social and environmental footprints, leading to the degradation of natural resources and the quality of local lives. A balanced approach is not just a suggestion but a necessity. Marinas and nautical tourism businesses must rethink their practices to actively include local community members in their plans and activities, fostering more sustainable development. This study explores the attitudes and opinions of locals on the benefits and adverse effects of the marina industry in a coastal area with numerous marinas, nautical tourism activities, and plans for industry expansion. Data were collected using a structured survey and analyzed through descriptive statistics and correlation analysis. The results show diverse effects, with key positive impacts such as contributions to local economic prosperity and job creation. Significant environmental concerns, including pollution and resource degradation, contrast these. Positive correlations between economic benefits and community well-being underline the importance of fostering economic growth, while weak negative correlations with environmental impacts highlight the need for sustainable practices. These findings emphasize the necessity of integrating community perspectives into marina planning to achieve balanced development that mitigates negative consequences while enhancing benefits. The study underscores the importance of sustainable and inclusive approaches in tourism-driven economies, particularly in coastal areas heavily reliant on marina and nautical tourism industries.

KEYWORDS

Marina industry; Nautical tourism; Local communities; Socio-Economic Impacts; Environmental Impacts; Sustainable Development

1. INTRODUCTION

Coastal and maritime tourism represents the largest sector of the European Union's blue economy in terms of gross domestic product and employment, with the EU's coastal regions being desirable destinations for both European and international travelers. As a vital segment of the blue tourism sector, nautical tourism is a significant source of employment and financial growth (EC, 2017).

The importance of coastal and maritime tourism, or blue tourism, as an essential part of the blue economy, has been recognized in various European Union strategic documents, including the Blue Growth Strategy (EC, 2012), the European Strategy for Coastal and Maritime Tourism (ECR, 2014), and the European Strategy for more Growth and Jobs in Coastal and Maritime Tourism (EC, 2014). These strategies emphasize the sector's economic potential while underlining the need for sustainable development to ensure long-term benefits.

Tourism impacts people and places, considering economic, social, and environmental aspects, and can potentially alter traditional lifestyles, natural resources, income structures, and more (Bove and Mazzola, 2023). While the economic importance of nautical tourism is undeniable, it is equally important to look at its broader impact. As a core segment of nautical tourism, the marina industry benefits local communities while placing notable pressure on natural ecosystems. For instance, nautical ports contribute to the local economy by generating income, creating new jobs, and providing employment opportunities (McKinley, 2016). However, they produce undesirable social and environmental footprints that affect the residents' quality of life and may destroy natural resources and habitats (Biondi and Lara, 2015). Thus, a balanced approach is crucial for managing the growth of nautical tourism, ensuring the sector's development aligns with societal needs and sustainability goals.

While environmental, economic, and social criteria generally define the concept of sustainability, only the environmental dimension is well-developed in the marina industry (Biondi, 2014). The social aspect of sustainability is mainly absent from existing marina planning guidelines and is rarely considered an essential objective in marina development (Biondi, 2014). This gap represents a significant challenge to the industry, precisely considering the active involvement of local people in the marina planning and operations. Marinas and nautical tourism companies should strive to involve local community members in their strategies and activities. However, ensuring that such involvement will generate tangible economic benefits for the local population is quite challenging for the industry. The lack of clear guidelines and frameworks for incorporating social sustainability into marina development further complicates efforts to enable communities to participate in and benefit from nautical tourism. Despite these challenges, encouraging the local community's engagement in industry affairs remains crucial. The industry can create new economic opportunities by actively involving local businesses and individuals in marina services while strengthening social cohesion (Bove and Mazzola, 2023). Addressing the current shortcomings in social sustainability requires that marina planning shifts towards a more inclusive policy and strategy, ensuring that communities affected by tourism are actively involved in and benefit from it. By prioritizing a comprehensive and inclusive approach, the marina industry can maximize its positive contributions while mitigating its negative impacts, ensuring a more sustainable future for local communities and the natural environment.

This study aims to investigate the impact of marinas and nautical tourism on local communities and the environment while exploring ways to promote a more balanced and inclusive approach to development. The aim is to analyze the attitudes and opinions of locals regarding the benefits and negative impacts of the marina industry in coastal areas. By examining these perspectives, this study seeks to understand the impact of the marina industry on the region's quality of life, economic opportunities, and environmental sustainability. In addition, the study focuses on identifying the key sustainability impact indicators of the marina industry, with a

particular emphasis on the highest and lowest impacts on the local economy, society, and environment. Understanding these factors is crucial for developing strategies that minimize adverse impacts while maximizing economic and social benefits.

The manuscript examines a coastal area in Croatia, a growing popular nautical tourism destination worldwide, boasting the most indented coastlines in Europe and featuring 1,244 islands, islets, reefs, and rocks. Among these numerous islands and coastal towns, approximately 140 nautical tourism ports offer basic and supplementary services for boaters and their vessels along the Croatian Adriatic coastline. Due to its unique coastline and natural attractions, high-quality nautical infrastructure, and favorable sailing conditions throughout the year, the Croatian nautical tourism sector has experienced significant growth over the last few decades. Moreover, Croatia positioned itself as one of the top destinations for sailors and maritime enthusiasts worldwide (CNTB, 2020).

The Republic of Croatia has significant potential for developing its nautical tourism sector, with a trend of continuous revenue growth from port services. In 2023, the total revenue reached € 160.9 million, representing an increase of approximately 12.1% compared to 2022, when the total revenue was € 143.6 million. Berth rental remains the primary source of income, generating EUR 115.2 million in 2023, up from EUR 100.6 million in 2022, representing a 14.6% increase (CBS, n.d.). The steady growth in revenues underscores the expansion and resilience of the Croatian nautical tourism sector, strengthening its position as one of the leading sailing destinations in the Mediterranean (Ministry of Tourism and Sport, 2022). Among the counties, Split-Dalmatia County has proven to be the dominant region, with 38% of total arrivals and overnight stays in nautical tourism. Zadar County followed it with 23% of arrivals and overnight stays and Šibenik-Knin County with 22% (CNTB, 2019, 2020). Such industry trends highlight the concentration of nautical tourism activities in central Croatia's Adriatic region, underscoring the importance of these coastal areas for the sector's overall development.

Furthermore, the local community's perceptions offer essential insights into the marina industry's impact, as its role is crucial in developing a sustainable and profitable sector. As the marina industry relies on human resources, with residents playing an essential role in its sustainable development, long-term success is possible only with the support of local community members (WTO, 2013; Ravikumar et al., 2022). Additionally, the local community's perspective on being included in the marina industry's plans and decision-making may contribute to balancing the needs of tourism-driven economic growth, social well-being, and the preservation of coastal ecosystems. The marina industry directly contributes to the socio-economic development of many coastal destinations by stimulating local businesses, employment, and revenues (Tonazzini et al., 2019; Santos et al., 2022). The research also investigated correlations between economic and social benefits, such as job and income generation, and the adverse environmental footprints of marina industry activities, aiming to determine whether socio-economic benefits outperform degradation of natural resources, pollution, and biodiversity loss. Therefore, this manuscript focuses on examining the impact of the marina industry on local communities, considering the economic, social, and environmental aspects of sustainability.

2. METHODS AND MATERIALS

This study explores the attitudes and opinions of locals on the benefits and adverse effects of the marina industry in a coastal area. It uses the example of Split-Dalmatia County as the most significant Croatian county in the central part of the Adriatic coast.

Figure 1 shows the research process comprising the five main steps: 1) identification of the sustainability impact indicators in the marina industry, classified into three groups; 2) operationalization of the research variables (economic, social, and environmental), i.e., creation and validation of the research instrument

(questionnaire); 3) data gathering using survey method; 4) statistical analysis and results (Cronbach's alpha, demographics, descriptive statistics and normality tests, correlation analysis, testing the differences in respondents' perceptions considering their demographical characteristics); and 5) results.

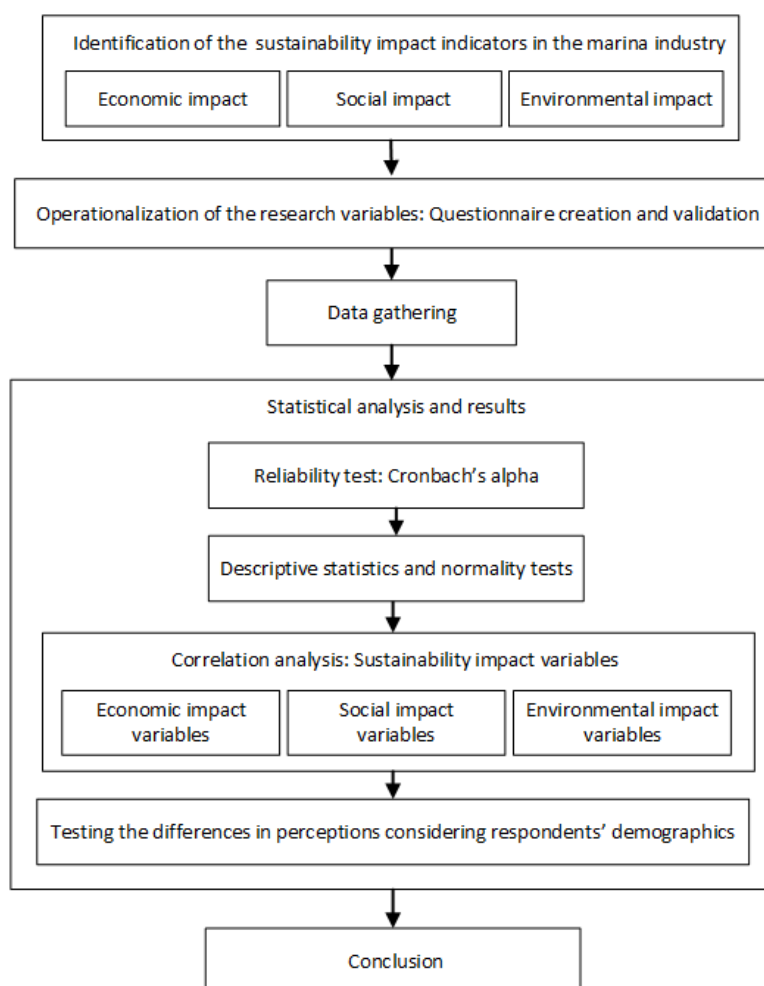


Figure 1. The research process model

Table 1. shows the research variables, economic (Econ1-Econ5), social (Soc1-Soc5), socio-economic (Soc-econ), socio-environmental (Soc-env), environmental (Env1-Env3), and marina plans (Plan1, Plan2).

This manuscript employs a quantitative method, and the data were collected through a survey of residents in Split-Dalmatia County in 2023. It operationalized the research variables through a structured online questionnaire that comprised demographic variables (gender, age, education, and experience), as well as economic, social, and environmental impact variables related to the marina industry, and variables related to marina plans. The questionnaire operationalized variables via statements using a 5-point Likert scale. The questionnaire content has been validated through informal, in-depth interviews with five experts from industry and academia. Data analysis was performed using SPSS (IBM SPSS Statistics, version 20) and JASP (version 0.17.12) statistical packages. The data analysis included descriptive statistics and inferential statistics.

Variables	Statements
Econ1	The marina industry generates substantial income, driving growth and prosperity within the local economy and benefiting the local population.
Econ2	The marina industry generates jobs and employment opportunities, boosting the economic well-being of the local population.
Econ3	The marina industry cultivates entrepreneurial initiatives within the local community, fostering innovation and helping to establish small businesses.
Econ4	The marina industry drives local economic development, fostering growth and prosperity within the community.
Econ5	The marina industry stimulates investment growth, driving economic opportunities in the region.
Soc1	The marina industry increases the local community's cultural exchange and social well-being.
Soc2	The marina industry fosters education and creates opportunities for professional development, empowering young people in local communities.
Soc3	The marina industry enhances social life by fostering the growth of cultural facilities, events, and activities within the local community.
Soc4	The marina industry supports the development of sports facilities and recreational amenities, enriching the local community's active lifestyle.
Soc5	The marina industry contributes to improving the living standards of local communities, enhancing their overall quality of life.
Soc-econ	The marina industry exacerbates traffic congestion and significantly strains local infrastructure, negatively impacting the socio-economic well-being of the community.
Soc-env	The marina industry negatively affects the local community's health and environment by increasing pollution (air, water, noise, light).
Env1	The construction and operations of marinas cause degradation of natural resources.
Env2	The marina industry pollutes the marine environment with waste, debris, garbage, and ballast water.
Env3	The marina industry endangers biodiversity, disrupting sensitive sea ecosystems.
Plan1	Marina construction and landscaping must align with spatial plans and adhere to sustainable principles of coastal zone management.
Plan2	Residents should be included in the marina construction, reconstruction, and development plans to ensure community engagement and support.

Table 1. Research variables

3. RESULTS AND DISCUSSION

The first step in data analysis (Figure 1) is testing the validity of the survey questionnaire and calculating Cronbach's alpha. The results show that the Soc-Econ, Soc-Env, Env1, Env2, and Env3 indicators negatively correlate with the scale. Cronbach's alpha value confirms that the questionnaire is a reliable instrument and provides reliable data for further analysis. Table 2 presents the reliability test and the Cronbach's alpha values.

Estimate	Cronbach's α
Point estimate	0.736
95% CI lower bound	0.658
95% CI upper bound	0.799

Table 2. Reliability test

Table 3. shows descriptive statistics and normality tests for the research variables. The results of the Shapiro-Wilk test indicated that the data are not normally distributed. Thus, this research will use non-parametric tests and methods for further analysis. The results (Table 3) show that the respondents gave the highest marks to the economic impact indicators Econ2 (Mean = 4.08) and Econ4 (Mean = 4.12) and the lowest marks to the indicator Soc-Econ (Mean = 2.68). The indicators Econ2 and Econ4 refer to job and employment opportunities and local economic development resulting from the marina industry. The indicator Soc-Econ, on the other hand, refers to the adverse impact of the sector on traffic congestion and local infrastructure. Respondents also assigned higher average scores to the indicators representing economic impact than those representing social and environmental impact. The results suggest that the positive impact of the marina industry on the local economy outweighs both its positive social impact and its negative environmental impact. Moreover, the results show that respondents are more focused on the economic benefits of the marina industry than its positive social effects and adverse environmental impact. Respondents perceive that the most significant positive impact of the marina industry comes from job and employment opportunities, as well as local economic development. At the same time, the highest adverse impacts relate to increased air, water, noise, and light pollution, which adversely affect the environment and social well-being (Soc-env, Mean = 3.94). The lower standard deviation value for the economic impact indicators (STD < 1) implies that the similarity in respondents' perceptions is higher for economic impacts relative to the social and environmental impacts of the marina industry. Finally, the results of descriptive statistics reveal that respondents evaluated higher scores for the inclusion of the local community in the marina construction reconstruction and development plans to ensure community engagement and support (Plan2, Mean 3.94) than for the compliance of marina construction and landscaping with spatial plans and adherence to sustainable principles of coastal zone management (Plan1, Mean = 3.38).

Variables	Mean	STD	Skewness	Kurtosis	Shapiro-Wilk
Econ1	3.81	1.048	-1.040	0.765	0.827
Econ2	4.08	0.863	-1.798	4.696	0.691
Econ3	3.93	0.847	-1.132	2.035	0.796
Econ4	4.12	0.863	-1.526	3.559	0.751
Econ5	3.96	0.940	-1.128	1.517	0.815
Soc1	3.87	0.785	-0.974	2.308	0.804
Soc2	3.54	1.056	-0.689	0.089	0.876
Soc3	3.59	1.016	-0.671	0.048	0.873
Soc4	3.48	1.057	-0.658	0.107	0.879
Soc5	3.70	1.048	-0.788	0.310	0.866
Soc-econ	2.68	1.024	0.360	-0.368	0.901
Soc-env	3.94	1.150	-0.311	-1.599	0.729
Env1	3.07	0.983	-0.012	-0.444	0.908
Env2	3.54	1.019	-0.424	-0.577	0.882
Env3	3.37	0.973	-0.299	-0.372	0.898
Plan1	3.38	0.955	-0.227	-0.194	0.899
Plan2	3.94	0.928	-0.840	0.702	0.846

Std. Error of Skewness = 0.236, Std. Error of Kurtosis = 0.467, P-value of Shapiro-Wilk = < .001

Table 3. Descriptive statistics (N=105)

Table 4. presents Spearman's correlations for the economic impact variables (Econ1-Econ5), social impact variables (Soc1-Soc5), and environmental impact variables (Env1-Env3). The results show that the correlation between the economic, social, and environmental impact variables is very strong and statistically significant, especially for the economic impact variable. Furthermore, the correlation between economic and social impact ranges from moderate to strong and is statistically significant. For example, the indicators Soc1 and Soc5 strongly correlate with all indicators of the economic impact variable, indicating that social factors closely relate to economic impact. The findings suggest an inextricable link between the economic and social effects of the marina industry, which is crucial for policymakers and industry professionals to consider. Finally, the negative values of the correlation coefficients between the economic and social impact indicators, on the one hand, and environmental impact, on the other hand, confirm that these are negatively correlated variables, highlighting the need for balanced decision-making in the marina industry.

	Econ1	Econ2	Econ3	Econ4	Econ5	Soc1	Soc2	Soc3	Soc4	Soc5	Env1	Env2	Env3
Econ1	—												
Econ2	0,672***	—											
Econ3	0.514***	0.594***	—										
Econ4	0.720***	0.547***	0.563***	—									
Econ5	0.644***	0.517***	0.662***	0.660***	—								
Soc1	0.503***	0.404***	0.376***	0.480***	0.439***	—							
Soc2	0.296**	0.137	0.239*	0.296**	0.245*	0.615***	—						
Soc3	0.272**	0.242*	0.421***	0.337***	0.370***	0.369***	0.542***	—					
Soc4	0.206*	0.186	0.240*	0.306**	0.257**	0.501***	0.493***	0.607***	—				
Soc5	0.568***	0.467***	0.543***	0.544***	0.615***	0.571***	0.443***	0.368***	0.419***	—			
Env1	-0.024	0.007	-0.083	-0.015	-0.122	-0.247*	-0.188	-0.173	-0.233*	-0.121	—		
Env2	-0.095	-0.057	-0.114	-0.040	-0.039	-0.239*	-0.297**	-0.210*	-0.244*	-0.177	0.589***	—	—
Env3	-0.127	-0.023	-0.078	-0.026	0.004	-0.225*	-0.257**	-0.105	-0.191	-0.081	0.571***	0.792***	—

* p < 0.05, ** p < 0.01, *** p < 0.001

Table 4. Spearman's correlations

Furthermore, non-parametric tests were used to test differences in respondents' perceptions of the marina industry's economic, social, and environmental impacts. The Mann-Whitney U test was used to assess the differences in respondents' perceptions regarding their gender and education. The Kruskal-Wallis test was performed to examine the differences in respondents' perceptions related to their age and experience. The differences in respondents' perceptions were examined across all categories of the economic, social, and environmental impacts of the marina industry, including perceptions related to the involvement of the local community in planning the construction of marinas. The results (Table 5) confirm that the perceptions of respondents with different demographic characteristics differ primarily in a smaller number of indicators related to the economic, social, and environmental impacts of the marina industry. For example, the perceptions of respondents from different genders and experiences in nautical tourism differ regarding the Econ3 indicator, specifically in how the marina industry fosters entrepreneurial initiatives within the local community, encourages innovation, and facilitates the establishment of small businesses. Furthermore, respondents with different experiences in nautical tourism differ in their perceptions of the indicator Plan2, according to which the local population should be included in plans for the construction, reconstruction, and development of the marina to ensure community engagement and support.

Null Hypothesis	Test	Sig.	Reject or do not reject the null hypothesis
The distribution of Econ3 is the same across Gender categories.	Mann Whitney U Test	0.008	Reject
The distribution of Soc2 is the same across Gender categories.	Mann Whitney U Test	0.035	Reject
The distribution of Soc-Econ is the same across Age categories.	Kruskal Wallis Test	0.023	Reject
The distribution of Econ1 is the same across Education categories.	Mann Whitney U Test	0.036	Reject
The distribution of Env1 is the same across Education categories.	Mann Whitney U Test	0.013	Reject
The distribution of Econ3 is the same across Experience categories.	Kruskal Wallis Test	0.015	Reject
The distribution of Plan2 is the same across Experience categories.	Kruskal Wallis Test	0.044	Reject

Table 5. Hypothesis Test Summary

4. CONCLUSION

The economies of coastal areas are heavily focused on developing marinas and promoting nautical tourism, yielding numerous economic and social benefits. Growth in new jobs, employment, income, profits, and living standards is a reliable indicator of the industry's positive economic and social impacts on the local community. However, developing the sector and constructing new marinas lead to significant adverse social and environmental effects. Researchers and industry experts continually seek solutions that balance positive economic and social impacts and adverse effects on society, the environment, and natural resources. Additionally, local communities play a vital role in the marina industry. Therefore, this manuscript investigated locals' perceptions of the benefits and adverse effects of the marina industry in a coastal area where the number of new marinas and plans for their construction are constantly increasing.

Respondents assigned higher values to positive economic and social impacts and lower to adverse social and environmental effects. The results suggest that respondents consider the economic and social implications of the marina industry to be more critical. Furthermore, the results indicate a moderate to strong correlation between economic and social impact and that both social and economic impacts are negatively correlated with environmental impacts. The economic effects of the sector directly enhance the standard and quality of life, while its ecological effects harm the community's health. Although the results suggest differences in respondents' perceptions regarding the sector's economic, social, and environmental effects for several indicators related to their gender, age, education, and experience, respondents' perceptions are relatively similar, especially in terms of the positive economic impact. Finally, respondents with varied experiences differed in their perceptions of resident involvement in reconstruction, construction, and development plans for marinas; however, they generally gave the above indicator a higher rating. The above confirms the assumption that local population involvement in the development of the marina industry can lead to greater community support. This paper confirms that the sustainable development of the marina industry in coastal areas depends on striking a balance between economic, social, and environmental impacts while involving local populations in marina development plans. Integrating community perspectives into marina planning is necessary to achieve balanced development that mitigates negative consequences while enhancing benefits.

This paper underscores the importance and complexity of the research problem. The results suggest the need for further research, which should involve a larger sample of the target population and a broader geographical area for the survey.

CONFLICT OF INTEREST: All authors declare that they have no conflicts of interest.

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Optimal Locations for Biomethanol Production Through Electrified Steam Methane Reforming: A Case Study Across Southern Europe

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This study explores optimal locations for establishing biomethanol production plants in Southern Europe, using an innovative electrified Steam Methane Reforming (SMR) process. This technology replaces the conventional fossil-fueled furnaces with electric resistance-heated reactors, reducing CO₂ emissions and improving energy efficiency. Using biogas or biomethane as feedstock, combined with renewable electricity to heat the reactor further enhances the sustainability of biomethanol, making it a promising biofuel for the maritime sector.

Key factors such as feedstock, electricity and water cost and availability and proximity to existing infrastructure and to ports, where the potential end-users are located, were considered. The study identified four suitable locations for the biomethanol plants: Marghera and Ravenna in Italy and Elefsina and Thessaloniki in Greece. Ports were prioritized due to their role as storage and bunkering hubs, ensuring efficient biomethanol distribution to maritime stakeholders. However, limitations such as the availability of updated data or reliance on information from stakeholders were observed. Future research should focus on economic feasibility studies, stakeholder engagement and policy frameworks to scale biomethanol adoption and the electrified SMR technology.

KEYWORDS

Biomethanol; Steam methane reforming; Maritime decarbonization; Green shipping; Biofuel; Shipping fuel

1. INTRODUCTION

Maritime transport is highly efficient, handling about 90% of global trade (Christiansen, 2020). However, the sector is a major source of greenhouse gas (GHG) emissions. Shipping accounts for almost 3% of global emissions caused by human activities (European Commission, 2024). Without intervention, the maritime emissions are expected to rise by 50 to 250% by 2050, driven by the growing global trade (IMO, 2014).

The European Union (EU) has introduced regulations to reduce emissions and achieve carbon neutrality by 2050, such as the European Green Deal. The “Fit for 55” package, part of the EU Green Deal, aims to reduce GHG emissions by 55% until 2030. This package includes regulations for the maritime sector, such as the EU Emission Trading System (EU ETS) and the FuelEU Maritime Regulation. Currently, about 99% of the shipping fuels come from fossil fuel sources (IRENA, 2021). The “Fit for 55” package imposes fines on heavy polluters and promote the adoption of low-carbon fuels.

Methanol is a promising low-carbon alternative fuel, with its market position as a shipping fuel getting stronger. Currently, nearly 30 vessels are methanol-powered, with over 300 more on order (DNV, 2024). Methanol offers several advantages, including its compatibility with existing infrastructure. It can be stored and transported as liquid under atmospheric conditions, unlike other low-carbon options, such as hydrogen or Liquefied Natural Gas (LNG), which face challenges and require special handling (Longspur Research, 2022). Additionally, in case of a methanol spill, the effects on the marine environment are most likely to be reversible and minimal compared to other fuels, such as Heavy Fuel Oil (HFO) or ammonia (Methanol Institute, 2023).

Currently, most methanol is produced from fossil fuels, mainly natural gas through the steam methane reforming (SMR) process. Natural gas serves both as the feedstock and process fuel. The reactions of the SMR process are strongly endothermic, requiring significant fossil fuel for heating and generating high CO₂ emissions (Shahriari et al., 2025). Several studies have investigated methods to improve the process’ thermal conductivity and reduce its environmental footprint. These include decreasing of the SMR temperatures by shifting the equilibrium (Johnsen et al, 2006), using high-conductivity materials to improve heat transfer (Roh et al., 2010; Nakasone et al., 2023) or developing novel reactor designs to improve heat distribution (Tonkovich et al, 2004).

Wismann et al. (2019) proposed an electrified SMR (eSMR) approach, where the large gas-fired furnaces used in conventional SMR are replaced by a reactor with resistance-heated walls. This eliminates direct CO₂ emissions and can reduce reactor volume by up to 10 times. From et al. (2024), have demonstrated the feasibility of eSMR at pilot scale. When powered by renewable electricity from sources such as solar, wind or biomass, the process’ sustainability is further improved. The first industrial scale eSMR plant is expected to begin operations in Norway, in the coming years.

This study investigates optimal locations for eSMR plants for biomethanol production in southern Europe. These plants will use biogas or biomethane as feedstock. The focus is on supplying the produced biomethanol as a shipping fuel, contributing to maritime decarbonization.

2. METHODOLOGY

The optimal locations for eSMR-based biomethanol plant were selected based on multiple criteria. These locations were carefully chosen to optimize operational efficiency and reduce emissions.

Feedstock Availability and Logistics

The eSMR plants will use biogas or biomethane as feedstocks. Locations with close proximity to biogas production facilities, such as anaerobic digestion plants, processing animal manure, agricultural residues, municipal waste or wastewater sludge, were prioritized. Biogas can be transported via pipeline or road transport. For road transport, a travel time of approximately one hour, corresponding to 50-80 km, was considered optimal to ensure a stable, high-quality of feedstock supply.

The site's connection to the national gas grid was also evaluated. Direct access to biogas or a large, stable supply may not always be possible, so biomethane from the gas grid was considered as an alternative. Biomethane is chemically identical to natural gas and can be injected into existing gas infrastructure, ensuring a steady supply and production rate. Priority was given to sites with existing grid connections, or those where a short pipeline extension (up to 5 km) could enable grid connection. In cases where direct biomethane supply was not feasible, the use of Guarantees of Origin (GoOs) were considered. These certificates validate that an equivalent amount of biomethane has been produced and injected into the grid elsewhere.

Electricity infrastructure requirements

Reliable electricity access was a key consideration. The plants require a stable, high-capacity power supply, as the eSMR technology relies on electrified reactor heating. For a medium-sized plant producing 150 metric tons per day (MTPD) of biomethanol, approximately 20 MW of electricity is required for the eSMR process. Not all areas can support such an industrial-scale demand. Constructing new electricity transmission infrastructure could have a substantial cost, so only sites with existing high-capacity grid connections were considered. Also, locations with high renewable energy penetration were preferred to enhance sustainability and produce low carbon biomethanol.

Water requirements

Water is an essential input for the eSMR plants, serving both as a feedstock material and for industrial cooling. Areas with water scarcity were excluded, as biomethanol production requires significant amounts of water. Locations near the sea were preferred, as water from the ocean could be used to provide large-scale cooling.

Proximity to end users

Since biomethanol is primarily intended for maritime fuel use, the selected plant sites had to be near major ports or logistics hubs. Ports with established bunkering infrastructure were preferred, as they facilitate fuel distribution to ships. Close proximity to ports also ensures access to ocean water for cooling systems.

Industrial Integration and Community Considerations

Locations within or near industrial zones were prioritized, as they typically have established permitting processes, utilities and logistics infrastructure. These areas can reduce capital and operational costs. Community acceptance was also considered. Large-scale can impact the surrounding environment, so industrial areas minimize such issues.

3. RESULTS

For Southern Europe major countries which have port facilities and end users' operation in the Mediterranean Sea have been considered. Several countries have been evaluated (Greece, Italy, Spain and Portugal), though

only Greece and Italy have been selected for potential eSMR biomethanol plant installations. This has been decided based on several reasons: (i) availability of data regarding the electricity and gas infrastructures' information in the national and English language, (ii) the information provided by key stakeholders experts active in the national energy and maritime market, (iii) information on biomass production plants in local / regional levels and (iv) national energy transition targets focused in the production of blue / green methanol products.

The study has identified four optimal locations for eSMR-based biomethanol plants in Southern Europe: two in Greece (Elefsina and Thessaloniki) and two in Italy (Marghera and Ravenna). These locations fulfill all the described requirements for feedstock availability, energy infrastructure, water access and close proximity to end users. All of them belong to industrial areas inside or adjacent to major ports.

3.1. Greece: Biogas potential and site selection

Greece has a strong agricultural and livestock sector, which indirectly provides feedstock for biomethanol production. According to the European Biogas Association Statistical Report (EBA, 2022), 67 plants produced 0.1 billion cubic meters of biogas in 2021. The country's biomethane potential is projected to reach 0.53 billion cubic meters by 2030 (European Commission, 2023).

3.1.1. The Port of Elefsina

Elefsina city is in a key position near Athens, with high industrial, maritime and cargo logistics activities. Elefsina is ideally located within 120 km from three different prefectures (Attica, Korinthos and Central Greece). This area benefits from established oil refineries, natural gas storage facilities, and biogas plants, ensuring both feedstock availability and infrastructure compatibility for biomethanol production. Specifically, Elefsina is in close proximity to the established Liquefied Natural Gas (LNG) Floating Storage and Regasification Unit (FSRU) in Revithousa, and oil & gas refineries and storage facilities of Hellenic Petroleum (HELPE). There is an additional oil refinery plant operated by Motor Oil in Agioi Theodoroi town, within a 50 km distance. Biogas plants operate 30 km away, with new biogas plants approved for construction 50 km away.

The Port of Elefsina is medium-sized and purely commercial. The main harbour serves dry bulk and general cargo ships and accommodates oil tankers and LPG carriers. The ex-military base terminal hub at the western terminal hub of the port is the most suitable for an eSMR facility. It requires 1-2 km pipeline infrastructure to deliver biomethanol directly into the terminal for bunkering operations. In Figure 1, the blue area marks the land coverage of Elefsina Port Authority. The red areas illustrate the two potential eSMR site locations plus the HELPE oil & refinery facilities (orange area) in close proximity. The first potential option (Option 1 - inside the HELPE refinery jurisdiction area) would need an additional 5 km pipeline to serve the methanol distribution to the bunkering terminal or the construction of a new bunkering terminal inside the refinery area, with 1 km direct pipeline feed. The second option (Option 2 - inside the port area) requires only 2 km of pipeline infrastructure to optimize bunkering operations.

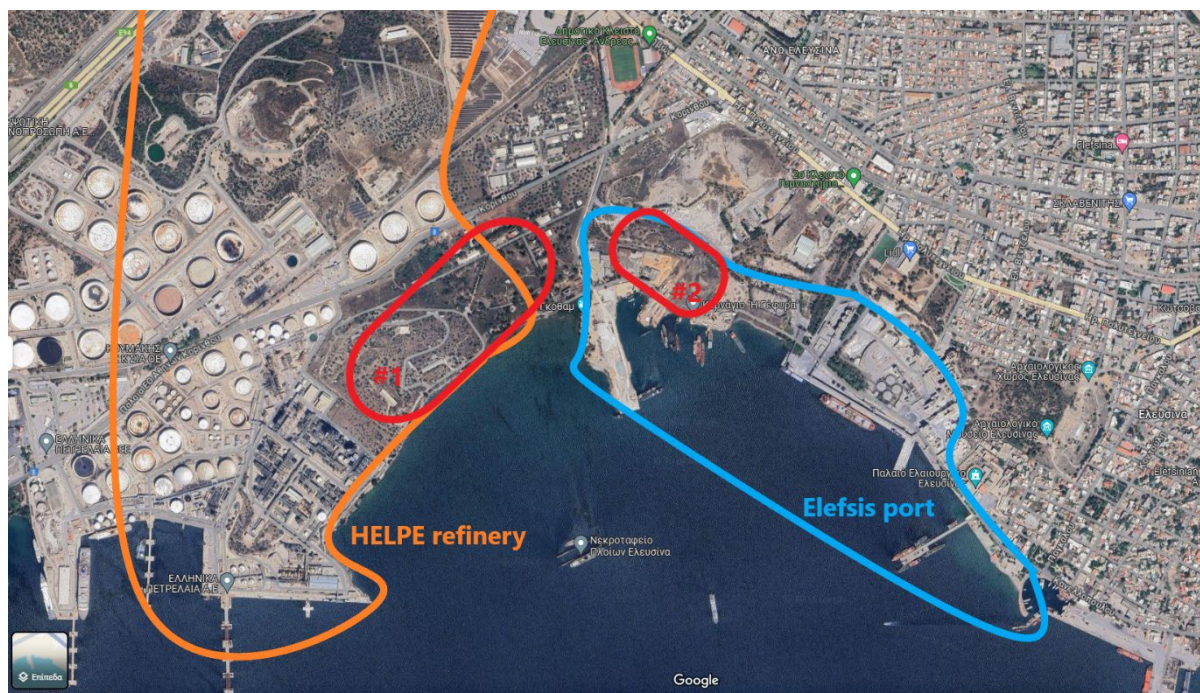


Figure 1. Map of potential installation of eSMR biomethanol plant in Elefsina port

Additionally, the established biogas plants in the region have individual production capacities up to 32 kW (small-sized biogas plants) per plant, mainly using waste and agricultural residuals. The Elefsina site is suitable for a medium-sized eSMR plant, with an estimated annual production of 41,000 metric tons of biomethanol.

3.1.2. Port of Thessaloniki

The Port of Thessaloniki is Greece's second-largest port and a critical export hub for northern Greece. It occupies a total space of 1.5 million square meters, with six piers and a total quay length of 6,200 meters. The port handles containers and conventional cargo, passenger traffic, cruise and coastal shipping.

Dedicated zones within the port host bunkering activities and loading operations for oil tankers and gas carrier vessels. The proposed eSMR site is in Kalochori, an industrial area adjacent to the bunkering operations and fuel storage zone. The site is next to the Hellenic Petroleum (HELPE) refinery, fulfilling infrastructure requirements. An additional 5 km pipeline will be required to deliver biomethanol directly to the port terminal for bunkering operations. In Figure 2, the blue area marks the land coverage of Thessaloniki Port Authority. The red areas illustrate the two potential eSMR plant locations. The HELPE oil and refinery activities are on the left side of Figure 2.

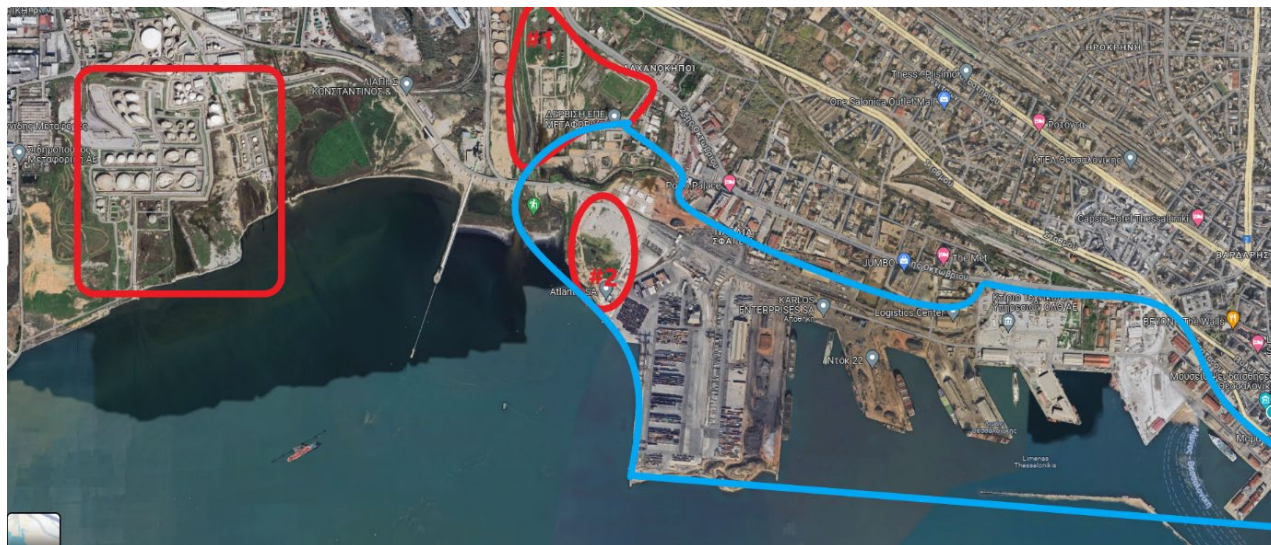


Figure 2. Map of potential installation of eSMR biomethanol plant in Thessaloniki port

Thessaloniki is well-positioned in terms of biogas supply. Several anaerobic digestion plants operate within a 50–80 km radius, processing organic waste, livestock manure and agricultural residues. Notable biogas plants include those in Lagadas, Pentelofos, Chalkidona and Mavrorachi, with capacities ranging from 1 MWe to 3.5 MWe. Also, two biogas plants in Serres with capacity of 1 MWe utilizing byproducts from dairy processing industries can ensure a reliable feedstock supply for the plant. The port of Thessaloniki can support a small to medium-sized plant, producing approximately 27,000 metric tons biomethanol per year.

The region also has wide access to renewable energy sources. Among these is a large-scale photovoltaic panel project in Ptolemaida, already operational with a capacity of 250 MW. Additionally, a plant located in Amyntaio is expected to produce up to 100 MW of green hydrogen in its initial phases and become operational by 2027. Plans have also been made to install several sustainable fuel production facilities to utilize green hydrogen and excess renewable energy from nearby solar panels.

3.2. Italy: Biogas potential and site selection

In 2022, Italy had 1,710 biogas plants in operation, making it one of the leading countries in Europe and worldwide for biogas production. These plants utilize a variety of feedstocks, including livestock manure, agricultural residues, agro-industrial waste, and the organic fraction of municipal solid waste. EBA reports that in 2021, 2.47 billion cubic meters of biogas were produced in Italy (EBA, 2022), while the country's biomethane potential is estimated at 5.8 billion cubic meters by 2030 (European Union, 2023). Northern Italy, particularly the regions of Lombardia, Veneto, and Emilia Romagna, dominate biogas production due to their rich biomass feedstock availability (GSE, 2021).

3.2.1. Port of Marghera

The Port of Marghera, located in the Veneto region of Italy, is a significant commercial and industrial hub. It is part of the larger Port of Venice, which is a major gateway for maritime trade in the Adriatic Sea. It has a total quay length of approximately 12 km accessible to the ships and a maximum depth of 11.5 meters, which allows it to accommodate large vessels. The port is well-equipped with facilities and infrastructure to handle various types of cargo, including bulk, liquid and containerized goods. The port handles over 26 million tons of cargo annually.

Figure 3 presents some of the biogas plants currently operating in Veneto region and the area's natural gas distribution grid. As illustrated in the figure, several medium to large-scale biogas plants are located within a 70 km radius of Port Marghera. These plants utilize agricultural waste, animal manure and organic residues, providing a steady supply of biogas. Approximately 0.8 billion cubic meters of biogas are produced in the Veneto region. The high availability of biogas could facilitate larger biomethanol plants, with an estimated production of 130,000 metric tons annually.

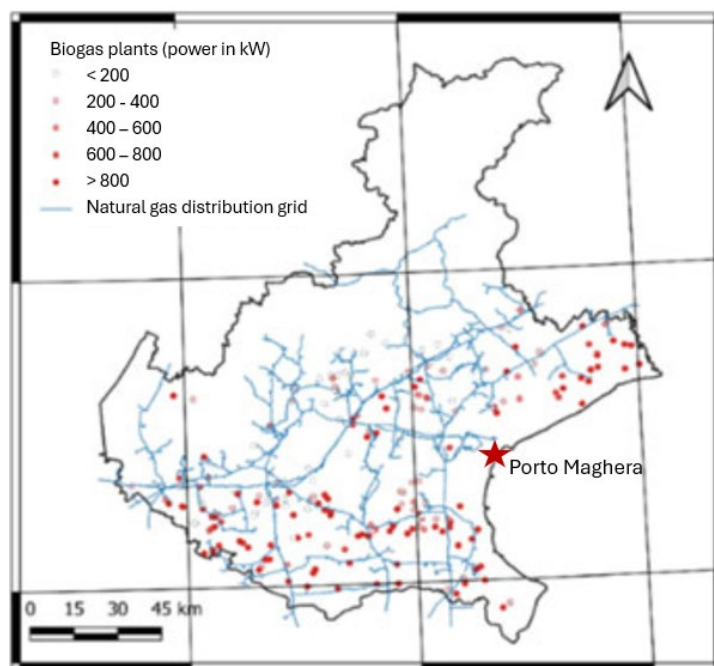


Figure 3. Biogas plants currently operating in Veneto region and natural gas grid distribution (Ferrari et al., 2023)

On Figure 4, highlighted areas represent possible areas for the installation of eSMR plants on Marghera's Port industrial area. The industrial area of the port also accommodates other chemical plants and refineries. Also, there are plans to develop green hydrogen production facilities in the region, which can be used as feedstock for the eSMR process.



Figure 4. Map of potential installation of eSMR biomethanol plant in Marghera port

3.2.2. Port of Ravenna

The port of Ravenna is located in Emilia-Romana region and is one of the largest ports in northern Italy. It serves as a hub for commercial and industrial activities with strong trade links to the Eastern Mediterranean and the Black Sea. The port also facilitates trade with the Middle and Far East. Ravenna's port handles more than 27 million tons of cargo annually. The region has established a simplified logistics zone for quick and easy transportation of raw materials to its port industrial area.

The Emilia-Romagna region is home to several biogas plants, with a combined production capacity of approximately 0.37 billion cubic meters, utilizing mostly agricultural and industrial waste. Such feedstocks could support a medium-sized eSMR plant of 82,000 metric tons annual production. Additionally, green hydrogen production projects are underway in the area, ensuring a consistent supply of hydrogen and energy for the facility. An LNG terminal operates in the industrial area of Ravenna's port since 2021, and less than 1 km from the port's industrial area, the FSRU of Ravenna is expected to start operations in 2025.

Figure 5 presents the map of Ravenna's port. The red highlighted areas represent structures on planning stage and the yellow highlighted areas represent possible areas for eSMR plants.



Figure 5. Map of potential installation of eSMR biomethanol plant in Ravenna port

The key characteristics of the selected locations are summarized in Table 1.

Site	Feedstock availability	Electricity infrastructure	Water access	Proximity to port	Industrial area	Estimated biomethanol production
Elefsina, Greece	Good	Yes	Yes	Inside port area	Yes	~41,000 metric tons/year
Thessaloniki, Greece	Good	Yes	Yes	Very close (needs <5km pipeline)	Yes	~27,000 metric tons/year
Marghera, Italy	Very good	Yes	Yes	Inside port area	Yes	~130,000 metric tons/year
Ravenna, Italy	Good	Yes	Yes	Inside port area	Yes	~82,000 metric tons/year

Table 1. Key characteristics of selected sites for biomethanol production

Overall, the analysis confirms that the selected sites fulfill all the criteria and conditions needed to establish eSMR-based biomethanol plants.

4. CONCLUSIONS

This study applied a multi-criteria evaluation approach, considering factors such as feedstock availability, proximity to the end-users or industrial integration. It identified four optimal locations for eSMR-based biomethanol production plants in Southern Europe, two in Greece (Ports of Elefsina and Thessaloniki) and two in Italy (Ports of Marghera and Ravenna). These locations fulfill a set of requirements to ensure feedstock quality and quantity, while keeping the capital and operational costs low.

Regulatory frameworks such as the EU ETS and FuelEU Maritime will increase the demand for sustainable maritime fuels, including biomethanol, in the coming years. Biomethanol production via eSMR provides a low-carbon alternative fuel, supporting maritime decarbonization. By strategically locating the eSMR plants in industrial and logistics hubs, our approach further enhances sustainability and cost-effectiveness.

Future research should focus on techno-economic assessments, stakeholder engagement and policy initiatives to scale biomethanol adoption and expand eSMR-based production.

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Analysis of the Optimization of Managing the Tug Fleet

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Port tugboats are an important element of port activity and issues of navigation safety. Safe operations are very important for the normal functioning of the port. Among the most difficult jobs in ports are the entry of ships into the ports, mooring and unloading ships, where tugboats are of the greatest importance. The role of a tugboat goes far beyond just towing and pushing ships. They are the guardians of maritime safety by providing the necessary support in day-to-day operations as well as in emergency and rescue situations. Without their presence, the global maritime trade chain would be seriously threatened, and the risk of accidents and environmental disasters greatly increased. The object of the research is the domestic fleet with a focus on the company "Brodospas" and its operations in the port of Ploče. The aim of the paper is to analyze the methods of optimizing the management of the tugboat fleet and to identify factors that affect costs and efficiency, with a focus on the company "Brodospas". The paper contributes to a better understanding of the specific challenges in the management of the fleet of port tugboats and provides concrete proposals for improving operations in this sector. In order to gain insight into the optimization of tugboat fleet management, the research analyzed technical data, business costs and operational performance of the tugboat fleet, as well as the impact of organizational resources on business efficiency. Based on the analysis of fuel consumption, it was found that older generations of tractors (built in the 20th century) had an average consumption of up to 50% higher, and the maintenance costs were incomparably higher. New tugboats become more profitable in the long term because the combination of reduced fuel and maintenance costs directly affects lower operating costs during their exploitation. It can be safely concluded that these compact yet immensely powerful vessels play an important role in ensuring the smooth operation of ports around the world.

KEYWORDS

Port tugboat; Navigation safety; Fleet management; Business optimization

1. INTRODUCTION

Biočić and Jurić (1974) defined tugboats as specialized vessels of significant importance for the safe and efficient operation of maritime traffic, particularly in ports, canals, and narrow passages. According to Van Hoydonk (2013), the port towing service originated in the first half of the 19th century when tugboat owners established the European Tugowners Association (ETA). This industry has its roots in England, where ETA was founded. It is believed that the first tugboat was Charlotte Dundas, built in 1802 for towing two barges on the Forth and Clyde Canal in Scotland. On the River Thames, the first tugboat was Majestic, constructed in 1816, followed by the tug Wear, built in 1825. During its maiden voyage, an operational failure occurred as the Wear demonstrated an inability to effectively navigate the Thames' river current, let alone generate sufficient power to tow heavy vessels.

Within a few years, the number of tugboats on the Thames, Tyne, and Clyde Canal increased significantly. One of the most notable tugboats on the Thames was Monarch, built in 1836. Other European ports also soon recognized the advantages of steam tugboats assisting sailing ships. For example, in Hamburg, the first steam tugboat entered service in 1833, and by 1878, there were approximately fifty such vessels in the port. Over the following decade, this number increased to 95 tugboats.

The development of the tugboat industry progressed in parallel with advances in shipbuilding and maritime operations. After World War II and the Suez Crisis in 1956, there emerged a need for larger ships capable of sailing on longer routes. In the early 1960s, when the ETA was founded, the European towing industry faced growing demand for larger and more powerful tugboats. This period also saw significant improvements in maritime safety, facilitated by the introduction of radar systems, radio communications, and the first port information systems.

In the last fifty years, tugboats have transitioned from steam to diesel propulsion, and specialized propulsion systems such as Schottel and ASD have significantly increased efficiency and maneuverability. With the increase in horsepower and tractive force, the dimensions of tugboats and the number of crew members have decreased (Van Hoydonk, 2013). Over time, it became evident that mechanically powered tugboats could be used for various types of operations, leading to the division of the port towing industry into several subsectors, enabling greater diversification for companies.

Members of ETA are primarily port companies providing towing services, but also maritime rescue operations. These operations include towing and pushing vessels to ensure safe passage through narrow or hazardous parts of the port. Occasionally, tugboats participate in salvage operations for grounded or sunken ships. Rescue companies are connected through the International Salvage Union, established in 1934, with which ETA often collaborates.

Safety, maintenance, and training are key components of effective tugboat operations. Adherence to best practices in these areas ensures not only the longevity and reliability of the vessels but also the safety of the crew and environmental protection. Through their multifunctional capabilities, tugboats not only assist in towing and berthing operations but also serve as emergency services, safeguarding lives, property, and the environment. Looking ahead, continuous advancements in tugboat technology and practices promise further increases in their contributions to the maritime industry, ensuring that these vessels remain at the forefront of maritime safety and efficiency in the years to come. Tugboats are a common sight in every port, and their ubiquity highlights their essential role. Both directly and indirectly, tugboats used in port areas are closely associated with the safety of navigation (Aydin, Karabulut, Ünal, Sariöz, 2017). The primary role of tugboats is to provide support to larger vessels that, due to their size, weight, and limited maneuverability, are incapable of

independently performing precise maneuvers in confined spaces. Tugboats are, therefore, essential for maintaining safety and order in maritime transport.

2. TYPES OF TUGBOATS

Many ports around the world have and utilize port tugboats. They can be classified based on capacity (bollard pull), propulsion type (conventional or tractor), functionality (dedicated tugs or multifunctional), and ice class (non-ice class or ice-class certified). Today, it is common practice to build multifunctional tugboats to avoid additional vessels with very narrow functions, such as firefighting ships and environmental protection vessels. Consequently, a significant number of these functions have been entrusted to port tugboats (Paulauskas, Simutis, Placiene, Barzdžiukas, Jonkus, and Paulauskas, 2021).

In many parts of the world, particularly in regions like Japan and Australia, a significant number of tugboats known as Azimuth Stern Drive (ASD) tugboats are in operation. An ASD tugboat, therefore, can be used in the same way as conventional tugboats, utilizing the towing position at the center of the vessel but with significantly improved maneuverability. When the bow towing position is used, usually directly from the bow towing winch, the ASD tugboat achieves its full potential. With nearly the entire length of the tugboat positioned between the propulsion units and the fore towing point, the ASD tugboat operates with very high levels of efficiency (Armstrong, 2019).

The conventional or classic tugboat, for years referred to as the workhorse of the maritime industry, is still widely used. However, it has two inherent design features that, according to modern standards, can limit its efficiency. These limitations are manifested as follows (Hooyer, 2009):

- a conventional propulsion unit with two propellers located at the stern,
- the position of the towing hook.

Although they are often characterized as economical and powerful, and have proven their reliability through many years of operation and use, they are still, according to modern standards, limited by relatively basic maneuvering capabilities (Hooyer, 2009).

The reverse tractor tug represents a complete departure from the traditional design of the conventional tugboat. The key to the propulsion of a true tractor tug lies in the use of two azimuthal thrusters while others consist of rotating vertical blades, known as cycloidal propulsion. These systems allow the tug's propulsion units to be positioned side by side, mostly near the vessel's center, enabling highly effective maneuvering. Notably, such propulsion systems have been successfully implemented and utilized for many years on specific ferries operating in coastal waters (Armstrong, 2019).

3. PREPARATION FOR TOWING

Before commencing towing operations, the ship's master and the pilot must agree on a comprehensive action plan. This plan should consider all relevant factors, including depth, wind, visibility, vessel size, type, characteristics, and specific mooring requirements (Goncharenko, 2014). A thorough understanding of the type and capabilities of the tugboats assigned to the task is also essential. This knowledge enables the master or pilot to ensure that the tugboats are suitable for the operation and positioned on the vessel in a manner that maximizes their efficiency for safely carrying out the required maneuvers (Smith, 2007).

The number of crew members involved in any towing operation must be determined by considering the vessel's size and the prevailing operational and environmental conditions. In all cases, there must be sufficient

crew to ensure that individuals are not exposed to unnecessary risks and that the operation can be performed safely and efficiently (Inoue, Okazaki, Murai, Hayashi, 2013). Human knowledge and experience, combined with the ability to simulate the correct use of tugboats in port environments, are of paramount importance. These aspects have been studied extensively by various researchers, who identify them as one of the key conditions for the effective use of tugboats in ports (Piaggio, Viviani, Martelli, and Figari, 2019).

A lack of preplanned towing processes is a critical factor and is responsible for up to 80% of maritime accidents and incidents due to errors made during the preparation of towing operations (Rolf and Asbjørn, 2018). The main risks in ports, highlighted by several authors, can be classified as follows: insufficient knowledge and training of ship and port personnel; the human factor in general; poor maintenance of port tugboats; ineffective communication between all participants during ship arrival, departure, or mooring operations (particularly when the ship's crew, port pilot, and tugboat masters communicate in different languages); poor or outdated towing equipment; and inadequate safety, among others (Çakır, Fiskin, and Bayazit, 2017).

4. FUNCTIONS AND IMPORTANCE OF PORT TUGBOATS

One of the primary functions of tugboats is to assist large vessels, such as container ships, bulk carriers, and tankers, when entering and leaving ports. These ships often carry large quantities of cargo, making them slow-moving and difficult to maneuver, especially at low speeds required for navigating narrow or congested waters. Tugboats use their exceptional towing power and maneuverability to help these vessels safely navigate through tight waterways, preventing collisions or damage.

In addition, tugboats play a crucial role in transporting vessels through narrow sea passages and canals, such as the Suez or Panama Canal, where precise maneuvering is absolutely essential. In such situations, even a small mistake can have serious consequences, not only for the involved vessel but also for global maritime traffic. In this context, tugboats play a crucial role in regulating the speed and direction of vessels as they navigate hazardous sections of the route.

Besides their daily operations in ports, tugboats are often engaged in rescue missions. In the case of accidents such as collisions, groundings, or engine failures, tugboats quickly intervene, towing the damaged vessels to safety, thus preventing further damage, pollution, or potentially dangerous situations. Additionally, when vessels lose power or are struck by severe weather conditions, tugboats can tow them to a safe port or shipyard.

Another important function of tugboats is assisting in the placement or removal of floating platforms, large structures, and other vessels or objects, such as oil drilling rigs. They perform demanding tasks related to towing and positioning and sometimes provide supply services afterward. Furthermore, tugboats are highly valuable in towing and pushing barges.

Modern tugboats are equipped with sophisticated technologies, including advanced navigation systems. Due to their favorable width, length, and depth, along with the design of their superstructure and hull, they are very stable, providing resilience to adverse weather conditions, ensuring the continuity of maritime traffic, and maintaining the safety of the maritime industry even during unfavorable weather (Hensen, 2003).



Figure 1. Assistance of tugboats in port water area (Source: <https://www.damen.com/vessels/tugs/asd-tugs>)

5. STATUS OF TUGBOATS IN THE MARITIME INDUSTRY

A significant trend in the tugboat market is the increase in automation. Automation refers to the integration of technology aimed at enhancing operational processes and efficiency. In the context of tugboats, automation may include advanced navigation systems, remote control capabilities, and data analytics for predictive maintenance. These technological advancements not only streamline operations but also reduce the risk of human error, ultimately improving safety. As industry progresses, the adoption of automation is likely to become standard practice, leading to improved performance and cost-effectiveness. The future of the tugboat market is characterized by growing customer demands and regulatory requirements, which continue to shape the dynamics of the industry. Stakeholders are increasingly focused on sustainability, driving innovations aligned with global environmental goals. The market is also adapting to challenges posed by geopolitical factors, fluctuating fuel prices, and the impact of climate change on maritime operations. As companies navigate these complexities, strategic partnerships and investments in research and development will be crucial to maintaining competitiveness in the tugboat market.

The methods of tugboat assistance in ports vary depending on the layout, the type of vessels arriving, available maneuvering space, water depths, geographical location, and prevailing weather conditions. These conditions directly influence the types of tugboats that must be present in the port, as well as the tugboat companies that must meet the requirements of the port's concession, which is often determined by the specific conditions of the port.

In recent years, there has been rapid development in the tugboat sector (Hensen, 2003). Modern tugboats are being designed with high maneuverability and power capabilities. The new generation of tugboats is equipped with advanced control consoles and high-quality towing devices and equipment. Internal ETA research shows an accelerated development of the European tugboat fleet, with more than 45% of tugboats possessing engine power greater than 3,500 hp (Van Hoydonk, 2013). This development directly impacts the methods of assistance, and the number of tugboats involved in port assistance. The Exxon Valdez tanker average directly influenced the requirements and regulations in certain ports for the mandatory use of escort tugboats. As tugboats evolve, the number of tugboats used in assistance operations has decreased. Due to economic factors within shipping companies, masters and pilots are often under pressure to use the minimum number of

tugboats. This reduction in the use of fewer tugboats necessitates the acquisition of modern tugboats capable of performing the most complex tasks and the training of qualified personnel (Hensen, 2003).

As many ports continue to develop and build new terminals and basins, pilots and tugboat companies are typically involved in the development of studies, where they advise study developers based on their experience. Tugboat companies consider all elements identified in these studies, which will assist them in acquiring new tugboats. Frequent consultations between tugboat companies, pilots, and port authorities significantly enhance safety levels in ports.

6. STRATEGIES FOR OPTIMIZING TUGBOAT OPERATION

Optimization of port tugboat operations can involve a range of strategies aimed at improving efficiency, reducing costs, and increasing competitiveness in the market. The analysis and optimization of operational processes, such as docking, undocking, vessel shifting, and towing, can significantly improve operational performance. This includes establishing best practices for vessel maneuvering, implementing technology for fleet tracking and management, and regularly updating operational procedures to reduce delays and optimize resource usage (Li, 2022).

Depending on the fleet size and the type of operations, tugboat companies adopt strategies that will yield the best results and ensure sustainability. For instance, if a company operates a small number of tugboats that are concession-bound to specific ports, it is clear that there is limited scope for fuel savings. However, managing human resources may be more efficient due to the smaller workforce. The integration of advanced technological solutions can greatly enhance the operational performance of port tugboats. This includes the implementation of fleet tracking and management systems, automated maneuvering systems, smart port technologies, and other digital solutions that optimize processes and aid in decision-making. Tugboat companies should always strive for service diversification, which enables them to expand their service portfolio and diversify their income, depending on the opportunities available. Service diversification involves providing additional services such as rescue operations, assisting with accidents, managing breakwaters or cleaning, supplying water to other vessels, and transporting goods or materials to ships and platforms. Resource management, including human resources, vessels, and operational assets, is also a key factor in optimizing tugboat operations (Devarapali, 2024). This encompasses the proper allocation of tugboats according to port needs, optimizing work schedules, investing in staff training, and maintaining and managing the fleet. Increased environmental awareness requires port tugboats to adopt environmentally sustainable business practices. Partnerships with other companies in the maritime sector, such as ports, carriers, logistics operators, or technology solution providers, can provide additional resources, expertise, and opportunities for the growth and development of tugboat operations. Overall, optimizing port tugboat operations requires a combination of operational improvements, technological innovations, service diversification, effective resource management, and environmental sustainability (Barbosa, 2023). The application of these strategies helps tugboat companies achieve a competitive advantage and secure long-term success in the market.

7. ORGANIZATION OF TUGBOAT OPERATIONS IN THE PORT OF PLOČE

Company "Brodospas" is the current concessionaire for towing and pushing operations in the port of Ploče. Since the tugboats present in the port of Ploče vary in maneuvering capabilities and towing power, effective communication between the pilots and the company is of utmost importance. Ships of different sizes and types arrive at the port, and it is essential to assess which tugboat will be engaged for the required assistance (Dundović, 2012). The scheduling and shifts of tugboats are organized on a weekly basis, but based on the pilot's assessment, other tugboats may be deployed if necessary. Tugboat masters receive daily coordination of vessel movements via email. They are also in regular communication with agents, where they receive

information regarding the arrivals and departures of vessels. In addition, the "Marine Traffic" application is regularly monitored, providing clear data on vessel speed, direction, and estimated time of arrival. When a vessel is arriving or departing and requires tugboat assistance, the port control center establishes contact with the on-duty tugboat on VHF Channel 9 up to an hour and a half before the pilot boarding. The assistance, including the number of tugboats required, is arranged based on the pilot's assessment, regulations, and weather conditions.

After completing the assistance operation, the pilot fills out a towing report containing all the necessary information regarding the operation. This report is provided to the tugboat masters and sent to the company, which then issues an invoice to the agents. The tugboats in the port of Ploče are occasionally engaged in other operations, such as providing water supplies, transporting materials and equipment to vessels anchored in the vicinity, and participating in rescue and firefighting activities. Depending on the traffic in the port of Ploče, and upon agreement between the company, the port, and the pilots, tugboats may also participate in operations at nearby ports and tow barges in the Adriatic Sea. Effective collaboration, organization, communication, and monitoring of traffic are crucial for the company, as they enable the company to rely on additional revenue beyond the primary operations.

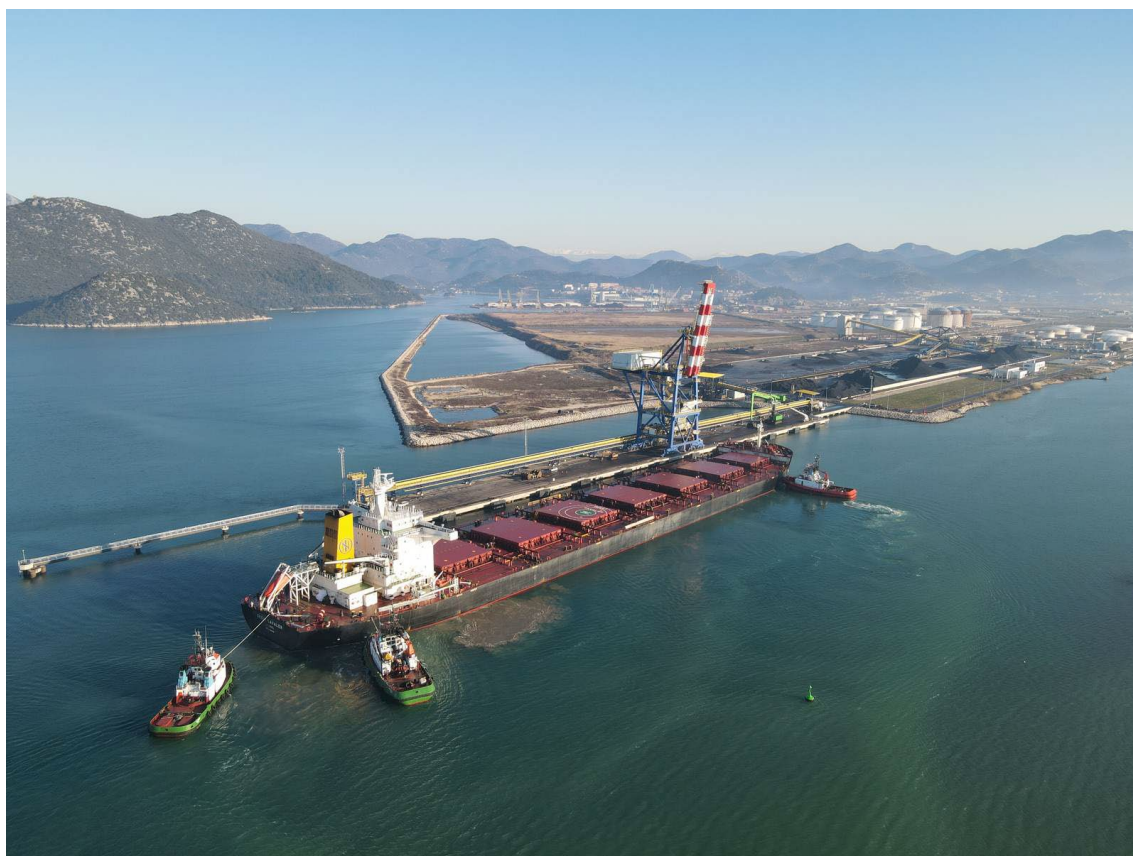


Figure 2. Assistance of tugboats: "Altair", "Smjeli" and "Jaki" for bulk carrier in the port of Ploče (Source: <https://www.luka-ploce.hr/>)

8. ANALYSIS OF THE NEW HIGH-QUALITY TUGBOAT "HRABRI"

The high-quality modern port tugboat "Hrabri" was built in 2023 in Hai Phong, Vietnam. It is 28 meters long and 11 meters wide, with a total towing power of 60 tons. The tugboat has a gross tonnage of 299 tons and is powered by two Caterpillar diesel engines with a combined output of 3,804 kW. "Hrabri" is a multifunctional tugboat capable of providing various services, including towing, salvage operations, and firefighting. It is also

suitable for offshore operations such as platform supply and towing, as well as barge towing and providing supplies to other vessels. Modern tugboats, like "Hrabri", offer numerous advantages in terms of cost-effectiveness in maintenance and fuel consumption due to advanced technology and innovative design. The new generation of tugboats typically utilizes energy-efficient engines that reduce fuel consumption without compromising power or performance. These engines are equipped with advanced fuel management systems, optimizing performance under different load conditions, which results in lower operational costs. Additionally, modern tugboats are equipped with performance monitoring and analysis systems, enabling precise control over the vessel's operation and identifying potential issues before they lead to major malfunctions. This significantly reduces maintenance costs, as preventive maintenance can be carried out more efficiently, minimizing the need for expensive repairs or parts replacements. Furthermore, the use of lighter and more durable materials in the construction of modern tugboats reduces wear and tear, thereby decreasing the frequency of servicing.

The tugboat "Hrabri", with a total engine power of 3,804 kW and two engines, consumes an average of 100 liters of fuel per hour, according to records from the machinery logbook. Under maximum load, fuel consumption can rise to 350 liters per hour. Older-generation tugboats (built in the 20th century) typically have fuel consumption rates up to 50% higher. For example, Brodospas's tugboat "Jaki", built in 1990, has a total towing force of 50 tons and a power output of 2,900 kW, consuming 150 liters per hour on average during assistance operations. Additionally, the maintenance costs for "Hrabri" are considerably lower in comparison.

To analyze fuel savings, we can use the example of the port of Ploče, where the annual average for assisting vessels is 480 operations per tugboat, equating to 960 hours of operation. When we multiply the hourly fuel consumption of tugboat "Hrabri" by the total hours, it shows that "Hrabri" will consume approximately 96,000 liters of fuel annually. In contrast, tugboat "Jaki" would consume 144,000 liters of fuel for the same number of hours. Thus, new tugboats become more cost-effective in the long term, as the combination of reduced fuel and maintenance costs directly impacts lower operational expenses over their service life.



Figure 3. Tugboat "Hrabri" during sea drills in Vietnam (Source: <http://www.brodospas.net/>)

9. CONCLUSION

Tugboats, with their robust construction, powerful propulsion systems, and versatile capabilities, are an indispensable part of the maritime industry. Their primary role includes towing or pushing larger vessels, enabling their safe passage through narrow waterways or into and out of port facilities. The history of tugboats is rich and diverse, with their evolution closely tied to advancements in maritime technology and the expanding scale of maritime vessels. Tugboat companies must focus on improving their operations as the industry environment is constantly changing, and they must be prepared for these shifts and adaptations. Key recommendations for achieving this include investing in new vessels, establishing quality management systems, implementing fuel-saving technologies on ships, adopting effective maintenance strategies, continuously monitoring organizational effectiveness, and refining successful control methods to ensure strategy implementation across all levels. Additional measures include preparing for market expansion into neighboring countries, systematically improving relationships with competitors, exploring new product and service opportunities, fostering workforce engagement in strategic areas, preserving and enhancing the existing corporate culture, and providing ongoing training for both seafarers and management personnel.

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Current European Union Tax Incentives Arising from the Application of Greenhouse Gas Emissions Trading System - Challenges for the Croatian Shipping Industry

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Paper examines the legal framework governing the taxation of shipping companies in Croatia. European Union (EU) regulations come into play when Member States grant tax exemptions or reductions to specific sectors, as such measures are classified as State aid. One example of State aid tailored to the shipping industry is the tonnage tax, a scheme dependent on the tonnage of a ship. Under the tonnage tax regime, the tax amount is not based on the profits generated from shipping activities. Instead, it is calculated as a flat rate directly related to the ship's tonnage. This makes tonnage tax a predictable taxation method for shipowners, with an overall tax burden generally lower than that of corporate income tax. At the EU level, the tonnage tax is regulated under the 2004 EU Guidelines on State Aid to Maritime Transport. Croatia adopted this system in 2013, and it has been extended in 2020. The paper analyses the main requirements of the Croatian tonnage tax regime. In addition, the paper also addresses the EU's current tax incentives aimed at decarbonizing the shipping sector, particularly through the introduction of the EU greenhouse gas emissions trading system with the changes of the Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the EU.

KEYWORDS

Tonnage tax; State aid; Croatian tonnage tax system; Decarbonization of shipping; Greenhouse gas emissions trading system

1. INTRODUCTION

Tonnage tax in the Republic of Croatia was first introduced through the 2011 Amendments to the Maritime Code, which took effect on January 1, 2013.¹ Its implementation was one of the requirements for the Republic of Croatia's (RC, Croatia) accession to the EU.

The European Commission (EC) approved the tonnage tax State aid for shipping companies in Croatia on 1st April 2015.² The Croatian tonnage tax system on yachts was expanded in 2020.³ The ten-year period since the EC approved Croatia's application of tonnage tax is expiring soon. The Croatian authorities committed to re-notify to the EC any prolongations to the tonnage tax scheme after that date. In the meantime, the existing tonnage tax system applies.

At the EU level, the tonnage tax is regulated under the 2004 EU Guidelines on State Aid to Maritime Transport (Maritime Guidelines).⁴ Croatia has implemented EU law into domestic regulations governing tonnage tax, the Maritime Code, and its sub-laws.

The paper provides a detailed analysis of the features of the Croatian tonnage tax system applicable to shipowners. In addition, the paper also addresses the EU's current tax incentives aimed at decarbonizing the shipping sector, particularly through the introduction of the EU greenhouse gas emissions trading system.

2. CROATIAN TONNAGE TAX SYSTEM

2.1. Eligible beneficiaries and activities

According to Article 429 a of the Croatian MC⁵ an eligible beneficiary for tonnage tax State aid is only a legal person established in the RC or with the actual management and supervision of its operations located in the RC, in respect of the profit generated by:

a) the maritime shipping activities⁶ and ancillary activities⁷ of its own ships, or those owned by dependent ship-owning companies, leased ships (on a bare-boat basis), or chartered ships (time or voyage-chartered):

- the share of ships bare-boat chartered out to third parties may not exceed 20% of the net tonnage of the taxpayer's fleet;

¹ Official Gazette of the Republic of Croatia, No. 61/2011.

² Commission decision of 1 April 2015 in the Croatian tonnage tax case SA. 37912, Brussels, 01.04.2015 C(2015) 2153 final.

³ State Aid SA. 55577 (2019/NN) – Croatia Extension to the Tonnage Tax Scheme, Brussels, 3.4.2020 C(2020) 1958 final.

⁴ Communication Community guidelines on State aid to maritime transport, (OJ C 13, 17.1.2004, p. 3); Communication from the Commission updating the Annexes to Commission Communication C(2004) 43 — Community Guidelines on State aid to maritime transport (OJ C 120, 13.4.2017, p. 10-11).

⁵ Official Gazette of the Republic of Croatia, No. 181/2004, 76/2007, 146/2008, 61/2011, 56/2013, 26/2015, 17/2019.

⁶ Maritime shipping activities or core shipowner's activities are transport of goods and passengers by sea between ports or between ports and offshore facilities.

⁷ Ancillary activities according to Article 429. of the Croatian MC are: provision of services to passengers during transportation on the ship in the tonnage tax regime, except casino services, sale of luxury goods and organization of trips, warehousing and customs of cargo, transport of cargo and passengers from the port area to and from the ship, which transport is included in the price of the transport service, container rental, loading and unloading of cargo, use of office facilities, use of facilities for the sale of tickets, passenger and port terminals and services of issuing and selling tickets, administrative work and insurance. These activities have been recognized as eligible for tonnage tax state aid in the European Commission's decision-making practice. See, Commission decision (EU) 2019/1116 of 19 December 2017 on State aid SA.33829 (2012/C) Maltese tonnage tax scheme and other State measures in favour of shipping companies and their shareholders, para. 266-274 (OJ L 176, 1.7.2019., p.7.).

- the net tonnage of ships time or voyage chartered-in may not exceed 75% of the net tonnage of the taxpayer's ships unless the ships chartered-in are registered in the register of the EU /EEA Member State.

The purpose of the limitation of the share of ships time or voyage chartered-in is to prevent shipping companies in the EU from becoming “pure” maritime brokers in the sense that they deal exclusively with commercial management or finding employment for ships and avoid responsibility for technical and crew management, which is contrary to the objectives of the Maritime Guidelines, in particular the objectives of maintaining and improving maritime expertise (maritime know-how) and protecting and promoting the employment of European seafarers.⁸ Also, in its previous practice, the Commission considered that “pure” ship lessors cannot be deemed to provide maritime transport services and, consequently, should not benefit from a tonnage tax regime.⁹

Under the MC the limitations are prescribed only in case of ships being bare-boat chartered out to third parties. According to the practice of the EC in the case of the Irish and Maltese tonnage tax scheme¹⁰ intra-group bareboat chartering is in line with the Maritime Guidelines since the beneficiary as a group performs maritime transport activities through an intra-group leasing structure.

When it comes to a charter outside of the group of affiliated companies, the provisions of the MC should be aligned with the terms set out in point 86 of the EC Decision on aid SA.37912 (2013/N) on the introduction of a tonnage tax system for the benefit of international maritime transport in the RC, by which the Croatian authorities committed themselves to amend that system by introducing certain restrictions, in order to ensure that companies that are substantially or exclusively engaged in bare-boat chartering out, and therefore cannot be considered as companies engaged in maritime transport within the meaning of the Maritime Guidelines, are excluded from the preferential tonnage tax system.

These are the following restrictions: firstly, bare-boat chartering out activities must be related to temporary excess capacity; secondly, temporary excess capacity must be related to the beneficiary shipping company's own shipping services, for a period of up to 3 years; thirdly, excess capacity specifically acquired (bought or chartered) for chartering-out purposes is ineligible for tonnage taxation; lastly, the proportion of bare-boat chartered-out capacity should not exceed 20% of the shipping company's fleet under the tonnage tax scheme.¹¹ The aforementioned provisions should be incorporated into the Maritime Code.

b) Ship management company performing the technical and/or crew management for the vessel, under the following conditions:

- not less than 51% of its employees are EU/ EEA citizens;
- 2/3 of the ships under its management are managed from EU / EEA Member States;
- 60% of the ships it operates are registered in the registers of EU/EEA Member States and
- meet all the requirements of the EU Guidelines on State aid to shipmanagement companies.¹²

⁸ Ibidem, para. 286 and 287.

⁹ See in particular Commission Decision 2014/200/EU of 17 July 2013 on the aid scheme SA.21233 C/11 (ex NN/11, ex CP 137/06) implemented by Spain (OJ L 114, 16.4.2014, p. 1); Commission decision of 1 April 2015 in the Croatian tonnage tax case SA. 37912, Brussels, 01.04.2015 C(2015) 2153 final, para. 86 (OJ C 142, 22.4.2016, p. 6)

¹⁰ Commission decision of 11 December 2002 in case N 504/02 on aid measure implemented by Ireland (OJ C 15, 22.1.2003, p. 5), para. 17 to 24.

¹¹ Commission decision of 1 April 2015 in the Croatian tonnage tax case SA. 37912, Brussels, 01.04.2015 C(2015) 2153 final, para. 86.

¹² Communication from the Commission providing guidance on State aid to shipmanagement companies (OJ C 132, 11.6.2009., p. 6.)

Aid in the form of tonnage tax is not allowed for companies engaged in "pure" commercial ship management, which consists of selling a ship's capacity (through chartering, taking bookings for cargo or passengers), marketing, and appointing agents. Therefore, for shipmanagement companies to qualify, they must also provide technical and/or crew management services for the vessel on behalf of the shipowner (Jürgen Werner, M, 2016).

c) Profit from the sale of ships, the sale of shares in shipping companies, dividends, shares in subsidiary shipping companies, interest, and other income derived from bank accounts, bank deposits, insurance, and contracts limiting currency risks, provided that the net tonnage of the ships is included in the tonnage tax of the group is eligible for tonnage tax treatment.

On the other hand, the payment of dividends to shareholders of shipping companies is subject to regular capital gains tax, as it is not intended for the provision of maritime shipping activities.¹³

2.2. Eligible ships

According to Article 429 of the Croatian MC ship that may qualify for the tonnage tax is ship registered in the Croatian register, certified to navigate outside the internal sea waters and the territorial sea of the RC to carry out maritime shipping activities or for research or other services related to offshore activities, or ship registered in the foreign register.

Regarding ships registered in a foreign ship register, it should be noted that Article 429.a of the MC stipulates that all ships included in the tonnage tax system must be strategically or commercially managed from the Republic of Croatia or another EU or EEA Member State.

Furthermore, Article 429.b states that in the fleet of ships participating in the tonnage tax system, at least 60% of the total net tonnage must consist of ships registered in the RC or in an EU or EEA Member State. Additionally, the taxpayer is required to maintain this minimum 60% threshold throughout the period for which they have applied for the tonnage tax system. These provisions ensure compliance with the flag link requirement from the Maritime Guidelines.

Under Article 429, paragraph 3 of the MC, aligned with the decision-making practice of the EC a ship that conducts research or provides other services related to offshore activities is:

- research ship,
- a supply ship for fixed and floating coastal facilities,
- a mobile offshore facility for exploration and exploitation of the undersea resources, along with its support ship,
- ship for laying cables or pipelines,
- –a crane ship.

It follows from the EC's decision-making practice that the provisions of the Maritime Guidelines may apply to certain activities even if they do not fall within the definition of maritime transport, provided that they require similarly qualified personnel and face similar exposure to international competition.¹⁴

¹³ Article 429.a of the Croatian MC.

¹⁴ Commission decision of 27 April 2010 in case N 714/09, the Netherlands — Extension of the tonnage tax scheme to cable layers, pipeline layers, research vessels and crane vessels (OJ C 158, 18.6.2010, p. 2).

In 2020 the Croatian tonnage tax system has been extended to yachts and large passenger yachts.¹⁵ According to Article 429, paragraph 2, item 3 of the MC, the tonnage tax system also includes yachts engaged in international navigation, as referred to in Article 126, paragraph 2 of the MA, provided they are used for commercial purposes. Yachts that are not used for commercial purposes are not included in the Croatian tonnage tax system. According to Article 126, paragraph 2, a yacht engaged in international navigation is a yacht, regardless of nationality, with a permanently onboard crew, which, during 365 consecutive days, sails from a Croatian port to a foreign port and vice versa, or between foreign ports, or sails on the high seas or in the territorial waters of foreign states, for at least 50% of the number of voyages.

This is in line with EC's decision-making practice, as reflected in its decision on the Maltese tonnage tax system,¹⁶ where the Commission extended the application of the tonnage tax system to commercial yachts. However, yachts not being used for commercial purposes and other pleasure craft are not covered by the tonnage tax benefit because their primary purpose is leisure, rather than carrying out shipping activities, as required by the Maritime Guidelines.

In accordance with Article 429, paragraph 4 of the MC the following ships are not included in the tonnage tax system:

- yacht,
- fishing vessel,
- technical vessel,
- tugboat unless at least 50% of the activities actually carried out by that tugboat during the year relate to the performance of maritime transport and if it flies the flag of the RC or one of the EU or EEA Member States.
- dredging vessel unless at least 50% of the activities actually carried out by that vessel during the year relate to the performance of maritime transport and if it flies the flag of the RC or one of the EU or EEA Member States.

The exclusion of the aforementioned vessel from the tonnage tax system is introduced due to the fact that its primary purpose is not maritime transport.

2.3. Tonnage tax rates

The Croatian tax authorities charge a flat tax for each vessel, determined based on its net tonnage, which is calculated and paid annually. According to Article 429e, paragraphs 1 and 2 of the MC, for each ship whose net tonnage participates in the calculation of the ship's tonnage tax, the following annual amount shall be determined and paid:

- a) for ships from 0 to 1000 net tonnage, for every 100 units of net tonnage, a ship's tonnage tax of HRK 270.00 (approx. 35,44 EUR);
- b) for every additional 100 units of net tonnage from 1001 to 10,000 units of net tonnage, a ship's tonnage tax of HRK 230.00 (approx. 30,19 EUR);
- c) for every additional 100 units of net tonnage from 10,001 to 25,000 units of net tonnage, a ship's tonnage tax of HRK 150.00 (approx. 19,69 EUR);
- d) for every additional 100 units of net tonnage from 25,001 to 40,000 units of net tonnage, a ship's tonnage tax of HRK 95.00 (approx. 12,47 EUR);

¹⁵ State Aid SA. 55577 (2019/NN) – Croatia Extension to the Tonnage Tax Scheme, Brussels, 3.4.2020 C(2020) 1958 final.

¹⁶ Commission decision (EU) 2019/1116 of 19 December 2017 on State aid SA.33829 (2012/C) Maltese tonnage tax scheme and other State measures in favour of shipping companies and their shareholders, para. 242-244 (OJ L 176, 1.7.2019., p.7.).

e) for every additional 100 a unit of net tonnage above 40,000 net tonnage is determined and pays a tax per ship tonnage of HRK 55.00 (approx. 7,22 EUR).

For each less than 100 units of net tonnage, tax per tonnage is determined proportionally.

Differentiated tonnage tax rates apply to eligible yachts. Yachts have higher profitability rates per unit of net tonnage compared to other vessels. According to Article 429e, paragraph 3 of the Croatian MC, tonnage tax rates for yachts are determined based on either the hull length or a combination of the hull length and the net tonnage operated. For yachts up to five years old, the above annual tonnage tax amount is reduced by 20%.

The tax rates and tax burdens resulting from the Croatian tonnage tax scheme align with the tax burdens of tonnage tax schemes previously approved by the EC.¹⁷ This compliance is in accordance with the Maritime Guidelines, which aim to prevent intra-EU tax competition or a "subsidy race."

3. EU LEGISLATION ON CO₂ EMISSION REDUCTION WITH A FOCUS ON THE EU EMISSIONS TRADING SYSTEM

The issue of reducing greenhouse gas emissions (GHG) from shipping has been addressed both at the global level, through the International Maritime Organization (IMO), and at the regional level, within the European Union (EU).

The IMO adopted an Initial Strategy to reduce total annual GHG emissions from shipping in 2018.¹⁸ The Initial Strategy was amended in 2023 with the IMO GHG Strategy 2023 marking a continuation of its efforts to curb emissions in international shipping. The 2023 IMO GHG Strategy has the target of zero GHG emissions by 2050 and the gradual transition to zero-emission fuels.¹⁹ Strategy is not legally binding; it functions as voluntary guidelines aimed at reducing greenhouse gas emissions from international shipping. So far, no binding regulations have been implemented on the international level.

Given the IMO's limitations in enforcing binding measures, the European Union (EU) has taken the lead in activities related to reducing CO₂ emissions in the maritime sector. The EU aims to achieve climate neutrality by 2050, requiring significant emission reductions as outlined in Regulation (EU) 2021/1119, also known as the "European Climate Law". The Regulation introduces a legally binding objective of climate neutrality by committing the EU to GHG emissions reduction, compared to 1990 GHG emissions levels, by 55% by 2030 and to climate neutrality by 2050.

In addition to this, in 2021, the EC adopted the Communication '*Fit for 55*': *Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality*.²⁰ This comprehensive package of proposals aims to reduce net GHG emissions by at least 55% by 2030 compared to 1990 levels (Schlacke et al, 2022). The *Fit for 55*

¹⁷ Tax load for Croatian shipowning companies is not much lower than the rates the EC has approved for Cyprus. The tax burden from the Croatian tonnage tax is not less than the one approved by the EC for Poland. Commission decision of 1 April 2015 in the Croatian tonnage tax case SA. 37912, Brussels, 01.04.2015 C(2015) 2153 final, para. 99 and 100.

¹⁸The 2018 Initial IMO Strategy, Available at: <https://www.imo.org/en/OurWork/Environment/Pages/Vision-and-level-of-ambition-of-the-Initial-IMO-Strategy.aspx>, accessed on: 30. 1. 2025.

¹⁹The 2023 IMO Strategy on Reduction of GHG Emissions from Ships, Available at: <https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>, accessed on: 30.1.2025.

²⁰ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, COM(2021) 550 final.

package includes several key legislative proposals²¹ affecting the maritime industry, including the revised EU Emissions Trading System (EU ETS) Directive.²²

As of 1st January 2024, the scope of the EU ETS system has been extended to include the maritime sector. The EU Emissions Trading System (ETS) operates as a 'cap-and-trade' mechanism, setting a maximum limit on the total greenhouse gas emissions that may be emitted by the operators covered by the system (the cap). This cap decreases annually and is represented by emission allowances, with each allowance granting the right to emit one tonne of CO₂ equivalent (CO₂eq). Operators must ensure their GHG emissions do not exceed their allocated allowances. Companies under the EU ETS are required to surrender allowances corresponding to their emissions in the EU Registry. Emission allowances are distributed through auctions, and companies can trade them on secondary markets. Shipping companies covered by the EU ETS must have an approved monitoring plan to track and report annual emissions.²³

CO₂ emissions from ships exceeding 5,000 gross tons that call at an EU port will fall under the EU ETS system, regardless of their flag. The system covers 100% of emissions from intra-EU/EEA voyages, 50% of emissions from voyages that start or end outside the EU/EEA, and all emissions generated while ships are at berth in EU/EEA ports. A phased transition applies, requiring operators to cover their GHG emissions with allowances at a rate of 70% in 2025, and 100% from 2026 and further.

The entity responsible for alignment with the EU ETS Directive is the shipowner or any other organization or individual that has agreed to fulfill all duties under the ISM Code. This includes parties that bareboat charters in a ship they operate. When time charter contract has been concluded, the responsibility falls on the shipowner rather than the charterer.

Some EU Member States are of the opinion that environmental taxes with limited territorial scope, such as the ETS system, can have a negative impact on the competitiveness of the EU shipping industry and ports, especially those in the EU's peripheral regions. In this sense, ministers from seven EU countries Spain, Italy, Malta, Greece, Portugal, Cyprus, and Croatia have written to the EC requesting to pause the inclusion of shipping in the EU's emissions trading scheme (ETS) started in January 2024. In their letter, they pointed out that the measure could divert business away from European ports while providing only limited environmental benefits.²⁴

Additionally, the seven Mediterranean countries claim that the risk of implementing regional regulations on matters that impact global trade is that they apply only to countries within the EU, rather than being universally adopted. As a result, these regulations may fail to achieve their intended goal, specifically, the decarbonization of shipping, while potentially creating an uneven playing field and, in some cases, directly harming countries in the EU's peripheral regions.

²¹These are the following proposals: the Monitoring, Reporting and Verification (MRV) Maritime Regulation, the Alternative Fuels Infrastructure Regulation (AFIR), the introduction of the FuelEU Maritime Regulation, and revisions to both the Renewable Energy Directive (RED) and the Energy Taxation Directive (ETD).

²²Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system, *OJ L 130*, 16.5.2023, p. 134–202.

²³ European Maritime Safety Agency (EMSA), 2024, FAQ – Maritime transport in EU Emissions Trading System (ETS), Available at: <https://emsa.europa.eu/reducing-emissions/extension-ets/faq-extension-ets.html>, accessed on: 21. 1. 2025.

²⁴ Financial Times, 26 November 2023, Telling, O., Hancock, A., EU states call on Brussels to rethink shipping emissions charge, Available at: <https://www.ft.com/content/203d3ba4-33c4-47aa-a619-ec1427b7d9a1>, accessed on: 30.1. 2025.

The European Commission has not taken any requested measures so far. It stated that its services will closely monitor the impact of applying the ETS system to the shipping sector and consider adjustments if necessary.

4. CONCLUSION

The particularities of the Croatian tonnage tax regime, applicable from 2013 and extended in 2020, have been presented. The ten-year period since the EC approved Croatia's application of tonnage tax is expiring soon. The Croatian authorities committed to re-notify to the EC any prolongations to the tonnage tax scheme after that date. In the meantime, the existing tonnage tax system applies.

The paper also includes an analysis of the EU ETS Directive, adopted at the EU level, addressing challenges related to the decarbonization of shipping. It introduces an obligation for covered shipowners to surrender an emission allowance for every ton of CO₂ emissions. This represents a significant financial burden for shipowners. Therefore, in addition to the favorable tax regime in the form of tonnage tax, the EU has created the ETS Innovation Fund. The EU ETS, the world's largest carbon pricing system, generates revenue for the Innovation Fund through the monetization of 530 million ETS allowances. The Innovation Fund is dedicated to supporting highly innovative technologies and flagship projects within Europe that have the potential to deliver significant emission reductions.²⁵

In addition, the shipping sector will be included in the EU Clean Industrial Deal,²⁶ a plan that will provide funding for new technologies to achieve climate goals and enhance the EU's competitiveness across various industries, including international shipping.

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²⁵The total funding for the Innovation Fund depends on the carbon price and could reach approximately €40 billion from 2020 to 2030, based on a carbon price of €75/tCO₂. European Commission, Directorate-General for Climate Action, *What is Innovation Fund?*, Available at: https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en#how-is-the-innovation-fund-financed , accessed on: 30.1.2025.

²⁶ A business plan to support the competitiveness and resilience of our industry. The Deal will accelerate decarbonisation, while securing the future of manufacturing in Europe. European Commission, Directorate-General for Communication, *EU Clean Industrial Deal - A plan for EU*, Available at: https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en, accessed on: 30.1.2025.

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Rethinking Compulsory Liability Insurance for Boaters in Croatian Waters

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This paper examines the concept of compulsory liability insurance for boat and yacht owners regarding third-party claims, as governed by Croatian law. It critically analyses the provisions of the Croatian Compulsory Insurance in Traffic Act of 2005, alongside its subsequent amendments. The author evaluates relevant premium and claims data published by the Croatian Insurance Bureau, addressing increasing criticisms within the yacht chartering sector regarding the relatively low insurance limits and the narrow scope of coverage. To enhance understanding of the legal framework, the paper provides a historical overview of the applicable legislative provisions. Furthermore, it explores potential legislative improvements and proposes specific amendments (*de lege ferenda*) to address identified shortcomings. The conclusions drawn and the suggestions offered are based on a balanced assessment of the arguments for and against increasing insurance limits and expanding the scope of coverage.

KEYWORDS

Marine insurance; Compulsory insurance; Boat; Yacht; Liability

1. INTRODUCTION

Croatia has a rich maritime heritage. Sailing, boating, and fishing are deeply embedded in the local culture. Nautical tourism in Croatia has been steadily growing since the late nineties. According to certain nautical tourism industry reports, Croatia is one of the leading sailing destinations in the world. In 2022, it was declared the most popular sailing destination with over 38% of all yacht charter bookings (Sail Croatia, 2024). Seven out of top ten marinas in the world are located in Croatia (Sail Croatia, 2024). According to the official statistical data of the Croatian Ministry of the Sea, Traffic and Infrastructure (hereinafter: MSTI), in 2024 there were 2.892 nautical charter companies and 7,526 yachts and boats registered for charter in Croatia (MSTI, 2024b) and 584,381 guests on nautical charters who achieved 3,765,492 overnight stays (MSTI, 2024b). The total number of all boats and yachts registered in Croatia is 113,439¹. Dense maritime traffic, concentrated around the busiest ports, harbours, and the most attractive nautical destinations, especially during the summer season, inevitably leads to some negative statistics related to maritime accidents. According to data from the MSTI for the past five-year period (2020-2024), the average number of injury or death cases at sea in Croatia is 68, showing a slight decreasing trend from 79 cases in 2020 to 56 cases in 2024.² These are certain numbers that should be kept in mind when discussing the regime of compulsory insurance of liability for boat and yacht owners.

Compulsory insurance for motorised boats and yachts was first introduced into Croatian legislation by the Insurance Act of 1994 (Official Gazette no. 9/94, hereinafter: IA 1994), subsequently amended in 1997 (Official Gazette no. 20/97, 46/97). According to Ćurković, the primary function of this legislative intervention was to protect the swimmers and other persons in the sea from the risk of careless or reckless powerboat use (Ćurković, 2013b, p. 167). The reasons for the introduction of compulsory insurance for boats and yacht were the increasing number of motorised pleasurecraft, stronger boat engines, larger number of persons potentially exposed to the risks of injury by such craft, public interest in the protection of human life and health from increasing risks related to the massive use of motorised pleasurecraft, additional protection for the potential injured third parties by enabling them to receive full and speedy financial compensation through insurance (Šantić, 2000, p. 25).

In 2005, the insurance legislation was thoroughly revised to harmonise with EU law in preparation for Croatia's accession to the EU. The provisions on compulsory insurance in traffic, including automobile liability insurance, liability insurance of air carriers, personal accident insurance of passengers in public transportation and insurance of liability of boat and yacht owners were extracted from the Insurance Act³ to form part of the new Compulsory Insurance in Traffic Act (Official Gazette, no. 151/05). The Act was subsequently amended several times (Official Gazette, no. 36/09, 75/09, 76/13, 152/14, 155/23) (hereinafter: CITA). Over the past 20 years the provisions relating to liability insurance of boat and yacht owners have not been substantially changed.

¹ The total number of registered boats is 112,600, and the number of registered yachts is 839. The numbers do not include vessels registered for inland waters navigation. This data is as of December 31, 2024. The information was obtained from the MSTI – Navigation Safety Administration, Sector for Navigation Safety Registries at the author's individual request.

² Source: tabular extract from the MSTI's electronic Information Receipt Log. The data contains all cases of death or injury at sea (swimmers, surfers, boaters, divers, maritime passengers, crews on cargo vessels etc.). Due to the criteria used for recording the data, it is impossible to extract statistical information specifically on injury or death cases caused by motorised boats and yachts to people in the sea or to those on board such vessels.

³ Simultaneously, the new Insurance Act (Official Gazette, no. 151/05) was also passed in 2005 regulating the conditions for the establishment and operation of insurance companies, the performance of internal audits and audits of insurance companies, the liquidation and bankruptcy procedure, the insurance intermediaries, the system of public supervision of insurance companies and insurance intermediaries, consumer protection, cross border insurance business etc. The Insurance Act of 2005 was subsequently amended (Official Gazette, no. 87/08, 82/09, 54/13) and then substituted by the new Insurance Act of 2015 (Official Gazette, no. 30/15, 112/18, 63/20, 133/20, 151/22, 152/24).

In particular, the scope of coverage and insurance limits have remained the same. The aim of this paper is to address increasing criticisms of the existing legislative solution coming from the nautical tourism industry, to explore potential legislative improvements and to propose possible amendments (*de lege ferenda*).

2. LEGAL FRAMEWORK

As explained above, compulsory insurance of liability of boat and yacht owners is prescribed and regulated by CITA. The Act prescribes the legal obligation of the owners⁴ of certain types of motorised vessels to conclude and maintain in force an insurance contract to cover potential liability for third party injury or death caused by the vessel, in accordance with the minimum standards provided by law.⁵ This insurance must be in effect as long as the vessel is in use.⁶ The legal regime for third party liability that is subject to compulsory insurance is defined by the Maritime Code (Official Gazette, no. 181/04, 146/08, 61/11, 56/13, 26/15, 17/19; hereinafter: MC), specifically in art. 810 which addresses liability for death and personal injury caused by a vessel (for further analysis see Ćorić, 2018; Skorupan Wolff, 2024). This liability of vessel owners is limited according to MC, art. 386-399, and the 1976/96 LLMC.⁷

CITA, among other things, defines the scope and limits of this compulsory liability insurance, prescribes the right to a direct claim against the insurer, limits the insurer's defences in the event of a third party's direct claim⁸, and further protects injured third parties in cases of damage caused by unregistered, uninsured, or unidentified vessels by providing the possibility of compensation for such damage through the Guarantee Fund operated by the Croatian Insurance Bureau.

Compulsory insurance under CITA requires the mandatory conclusion of an insurance contract with a commercial insurer (Kocijan, 2009, p. 31). Any commercial insurer licensed to provide this type of insurance in Croatia is obliged to enter into such a contract in accordance with CITA provisions and its own standard terms and conditions for this type of coverage, provided that the prospective policyholder accepts the terms and conditions under which the insurer provides the coverage (CITA, art. 8; Kocijan, 2009, p. 31).

It is well established in the legal literature that the contract for compulsory insurance of boat or yacht owner liability is considered a marine insurance contract (see Ćurković, 2013b, p. 168; Pavić, 2011, p. 30; Kocijan, 2009, p. 24; Bolanča, 2017, p. 111). Thus, CITA serves as a *lex specialis* regulating this specific type of insurance, while MC is the *lex generalis* for all marine insurance contracts⁹ (Ćurković, 2013b, p. 168, Bolanča, 2017, p. 111).

3. VESSELS SUBJECT TO THE COMPULSORY INSURANCE REQUIREMENT

⁴ The obligation to conclude the insurance contract lies on the registered owner, and on the so-called disponent owner (see MC, art. 5, para. 1, item 17), such as bareboat charterer or lessee, but besides their liability this insurance also covers the potential liability of any person (natural or legal) who with the approval of the owner uses or operates the vessel (see CITA, art. 3, para. 1, item 10, art. 4, para. 3 and art. 5).

⁵ The obligation to insure liability is reinstated in art. 8 of the Ordinance on Boats and Yachts (Official Gazette, no. 13/20).

⁶ Failure to obtain such insurance is an offense punishable by a fine (CITA, art. 65). Without this insurance policy, the vessel cannot be registered or issued the necessary sailing permit by the competent harbour master's office (CITA, art. 4, para. 2).

⁷ Croatia is a party to the Convention on Limitation of Liability for Maritime Claims (LLMC) 1976 and the Protocol of 1996 as further amended in 2012. MC is aligned with this international regime of limitation of liability for maritime claims.

⁸ In the case of a direct claim against the insurer, no legal or contractual defence that would otherwise be available to the insurer against the insured can be used against the third-party claimant. For a more detailed discussion on direct action in this specific context, as opposed to voluntary marine insurance of liability see Pavić, 2011; Kocijan, 2009; Orešković, 2004.

⁹ See MC, Art. 684-747.d.

According to CITA, compulsory liability insurance requirement applies to all yachts and boats whose engine power is 15kW or more, regardless of their registered purpose, whereas:

- the term yacht means “a vessel for sports and leisure, regardless of whether it is used for personal needs or for commercial purposes, with a hull length of more than 15 meters and intended for extended stays at sea, and which is authorised to carry up to 12 passengers in addition to the crew” (MC, art. 5, para. 1, item 13, in connection with CITA, art. 3, para. 1, item 7)¹⁰, and
- the term boat means “a vessel intended for sea navigation and authorised to carry a maximum of 12 passengers, with a hull length of more than 2.5 metres and less than or equal to 15 metres”, excluding vessels belonging to another vessel or maritime facility, vessels intended exclusively for competitions, canoes, kayaks, gondolas and pedal boats, windsurfs and surfboards (MC, art. 5, para. 1, item 7, in connection with CITA, art. 3, para. 1, item 3).

By analogy, CITA provisions on compulsory insurance of yachts and boats apply to boats of inland navigation with engine power of 15 kW or more (CITA, art. 41, para. 5).

CITA provisions on compulsory liability insurance do not apply to ships, i.e. to seagoing vessels with a hull length exceeding 15 meters or authorised to carry more than 12 passengers (MC, art. 5, para. 1, item 2).

Historically, the types of vessels subject to compulsory insurance have changed. Originally, IA 1994 prescribed compulsory insurance for a) yachts and b) motorised boats with engine power exceeding 15 KW and hull lengths of up to 12 meters, provided they were registered for sport or recreation (Šantić, 2000, p. 26). In 2005, with the introduction of CITA, the qualification of being "registered for sport and leisure" was removed from the definition of boats subject to compulsory insurance. As a result, compulsory insurance began applying to all types of boats, regardless of their intended use (Ćurković, 2013b, p. 169). Consequently, the number of boats required to have compulsory insurance significantly increased in 2005. Furthermore, MC was amended in 2019 (Official Gazette, no. 17/19), redefining a "boat" to include vessels up to 15 meters in length. As a result, many vessels that previously qualified as ships automatically became classified as boats under the amended MC. Subsequently, the 2023 revision of CITA aligned the definitions of boats and yachts with those in the MC 2019. Consequently, vessels with hull lengths between 12 and 15 meters that were previously classified as ships and exempt from compulsory liability insurance under CITA are now classified as boats, thus falling under the provisions of CITA regarding compulsory liability insurance for boat and yacht owners.

It is submitted that at this point it would be recommendable to assess whether there is a need for revision of the vessel type criterion for the application of the compulsory liability insurance requirement. In particular, certain issues that should be considered are the following:

a) Is the 15-kW engine power criterion still relevant as the primary determining factor for the application of CITA? MSTI should evaluate the appropriateness of raising this limit based on recent statistics regarding maritime accidents involving boats and yachts in Croatian waters. According to Ćurković, there are arguments supporting such a review from the perspective of safety of navigation, as it appears that 15 kW does not represent a significant risk that frequently results in accidents (Ćurković, 2013b, p. 169). However, it is important to consider that a change to this criterion could substantially decrease the total number of insurance

¹⁰ The term yacht for the purposes of CITA does not include the co-called large passenger yacht defined by MC, art. 5, para. 1, item 60, because such vessel is considered a ship since it is authorised to carry more than 12 passengers. Thus, compulsory liability insurance prescribed by CITA does not apply to large passenger yachts.

policies issued. This reduction would lead to a decrease in the number of policyholders and, consequently, an increase in insurance premiums.

On the other hand, for comparison, in Slovenia, compulsory insurance applies to boats with an engine power of 3.7 kW or more.¹¹ In Italy, liability insurance is compulsory for all motorised pleasurecraft and for vessels of up to 25 GRT with an inboard engine exceeding 3 kW and registered for private use, other than leisure, or for public transportation of passengers. Compulsory insurance requirement extends to all outboard engines of any power regardless of the vessel on which they are placed.¹²

b) It has been discussed whether compulsory liability insurance for third party injury or death claims should be extended to ships of less than 300 GRT. According to MC, Articles 747.a to 747.d all seagoing ships of 300 GRT or more must carry an insurance policy covering shipowner liability for maritime claims. These provisions of the MC transpose Directive 2009/20/EC of the European Parliament and of the Council of 23 April 2009 on the insurance of shipowners for maritime claims into Croatian law.

If the Croatian legislator wishes to prescribe compulsory liability insurance for ships of up to 300 GRT, it is hereby suggested that the correct and more effective approach would be to provide for it as part of future amendments to MC, since this Code already addresses the issue. Such requirement could be imposed on the ships registered in Croatia. However, it is questionable whether it could be enforced against foreign flag ships in Croatian waters, and in particular against ships registered in other EU member states. The problem is that such national law requirement that is stricter than the existing EU standard (Directive 2009/20/EC) or a generally accepted international standard¹³ might potentially be challenged as an impediment to the freedom of navigation.

Finally, statistics on maritime accidents and current levels of maritime safety do not indicate a pressing need for the introduction of compulsory liability insurance for third-party personal injury or death claims, as will be discussed further in this text.

4. THE SCOPE OF INSURANCE COVERAGE:

4.1. Defining a Third Party

De lege lata, compulsory liability insurance for boats and yachts exclusively covers third party claims for personal injury, health impairment, or death. The term “third party”, as defined by the relevant legislative provisions, does not include any person on board the vessel for which the insurance policy is effected, nor does it include any person on board another vessel, typically in the event of a collision (MC, art. 41, para. 2). Thus, the insurance only covers claims from individuals who were at the time of the accident outside the vessel to which insurance applies; in other words, it includes swimmers and other persons in the water, such as surfers,

¹¹ See art. 33.a of the Slovenian Compulsory Insurance in Traffic Act (Official Gazette, no. 70/94, 67/02, 13/05, 30/06, 110/06, 52/07, 45/24, hereinafter: Slovenian CITA).

¹² See art. 123 of the Italian Private Insurance Act (Legislative Decree of 7 September 2005, n. 209, hereinafter: Italian PIA).

¹³ IMO conventions prescribing compulsory shipowner liability insurance that have so far been in force are International Convention on Civil Liability for Oil Pollution Damage 1992, International Convention on Civil Liability for Bunker Oil Pollution Damage 2001, Nairobi International Convention on the Removal of Wrecks 2007 and Athens Convention relating to the Carriage of Passengers and their Luggage by Sea 2002. As for other types of maritime claims, shipowners are urged to effect liability insurance in respect of ships of 300 GRT or more in accordance with IMO Resolution A.898(21), 25 November 1999, Guidelines on Shipowners' Responsibilities in Respect of Maritime Claims.

kitesurfers, windsurfers, kayakers etc. This limited scope of coverage has faced significant criticism in professional circles, particularly within the nautical charter industry.

It is worth noting that under IA 1994, the term "third party" was not explicitly defined within the provisions concerning compulsory insurance for boat and yacht owners. However, the prevailing interpretation was that it included any natural person who, at the time of the accident, was not on board the vessel that caused the damage. This interpretation encompassed swimmers and other individuals in the water, as well as persons on board another vessel in the event of a collision (Šantić, 2000, p. 26).¹⁴

The question arises whether the scope of coverage should be expanded to include a broader range of third parties, specifically to encompass individuals on the insured vessel as well as those on another vessel in the event of a collision. In my opinion, if this approach is adopted, it is essential to clarify that liability insurance will not cover injury, death, or health impairment of individuals on board when such damages are not directly related to navigation. This distinction aims to exclude risks associated with hotel, tourism, and sports-recreational activities, including injuries and health-related issues.

Arguments in favour of maintaining the current scope of coverage stem from the original motivation for introducing this type of compulsory insurance, which was primarily to protect individuals outside the vessel, particularly swimmers and others in the water, from the reckless use of powerboats and other motorised pleasurecraft (Ćurković, 2013b, p. 171). However, once the obligation to insure was expanded from pleasurecraft to all types of boats, regardless of their use, it became logical to extend coverage to a larger group of potential third-party claimants (Ćurković, 2013b, p. 171).

During the drafting of the 2013 amendments to CITA, representatives of the insurance industry proposed extending the definition of third parties. However, this proposed amendment was ultimately dropped for unexplained reasons (Ćurković, 2013b, p. 171). It has been suggested that CITA should be amended to expand the scope of compulsory liability insurance coverage for boat and yacht owners to include all injured persons, including those on board the insured vessel and on board another vessel in the event of a collision. Relying solely on voluntary liability insurance in such cases is insufficient (Ćurković, 2013b, p. 171).

In my opinion, there is justification for expanding the circle of third parties. Compulsory insurance for boat and yacht owners should cover claims of all individuals outside the insured vessel, including those on another vessel in the event of a collision. Additionally, it should cover all persons who, with the consent of the owner of the insured vessel, are on board at the time of the adverse event, excluding crew members of the insured vessel, meaning those who are paid to work on board. The person sailing the vessel at the time of the harmful event should also be excluded from coverage. Furthermore, all adverse events that are not directly related to navigation should be excluded from coverage.

4.2. Claims Caused by the Use of the Vessel

The prevailing position in practice and theory is that compulsory insurance covers claims arising from the use of a vessel, including actual navigation and manoeuvring, as well as mooring, unmooring, anchoring, and similar activities related to navigation. It has been argued that the term "use of the vessel" in this context should also encompass the period when the vessel is anchored or berthed in the water. Conversely, claims arising while the vessel is in a dry berth are not covered (Skorupan Wolff, 2024, p. 66; Ćurković, 2013b, p. 170; Bolanča, 2017, p. 113).

¹⁴ See, for example, the decision of the High Commercial Court of the Republic of Croatia, Pž-3038/06 of 23. Septemeber, 2009.

4.3. Should other types of third party claims be included?

De lege lata, compulsory insurance only covers claims for third-party injury, death, or health impairment. Under Croatian law, this includes claims for compensation for physical pain and mental distress suffered, as well as indemnity claims for incurred costs (such as medical expenses, costs of caretakers, funeral expenses, etc.) and for any loss of earnings or financial support from a family member resulting from such injury, health impairment, or death.

De lege ferenda, it has been discussed whether to include other types of third party claims in the scope of compulsory liability insurance for boats and yachts. In particular, the issue is whether compulsory insurance should include:

- a) liability for third-party property damage; if so, how should the insured event be defined? Should it encompass only accidents closely related to the navigational function of the vessel, such as collisions, contact with fixed or floating objects, stranding or similar? Alternatively, should it include other types of occurrences, such as fires, explosions, or other harmful events not directly connected to navigation?
- b) liability for bunker oil pollution damage;
- c) liability for wreck removal.

The scope of coverage for voluntary liability insurance for boats and yachts typically includes non-contractual liability for damage to third-party property. However, this coverage generally extends only to damages resulting from collisions with other vessels (as defined by MC), contact with fixed or floating objects, stranding, capsizing, sinking, damage to underwater infrastructure caused by anchors, or similar harmful events related to navigation. In my opinion, any potential expansion of the compulsory liability insurance scope of coverage should align with these considerations.

Conversely, third-party claims arising from incidents such as fire, explosions on board, or similar occurrences are not inherently tied to navigation and participation in maritime traffic. Therefore, it can be argued that these claims should not be included in the coverage of compulsory liability insurance for boat and yacht owners, nor should liability for cargo transported on the insured vessel. There is no compelling public interest necessitating compulsory insurance in these cases.

While there may be compelling arguments in favour of expanding the scope of compulsory insurance coverage to include liability for bunker oil pollution damage and wreck removal, it is suggested that the appropriate approach would be to address these issues as part of future amendments to MC. This Code already regulates similar matters concerning vessels over 300 GRT for wreck removal and vessels over 1,000 GRT for bunker oil pollution.

5. LIMIT OF INSURANCE

According to IA 1994, the limit of compulsory liability insurance for boats and yachts was set at 1,400,000 HRK for all claims arising from the same occurrence. The equivalent value at today's exchange rate is approximately € 187,000. In CITA 2005, this limit was increased to 3,500,000 HRK per occurrence. As part of the 2023 amendments to CITA, the limit was expressed in Euro and is now set at € 464,520 per occurrence (CITA, art. 42).

It is noteworthy that this limit has not been raised for 20 years, despite inflation and a substantial increase in the orientational criteria established by the Supreme Court for determining the amount of fair monetary compensation for non-pecuniary damages caused by violations of personal integrity (Supreme Court, 2020, Su-

IV-47/2020-5). Compared to the Supreme Court's criteria established in 2002 (Supreme Court, 2002, Su-1331-VI/02 and 1372-11/02), the amounts accepted at that time have increased by 50%.

When considering the compulsory insurance limit, one should take into account that, as mentioned above, the MC/LLMC limits of the vessel owner's liability for maritime claims, in particular for third party injury and death claims.

According to MC, art. 381 and 399 and the corresponding provisions of LLMC 1976/1996 as amended, the limit of liability for claims for loss of life or personal injury caused by boats or yachts not exceeding 2,000 GRT is 3.02 million SDR (cca € 3.7 million) per occurrence. For larger yachts, the following additional amounts are used in calculating the limitation amount:

- For each ton from 2,001 to 30,000 tons, 1,208 SDR (cca € 1,481)
- For each ton from 30,001 to 70,000 tons, 906 SDR (cca € 1,208)
- For each ton in excess of 70,000, 604 SDR (cca € 740)

Since most of the yachts registered in Croatia fall into the group of vessels not exceeding 2,000 GRT, technically the correct approach would be to set the compulsory insurance limit to the amount of € 3.7 million per occurrence.

The decision to raise the compulsory liability insurance limit for boat and yacht owners can be made by the Government of the Republic of Croatia based on a proposal from the Croatian Financial Services Supervisory Agency (HANFA). This decision must be published in the Official Gazette (CITA, art. 42, para. 3, 4). This approach allows for changes to the insurance limit outside the standard legislative amendment procedure and should indeed be utilised by the competent authorities.

For comparison, according to Slovenian law, the minimum compulsory liability insurance limit for boats and yachts is set at € 210,000 per occurrence for third party injury and death claims (Slovenian CITA, art. 33.b). Under Italian law the minimum insurance limits are in the case of personal injury, an amount of € 6,450,000 per occurrence, regardless of the number of victims, and in the case of property damage, € 1,300,000 per incident, regardless of the number of victims (Italian PIA, art. 128).¹⁵

Another issue with the existing legislative framework in CITA is the absence of a specific provision addressing situations where the insurance limit is insufficient to cover multiple competing claims arising from the same occurrence. This problem was partly addressed by the Croatian Insurance Bureau's Agreement on the Procedure for Applying the Compulsory Traffic Insurance Act, dated 6 April 2006, which serves as a self-regulatory tool for the insurance industry in implementing CITA (Ćurković, 2013a, p. 9). It is suggested that, *de lege ferenda*, CITA should be amended to include specific provisions that address the issue of multiple competing claims when the insurance limit is inadequate to cover all of them by defining priority claims and the proportionate reduction of the equal ranking claims.

A possible *de lege ferenda* solution for CITA art. 42 could be as follows:

¹⁵ Italy applies the same insurance limits to boats and yachts as it does to motor vehicles. These sums are established in accordance with art. 9 of the Directive 2009/103/EC of the European Parliament and of the Council of 16 September 2009 relating to insurance against civil liability in respect of the use of motor vehicles, and the enforcement of the obligation to insure against such liability (codified version). The limits are unnecessarily high, considering that liability for maritime claims is also limited in Italy.

(1) *The insurer's liability under the insurance contract referred to in article 41 of this Act shall be limited by the insured sum valid on the date of the loss occurrence, unless a higher amount is agreed upon in the insurance contract.*

(2) *The lowest insured sum under the insurance contract referred to in article 41 of this Act shall be €3,700,000 per occurrence, regardless of the number of injured parties.*

(3) *If there are several injured parties and the total loss exceeds the amount referred to in paragraph 1 of this article, the insurance shall first settle the claims resulting from death, bodily injury and health impairment, and only then the damage to property, whereby the priority shall be given to the settlement of claims of natural persons.*¹⁶

(4) *If there are several injured parties and the total loss exceeds the amount referred to in paragraph 1 of this article, the rights of injured parties of the same ranking shall be reduced proportionately so that the total amount of insurance proceeds for all claims arising from one occurrence does not exceed the insured amount referred to in paragraph 1 of this article.*

(5) *An insurer that has paid an injured party an amount greater than that due to it in accordance with the rules on the ranking of claims and the proportional reduction of compensation referred to in paragraphs 3 and 4 of this article, because despite the measures taken, it could not have known that there were other injured parties, shall remain liable to those other parties only up to the amount referred to in paragraph 1 of this article.*

(6) *Every five years from the date of entry into force of this provision, the Government of the Republic of Croatia shall, at the proposal of the supervisory agency, review the amount referred to in paragraph 2 of this article and, if necessary, adopt a decision to increase it in accordance with the consumer price index published by the Central Bureau of Statistics, provided that the reduction in the index in question shall not affect the amount of the insured amounts.*

In any case, it should be noted that expanding the scope of coverage, broadening the circle of third parties, and raising the minimum insurance amount will likely result in a significant increase in the premium for compulsory insurance. Additionally, such an expansion of compulsory insurance coverage will presuppose the capacity of the Croatian Insurance Bureau to ensure that claims arising from unregistered, uninsured, or potentially unidentified vessels are covered by the Guarantee Fund, subject to certain conditions.

6. DAMAGE CAUSED BY UNREGISTERED, UNINSURED OR UNIDENTIFIED VESSELS

De lege lata, in case of an injury or death caused by an uninsured or unidentified boat or yacht, third party injury and death claims may be directed to the Croatian Insurance Bureau to be paid from the Guarantee Fund (CITA, art. 41, para. 4; art. 29, 30 and 44).

Given the large number of vessels to which the provisions of CITA on compulsory liability insurance do not apply, and considering that the facts and circumstances of maritime accidents are often difficult to prove and establish for practical reasons, it is suggested that the possibility of compensation for damage caused by

¹⁶ This provision is proposed only in case that the scope of insurance coverage is extended to include third party property damage. Otherwise, it should be left out.

unknown yachts or boats from the Guarantee Fund should not be prescribed. Such claims are inherently associated with a high level of legal uncertainty and the potential for abuse of this legal benefit in practice.

Regarding the compensation system for damage caused by unregistered and uninsured boats and yachts from the Guarantee Fund, its effectiveness necessitates extending the application of the provisions concerning the Croatian Insurance Bureau's Information Center to include data on boats and yachts that are subject to compulsory insurance. It is suggested that the Guarantee Fund should only be liable for claims arising from yachts and boats for which compulsory insurance is required and for which, at the critical moment of the loss occurrence, no valid liability insurance, as mandated by CITA, was in place.

7. CLAIMS AND PREMIUM STATISTICS

From the Croatian Insurance Bureau's statistical data on premiums and claims for the period from 2018 to 2023, it is evident that compulsory liability insurance for boats and yachts constitutes a relatively small portion of the insurance portfolio in Croatia. In 2023, the gross collected premium for all non-life insurance in Croatia totalled €1.43 billion. The largest share of this premium was from compulsory automobile liability insurance, amounting to €485.2 million, or approximately 34%. Compulsory liability insurance for boats and yachts in that year accounted for €2,631,415, or 0.2% of the gross collected premium for all non-life insurance. When compulsory insurance is combined with voluntary liability insurance for ships, yachts, and boats, the gross collected premium in 2023 amounts to € 6,208,395, or 0.4% of the total gross collected premium for all non-life insurance. Judging by the premium, this type of insurance plays no significant role in the local insurance market (Ćurković, 2013b, p. 167).

Below is the statistical data for related insurance groups (compulsory liability insurance for boats and yachts, voluntary shipowner liability insurance for owners of sea-going ships and other types of vessels; marine hull insurance) and, for comparison, the data on compulsory automobile liability insurance. The comparison helps to compare and get an understanding of the insurance results that are relevant for considering potential expansion of coverage of compulsory liability insurance for owners of boats and yachts. It is important to note how the loss-to-premium ratio stands in comparable insurance types, and this is the statistic that is generally aimed for in insurance, namely, to keep the loss-to-premium ratio below 60%. In this context compulsory liability insurance for boats and yachts truly stands out with the loss-to-premium ratio being around 3% on average. On the other hand, it should be noted that as a result of expanding coverage in compulsory insurance for boats and yachts, a large portion of claims from voluntary liability insurance will spill over into this type.

The current analysis also highlights an anomaly in the statistics, specifically the discrepancy between the total number of insurance policies issued annually and the number of boats and yachts registered in Croatia. In 2023, the number of policies reached a six-year high of 44,028. At the time of writing, the insurance statistics for 2024 had not yet been published. Conversely, as mentioned earlier, the number of registered boats and yachts in Croatia exceeds 113,000 (112,600 boats and 839 yachts).

Although the available data does not allow us to determine the number of boats with engine power below 15 kW, it is improbable that more than 50% of all registered boats fall into that category. More likely, a significant number of boats registered in Croatia are not complying with the compulsory insurance requirement.

One issue affecting compliance is the fact that a large group of boats are subject to a 5-year regular inspection, which means they are only inspected by the harbour master's office once every five years. In contrast, compulsory insurance policies are typically issued annually, with no enforcement mechanism to ensure compliance between inspections. Furthermore, some boats are under a single permanent registration, with no obligation for regular inspections.

Before 2020 and the introduction of the new Ordinance on Boats and Yachts, about 97,000 boats in Croatia were under this permanent registration regime, largely owned by locals and registered for private purposes (More, Slobodna Dalmacija, 2020). After January 2020, the new Ordinance introduced a regular 5-year inspection for private-purpose boats over 7 meters in hull length or with engine power over 15 kW, provided they have a sanitary facility, or a kitchen with an installed gas appliance, or an inboard engine, or an installed gasoline fuel tank, or are intended for extended sea stays. The number of such boats in 2020 was around 16,000 (Morski.hr, 2020).

Thus, it is likely that a significant number of boats with engine power of 15 kW are not complying with the compulsory insurance requirement due to a lack of enforcement. It is suggested that an improvement in compliance implementation could be achieved by extending the Croatian Insurance Bureau's Information Centre regime (see CITA, art. 51 et seq.) to include compulsory liability insurance for boat and yacht owners. Currently, the Information Centre is only used for compulsory automobile liability insurance.

	Gross written premium (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2018	2.112.573,23	36.207	61.651,60	26	2,92
2019	2.297.099,87	38.706	66.366,05	12	2,89
2020	2.218.439,45	37.396	38.159,67	9	1,72
2021	2.324.373,61	39.987	23.735,22	9	1,02
2022	2.476.933,17	41.875	78.302,48	12	3,16
2018-2022	11.429.419,34	194.171	268.215,01	68	2,35

	Gross premium collected (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2023	2.631.415,00	44.028	176.103,00	20	6,69

Table 1: COMPULSORY INSURANCE OF BOAT/YACHT OWNER'S LIABILITY FOR THIRD PARTY INJURY 2018 - 2023 (source: Croatian Insurance Bureau)

	Gross written premium (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2018	2.498.766,21	13.960	670.107,37	226	26,82
2019	1.986.700,91	15.607	2.033.765,21	190	102,37
2020	1.985.040,68	13.076	980.684,45	139	49,40
2021	2.054.931,85	13.692	1.392.790,23	150	67,78
2022	2.528.701,04	15.162	863.347,93	151	34,14
2018-2022	11.054.140,69	71.497	5.940.695,20	856	53,74

	Gross premium collected (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2023	2.625.322,00	16.119	908.045,00	171	34,59

Table 2: VOLUNTARY INSURANCE OF SHIPOWNERS' LIABILITY 2018 - 2023 (source: Croatian Insurance Bureau)

	Gross written premium (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2018	582.047,78	5.174	337.328,02	238	57,96
2019	754.577,61	6.740	162.438,65	297	21,53
2020	794.567,26	8.367	301.005,51	96	37,88
2021	937.837,68	9.732	136.130,86	234	14,52
2022	1.055.738,80	12.298	152.806,56	210	14,47
2018-2022	4.124.769,13	42.311	1.089.709,60	1.075	26,42

	Gross premium collected (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2023	951.768,00	10.970	192.820,00	270	20,26

Table 3: OTHER VOLUNTARY INSURANCE OF VESSEL OWNERS' LIABILITY 2018 - 2023 (source: Croatian Insurance Bureau)

	Gross written premium (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2018	274.404.279,51	2.219.108	144.163.360,67	87.841	52,54
2019	289.550.841,86	2.335.060	168.802.774,84	97.852	58,30
2020	327.697.398,77	2.403.103	165.830.683,26	88.630	50,60
2021	374.753.252,37	2.596.567	190.988.813,06	98.798	50,96
2022	409.875.270,16	2.707.285	221.774.968,61	110.372	54,11
2018-2022	1.676.281.042,67	12.261.123	891.560.600,44	483.493	53,19
	Gross premium collected (EUR)	Number of policies	Claims paid (EUR)	Number of claims	Loss record (claims/premium) %
2023	485.232.700,00	2.821.460	276.401.743	127.043	56,96

Table 4: COMPULSORY AUTOMOBILE LIABILITY INSURANCE 2018 - 2023 (source: Croatian Insurance Bureau)

8. THE AIM OF COMPULSORY INSURANCE OF LIABILITY

While the conclusion of insurance contracts is generally left to the discretion of the contracting parties, the concept of compulsory insurance mandated by law represents an exception to this general principle. Such exceptions are implemented when the legislator restricts the freedom of contract to protect general interests, socialises the risk of liability, and assigns insurance a public function to protect third (innocent) parties (Pavić, 2011, p. 30).

Initially a rare exception, compulsory liability insurance has over time become increasingly prevalent in national laws and international conventions. Today, it encompasses a wide variety of liability sources, with its scope continuously expanding (Kocijan, p. 24).

Compulsory liability insurance is introduced when there is a broader general social interest in protection against the consequences of specific risks, particularly those associated with inherently dangerous activities or objects (Belanić, 2009, p. 554). The reasons that must be considered when prescribing compulsory insurance typically include the potentially high number of individuals at risk from a particular activity and the possible magnitude of damage or harm. These reasons must clearly represent a broader social interest that justifies the requirement for compulsory liability insurance. While liability insurance's primary goal is to protect the insured from the financial consequences of liability and to safeguard the injured party from damage, once it is mandated, the focus of protection shifts primarily towards the injured party (Belanić, 2009, p. 554). However, the potential interest of insurers in increasing the accumulation of insurance premiums should not be overlooked when mandatory regulations require the contracting of certain types of insurance. (Belanić, 2009, p. 555).

The introduction of compulsory insurance for boats and yachts was motivated by the need to protect third parties increasingly threatened at sea and in other waters by the growing fleet of various types of motorised vessels used for sport and leisure or recreation (Ćurković, 2013b, p. 167).

9. CONCLUSION

In general, the purpose of compulsory insurance is to protect third injured parties when there is a general social interest in doing so. This interest may arise from the frequency and extent of a certain type of harm, the number of potential victims, their weaker legal or financial positions, and the challenges of enforcing claims against the perpetrators, considering the likelihood and speed of claim enforcement. Compulsory insurance and the possibility of direct action by an injured third party against the insurer should be viewed as exceptions to the general principle of freedom to contract insurance. Nonetheless, there is a noticeable trend toward an increase in the number of compulsory insurances overall, and particularly in maritime transport.

In Croatia, liability insurance for boat and yacht owners covering third-party death, bodily injury, or health impairment is compulsory. Insurance is compulsory for all yachts and boats with propulsion engines exceeding 15 kW. The required amount of compulsory liability insurance is €464,520 per occurrence, and the injured party has the right to a direct claim against the insurer. Claims arising from an uninsured or unidentified vessel can be compensated from the Guarantee Fund managed by the Croatian Insurance Bureau.

There has been significant public criticism of the current legislative framework, particularly regarding the relatively narrow scope of insurance coverage and the low insurance limit.

We can conclude that, in general, this criticism is justified. The *de lege ferenda* suggestions presented in this paper aim to expand the current scope of coverage to include third-party claims for death, injury, and health impairment of any person outside the insured vessel (such as swimmers and others in the water or on shore, or individuals on board another vessel in the event of a collision etc.), as well as any person on board the insured vessel, excluding the person sailing the vessel and the employed crew. The proposed limit of insurance is €3.7 million per occurrence, which aligns with the binding maritime law rules on the limitation of liability for maritime claims.

It is suggested that the scope of coverage should not be expanded to include third-party property damage claims due to the lack of compelling public interest. The risk of property damage should remain with the owners. Particularly, the vessel owners should insure their vessels under hull policies and be encouraged to obtain regular voluntary marine liability insurance. This practice is already standard in the nautical charter industry.

It is argued that this type of compulsory insurance should remain limited to boats and yachts, and not extended to ships, due to the unique characteristics of the boat and yacht fleet, including their purpose, ownership, method of use, traffic density, and the prevailing insurance arrangements that exist in practice.

To ensure better implementation and compliance with the requirement for compulsory liability insurance for boats and yachts, it is proposed that the Croatian Insurance Bureau's Information Center regime should be applied to this type of insurance, rather than being restricted to compulsory automobile liability insurance, as is currently the case.

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Concession Agreement in Sports Ports

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The Maritime Domain and Seaports Act (2023) regulates the status of special-purpose ports in the Republic of Croatia. One of the special-purpose ports is a sports port. A sports port is a port intended for the mooring, storage and maintenance of boats registered in the Croatian Register of boats for non-commercial use, owned by members and concessionaires of the sports port. A sports port is granted as a concession to an economic entity. A maritime domain concession for a sports port is granted to legal entities of the sports system that practise sports on or in the sea and have active participants in at least three age categories. The concession agreement grants the management of the sports port to the concessionaire of the port. A concession agreement is an administrative agreement concluded in writing. The concession agreement regulates in detail the powers of the concession grantor and the rights and obligations of the concessionaire, in particular the port area assigned for concession, the term of the concession, the fee to be paid for the concession, the possibility of concluding a commercial cooperation agreement and/or a sub-concession agreement, the grounds for revoking the concession, the termination of the concession as well as the interpretation of the agreement and the method of dispute resolution. The paper provides an overview and analysis of the main provisions of concession agreements in sports ports.

KEYWORDS

Maritime domain; Sports port; Concessionaire; Concession agreement; Boats for non-commercial use.

1. INTRODUCTION

The legal framework regulating the status of sports ports in the Republic of Croatia includes a number of regulations concerning the construction, use and management of sports ports to ensure a balance between sporting and other commercial activities at sea.

The new Maritime Domain and Seaports Act in the Republic of Croatia entered into force in July 2023. As a *lex specialis*, it is the most important law that regulates the status of maritime domain and governs the affairs of seaports and port operations. As one of the types of seaports, namely special purpose ports, the Maritime Domain and Seaports Act specifically regulates the status of sports ports. While sports ports have a specific function, they are subject to the general regulations for the management of maritime domain.

In addition to the Maritime Domain and Seaports Act, a number of ordinances have been issued on the basis of this Act that affect the operation of sports ports. Of particular note are the Ordinance on the Classification of Ports for Public Transport and Special Purpose Ports, the Ordinance on the Procedure for Granting Concessions for Maritime Domain, the Ordinance on Defining the Boundaries of Maritime Domain, the Ordinance on the Registration and Marking of Maritime Domain and other ordinances dealing with maritime domain and port issues.

In addition to the Maritime Domain and Seaports Act, the Concessions Act should also be highlighted as an important legal source for regulating the status of sports ports. As a *lex generalis*, it is the basic law for the granting of concessions and concession policy in the Republic of Croatia. The Concessions Act regulates all matters not covered by the Maritime Domain and Seaports Act.

2. SPORTS PORTS

The Maritime Domain and Seaports Act defines a port. According to the Act, a port is a maritime port, or a maritime and land area directly connected to the sea, where the boundaries of the port area have been established. It consists of both developed and undeveloped shores, breakwaters, devices, facilities, and other structures intended for the docking, anchoring and protection of vessels, embarkation and disembarkation of passengers and cargo, storage, and other cargo handling activities, as well as the production, processing, and refinement of goods, and the performance of other economic activities related to these functions through economic, transport, or technological connections. [MDSA] Ports are located within maritime domain areas.

According to their intended purpose, ports are categorized into ports open to public transport and special purpose ports. One type of special purpose port is a sports port. A sports port is a type of port intended for docking, storage, and maintenance of boats for personal use, which are owned by members and concessionaires of the sports port. These boats must be registered in the Croatian Ship Register. [MDSA]

According to their significance, sports ports can be of national or regional importance. The classification of sports ports is carried out based on the area of the port that each port covers. Sports ports of national importance are those where the port area exceeds 5 hectares, while sports ports of regional importance are those where the port area is smaller than 5 hectares. [MDSA] According to the previously applicable regulations, sports ports of national importance were ports with more than 200 berths, while sports ports of regional importance were ports with fewer than 200 berths. [Panžić, 2010]

A sports port is managed by a concessionaire. A concessionaire in a sports port is a business entity that, in accordance with the Maritime Domain and Seaports Act, has entered into a concession agreement with the concession grantor. A concession for a sports port can only be granted to legal entities that are part of the

sports system, engaged in sports on or in the sea, and have active competitors in at least three age categories [MDSA].

The concessionaire who has been granted a concession for a sports port is authorized to provide the following commercial services on the land area of the port: boat maintenance, catering services, boat lifting and lowering services, accommodation services for athletes, sales of equipment for vessels and sports competitions, and other services related to the development of sports in accordance with the spatial plan [MDSA]. The concessionaire granted a concession for a sports port is obliged to use the income generated for the development of sports and the maintenance and improvement of port superstructure and infrastructure, without making a profit [MDSA].

3. CONCESSION AGREEMENT IN SPORTS PORTS

A concession for maritime domain is a time-limited right to the economic exploitation of maritime domain, with or without the right to build, which is acquired through a concession agreement. A concession agreement is an administrative contract concluded between the grantor and the concessionaire for a specific period of time, which sets out the mutual rights and obligations related to the concession granted. A concession for maritime domain is granted for purposes provided for in the spatial development plan, including sports ports. The concession grantor for sports ports of national importance is the Government of the Republic of Croatia, while the concession grantor for sports ports of regional importance is the county. The concessionaire is the economic entity with which the grantor has concluded a concession agreement. The concessionaire is prohibited from carrying out activities outside the scope of the concession activities specified in the concession agreement.

The concession for a sports port is granted on the basis of a procedure that begins with the announcement of the intention to grant the concession and ends with the decision to grant the concession. In exceptional cases, a concession for sports ports within the top-level sports system may be granted upon application. The concession notice sets out the content of the concession, the subject matter of the concession, the term of the concession, the general conditions, the initial concession fee, the personal, professional and financial requirements to be met by the bidders and the documents proving that they have been met, the deadline for submitting offers, the criteria for selecting the best offer, the procurement of tender documents, the opening of offers, the decision-making procedure, the legal remedies and the final provisions. The decision to grant the concession sets out the legal basis for the decision, the area and scope of the concession, the duration of the concession, the rights and obligations of the concessionaire, the required investments in the sports port, the concession fee, the conditions for the termination, revocation and suspension of the concession and the provisions on the obligation to conclude a concession agreement.

The concession agreement sets out the rights and obligations of the grantor and the concessionaire on the basis of the decision to grant the concession in accordance with the provisions of the Concessions Act and the Maritime Domain and Seaports Act. The concession agreement is drawn up in accordance with the decision to grant the concession.

The concession agreement for sports ports precisely defines the powers of the concession grantor and the rights and obligations of the concessionaire. It contains provisions on the port area allocated under the concession, the duration of the concession, the concession fee, the possibility of concluding a business cooperation agreement and/or a sub-concession agreement, the grounds for revoking the concession, the termination of the concession, the interpretation of the agreement and the method for settling disputes.

3.1. Deadline for granting the concession

The concession grantor shall determine the period for which the concession is granted in such a way that this period does not restrict competition in the market more than is necessary for the amortization of the real value of the concessionaire's investment and a reasonable return on the capital invested, also considering the costs and risks to be borne by the concessionaire during the concession period. [CA] The Maritime Domain and Seaports Act stipulates the period for granting a concession. Accordingly, the Government of the Republic of Croatia grants concessions for state-significant sports ports for a period of up to 50 years, and exceptionally, if there are legitimate economic interests and the concession involves the construction of new buildings with investments that cannot be amortized within 50 years, and the overall economic effects cannot be achieved within this period according to the feasibility study for the award of the concession, for a period of more than 50 years, with the prior consent of the Croatian Parliament to announce the intention to award the concession. On the other hand, the county grants concessions for county-significant sports ports for the county for a period of up to 20 years.

3.2. Concession fee

The concession fee for sports ports is considered a public payment and is paid in money consisting of a fixed and a variable part. The fixed part of the concession fee is determined based on the area of the maritime domain (both land and sea) allocated in the concession. The variable part of the concession fee is determined as a percentage of the revenue from the activity for which the concession was granted, whereby the annual amount of the variable part of the concession fee for all years of use may not be less than the amount offered in the feasibility study. [MDSA] The initial amount of the concession fee is determined on the basis of calculations and analysis of the feasibility study for granting the concession, which depend on the subject of the concession, the estimated value of the concession, the duration, the risks and costs to be borne by the concessionaire, the expected profit, the value of the equipment and assets, and the area of the maritime domain granted in the concession. The concession fee is a revenue for the state budget of the Republic of Croatia and/or the county budget.

3.3. Subcontracting concession agreement

During the term of the concession agreement, the concessionaire may conclude a subcontracting concession agreement with third parties. A subcontracting concession is a legal relationship between the concessionaire and a third party for the economic exploitation of part of the maritime domain covered by the concession, which requires the construction of buildings to carry out activities related to those for which the concession was granted. These activities are those which the concessionaire cannot carry out or which he considers can be carried out more efficiently in the concession area if he grants a third party the right to construct and carry out the related activities. [MDSA] Before entering into a subcontracting concession agreement, the concessionaire must obtain the written consent of the concession grantor. The subcontractor must meet the conditions prescribed for the concessionaire in the Maritime Domain and Seaports Act.

The possibility of concluding a subcontracting concession agreement is provided for by the concession grantor in the feasibility study for granting the concession, in the tender documents, in the notice of intention to grant the concession and in the concession agreement. The subcontracting concession agreement may not cover the main activity of the concession. The subcontracting concession agreement cannot be concluded for a period longer than the term of the concession agreement. [CA]

3.4. Business cooperation agreement

A business cooperation agreement regulates ancillary activities in sports ports. An ancillary activity is a service activity carried out on the area granted in the concession by legal entities or craftsmen as a complementary activity linked to the main purpose of the concession and which does not require the construction of buildings. [MDSA] The concessionaire is obliged to submit to the grantor for approval the business cooperation agreement together with proof that there are no reasons to exclude the economic entity from the concession award procedure. The performance of ancillary activities may not be entrusted to an economic entity that has debts due to the Republic of Croatia. [Baće – Mandić, 2023]

3.5. Termination of the concession and termination of the concession agreement

The concession in sports ports ends in the following cases:

- on the expiry of the term for which it was granted
- upon the death of the individual concessionaire or the dissolution of the legal entity of the concessionaire, unless otherwise stipulated in the concession agreement
- by the annulment, revocation or declaration of invalidity of the concession decision after conclusion of the concession agreement.

The concession agreement may be terminated for reasons of public interest or by unilateral termination.

The concession agreement must contain a provision on the concession grantor's right to terminate the concession agreement in whole or in part by resolution if the Croatian Parliament determines that this is necessary in the public interest. If the concession agreement is partially terminated, the concessionaire may apply for full termination of the concession agreement within 30 days of receiving the termination decision. In case of termination of the concession agreement, the concessionaire is entitled to compensation in accordance with the provisions of the concession agreement and the Civil Obligations Act.

The Concessions Act lists several cases in which the concession grantor may unilaterally terminate the concession agreement by decision. Some of these cases are:

- if the concessionaire has failed to pay the concession fee more than twice in succession or generally fails to pay the concession fee properly
- if the concessionaire fails to carry out the prescribed measures and actions required to protect maritime domain
- if the concessionaire has provided incorrect information in the bid on the basis of which compliance with the capacity requirements set out in the tender documents was determined
- if the concessionaire takes actions contrary to the concession agreement or if it fails to take the actions prescribed in the concession agreement
- if, at the time of the decision to grant the concession, there was a reason for excluding the concessionaire
- in other cases, in accordance with the provisions of the Concessions Act, the Concession Agreement and the General Administrative Procedure Act.

Before the grantor unilaterally terminates the concession agreement, it must first notify the concessionaire in writing of its intention to do so and set a reasonable deadline for the concessionaire to eliminate the grounds for terminating the concession agreement and to submit a statement on these grounds. If the concessionaire does not eliminate the reasons for the termination of the concession agreement within the specified deadline, the concession grantor shall terminate the concession agreement.

If the concession grantor fails to fulfil its obligations under the concession agreement, the concessionaire may lodge an objection in accordance with the provisions of the General Administrative Procedure Act. The concessionaire may also demand that the grantor terminate the concession agreement for the concession grantor due to justified reasons specified in the Maritime Domain and Seaports Act.

3.6. Amendments to the concession agreement

The concession agreement can be amended in the following cases without having to initiate a new concession granting procedure:

- if the Croatian Parliament determines that national security and defense, the environment or human health are at risk
- if the concessionaire requests a change in the scope of the concession when amending spatial planning documents and/or implementing acts to spatial planning documents
- due to an investment not provided for in the tender documents, which is necessary due to force majeure events or due to adaptation to new technological operating conditions, if the concessionaire is forced to make these adjustments due to changes in the regulations. [CA]

During the term of the concession, the concessionaire may submit a reasoned request to amend the concession agreement, accompanied by a study on the economic justification for the amendment. The grantor then decides whether to approve the amendment or reject the application. The value of the amendment to the concession agreement may not exceed 50% of the originally estimated value of the concession. [CA] The amendments to the concession agreement may not change the subject matter of the concession agreement. The concession agreement may not be amended in such a way that the initiation of a new concession granting procedure is unjustifiably avoided.

If material changes to the concession agreement are necessary, the concession grantor shall initiate a new concession granting procedure and conclude a new concession agreement. In the event of non-substantial amendments to the concession agreement, the concession grantor and the concessionaire must reach an agreement and an annex to the concession agreement is concluded after the decision on the amendment to the concession granting decision has been issued.

3.7. Status of existing concession agreements

For concession agreements for sports ports concluded before the entry into force of the Maritime Domain and Seaports Act (2023), the concessionaires had to provide the concession grantor with proof within three months of the entry into force of this Act that they are legal entities of the sports system that practise sports on or in the sea and have active participants in at least three age categories. Concessionaires of sports ports who meet these conditions may continue to use the sports port within the scope of the concession granted. If the concession grantor determines that the sports port does not meet these criteria, a procedure shall be initiated within one year to include the area of the sports port within the scope of a port open to public traffic, regardless of the designation of the port in spatial plans. [MDSA]

4. INSTITUTE OF TEMPORARY ECONOMIC USE OF A SPORTS PORT

In contrast to the institute of the economic use of a sports port based on a concession agreement, the Maritime Domain and Seaports Act (2023) also contains a specific provision for the temporary economic use of maritime domain. According to this provision, the Government of the Republic of Croatia, in cases of extraordinary circumstances that could not have been anticipated, avoided or remedied, regardless of the scope of the interference according to the spatial planning documents, the Government of the Republic of Croatia may,

in the interest of the public good, the management of the port area of a sports port, or to prevent damage (e.g., the procedure for granting a new concession has not been completed, the previous concessionaire no longer exists, the concession has expired and the conditions for granting a new concession are not met or the port is being used illegally), make a decision to grant temporary economic use of the port area of a sports port to the port authority. This decision is made ex officio for a period of up to one year. If the legal requirements for the granting of a concession are not met within this period, the maritime domain is transferred to general use. [MDSA]

The mentioned solution, whereby a sports port is granted to the port authority for temporary economic use, is controversial. The Maritime Domain and Seaports Act regulates port authorities as institutions that manage ports open to public transport and not as ports for special use. This means that when defining the remit of a port authority, no provision was made for it could, even temporarily, manage sports ports or other special purpose ports on a temporary basis. Such an authorization only results from the legal provision that regulates the institute of temporary economic use of maritime domain. In this sense, it is proposed *de lege ferenda* to amend the provisions of the Maritime Domain and Seaports Act in the part regulating the status of port authorities in order to exceptionally provide for the possibility that a port authority may temporarily economically use a special purpose port on the basis of a decision of the Government of the Republic of Croatia.

4.1. Presentation of the Decision of the Government of the Republic of Croatia on the Temporary Assignment of Port Authority for the management and use of Port Areas of the existing sports ports

The institute of temporary economic use of maritime domain is a new concept introduced by the Maritime Domain and Seaports Act (2023). This institute was created on the basis of the actual situation in sports ports in the Republic of Croatia and was established by the Government of the Republic of Croatia with reference to Article 10, paragraph 1 of the Maritime Domain and Seaports Act (2003). In December 2019, the Government issued a decision entrusting the Split-Dalmatia County Port Authority with the temporary management and use of the port areas of the existing sports port Zenta and the existing sports port Špinut. According to this decision, the port areas of the Zenta and Špinut sports ports were temporarily transferred to the Port Authority of Split-Dalmatia County for one year, which was later extended twice.

According to the decision, the Port Authority was obliged to ensure the continuation of sports activities, maintenance, management, protection and improvement of maritime domain and safety of navigation. It was also responsible for the provision of services of general interest, such as the lifting and/or lowering of boats and catering for guests. On the port areas of the sports ports, the Port Authority was obliged to ensure order, surveillance and protection of the facilities, boats and equipment located on the port areas that were subject to the Decision on the day the port was taken over. When the Decision entry into force, the Port Authority took over the sports ports and the existing boat mooring contracts.

4.2. Presentation of case law related to the Decision on the temporary management and use of port areas of existing sports ports

In December 2019, the Government of the Republic of Croatia adopted a Decision to transfer the temporary management and use of the port areas of the existing Zenta sports port and the existing Špinut sports port to the Port Authority of Split-Dalmatia County. The Maritime Sports Society Špinut, which was the concessionaire of the Špinut sports port, filed a complaint with the Administrative Court against the legality of the aforementioned Decision.

In the lawsuit, the concessionaire claimed that the Decision unlawfully decided on their right, obligation, and legal interest, that it was unjustified and that there was no valid reason for assigning the port areas to the Port Authority for temporary management and use. They argued that, despite the expiry of their concession in 2015, they had taken a number of measures to create the conditions for the granting of a new concession (e.g. defining the boundaries of the port area). If the legal requirements were met, the existing port of Špinut should have been handed over to them for temporary management and use, which they justified in detail. Furthermore, the concessionaire took the view that, according to the legal conditions, it was not possible to assign the port areas to the Port Authority for temporary management and use, as the management and protection of maritime domain was the responsibility of the Republic of Croatia, either directly or through the municipalities, cities and counties. The concessionaire requested the annulment of the contested Decision.

The court decided to dismiss the claim as inadmissible. The court explained that, on the basis of the Administrative Disputes Act and the General Administrative Procedure Act, the following cumulative conditions must be met for a matter to be considered an administrative matter: a) a decision of a public law body, b) a decision in an administrative procedure, c) a decision affecting the rights, obligations or legal interests of natural or legal persons, and finally d) the direct application of laws, other regulations or general legal acts regulating a specific administrative area. In the present case, the concessionaire challenges the legality of the decision taken by the Government of the Republic of Croatia. According to Article 10, paragraph 1 of the Maritime Domain and Seaports Act (2003), maritime domain is administered and protected by the Republic of Croatia directly or through municipalities, cities and counties, and the responsibility for this lies with the Republic of Croatia. Paragraph 2 of this article defines the management of maritime domain as including the maintenance, development and protection of property within the framework of general use, as well as special use or economic use of maritime domain on the basis of a concession or concession permit. The content of the contested decision shows that it allocates part of the maritime domain, namely the port areas of the existing Špinut sports port, for temporary management and use by the Port Authority for a period of one year. The court concluded that the contested decision does not grant a concession or authorization for a special use or economic use of maritime domain, but is an act of administration of that property pursuant to Article 10, paragraph 1 of the Maritime Domain and Seaports Act (2003), and that it was not adopted in an administrative procedure. Therefore, it does not have the status of an administrative act that could be challenged in the context of an administrative dispute. Furthermore, the concessionaire's concession had already expired at the time the government decision was issued, so that the contested decision did not interfere with its individual rights or legal interests on the basis of administrative law. Therefore, the concessionaire could not apply to the administrative court for legal protection against the decision.

The concessionaire has appealed the judgment of the High Administrative Court of the Republic of Croatia against the judgment of the Administrative Court. They emphasize that the contested decision constitutes an administrative act, which results from the authority of the body that issued it, the form and content of the act, the facts created by the act and the substantive law applied. They claim that the court of first instance misinterpreted the provision of Article 10, paragraph 1 of the Maritime Domain and Seaports Act (2003), which served as the basis for the contested decision. The concessionaire argues that it is not an administrative act, as the court of first instance wrongly assumed, but a decision on the maritime domain concession. They argue that the contested decision must contain a notice of appeal, as the decision affects not only the rights and obligations of the concessionaire, but also the rights of all users of the berths in the sports port's scope. They invoke the constitutionally guaranteed right to judicial review of the legality of individual acts of administrative authorities and public bodies and argue that they could not seek legal protection in other judicial proceedings outside of an administrative dispute. They are therefore of the opinion that the court of first instance wrongly dismissed the action. The concessionaire requests that the High Administrative Court of the Republic of Croatia allow the appeal.

The court finds that the appeal is unfounded. The High Administrative Court of the Republic of Croatia states that the court of first instance correctly assumed that the contested decision does not grant a concession or concession permit for a maritime domain, but an administrative act that was not issued in an administrative procedure and therefore does not have the character of an administrative act that could be contested in an administrative dispute. The Court finds that, in view of the content of the contested decision, the court of first instance rightly concludes that it is not an administrative act issued in an administrative procedure, but an act of administration of maritime domain within the meaning of the cited provision, so that the concessionaire cannot seek legal protection in the administrative dispute procedure.

5. CONCLUSION

Sports ports have an important place in the port infrastructure of the Republic of Croatia. The modern legal framework regulating seaports specifically recognizes the status of sports ports. Concessions for sports ports are granted for the purpose of sports development and not for the development of nautical tourism. According to the Maritime Domain and Seaports Act, a concessionaire of a sports port must have active competitors in at least three age categories and the revenue generated must be used exclusively for the development of sport and for the maintenance and improvement of the port, with no profit for its members. The concessionaire of a sports port must invest the income and profits generated on the lake area in the organization and maintenance of the maritime domain. Moorings in sports ports may not be used for commercial purposes, but only for mooring boats for personal use.

A concession agreement is an administrative contract concluded for a specific period of time between the concession grantor and the concessionaire regarding their mutual rights and obligations related to the given concession. The grantor of concessions for sports ports of national importance is the Government of the Republic of Croatia, while the grantor of concessions for sports ports of regional importance is the county. The Government of the Republic of Croatia grants concessions for sports ports of national importance for a period of up to 50 years, and in exceptional cases for a period of more than 50 years if the Croatian Parliament has given prior notification of the intention to grant the concession. On the other hand, the county grants concessions for sports ports of regional importance for a period of up to 20 years.

In addition to the conclusion of the concession agreement, the legislator also provides for a temporary solution for the economic use of the sports port in the form of the establishment of the institute for temporary economic use of maritime domain. The case law presented has confirmed the justification for the introduction of this institute.

To summarize, the Maritime Domain and Seaports Act (2023) contains better and more precise solutions regulating the status of sports ports compared to the previous legal framework. A possible point of criticism of the legal framework could be the lack of a provision in the part regulating the jurisdiction of the port authority that would allow the port authority, in exceptional cases, to make temporary commercial use of a special purpose port. Therefore, as a *de lege ferenda* solution, it is proposed to amend the provisions of the Maritime Domain and Seaports Act in the part regulating the status of port authorities in order to provide that an exception that would allow the port authority to temporarily economically exploit a special purpose port on the basis of a decision of the Government of the Republic of Croatia.

CONFLICT OF INTEREST: There is no conflict of interest.

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Development of Occupational Standards and Qualification Standards in Maritime Education

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The development and enhancement of study programs at maritime faculties are based on alignment with the Croatian Qualifications Framework (HKO) [Hrvatski kvalifikacijski okvir, 2017]. The methodology focuses on equipping students to meet labour market demands [Andrews & Russell, 2012] by acquiring relevant knowledge and skills. Key steps include linking occupational standards, qualifications, and study programs through sectoral needs analysis [Crnković-Požaić, 2011] and defining learning outcomes that are assessed within educational programs. Due to the transformation of the domestic and international maritime market in the context of high specialization, the emergence of new occupations [Weinberger, 2014], knowledge, and competencies, the development of new technologies and technological trends, the demand for technological knowledge as a fundamental life skill, and the gradual shift towards decarbonization and the blue-green transition, educational programs are continuously adapted to ensure the relevance of acquired competencies. This study proposes a structured methodology for aligning educational programs with occupational and qualification standards, resulting in a competency-based framework that better connects maritime education with labor market needs. Both top-down and bottom-up approaches are employed to align programs with qualification standards [Divjak & Begićević Redep, 2016]. A systematic approach to program development enables the integration of technological innovations [Frey & Osborne, 2013] and the creation of professionals capable of addressing the needs of both domestic and international markets.

KEYWORDS

Croatian Qualification Framework; Occupational standards; Qualifications standards; Learning outcomes

1. INTRODUCTION

Maritime education is essential for preparing a skilled workforce in a rapidly evolving industry driven by technological advancements and regulatory changes. Occupational and qualification standards define the competencies required for various roles, ensuring alignment with labor market demands [European Centre for the Development of Vocational Training, 2017] [Divjak & Begićević Ređep, 2016]. In Croatia, specialization in ship management, including crew and technical management, is increasingly sought after, yet professions such as HSEQ Manager and Marine Superintendent lack formal integration into curricula.

International maritime education frameworks [European Higher Educational Area, 2017] provide global qualification benchmarks but primarily focus on traditional seafaring roles, necessitating updates for fields like LNG ship operations and maritime cybersecurity. The Croatian Qualifications Framework (HKO) [Hrvatski kvalifikacijski okvir, 2017] facilitates qualification standardization and international recognition, ensuring compliance with regulations like the IMO's STCW Convention [Ministarstvo znanosti i obrazovanja, 2017]. Several EU-funded initiatives, including the KIKLOP and MEDUSA projects, have enhanced Croatian maritime education by aligning programs with European frameworks and emphasizing competency-based learning [Gundić, Maglić & Zec, 2015] [Tkalec, Vizek & Žilić, 2016]. However, gaps between theoretical knowledge and industry requirements persist, highlighting the need for continuous curriculum updates, practical training, and stronger industry-academia collaboration.

This research develops a structured methodology for implementing occupational and qualification standards in maritime education. It aims to define key occupational roles, establish competency-based frameworks, and improve accreditation processes, ultimately bridging the gap between education and industry to create a globally competitive maritime workforce.

2. METHODOLOGY FOR THE DEVELOPMENT OF OCCUPATIONAL AND QUALIFICATION STANDARDS IN MARITIME EDUCATION

The development of occupational and qualification standards in maritime education [Sihombing, D. W., Dwiyani, N., Martha, Y. N., Hutabarat, C., Sutrisno, 2024] follows a mixed-methods approach, integrating quantitative and qualitative research to ensure industry-aligned, data-driven outcomes. This includes analyzing study programs, accreditation requirements, and labor market demands through surveys and interviews while mapping competencies to maritime roles. A key focus is designing competency matrices and updating qualification standards [Divjak & Begićević Ređep, 2016].

Standardized frameworks are essential for aligning competencies across maritime professions and ensuring competency-based education meets industry demands. While international regulations have guided qualification standardization, EU-level initiatives provide new opportunities, supporting specialized programs for emerging maritime roles. The KIKLOP project successfully standardized undergraduate qualifications, while the MEDUSA project extends these efforts to graduate-level programs, addressing industry needs for specialized competencies. By integrating this methodology with EU-driven projects like KIKLOP and MEDUSA, maritime education ensures alignment with global standards, preparing graduates for specialized roles and strengthening the maritime sector.

2.1. Occupational Standards

The development of occupational standards requires a comprehensive approach based on a thorough analysis of labor market needs. The goal is to establish a functional education system and lifelong learning framework, effectively linking labor market requirements with educational qualifications.

The methodological approach for developing occupational standards involves several critical steps. Initially, an extensive analysis of existing databases, including the Ministry of Labor databases, Croatian Employment Service records, and the National Classification of Occupations, is conducted. Collaboration with employers and project stakeholders is essential to identify new and emerging occupations driven by market demands. Subsequently, the analytical depiction of the sector's current state and forecasts for the next five years are developed. Primary data collection methods include surveys of relevant stakeholders, structured interviews with employers, alumni, and project partners, and thematic workshops. The survey instruments, specifically designed by the Ministry of Labor and the Croatian Employment Service, focus on capturing key tasks, competencies, generic skills, psychomotor abilities, and specific workplace characteristics. These competencies are categorized into logical clusters, each forming a clearly defined competency set essential for occupational performance.

Identifying key tasks and competencies constitutes the central component of creating occupational standards. These identified competencies are then systematically integrated into occupational standards, subsequently informing the qualification standards [Makashina, I., Fayvisovich, A., & Truschenko, I. V., 2019] and corresponding educational programs.

2.2. Qualification Standards

The Croatian Parliament adopted the Croatian Qualifications Framework Act (HKO) on February 8, 2013, [Hrvatski kvalifikacijski okvir, 2017] to enhance transparency, improve educational quality, and align programs with labor market needs. This framework facilitates the recognition of formal, informal, and non-formal learning.

Qualification standards under HKO define a qualification's content, structure, level, and scope, ensuring alignment with the European Qualifications Framework. Accredited programs must meet these standards to guarantee quality and equip graduates with relevant skills. Standardization enhances transparency, minimizes conflicts of interest, and supports flexibility in education while establishing a framework for recognizing competencies and linking them to clearly defined learning outcomes [Divjak & Begićević Ređep, 2016].

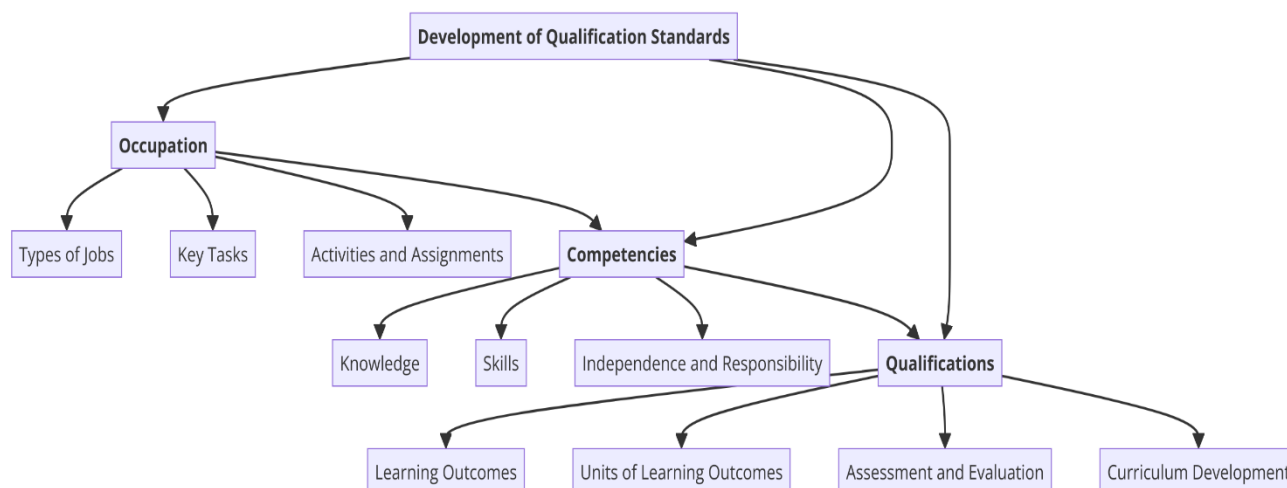


Figure 1: Development of Qualification Standards (Source: Created by the Authors according to European Higher Educational Area, 2017)

Figure 1 presents a diagram with a structured framework for the Development of Qualification Standards, illustrating the relationship between occupational roles, competencies, and qualifications within the maritime education [European Higher Educational Area, 2017] sector. It emphasizes the classification of occupations based on types of jobs, key tasks, and specific activities and assignments, which serve as a foundation for defining professional standards. The competency-based approach is highlighted through the integration of knowledge, skills, and independence and responsibility. Furthermore, the qualification segment includes learning outcomes, assessment, and curriculum development, which are crucial for standardizing maritime education [European Higher Educational Area, 2017].

In designing qualification standards [Divjak & Begičević Ređep, 2016], the methodology outlined by the Ministry of Science and Education through its Guidelines for Qualification Standards Development is employed. The HKO is supported by a registry that contains standards approved by sector councils comprising impartial industry experts, educational representatives, employers, labor market professionals, professional associations, and unions. This structured approach ensures consistency in the creation and evaluation of new qualification standards and establishes a quality assurance system.

2.3. Integrated Analysis of Maritime Occupations and Qualification Frameworks

A comprehensive analysis assessed the alignment between maritime education [European Higher Educational Area, 2017] and labor market demands in transport and logistics. Quantitative methods examined curricula, accreditation, and labor market data, while qualitative research, including stakeholder interviews and employer surveys, provided insights into industry expectations and emerging skills.

Competencies were systematically mapped to maritime occupations, categorized as technical, managerial, or regulatory. Particular focus was placed on emerging fields like LNG vessel management, maritime cybersecurity, and autonomous shipping, requiring specialized training beyond traditional education. This mapping process supported the development of competency matrices linked to educational content and occupational roles, using competency-based education principles. The resulting framework informs the creation and revision of qualification standards, ensuring alignment with regulatory requirements and industry needs at both national and international levels [Castro, G. C., 2024].

3. OVERVIEW OF THE DEVELOPMENT OF SHIP MANAGEMENT QUALIFICATION STANDARDS

Ship management is a complex discipline encompassing three key domains: fleet management, crew management, and HSEQ (Health, Safety, Environment, and Quality) management. This integrated approach ensures comprehensive vessel operations, addressing the technical, human, and regulatory aspects of the maritime industry.

3.1. Required Occupational Standards for the Development of Ship Management Qualifications

In order to develop a qualification in ship management, it is essential to identify the key tasks and competencies for all three defined occupational domains. The process of establishing occupational standards was conducted exclusively using the Croatian Qualifications Framework (HKO) [Hrvatski kvalifikacijski okvir, 2017] methodology.

The number of competencies associated with each defined occupation is presented in Table 1.

Occupations	Count of Competences
HSEQ Manager	52
Crew management	30
Fleet management	31
Grand Total	113

Table 1: Number of Competencies per Defined Occupation (Source: Created by the Authors)

HSEQ MANAGER

The Health, Safety, Environmental, and Quality (HSEQ) Manager oversees the development and implementation of organizational safety, health, environmental, and quality programs. Key responsibilities include maintaining compliance with laws and standards, updating policies, conducting risk assessments, and developing safety management frameworks. This role involves analyzing reports to identify weaknesses and implementing improvements across all HSEQ areas. To succeed, the HSEQ Manager must possess strong communication skills in Croatian and English, independent decision-making abilities, and analytical expertise. Specialized knowledge in HSEQ management, leadership, and resource coordination is essential. Continuous professional development and staying informed on industry trends are vital for ensuring ongoing improvements in safety and quality management.

CREW MANAGER

The Maritime Human Resources Manager oversees workforce planning, recruitment, deployment, leadership, and professional development in the maritime sector. Key responsibilities include managing seafarer assignments, hiring personnel for shipping companies, conducting labor market analyses, and ensuring compliance with employment regulations. This role also involves monitoring employee performance and verifying that crew members meet certification and contractual requirements. Success in this role requires proficiency in Croatian and English, a strong understanding of maritime labor laws, and expertise in recruitment, decision-making, and leadership. Ethical conduct, teamwork, and effective communication are essential. The ability to make independent decisions, particularly in unforeseen situations or emergencies, is crucial for ensuring smooth and compliant operations.

FLEET MANAGEMENT

A Fleet Manager is responsible for planning, maintaining, and operating vessels to ensure technical functionality, safety compliance, environmental protection, and economic efficiency. This role involves strategic planning in maritime transport, overseeing ship maintenance and dry-docking, and managing financial, human, and material resources. Proficiency in ship construction, onboard systems, and maintenance methods enables continuous oversight of technical processes. Ensuring fleet compliance with safety, environmental, and operational standards is fundamental. The role also includes managing cargo handling equipment, negotiating shipping contracts, and optimizing fleet efficiency. Success requires expertise in maritime regulations, strong teamwork, ethical decision-making, and proficiency in English. Continuous professional development is essential to keep pace with technological advancements, market trends, and evolving fleet management strategies.

3.2. Ship Management Qualification Standard

The primary goal of systematic maritime education is to develop competencies that enhance navigation safety, integrate modern business models, and adapt to evolving maritime technologies, supporting Croatia's economic development. Shipping remains a crucial driver of global trade, necessitating specialized training programs such as the Ship Management study program, designed to equip students with essential managerial skills. [Yıldırım, U., Şükür, F., & Inegöl, G. M., 2022]. This qualification aims to develop expertise in decision-making, organizational operations, and market dynamics, preparing students to address complex business challenges. Emphasizing strategic management, leadership, and adaptability, the program fosters skills crucial for competitive maritime operations. Work-based learning (WBL) plays a key role, enabling students to apply theoretical knowledge in practical settings, refining critical thinking, problem-solving, and decision-making abilities for real-world business environments.

The study program is designed as an advanced level of education, building upon the content of undergraduate studies. The primary purpose of the program is to prepare students for higher organizational roles and enable them to work successfully in various maritime institutions and companies whose activities are closely related to the maritime industry. Graduates of this program will have opportunities to pursue diverse career paths, ranging from import/export business, ship management, freight forwarding, logistics, port management, maritime trade and finance, to maritime regulation and policy.

Learning Outcome Set	Individual Learning Outcomes
International Maritime Safety System	Formulate and present the structure and operational framework of the IMO.
	Classify the legal framework related to navigation safety and marine environmental protection.
	Present the rights and obligations of Recognized Organizations (ROs).
	Present the rights and obligations of the Flag State Administration (FS).
	Identify the role of Port State Control (PSC) inspections and present inspection procedures.
	Assess the impact of maritime safety measures on the economic performance of shipping companies and shipowners.
Ship Technical Maintenance Organization	Develop ship inspection and supervision procedures.
	Create maintenance plans and procurement strategies for spare parts and consumable materials.
	Manage failure diagnostics.
	Interpret the functionalities of software tools for ship maintenance.
	Develop maintenance and spare parts procurement budgets.

Budgeting, Cost Management, and Procurement	Evaluate reports on the condition of ships and equipment.
	Generate reports on the condition of monitored vessels.
Technical Supervision and Ship Certification	Analyze and interpret international regulations relevant to ship certification.
	Interpret and analyze classification society technical rules.
	Evaluate methods and procedures for ship construction and dry-docking supervision.
	Assess ship inspection methods and types, including associated equipment.
	Identify administrative tasks related to inspections, supervision, and ship certification issuance.
	Analyze and interpret specific requirements of states and institutions regarding ship certification.
Marine Insurance and Premium Coverage	Interpret international and national legal sources of marine insurance.
	Explain fundamental concepts of marine insurance.
	Assess the significance and characteristics of Institute Clauses for ship insurance.
	Analyze documentation and procedures for filing damage claims with insurers.
Protection & Indemnity (P&I) Insurance	Explain the structure and function of P&I Clubs.
	Analyze and interpret types of damages covered by P&I insurance.
	Describe the damage claim process within a P&I Club.
	Interpret the significance of P&I Club mutual associations.
International Commercial Law	Explain the principles of International Commercial Law.
	Analyze and interpret sources of International Commercial Law.
	Examine the structure of INCOTERMS and apply the appropriate terms depending on the sales contract.
	Interpret the use of international documentary credit.
Contracts in Maritime Shipping	Analyze and compare international conventions regulating the carriage of goods by sea.
	Evaluate the fundamental characteristics of different types of contracts.
	Interpret and analyze the interrelation between shipping contracts and other transport documents.
	Propose the most suitable type of contract for maritime freight transport services.
	Analyze and interpret other contractual agreements in maritime shipping.
	Assess the rights, obligations, and responsibilities of contracting parties.
Shipping Company Organization and Management	Interpret advanced principles of shipping company management.
	Compare and analyze organizational management models.
	Explain the roles and functions of departments and services within a shipping company, including outsourcing utilization.
	Explain and compare elements of human resource management within a shipping company.
	Identify, explain, and differentiate factors influencing a shipowner's business planning.
	Develop and explain methodologies for making optimal organizational and business decisions.
Business Processes in Shipping	Organize the management of a ship and fleet
	Organize fleet operations.
	Explain the methodology and compare business communication procedures within and outside the shipping company.
	Identify, explain, and differentiate factors influencing a shipowner's business planning.
	Plan, organize, execute, and control various tasks of the shipping operator.

International Trade and Maritime Shipping	Categorize the global maritime market
	Compare supply and demand in the maritime shipping market
	Evaluate the global merchant fleet based on various criteria.
	Analyze the maritime shipping market
	Analyze the formation of freight rates in maritime shipping
	Evaluate the importance of maritime shipping in relation to the global economy
Market Strategies of Shipping Companies	Analyze the functioning of the maritime market
	Explain the correlation between supply and demand and the freight market
	Relate the correlation of high and low markets to the shipbuilding, second-hand, and demolition ship markets.
	Explain different commercial strategies for ship employment
	Analyze contracting policies and explain business relationships between shipowners, operators, charterers, and shippers
Stakeholders in the Shipping Industry	Identify and interpret the role of land-based and maritime stakeholders in the shipping industry
	Explain the interaction between various stakeholders and institutions in the shipping industry
	Analyze regulatory bodies and international organizations in the global maritime industry
	Present the regulatory system in shipping
	Examine the importance of integrated port information interfaces and electronic commerce
	Explain business ethics and corporate social responsibility, and identify potential fraud in maritime affairs along with global maritime industry regulatory measures against fraud and corruption
Human Resource Management	Interpret the role and significance of human capital in the shipping industry
	Analyze and describe job positions, duties, and tasks in shipping companies
	Select sources and design methods for recruiting and selecting personnel for shipboard and shore-based positions
	Conduct tests and interviews related to candidate selection for employment
	Describe the phases of onboarding employees on ships and in shipping companies
	Compare and apply techniques for evaluating employee
Seafarer Management in a Shipping Company	Understand international and national requirements for the qualification of seafarers on ships
	Interpret the requirements of the Maritime Labour Convention (MLC) concerning seafarers' employment
	Present the requirements of the STCW Convention, along with additional requirements imposed by shipowners and national administrations regarding seafarer training
	Understand the organization of seafarer recruitment and employment
Financial Management in Shipping	Explain and apply the principles of financial management in shipping
	Explain the principles of corporate financial governance and reporting, and make informed judgments on operations, investment, and financing in shipping
	Analyze costs, revenues, and cash flow in a shipping company
	Understand and explain the basics of investment in shipping
	Analyze the capital market, explain bank lending policies and bank loans, and assess credit risk
Business Risk Management in Shipping	Critically assess the importance of the risk management concept in shipping
	Establish a methodology for assessing business risks in shipping

	Analyze business risks in ship space markets
	Forecast potential risks in the purchase of new and second-hand ships
	Forecast trends in business risk management in shipping
Communication Skills and Multiculturalism	Critically evaluate the role and importance of language and different communication styles on board and in maritime business
	Critically assess the impact of multiculturalism on board as a multinational community
	Apply models of multicultural research and studies in the organization of maritime business and the employment of seafarers
	Critically evaluate the advantages and disadvantages of quantitative and qualitative methods of cultural research in maritime affairs
Business Correspondence	Differentiate and apply terminology from maritime shipping, shipping and port economics, agency operations, and maritime property law in business communication in English
	Interpret and communicate information in written and spoken English in the fields of maritime shipping, shipping and port economics, agency operations, and maritime property law
	Express oneself verbally and discuss professional topics in English
	Use language skills in spoken and written English communication among business entities in the maritime public and private sectors
Maritime Logistics	Explain the importance of supply chain management in a business environment
	Identify different types of supply chains and the stakeholders involved in the entire supply process
	Explain the importance of integration and coordination among supply chain stakeholders and propose ways to improve business processes
	Consider the role of shipping and ports in the supply chain
	Use statistical methods to forecast supply and demand in the supply chain
	Combine technical components and operational concepts into cargo transport systems based on maritime transport
	Assess transport and storage costs to ensure appropriate pricing of logistics services
	Evaluate trends and challenges in the maritime freight industry

Table 2: Mandatory Learning Outcomes for the Ship Management Qualification (Source: Created by the Authors)

Table 2 presents an overview of the mandatory learning outcome sets, along with their corresponding individual learning outcomes. The qualification for Master of Science in Ship Management Engineering includes 22 mandatory learning outcome sets and 10 elective learning outcome sets.

4. DISCUSSION

The evolving maritime industry requires continuous adaptation of educational frameworks to address its increasing complexity. This discussion synthesizes key findings on occupational and qualification standards [Medar, A., Tanović, L., & Boban, L., 2023], emphasizing the alignment of maritime education [European Higher Educational Area, 2017] with industry needs. The analysis highlights the importance of closing competency gaps, adopting innovative training methods, and harmonizing education with global standards. By examining structural challenges, competency-based learning, and industry collaboration, this chapter outlines strategies for improving maritime professional education.

4.1. Structural and Regulatory Challenges in Maritime Education

Maritime education institutions frequently encounter delays due to complex and prolonged accreditation processes, creating significant barriers to the timely modernization of curricula. Regulatory disparities between international frameworks such as the Standards of Training, Certification, and Watchkeeping for Seafarers (STCW), the European Qualifications Framework (EQF), and national qualification frameworks generate administrative complexities, restricting seamless cross-border qualification recognition and mobility. Moreover, inadequate faculty training on contemporary industry practices and emerging technologies exacerbate the difficulty in integrating new pedagogical approaches such as competency-based learning into traditional educational structures. [Klöpotek, N., Dmowski, P., & Szkiel, A., 2023]. Institutional rigidity further slows curriculum updates, indicating an urgent need for more flexible and responsive accreditation processes.

4.2. Competency-Based Education and Integration of Practical Training

The shift towards competency-based education represents a transformative step in maritime studies, emphasizing specific, measurable learning outcomes directly aligned with occupational requirements. By structuring maritime programs around clearly defined competencies, institutions ensure graduates possess practical skills immediately applicable to the workplace, thus enhancing employability and industry readiness.

Practical training constitutes an essential component of competency-based education. Structured internships, simulator-based training, and real-world industry engagements significantly improve graduates' preparedness. Simulators offer controlled environments where students can safely develop critical skills in navigation, engineering operations, and safety management. These controlled learning scenarios reduce risk while promoting experiential learning. Structured internship programs facilitate direct industry exposure, allowing students to gain valuable practical skills and real-life insights, thus addressing existing competency gaps between theoretical knowledge and practical application.

4.3. Enhancing Industry-Academia Partnerships and Policy Harmonization

Effective harmonization of national maritime education policies with broader European frameworks is pivotal to fostering international recognition and enhancing labor market mobility. Aligning domestic qualification standards with the European Qualifications Framework (EQF) and the Qualifications Framework of the European Higher Education Area (QF-EHEA) ensures consistent competency criteria across borders, simplifying workforce mobility and fostering greater professional development opportunities.

Industry-academia partnerships further facilitate the alignment of maritime education [Bokau, J. R. K., & Sulistiana, O., 2024] programs with evolving labor market needs. Regular collaboration, including internships, joint research projects, and curricular co-design, enables educational institutions to swiftly respond to technological innovations [Frey & Osborne, 2013], regulatory updates, and industry trends. Establishing formalized partnerships and shared research initiatives ensures continual adaptation and mutual benefit, ultimately producing graduates equipped with relevant, industry-aligned competencies and practical experience. Addressing structural challenges through policy alignment, embracing competency-based educational models, and reinforcing industry collaboration are key strategies for ensuring maritime education remains responsive and competitive.

5. CONCLUSION

The development of occupational and qualification standards in maritime education represents a significant step toward ensuring that graduates are equipped with the necessary competencies to meet industry

demands. This study has provided a structured approach to aligning educational programs with labor market needs, highlighting the importance of competency-based education, practical training integration, and harmonization with international qualification frameworks.

By establishing clear competency matrices and qualification frameworks, maritime institutions can create a more structured and industry-relevant educational pathway that enhances both student employability and workforce adaptability. Standardizing maritime education is essential for maintaining global competitiveness in an industry that is constantly evolving. With advancements in automation, digitalization, and sustainability initiatives, maritime professionals must possess specialized skills that go beyond traditional seafaring roles. Aligning national curricula with European and global standards, maritime institutions can ensure that their graduates are prepared to work across international markets while maintaining compliance with regulatory requirements. Strengthening partnerships between universities and shipping companies, port authorities, and regulatory agencies will ensure that academic programs remain responsive to the evolving needs of the maritime sector. Policymakers must play an active role in facilitating these collaborations by supporting accreditation reforms, funding workforce development initiatives, and promoting the integration of modern training methodologies into maritime education.

Moving forward, maritime education must remain flexible and adaptable to industry trends. Continuous curriculum modernization, expansion of competency-based training models, and greater investment in practical learning opportunities will be critical in maintaining the relevance and quality of maritime education. By fostering a culture of continuous improvement and cooperation, the maritime sector can ensure that its workforce remains skilled, competitive, and prepared to navigate the challenges of an increasingly complex and technology-driven industry.

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Challenges for Port Infrastructure and the Future Hinterland Distribution of Green Ammonia in Germany

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Ammonia is emerging as a central component in the transition towards sustainable energy systems. It is expected to play a significant role in the future energy landscape, offering a versatile solution for energy storage and transport. This study explores the challenges and opportunities associated with port infrastructure and the future hinterland distribution of green ammonia, focusing on infrastructure, logistics and policy frameworks. A systematic review of existing infrastructure, including ocean-going vessels, barges and tank cars was conducted. Scenario-based estimations were used to determine the projected quantity of transport units required for effective hinterland distribution. The analysis highlights following key factors a successful green ammonia economy in Germany:

- The German federal government's plans indicate a significant increase in ammonia demand by 2035.
- Planned capacity expansions at key import ports aim to accommodate ~24 million metric tons per annum.
- Current world fleet of ocean-going vessels to be expanded by up to 26 vessels required for supplying only Germany.
- Distribution scenarios indicate a demand for 320 full trips with barges per year and 3,724 additional tank cars.

Germany faces critical challenges in scaling its port infrastructure and ammonia distribution network to meet future demand. Additionally, Germany is largely dependent on its neighboring countries for importing the required quantities of ammonia. While import port expansions are underway, hinterland transport capacity remains a bottleneck. The increase in traffic volumes tightens the existing shortage of skilled labor, while production capacities for ships and other transport equipment remain limited. The planned hydrogen core network might be insufficient and ammonia pipelines should be reconsidered. Germany must approach all challenges associated with the hydrogen economy, including infrastructure integration, regulatory frameworks and market readiness. These issues are crucial for the country's transition to green ammonia. Further research should focus on policy incentives and technological advancements.

KEYWORDS

Green ammonia; Energy transition; Hinterland distribution; Port infrastructure

1. INTRODUCTION

Ammonia (NH_3) is a colorless, pungent gas composed of nitrogen and hydrogen. Toxic at high concentrations, it poses risks to humans and the environment. At room temperature, it is gaseous but can be liquefied for easier transport. Ammonia forms explosive mixtures useful in combustion engines, and because it contains no carbon, its combustion produces no CO_2 , helping to mitigate climate change. However, engines and industrial facilities must be modified for its safe and efficient use. This requires investments in research and development as well as in the retrofitting of existing infrastructure. The production of ammonia is a significant industrial process that plays a central role in the global chemical industry. Ammonia is primarily synthesized from nitrogen and hydrogen using energy. There are various methods for ammonia production, with the Haber-Bosch process being the dominant industrial method.

Ammonia production is a key industrial process, primarily using the Haber-Bosch method to synthesize ammonia from nitrogen and hydrogen. Sustainable alternatives, such as blue ammonia (produced from fossil fuels with CO_2 capture) and green ammonia (derived from renewable energy via electrolysis), are gaining importance. In 2019, 75% of the 186 million tons of ammonia consumed globally went to fertilizer production. Future applications include its role as a non-fossil energy carrier (Huddleston, 2021).

2. OBJECTIVES OF THIS STUDY, METHODOLOGY AND LITERATURE REVIEW

This study aims to present a potential model for a future strategy for the import and logistics of ammonia in German ports, focusing on the necessary means of transport for both import and distribution. It combines theoretical insights, independent research, and expert interviews, analyzing data from port reports, legal documents, and project announcements to provide practical recommendations for ammonia logistics strategies.

The study focuses on German ports, evaluating their capacities, infrastructure, and logistics for ammonia imports, including comparisons with Belgian and Dutch ports. Data sources include international port reports and best-practice logistics studies. The analysis is limited to green and blue ammonia imports for the energy sector, excluding ammonia used for fertilizers or other applications.

The use of ammonia as a hydrogen carrier is discussed, for instance, in (Royal Society, 2020) and (German Environment Agency, 2022). Technical solutions for ammonia transport, storage, and direct use already exist, and ongoing research addresses further improvements (Weltenergierat e.V., 2023), (Agustin Valera-Medina, 2021). Despite the anticipated hydrogen demand in Germany, studies addressing infrastructure and transport requirements remain lacking. This study aims to fill that gap.

3. FUTURE HYDROGEN/AMMONIA DEMAND IN GERMANY IN 2035

To assess port infrastructure capacities, future ammonia demand for 2035 must first be forecasted based on market analyses, policies, and technological trends. A scenario is developed to estimate ammonia imports via seaborne shipping, as industry will be the primary consumer. While Germany will produce green hydrogen and import some via pipelines, domestic supply will be insufficient, necessitating imports from distant regions in ammonia form. Ports' suitability for handling these imports will be analyzed, along with potential international suppliers. The forecast, set for 2035, aligns with Germany's climate goals, targeting a 55% emissions reduction by 2030 and climate neutrality by 2045, with an estimated hydrogen demand of 83 TWh. Germany aims to establish 10 GW of domestic electrolysis capacity by 2030, producing about 850,000 tons (28.3 TWh) of hydrogen, covering one-third of demand (Deutsche Akademie der Technikwissenschaften e.V., 2024). The National Hydrogen Strategy estimates 50–70% of hydrogen and derivatives will be imported (BMWK, 2023). With pipeline imports from North Africa, Spain, and Eastern/Northern Europe expected to cover another

third, the remaining demand will be met via maritime ammonia imports. This study assumes all seaborne hydrogen imports will be in ammonia form, requiring reconversion in Germany. Including cracking losses, 26.75 TWh (5.7 million tons) of ammonia is expected to be imported by sea in the reference year 2035.

4. AMMONIA INFRASTRUCTURE AND TRANSPORT

Airports and roads are irrelevant for ammonia transport and are not considered in this study. Railways provide an energy-efficient alternative for freight transport, while waterways (rivers, canals, and coastal routes) support goods movement with infrastructure like locks and ports. Ports and terminals require specialized facilities for safely handling ammonia transfers between ships, rail tank cars, road tankers, and storage, featuring leak detection, emergency shut-offs, and safety zones (Weltenergierat e.V., 2023).

Ammonia's toxicity and flammability require strict safety standards, including inspections, maintenance, emergency plans, and staff training (Fertilizer Industrial Services, 2024). Ammonia terminals are specialized for import or export at the sea-land interface, with dual-purpose facilities being rare (IRENA, 2022).

Ammonia terminals consist of land-based and offshore components. Land-based facilities include large storage tanks, loading stations, export pump stations for controlled transfer, and evaporators/cooling systems for safe ammonia processing. Control buildings manage operations, while additional infrastructure supports maintenance. Offshore facilities feature docking stations with loading/unloading systems, temporary storage tanks, safety systems (flare disposal, emergency handling), and power supply via generators and transformers (Fertilizer Industrial Services, 2024). Modern terminals unload ammonia tank cars at up to 130 tons per hour, while loading from storage tanks or ships reaches 600–1,200 tons per hour (Freeport of Ventspils authority, 2024). Ship unloading uses onboard pumps to transfer ammonia to storage tanks or tank cars (ROSTOCK PORT GmbH, 2017). Ship pumping capacity limits unloading rates, with 30,000 tons discharged in 24 hours. Ammonia is loaded in a cooled liquid state to reduce energy use. Tank car loading is constrained by track length, loading arms, and staffing, with more arms allowing simultaneous loading.

4.1. Rail

Rail tank cars are another important means of transporting ammonia, particularly for long-distance land transport. These cars are pressure-resistant and specifically designed for transporting liquid ammonia. The capacity of a single tank car typically ranges between 50 and 110 cubic meters. Rail transport offers a safe and cost-effective way to move large quantities of ammonia. In 2008, more than 1,500,000 tons of ammonia were transported by rail in Western Europe (European Fertilizer Manufacturers Association, 2007). A survey found that approximately 3,000 pressurized tank cars are available for ammonia transport in Europe. These are provided by six different rail vehicle leasing companies. The average age of this fleet is 20 years, while the general lifespan of the cars ranges between 40 and 50 years. Currently, the existing equipment is fully utilized. For future transportation of green ammonia within Europe, new rail tank cars will be required.

4.2. Inland Waterway

Inland waterway vessels transport ammonia on rivers and canals. These ships have smaller capacities than seagoing vessels, typically ranging from 400 to 2,500 tons, making them suitable for regional transport. They offer an environmentally friendly alternative to road transport and can efficiently move large quantities of ammonia (Agustin Valera-Medina, 2021). Transporting ammonia by inland waterway is the most cost-effective method for freight movement between locations along navigable waterways. Currently, 10 to 12 inland vessels in Europe are certified for ammonia transport. However, it is estimated that only three of these vessels regularly carry ammonia. This highlights that ammonia transport by inland waterways in Europe remains a niche service.

4.3. Seaborne Transport

Currently, 25 to 30 million tons of ammonia are transported annually by road, rail, ship, or pipeline, with 18 to 20 million tons moved by sea transport (International Renewable Energy Agency, 2022). LPG tankers transport ammonia long distances using pressure-resistant, insulated tanks to maintain -33°C . Capacities range up to $60,000\text{ m}^3$, with $20,000\text{--}60,000\text{ m}^3$ ships commonly used for ammonia. $20,000\text{--}30,000\text{ m}^3$ vessels optimize port operations, while smaller ships ($<20,000\text{ m}^3$) handle regional transport. Larger vessels $>60,000\text{ m}^3$ mainly carry LPG. Advanced safety systems prevent leaks and accidents (Agustin Valera-Medina, 2021).

According to the Equasis database, 2,310 gas tankers are in operation. Of these, 625 LNG and 526 LPG tankers have a capacity of $\geq 20,000\text{ GT}$ ($\sim 12,000$ tons of ammonia). The average LPG tanker age is 8.6 years, with the oldest at 25 years, the typical lifespan. 34 vessels exceed 20 years, potentially operating up to 30 years if demand rises. A study of 421 LPG ships found 110 certified for ammonia transport, based on Vessel Particulars (FORM C) analysis. Figure 1 illustrates this distribution.

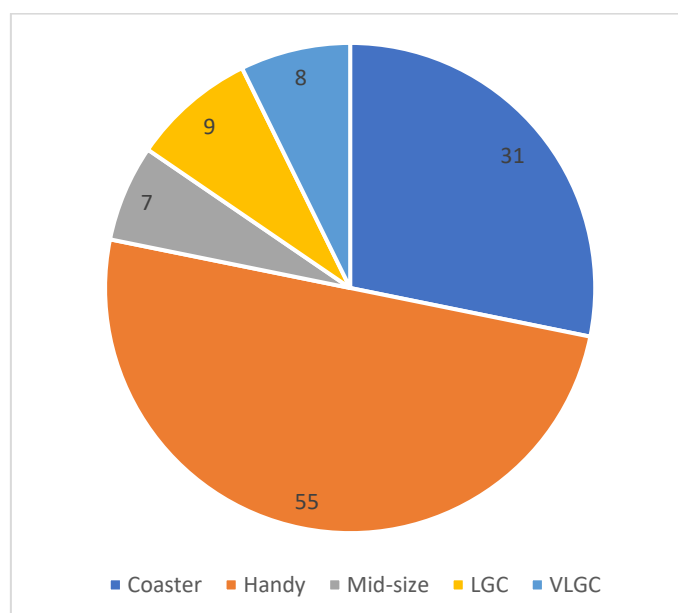


Figure 1. Ammonia ships by capacity class, (Source: own representation)

This analysis confirms that the majority of the available ships are smaller vessel types, such as coasters and handy size tankers. These ships are not efficient enough for transporting large amounts of energy in the form of ammonia across the world's oceans.

5. FUTURE (GREEN) AMMONIA SUPPLIER

The identification of key potential suppliers for green hydrogen in the form of liquefied hydrogen and ammonia is crucial. For the source analysis, certain countries are excluded based on qualified assumptions. Japan, China, South Korea, and India are considered major importers of green and blue ammonia and are therefore not regarded as suppliers in this study. This leaves the classification of potential suppliers via maritime transport. The final assessment is based on several critical criteria. One key factor is the planned production volume, which is derived from press releases, project updates, and the DNV study "Availability of Green and Blue Ammonia in 2030 to 2050" (DNV AS, 2024). The timeline for the first ammonia delivery also plays a crucial role and is determined by current press releases and updates. Another important criterion is the production

costs, which are based on estimates from the Fraunhofer IEE in the "Global Power-to-X Atlas of Potentials" (Fraunhofer IEE; University of Kassel, 2024). The potential production volume is also estimated using the "Global Power-to-X Atlas of Potentials" by Fraunhofer IEE. Additionally, proximity to Germany and the associated transport costs are considered. The socioeconomic potential of a country also plays a role, based on estimates from Fraunhofer IEE. In the long term, green ammonia is regarded as a better alternative to blue ammonia, with blue ammonia serving as a transitional solution. After analyzing the data, supplier alternatives are prioritized through a qualitative overall assessment. The goal of this evaluation is to narrow down the potential suppliers and focus on the selected alternatives. These alternatives can then be used to assess the available capacities in maritime transport. In summary, the following supplier ranking for Germany in 2035 is proposed for future demand and supply analysis via long-distance seaborne transport:

- 1) Canada
- 2) Australia
- 3) Chile
- 4) Brazil
- 5) Egypt
- 6) Morocco, Namibia, Argentina, Saudi Arabia, Oman, UAE

In the following analysis, only the first five countries will be considered to maintain a focused approach and because these five countries are sufficient to avoid excessive dependence on individual partners. It is worth noting that the United States has significant potential for blue ammonia production. However, this ranking focuses on the production of green ammonia. The relatively large-scale production of blue ammonia could serve as a promising transitional solution to meet the demand for clean ammonia. For simplification, a representative export port is selected for each supply country as the basis for later calculations.

Country	Port
Canada	Belledune
Australia	Newcastle
Chile	Mejillones
Brazil	Pecem
Egypt	Port Said

Table 1. Assignment of Selected Ports per Country of Origin, (Source: own representation)

6. CURRENT AND FUTURE (PORT) INFRASTRUCTURE IN GERMANY

The current and newly planned ammonia terminals for Germany, the Netherlands, and Belgium were analyzed based on qualitative, quantitative, and legislative requirement criteria.

Country	Port	Trade	Capacity [t]	Storage facilities [t]
DE	Brunsbüttel	Export	720.000	34.000
DE	Rostock	Import	1.000.000	35.000
NL	Rotterdam	Im- & Export	400.000 (Import)	30.000
NL	Terneuzen	Export	n/a	2.000
NL	Sluiskil	Export	n/a	25.000
BE	Antwerp	Import	n/a	45.000
BE	Willebroek	Import	n/a	2.000

Table 2. Existing ammonia terminals in DE, NL, and BE, own representation based on DNV (Source: DNV Alternative Fuels Insight and Argusmedia)

6.1. Research of Existing and major Future Capacities and Infrastructure (Germany, Netherlands, Belgium)

Country	Port	Operator	Import (t.p.a)
DE	Rostock	Yara GmbH & Co. KG	1.000.000 (Yara Deutschland, 2023)
	Brunsbüttel	Yara GmbH & Co. KG, RWE	2.000.000 (RWE AG, 2023)
	Wilhelmshaven	Uniper SE	2.600.000 (Energie & Management GmbH, 2023)
	Hamburg	Mabanaft GmbH & Co. KG	600.000 (Augsten, 2024)
NL	Rotterdam	OCI N.V.	3.000.000 (Port of Rotterdam, 2022)
	Rotterdam	Chane Terminals B.V.	5.000.000 (Chane Terminals B.V., 2024)
	Rotterdam	N.V. Gasunie, Vopak, HES International B.V	1.200.000 (Gasunie, 2024)
	Vlissingen	Uniper SE, Vesta Terminals B.V.	2.000.000 (Uniper SE, 2022)
BE	Antwerp	Fluxys Belgium SA, Advorio N.V.	7.000.000 (Argus Media Group, 2023)

Table 3. Ammonia handling capacities after the construction, expansion, and upgrade of terminals in Germany and major ports Belgium, and the Netherlands from 2035 onwards, own representation.

6.2. Qualitative, Quantitative and Legislative Requirements

The technical condition and modernity of facilities must meet high standards to ensure efficiency and compliance. Strict safety standards and regular maintenance practices are essential for secure operations. A skilled workforce is crucial to maintaining safety and operational reliability. Additionally, the level of urbanization around the port can influence infrastructure, logistics, and environmental considerations.

A port's capability depends on its handling capacity and its storage capacity. Sufficient open space is necessary for operations and future expansions. Nautical conditions, including draft depth and navigational

accessibility, play a critical role in accommodating large vessels. Additionally, strong landside connectivity ensures seamless transport of goods via road, rail, or inland waterways.

Port operations must comply with national regulations, ensuring adherence to domestic laws, safety standards, and environmental policies. Simultaneously, compliance with international regulations, such as IMO conventions and global trade agreements, is essential for seamless and legally sound maritime operations.

Port	Handling	Storage	Open spaces	Nautical conditions	hinterland connectivity
Hamburg	--	--	o	o	++
Rostock	++	+	+	-	--
Brunsbüttel	o	o	+	+	-
Wilhelmshaven	--	--	o	++	o
Rotterdam	++	++	++	++	++
Antwerp	++	++	+	++	++

Table 4: Summary overview of the current conditions in the considered ports, (Source: own representation).

In summary, Rotterdam and Antwerp offer the best combinations of land connections, nautical conditions, and opportunities for further transport by inland vessels. Hamburg is also very well-suited, especially due to its connection to the German inland waterway network. Brunsbüttel has advantages due to the Kiel Canal, but it is limited in other areas. Rostock and Wilhelmshaven are less ideal for inland waterway transport as they lack direct connections to major inland waterways.

7. CHALLENGES FOR PORTS AND HINTERLAND DISTRIBUTION

Based on the planned ammonia import capacities for 2035 in the German ports, a deficit of at least 100.000 tons per year is projected. Since it is neither realistic nor sensible to plan the utilization of terminals at more than 100%, the port of Rotterdam is also considered with a proportional amount. Rotterdam is particularly suitable as it can supply large parts of Western Germany effectively. From the values determined so far, theoretical ideal values for the number of shipments are derived, requiring 156 or 117 necessary trips with 60,000 or 80,000 cubic meter ammonia tankers per year, respectively.

Demand (Ammonia) for DE in 2035		5.700.000 t	
		Assumed vessel size	Assumed vessel size
Vessel capacity	in cbm	60.000	80.000
	in t	37.080	49.440

Table 5. Basic Assumptions for the Circular Run Calculation, (Source: own representation)

Importing Port	Share	Quantity in t	# port calls (vessel size 60.000 cbm)	# port calls (vessel size 80.000 cbm)
Rostock	9%	484.500	14	10
Brunsbüttel	26%	1.482.000	40	30
Wilhelmshaven	37%	2.109.000	57	43
Hamburg	9%	484.500	14	10
Rotterdam	20%	1.140.000	31	24
Sum p.a.	100%	5.700.000	156	117

Table 6. Theoretical Ideal Load Trips of Import Ports, (Source: own representation)

Exporting Port	Share	Quantity in t	# port calls (vessel size 60.000 cbm)	# port calls (vessel size 80.000 cbm)
Belledune	41%	2.309.070	63	47
Newcastle	20%	1.148.550	31	24
Mejillones	15%	839.040	23	17
Pecem	15%	839.040	23	17
Port Said	10%	564.300	16	12
Sum p.a.	100%	5.700.000	156	117

Table 7: Theoretical Ideal Load Trips of Export Ports, (Source: own representation)

To achieve an appropriate distribution between all routes, the respective percentage shares were multiplied together. As a result, the required number of shipments increases by 10 for each case. This means that, on average, the ships have a slightly lower utilization. However, this assumption simplifies the calculation and is also more likely in reality. By combining all export ports with all import ports, high flexibility is achieved in the supply chain.

To calculate gross voyage times, factors such as port times, loading/unloading rates, and maneuvering were considered. While a theoretical unloading rate of 30,000 tons/day is possible, practical constraints reduce this to 20,000 tons/day. Export ports, benefiting from efficiency improvements, are assumed to load at 25,000 tons/day. Docking and undocking add 5–6 hours per stop. With 60,000 m³ tankers, 6,926 operating days/year are needed (5,451 days with 80,000 m³ tankers). Since continuous operation is unrealistic, a 25% reduction accounts for delays, maintenance, and waiting times, increasing the required operating days to 9,235 and 7,268, respectively. To meet Germany's 2035 green ammonia demand, a fleet of 26 (60,000 m³) or 20 (80,000 m³) tankers will be required.

If half of the 5.7 million tons of ammonia is cracked at the port, 2.85 million tons must be transported inland. Using 2,500-ton inland vessels and 55-ton rail tank cars, with a 72% rail / 28% vessel split, 800,000 tons will go by water and 2.05 million tons by rail.

Germany will need 320 inland vessel trips and 37,273 rail tank car trips, equating to 1,862 full train trips per year (~5 per day), straining the rail network. With each rail tank car making 10 trips annually, 3,724 new cars must be built by 2035, costing €670.32 million (€180,000 per car). However, only two European factories produce these cars, and additional locomotives and operators will also be needed.

8. CONCLUSION

The expansion goals for import terminals are highly ambitious. German ports face significant infrastructure and logistics challenges for ammonia imports, as capacities will barely meet demand by 2035. However, new ship orders are insufficient, and throughput calculations reveal major discrepancies. Shipping space also competes with the global fertilizer trade and the expanding LPG market. After 2035, existing infrastructure will struggle with rising demand, and it is uncertain if planned capacities will be realized in time. Germany relies on the Netherlands and Belgium to meet its ammonia needs. Long-term, an ammonia pipeline is the only viable solution, as transporting large volumes via inland vessels or rail is inefficient. However, pipeline construction requires secure volumes to justify investment, and the gas industry cannot operate this infrastructure with natural gas. German ports must prepare for increased imports by 2035, reserving space accordingly. Pipelines should be developed along main corridors from seaports to major consumers or cracking facilities. Growing ammonia imports will increase the demand for qualified personnel. To mitigate labor shortages and improve efficiency, supply and service chains must be further automated. Additionally, market design mechanisms, trading platforms, standards, and certification are critical to establishing a functional hydrogen and ammonia market. A major challenge remains the long approval processes for hydrogen and ammonia infrastructure. Administrative delays could slow down industry growth and hinder infrastructure expansion. Given demand uncertainties, there is a risk that growth may fall short of expectations or occur later than anticipated. Ensuring a reliable supply chain and regulatory framework is essential for ammonia's role in Germany's energy transition. Strategic planning, infrastructure investment, and automation will be key to overcoming these challenges and securing future supply.

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Situational Awareness in High-Risk Navigational Areas: Case Study of an Aframax Tanker Collision and Grounding in the Singapore Strait

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Located at the crossroads of the world's two largest trade routes, the Straits of Singapore is a major maritime hub connecting the East to the West. Its efficient port infrastructure makes Singapore one of the busiest ports in the world. However, high traffic density and limited berths and anchorages pose significant challenges to shipping, especially for large vessels. Many ships anchor off port limits (OPL) to save costs, often under commercial pressure, despite the risks involved. This paper analyzes a real-world incident in which an Aframax tanker suffered catastrophic hull damage during an OPL anchoring maneuver east of P. Mungging Lighthouse. The case study highlights the critical importance of situational awareness, adherence to safety procedures, and effective bridge resource management in high-risk navigational conditions. The analysis identifies key contributing factors, including violations of company policies, inadequate planning, and poor communication. Recommendations are provided to improve decision-making processes, enhance contingency planning, and ensure safer operating practices in similar scenarios. This study serves as a cautionary example for maritime professionals and emphasizes lessons learned to mitigate risks associated with OPL anchoring practices.

KEYWORDS

Handling large tanker; Situational Awareness (SA); Off Port Limits (OPL); Collision and Grounding.

1. INTRODUCTION

The Straits of Malacca and Singapore form one of the most important shipping passage in global trade and serve as the shortest shipping route between the Indian and Pacific Oceans. This strategically important waterway connects the economies of East Asia and Europe, with Singapore acting as a central maritime hub. Ships passing through the strait often stop in Singapore for bunkering, repairs, crew changes and spare parts. The extensive infrastructure of the Port of Singapore supports these activities, handling all types of vessels and reinforcing the city-state's status as Southeast Asia's leading maritime economy (Qu and Meng 2012b).

The safety of shipping in the Straits has gradually improved since the introduction of the Traffic Separation Scheme (TSS) in 1981 and speed restrictions at critical points. Further improvements were introduced in 1988 with the mandatory ship reporting system (STRAITREP) of the International Maritime Organization (IMO). The system's Vessel Traffic Service (VTS), which is divided into nine sectors with dedicated VHF channels, provides real-time navigational data to ships. Within Singapore's port boundaries, Maritime and Port Authority (MPA) regulations require all ships entering, leaving or transiting fairways and anchorages (Figure 1) to be piloted (International Maritime Organization (IMO) 1998; Weng et al. 2012; Maritime and Port Authority of Singapore (MPA) 2024).

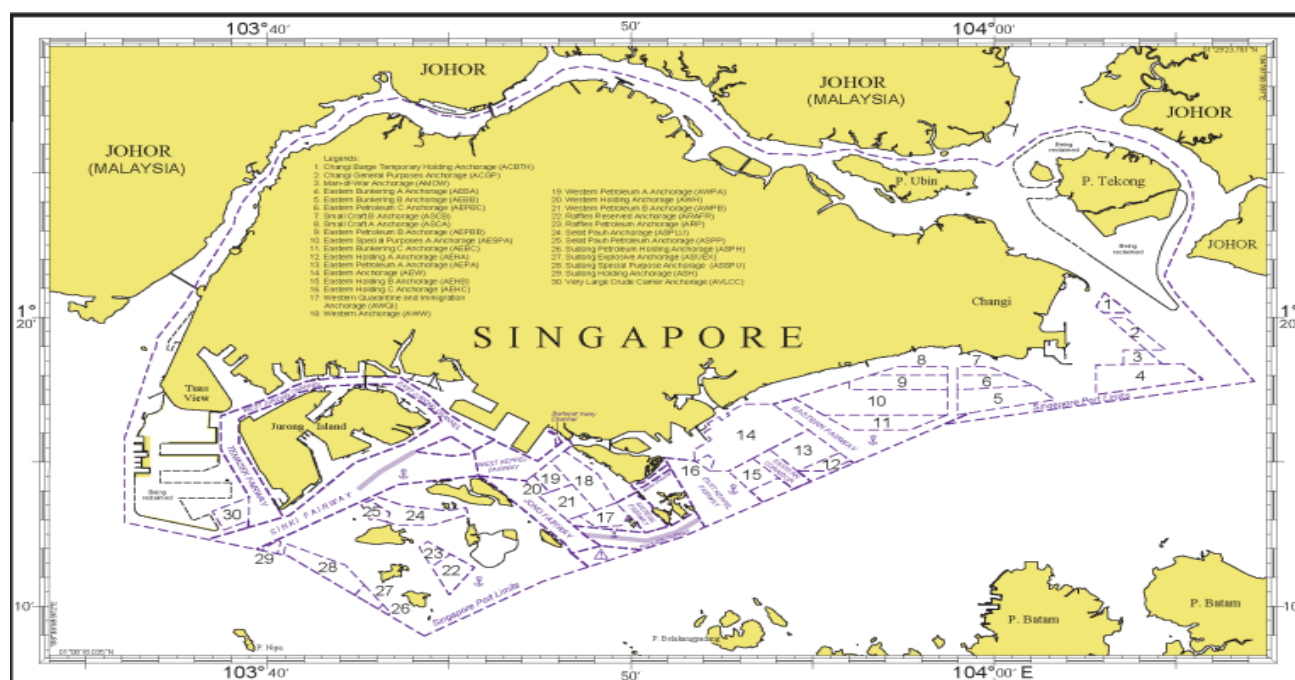


Figure 1. Port of Singapore – Anchorages and Fairways in the Port (Qu et al. 2011).

Despite these safety precautions, the high traffic density in and around Singapore poses considerable risks. Narrow, shallow sections of the strait pose a challenge for deep-draft vessels and large ships whose maneuverability is limited (Figure 1). Shipping companies are enforcing strict procedures for these vessels to improve situational awareness, including:

- Day transit for loaded vessels;
- Speed limits ≤ 12 knots in designated zones;
- Increased bridge watches with additional lookouts, etc.

The confluence of eastbound and westbound traffic at the Singapore port entrance increases the risks as tidal currents reach up to 6 knots and the channels are narrowed to <2 nautical miles (Qu et al. 2011).

When approaching Singapore harbor, traffic density is greatly increased as many vessels arrive, depart and cross the TSS lanes to enter the harbor, making this a high-risk area. The westbound and eastbound TSS lanes in the Singapore entry area are constricted by limited water depth and strong currents, which significantly affects the safety of navigation (Abdullah 2000). The MPA is responsible for the safety and environmental protection of vessels operating within the confines of the Port of Singapore.

A growing problem is the practice of anchoring outside the port limits (OPL) to avoid pilotage fees and harbor dues. Singapore's eastern and western OPL anchorages are often home to 120–150 ships, leading to overcrowding in the port. Anchored vessels often swing unpredictably due to opposing wind and tidal currents (up to 4 knots), requiring constant engine readiness for emergency maneuvers. At night, approaching ships can misjudge swinging patterns, which increases the risk of collisions. These factors make OPL anchoring—especially in the dark—a high-risk practice (Chen et al. 2005; Smith 2019).

This paper analyzes an incident in which an Aframax tanker collided and ran aground during an OPL anchoring maneuver near Singapore. The case study highlights the critical importance of situational awareness, adherence to safety procedures and effective coordination of bridge resources under high-risk navigational conditions.

2. SINGAPORE EASTBOUND AND WESTBOUND PASSAGE

The Singapore Strait, forming part of the 550-nautical-mile (NM) Malacca-Singapore maritime corridor, is one of the world's busiest waterways, facilitating one-third of global maritime trade and over 200 daily vessel transits. At its narrowest point (Phillips Channel), the strait narrows to 3 NM between Singapore and Indonesia, with navigable channels reduced to less than 2 NM due to shallow bathymetry and extreme traffic density.

The Mandatory Ship Reporting System (STRAITREP), operational since 1988, divides the corridor into nine Vessel Traffic Service (VTS) sectors, each monitored via dedicated VHF channels. This system provides real-time traffic advisories, meteorological updates, and navigational hazard alerts. All vessels must adhere to local navigation rules and report to VTS authorities (West of England P&I Club 2007; Qu and Meng 2012a; Nofandi et al. 2022).

The TSS enforces strict lane discipline for eastbound (Indian Ocean → South China Sea) and westbound (South China Sea → Indian Ocean) traffic. Key operational constraints include:

- Deep-Water Routes (DWR): Mandatory for vessels with draught $\geq 15\text{m}$, requiring 3.5m minimum under-keel clearance (UKC), speed limits ≤ 12 knots, and overtaking prohibitions;
- Standard Lanes: For vessels $< 15\text{m}$ draught, with COLREG-compliant crossing procedures.

Eastbound vessels requiring pilotage at the Malaysia-Singapore boarding ground ($1^{\circ}19.8'\text{N}$, $103^{\circ}34.6'\text{E}$) must cross TSS lanes, creating collision risks during transitions. Night operations mandate COLREG Rule 28 compliance, requiring three vertical green lights for TSS-crossing vessels, alongside continuous radar position fixes at ≤ 5 - minute intervals (Maritime and Port Authority of Singapore 2019).

Singapore is located in Southeast Asia with a tropical climate that includes monsoon seasons. Sudden thunderstorms with heavy rainfall can be expected between June and August and October and December. Transiting through the Strait during this time poses an additional problem due to restricted visibility and heavy traffic. Sudden heavy rain can seriously disrupt the ship's electronic equipment and cause the officers to navigate blind. There are no fog problems in the Singapore Strait, but in the dry season, forest fires on the Indonesian islands regularly cause smoke haze. The smoke haze causes reduced visibility when strong winds occur during the monsoon, which affects the safety of navigation (Qu et al. 2011).

Considering all the factors, it can be concluded that Singapore and the Straits of Malacca are a high-risk area for navigation. It is particularly challenging for ships that have to call at a harbor in Singapore, as the heavy traffic and narrow channels increase the risk of navigational errors. The Master and officers must take all precautions for safe navigation through the Straits by carefully planning the passage, checking and maintaining the appropriate equipment and instruments, keeping a sharp lookout and manoeuvring the vessel carefully. Other important factors that should be considered are visibility, weather and sea conditions, traffic density, especially when passing through the Traffic Separation Scheme (TSS), and listening and reporting to the VTS. Ensuring a proper watch when passing through Singapore and the Straits of Malacca is of paramount importance to navigational safety.

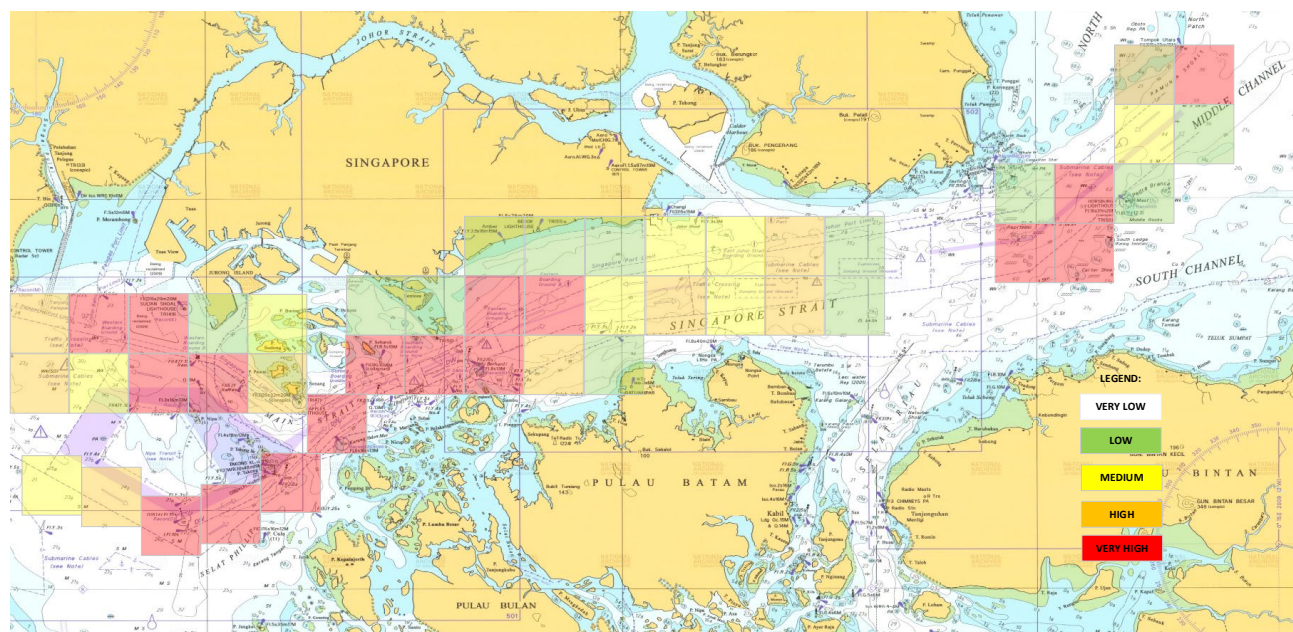


Figure 2. Singapore strait traffic density map. Adopted from (Yildiz et al. 2022), National Archives of Singapore.

As shown in Figure 2, the eastern TSS approach near Horsburgh Lighthouse records traffic densities exceeding 150 vessels/NM² during peak periods. Over 90% of incidents in this corridor involve collisions during TSS lane transitions, with 68% occurring at night due to delayed reactions in congested zones (Yildiz et al. 2022).

The Singapore Strait, one of the world's most critical maritime corridors, faces escalating risks due to its narrow structure (minimum 1.96 NM width at Phillips Channel), extreme traffic density (>150 vessels/NM²), and complex hydrographic conditions. Despite advanced safety measures like the TSS and STRAITREP reporting system, marine accidents persist, with 90% of incidents involving collisions and a notable rise during monsoon seasons (June - September) and reduced daylight hours.

Key Spatial-Temporal Patterns:

- High-risk zones: 78.7% of incidents occur in congested areas such as the eastern OPL anchorages and TSS transition zones (e.g., near Horsburgh Lighthouse);
- Seasonal vulnerabilities: 42.6% of accidents coincide with southwest monsoons, when visibility drops below 2 NM and tidal currents exceed 3 knots;
- Vessel-specific risks: 68% of incidents involve vessels >150m LOA, particularly during spring tides.

Kernel Density Analysis confirms that accident "hotspots" align with TSS lanes, underscoring the need for targeted risk mitigation strategies in these areas (Yildiz et al. 2022).

The Singapore Strait, a critical global shipping artery handling 70,000–94,000 annual transits, faces escalating risks due to extreme traffic density and complex hydrographic conditions. Table 1 and Table 2 summarizing the key navigational and situational awareness challenges in the Singapore Strait.

Challenge Category	Specific Issue	Impact/Consequence	Example/Statistic
Traffic Bottlenecks	Narrow segments (e.g., Phillips Channel: 1.96 NM width)	Congestion-induced collisions in high-density zones	78.7% of accidents occur in "very high density" zones
Environmental Hazards	Southwest monsoons (June–Sept) with Sumatra squalls	Reduced visibility (<2 NM) and grounding risks	42.6% of accidents occur during monsoon months
Tidal Currents	Strong currents (up to 3 knots) in VTIS Central sector	Maneuvering difficulties for large vessels (>150m LOA)	68% of accidents involve ships >150m length
Night Navigation	Limited visibility in crowded lanes	Higher collision probability due to delayed reactions	68% of accidents involve ships >150m length
Human Error	Non-compliance with COLREGs or improper use of navigation tools (AIS/ECDIS)	Collisions during TSS transitions (e.g., Tahong Buoy area)	Primary cause of 90.2% of collisions
Security Risks	Armed robberies targeting slow-moving vessels	Operational disruptions and crew safety threats	11 piracy incidents reported in early 2025 (freeboard <10m vessels)
TSS Constraints	Limited under-keel clearance (≤ 25 m depth in choke points)	Grounding risks for deep-draught vessels	Mandatory 3.5m under-keel clearance required in critical zones

Table 1. Singapore Strait passage key challenges. Adopted from: (Yildiz et al. 2022),(Arguedas et al. 2015; Wuryantari et al. 2025).

Challenge	Impact	Example/Statistic
Poor Tool Utilization	Delayed collision avoidance despite VTIS alerts	90.2% of collisions linked to bridge teams ignoring AIS/ARPA/ECDIS advisories
Communication Failures	Misaligned passage plans during lane transitions	68% of incidents in Tahong Buoy area involved pilot-master communication breakdowns
Night Navigation Gaps	Reduced reaction time in congested zones	70.5% of incidents occur at night due to limited visibility and complacency
Complacency in Automation	Over-reliance on autopilot during critical maneuvers	42% of grounding incidents occurred with autopilot engaged in <25m depth zones
Fatigue-Driven Errors	Degraded decision-making during long transits	Crews exceeding 12-hour watches in 33% of accidents involving human error

Table 2. Crew Situational Awareness Challenges in the Singapore. Adopted from: (Yildiz et al. 2022), (Maljković et al. 2022; Nofandi et al. 2022; Palbar Misas et al. 2024).

3. CASE STUDY – COLLISION AND GROUNDING OPL SINGAPORE

3.1. What happened?

The Aframax tanker was approaching an OPL anchorage due to an anticipated delay of 23 days, awaiting the readiness of the discharge terminal. The tanker was fully loaded and had received instructions from charterers to proceed towards Singapore and anchor OPL until berth availability was confirmed. Initially, the master anchored OPL Singapore; however, VTIS strongly instructed the tanker to heave up anchor and relocate, as its position was reportedly obstructing the movement of other vessels. Complying with these instructions, the Master ordered to heave up anchor and proceeded towards a new anchoring location approximately 2 nautical miles south-south east (SSE) of P. Mungging lighthouse (position 01°21.8'N; 104°17.9'E). This particular position had originally been designated as an emergency contingency anchorage—not intended for routine anchoring—and was selected by the Master without prior consultation with the bridge team. At the time, there was an easterly current running at approximately 2.6 knots at this location. During the approach to new anchoring position, the Master's anchoring manoeuvre failed, resulting in a collision with another vessel already at anchor. In an attempt to separate from the anchored vessel, the Master executed engine manoeuvres he deemed appropriate; however, shortly thereafter, the tanker ran aground at position 01°20.36'N; 104°17.17'E. Following the incident, no pollution or injuries were reported onboard. The tanker was successfully refloated but sustained severe damage requiring its removal from service for a period of four months. Immediate drug and alcohol tests conducted on all officers with returned negative results. Figure 3 present location of the accident and a brief description of actions taken on the bridge while maneuvering to the intended anchoring position.

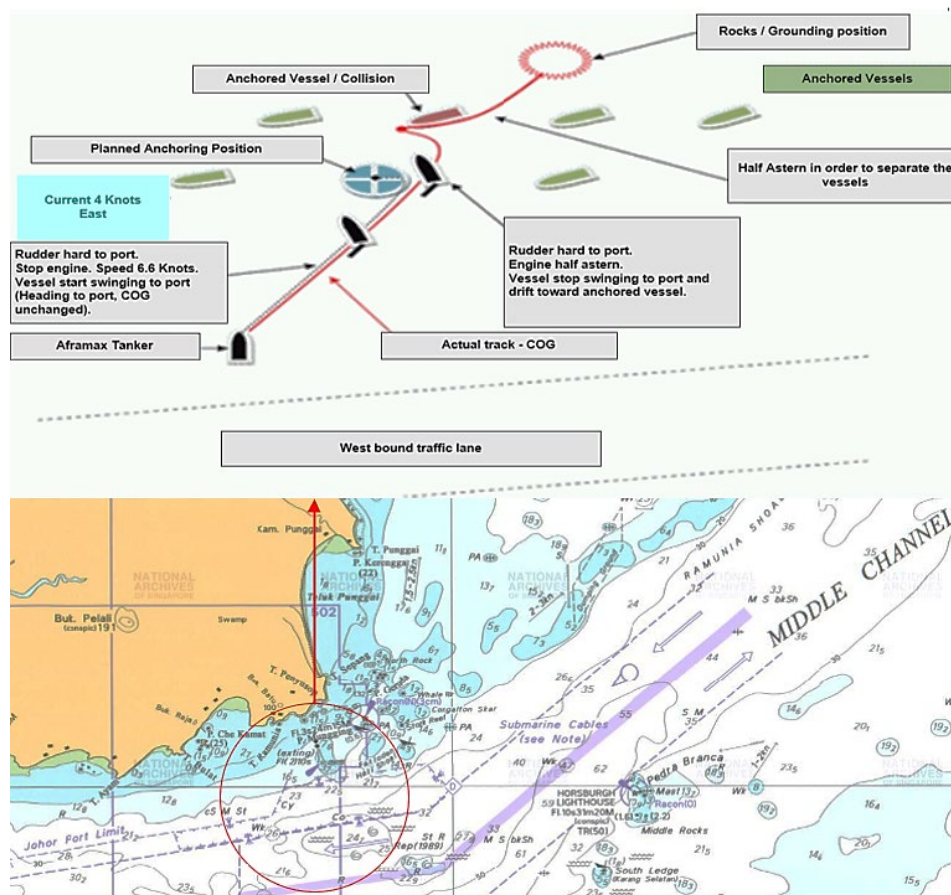


Figure 3. Brief description of action taken on bridge and accident area. Adopted from: National Archives of Singapore

3.2. Consequences and What went wrong?

After colliding with a container vessel, the ship ran aground on the shoal near P. Mungging, sustaining significant damage to its bottom structure. All ballast tanks from 1 to 6 on both the port and starboard sides (1-6 WBT P and 1-6 WBT S) were breached, with visible cuts and structural compromises. Additionally, the pump room flooded with approximately 15 meters of seawater, submerging all cargo and ballast pumps. As a result, the entire cargo handling system was rendered inoperable. Following refloating operations assisted by 8 tugboats, the ship's cargo was transferred to another vessel from the same company through a Ship-to-Ship (STS) operation conducted at anchorage. Once the cargo transfer was completed, the damaged tanker proceeded to Singapore shipyard for extensive repairs. The repair process lasted four months, during which all necessary restorations were carried out. One of the most significant challenges during the repair process was the deformation of the rudder stock, which caused delays in completing the repairs. Figure 4 provides a brief chronological overview of the events.



Figure 4. Aframax tanker: (a) Grounding position; (b) Salvage operation; (c) STS operation; (d) Discharging operation with portable hydraulic pumps; (e) Removal of damaged bottom plating (f) Renewal of bottom plating.

Several contributing factors led to the collision and grounding incident off OPL Singapore:

- Lack of Awareness and Compliance with Company Policies: The Master and officers onboard were unaware of the company's explicit policy prohibiting anchoring OPL off Singapore. Consequently, no one onboard challenged the charterer's instructions to await berth availability at OPL Singapore;
- Cultural Factors and Authority Pressure: The Master's cultural background contributed to his reluctance in challenging instructions from charterers and VTIS authorities. This reluctance was compounded by strong pressure from VTIS to immediately move from the initial anchorage position, creating significant stress for the Master and bridge team;
- Inadequate Communication and Teamwork: There was a clear breakdown in bridge team communication and collaboration. The Master selected the new anchoring position without consulting or discussing it with the bridge team, and none of the junior officers questioned or challenged this decision or the subsequent manoeuvre;
- Office Oversight and Support Failures: The shore-based office team failed to identify and rectify charterers' instructions that contravened company policy. Additionally, there was no effective communication between the Master onboard and office personnel for support or consultation prior to relocating to the new anchorage;
- Absence of Passage Planning: No formal passage planning was conducted for the transit between the initial anchorage position and the alternative anchorage location. Additionally, no formalized passage planning meeting took place onboard, leading to inadequate risk management;
- Failure in Contingency Planning: The crew did not adequately consider contingency scenarios or alternative actions when selecting a new anchorage location;
- Misjudgment of Local Tidal Conditions: The Master failed to accurately assess local tidal conditions. The tidal information available from standard sources proved inaccurate due to extensive dredging and reclamation works off Malaysia and Singapore. Furthermore, the Master misjudged how the strong easterly current (2.6 knots) would affect tanker manoeuvrability during anchoring;
- Ineffective Use of Technology and Navigational Equipment: The bridge team did not effectively utilize available navigational technology, such as radar, ECDIS, or GPS verification methods, which could have provided early warnings about shallow waters or potential collision risks.
- Inadequate Leadership Skills Onboard: Leadership onboard lacked assertiveness, resulting in poor decision-making processes, ineffective delegation, inadequate monitoring of junior officers' actions, and insufficient challenge-response interactions within the bridge team.
- Insufficient Shore-Based Support: Office staff provided inadequate support for seafarers' operational needs, failing to proactively assist or intervene when critical decisions were made onboard.

These factors collectively highlight significant shortcomings in bridge resource management (BRM), risk assessment practices, communication protocols, leadership quality onboard, shore-based oversight, and adherence to established company policies.

3.3. Root cause analysis

Once the tanker had been instructed by VTIS to proceed to an alternate anchoring position, there was a lack of passage planning. There was no contingency plan for dealing with unforeseen situations or in case the anchorage was not available. Better planning and utilization of all company resources and publications available would have resulted in the planning team picking up the 'No OPL Singapore' circular in the SMS system. In

addition, a pre-departure bridge team meeting would have assisted in all team members knowing the intention of the master and thus a team member questioning the anchoring position and or the manoeuvre being planned.

The root cause is therefore considered to be:

- Violation of checklists and standard operational procedures;
- Poor situational awareness;
- Lack of Planning;
- Commercial pressure and lack communication.

The officers onboard acted in a very proficient manner in handling the post incident emergency situation onboard. Excellent support was provided by officer and crew onboard for lightering and refloating the tanker after the incident. The breakdown in shared situational awareness aligns with findings that 86% of maritime accidents stem from human factors related to cognitive tunneling and poor tool utilization (Praetorius et al. 2020; Wei et al. 2021).

4. CONCLUSION AND GUIDELINES

The incident involving this tanker highlights critical lessons learned and provides recommendations for improvement, as outlined below:

- Comprehensive Passage Planning: A detailed "berth-to-berth" passage plan must always be prepared by a competent navigation officer and agreed upon by the entire bridge team prior to commencing any voyage or vessel movement. This plan must explicitly document the assessment of tidal and current conditions, clearly identify navigational hazards, and specify appropriate precautions to mitigate associated risks;
- Clear Contingency Planning: Passage plans must incorporate clearly defined contingency measures, including alternative anchorage positions, emergency anchorages, and clearly marked no-go areas on charts. Such contingency planning enables bridge teams to effectively respond to unforeseen situations or changing circumstances;
- Enhanced Bridge Team Management (BTM) Training: Bridge Team Management courses attended by officers should be revised to include comprehensive modules on passage planning, effective delegation techniques, and detailed consideration of tidal and current factors. Scenario-based exercises reflecting similar incidents should be introduced into training programs to reinforce lessons learned from real-world incidents;
- Increased Practical Training Using Simulators and Manned Models: Greater emphasis should be placed on practical training through simulator exercises and manned model courses. These training methods provide officers with realistic experience in handling vessels under various environmental conditions, particularly regarding the effects of tides, currents, shallow waters, and anchoring procedures;
- Leadership and Assertiveness Training for Senior Officers: Senior officers' confidence in their decision-making abilities must be strengthened through targeted leadership and assertiveness training. Courses specifically designed to enhance leadership skills, assertive communication, effective delegation practices, stress management, workload management, and decision-making processes should be introduced for senior officers onboard;
- Incident Learning Dissemination: Lessons learned from this incident should be formally presented at officer seminars and safety meetings. Sharing incident details—including root causes identified—will raise awareness among seafarers and assist in preventing similar occurrences in the future.

By implementing these guidelines and recommendations comprehensively across the fleet and shore-based operations, improvements in navigational safety could be achieved. The incident emphasizes the critical importance of thorough planning processes, contingency preparations, effective communication between shipboard personnel and shore-based management, proactive leadership onboard vessels, continuous training enhancements, and strict adherence to established company procedures.

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Impact of the IHO Resolutions and Standards for ENCs on the Use of ECDIS

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The International Convention for the Safety of Life at Sea (SOLAS) requires certain ships to carry an Electronic Chart and Display System (ECDIS). In order to meet the requirements of the SOLAS Convention, the International Hydrographic Organisation (IHO) has developed a set of comprehensive standards for Electronic Navigational Charts (ENC). The aim of these standards is to ensure the uniformity, consistency and reliability of ENCs as well as the data protection and updating of charts. The production, publication and updating of ENCs is carried out in accordance with the work programme of the national hydrographic organisations (HOs) as members of the IHO and in accordance with the technical resolutions and standards of the IHO. The paper aims to analyse the current IHO standards and regulations and their impact on the production of ENCs in terms of accuracy, reliability and correct interpretation as well as the use of ENCs on ECDIS. During the analysis, the authors identified certain shortcomings in the production, updating and use of ENCs. These shortcomings could have an impact on the safety of navigation. In order to increase the safety of navigation, the authors propose the modification of certain practises and the standardisation of the production and updating of ENCs.

KEYWORDS

IHO resolutions and standards; ECDIS; ENC; Safety of navigation

1. INTRODUCTION

ECDIS was developed to enable safer navigation. The use of ECDIS on ships is defined by various regulations and standards. These regulations and standards in the form of convention and resolutions were developed by the International Maritime Organization (IMO). The SOLAS Convention prescribes the obligation to carry ECDIS (including the application deadline of July 1, 2018) only for certain types of ships (UKHO, 2019; Weintrit, A., 2010).

According to SOLAS regulation V/19.2.10, passenger ships of 500 GT or more, tankers of 3000 GT or more and cargo ships other than tankers of 3000 GT or more must be equipped with ECDIS on international voyages (SOLAS, 2020). Accordingly, ships of the same category and gross tonnage do not have to be equipped with ECDIS if they only sail on domestic voyages. Since the use of ECDIS is not mandatory for all SOLAS and non-SOLAS ships, the decision on the type of electronic system for displaying electronic navigational charts lies primarily with the shipowners.

In the resolutions, the IMO defines performance standards for ECDIS and its ability to operate as a Raster Chart Display Information System (IMO, 1995; IMO, 2006). According to SOLAS regulation V/19.2.1.5, it is considered that official ENC's can serve as a substitute for paper charts if they meet the required specifications (SOLAS, 2020), if an independent ECDIS is on board as a backup. In addition, the SOLAS Convention requires in regulations V/19 and V/27 that ships must carry regularly updated official nautical charts (SOLAS, 2020), as up-to-date ENC's and reliable ECDIS have a direct impact on the safety of navigation. The IMO is also aware of the risk of over-reliance on the infallibility of ECDIS by officers in charge of navigational watch (OOW) (IMO, 2017). Among the errors that can arise when OOWs rely too much on ECDIS information is the use of information from charts, which can sometimes be inaccurate and incomplete.

The ENC producing countries are responsible for the accuracy and completeness of the information on ENC. According to SOLAS regulation V/9, the parties are obliged to collect, compile, process, exchange and update all nautical information necessary for safe navigation. The parties are obliged to draw up and issue nautical charts that meet the requirements of safe navigation. Regulation V/9 also requires that uniformity in the production of nautical charts must be standardized and that activities must be coordinated at a global level. In addition, the contracting parties are obliged to issue Notice to Mariners (NTM) to keep the nautical charts and publications up to date (SOLAS, 2020).

The IHO standards for ENC are designed to implement the requirements of the SOLAS Convention and are based on the Worldwide Electronic Navigation Charts Database (WEND) principles. The WEND principles represent the concept on which the current ENC production and distribution system is based. This paper provides an analysis of IHO standards for the production, presentation, data protection, distribution and updating of ENC as an important source of information for contemporary navigation. The paper identifies some shortcomings in the implementation of these standards, focusing particularly on the inconsistencies in the updating of ENC's in terms of the selective use of Temporary (T) and Preliminary (P) NTM and shortcomings in the production of ENC's in terms of overlapping data coverage which may make difficult to use ENC's in certain ECDIS. The paper is structured as follows: Section two describes the IHO standards for transfer of digital hydrographic data, ENC validation checks, data protection and specifications for chart content and display aspects of ECDIS. Section three presents the IHO standard for production, distribution and ENC updates, and Section four refers to analysis of inconsistencies in the updating and shortcomings in the production of ENC's. Section five presents the conclusions.

2. IHO STANDARDS FOR ENC DATA TRANSFER, VALIDATION, PROTECTION, CHART CONTENT AND DISPLAY ASPECTS

The aim of the IHO standards is to achieve uniformity and conformity of nautical charts and publications produced by national HOs. Today, the role of the IHO is particularly important in the development of ENC standards. The above standards were created with the aim of supporting the requirements of the SOLAS Convention for ENC. The standards ensure that all ENCs are accurate and reliable and can be correctly displayed on ECDIS.

The S-57 standard defines the data format used for the transfer of digital hydrographic data between national HOs and for further distribution to manufacturers, navigators and other data users (IHO, 2000). This standard is intended to allow distributors to use data in a format for transfer or in a format intended only for the display of data on ECDIS. Data transfer and distribution must be carried out in such a way that no meaning of the data is lost (IHO, 2000). The ENC product specification within this standard defines how the HO will create the ENC. By meeting these specifications, HOs ensure that all ENCs contain all cartographic data required for safe navigation (UKHO, 2023).

The S-58 standard defines the process of ENC validation that should be performed by the HO before they are released for distribution. Validation is carried out using appropriate software to enable HOs to check that the data in their ENCs complies with the ENC product specification from the S-57. This ensures that ENC irregularities that may affect the proper operation of ECDIS are avoided (UKHO, 2023). The validation process includes checks related to the S-57 data structure, ENC product specifications, data exchange set levels, the use of the S-57 objects catalog and checks related to allowed attribute values (IHO, 2000). In this way, end users can obtain ENCs that are harmonized with the relevant IHO standards in terms of format and information content (UKHO, 2023).

The S-63 standard defines the ENC data protection system. The aim of the S-63 is to protect the copyrights of ENC producers. In addition to preventing financial losses in the event of piracy of ENC data, cases of data modification can also occur that can have a direct impact on the safety of navigation. Therefore, producers have protected their data with certificates of authenticity by implementing a data protection scheme (IHO, 2015). The purpose of S-63 is to prevent the unauthorized use of data (piracy protection), selective access and authentication. For end users, this means that data that complies with IHO standards is authenticated and comes from an official source (IHO, 2015).

The S-52 standard is used by ECDIS manufacturers. It defines how ENC data is displayed on the ECDIS by symbols, line styles, colors and other visual signs. This means that what the user sees on the screen is displayed in the same way in all approved ECDIS types and models (UKHO, 2023). The aim of the S-52 is to ensure a base, standard and full display of ENC, standardization of symbols, colors and their application, limitation of data presentation, clear presentation of ENC and the use of objects familiar to mariners (IHO, 2015a).

In addition to these standards, the IHO has developed a new S-100 set of standards relating to the future development of new aspects of ENC. It represents a major challenge for HOs in the technical-technological sense (Smith, Wallhagen 2020). The S-100 will allow the use of data from different sources, dynamic sea surface display, ice reports, display of meteorological and oceanographic data, etc. Testing of the use of the S-100 is currently underway (CHS, 2025). This new IHO standard provides a framework for the development of the next generation of ENCs (S-101) as well as other digital products (Palikaris, Mavraeidopoulos 2020). The S-101 serves mainly as a conversion or extension of S-57 ENC-based data using a converter provided by the IHO. However, the conversion requires validation to ensure the conformity, accuracy and reliability of the converted data. In their study, Hyun, S. N., et al. point out problems with the automatic conversion method, which is neither

accurate nor reliable for ENC production data (Hyun, S. N., et al., 2025). Analyzing the implementation of existing IHO resolutions and standards that have been in use for years can help to understand the impact of the new S-100 standards on the use of ECDIS in the near future.

3. IHO STANDARD FOR PRODUCTION, DISTRIBUTION AND ENC UPDATES

The key steps in the production of ENCs are defined in IHO standard S-65. The process consists of ten steps. The application of these formal steps ensured the highest possible level of quality, harmonization, data verification and validation, distribution and updates of ENCs. The authors have identified some problems and inconsistencies in the application of matching data reconciliation at cell boundaries, ENC updates and the distribution of ENC data steps from the S-58 standard.

The IHO specifies procedures for processing data at the boundaries of adjacent cells of the same and different navigation purposes. In areas where adjacent producing countries are involved, HOs should cooperate to establish and agree on a homogeneous ENC scheme, including responsibility for data coverage within each navigation purpose (IHO, 2017). This step is important to harmonize the presentation of data from adjacent ENC cells regardless of their producer. Therefore, adjacent HOs should agree on cartographic boundaries to avoid overlaps and data gaps (IHO, 2018).

The IHO prescribes that ENCs must be updated regularly in accordance with the principles of the S-4. ENC cells must be corrected with NTM, Preliminary (P) and Temporary (T) Notices. The principles apply equally to official paper charts and ENCs. The update processes of paper charts and their ENC equivalents should be synchronized (IHO, 2017). According to the WEND principles, the data for ENC updates must be available for a period at least equal to the period for which the data for paper chart corrections are available (IHO, 2018). The data for ENC updates must include all data for paper chart updates and be available at equal intervals (e.g. once a week) (IHO, 2017).

The IHO defines distribution mechanisms that must ensure the continuity of the service and the integrity of the data by applying the S-57 and S-63. The distribution of update data must take place at regular intervals. The data distribution mechanism must provide the user with current and timely ENC data in such a way that the end user can perform the update independently (IHO, 2017). IHO Member States are encouraged to distribute their ENCs through RENCs to share common experiences and reduce costs, as well as to ensure the highest possible standardization, consistency, reliability and availability of ENCs (IHO, 2018). Distribution through RENCs is optional. If the data is not distributed through RENCs, a data protection system should be implemented to ensure the integrity of the data, prove its authenticity and prevent unauthorized copying (IHO, 2017). The USA, for example, distributes the ENC cells and their updates independently, i.e. without the RENC system.

4. INCONSISTENCIES IN THE UPDATING AND SHORTCOMINGS IN THE PRODUCTION OF ENC

ENCs must be regularly updated with the information from the NTM. The use of the information contained in the T and P notices is considered one of the key factors in the updates of navigational charts. Updating is the process of correcting nautical charts and publications based on the latest information published in NTM. One of the shortcomings of the existing ENC updating system is that the information contained in the T and P notices is not utilized. In cases where the HO includes the T and P notices in their ENCs, the ENCs are updated and therefore no additional information layers (AIO) of data are required (IHO, 2014).

4.1. The inclusion of T and P notices in ENC corrections

The inclusion of information from the T and P notices is considered to be one of the key factors for the ENC updates. One of the shortcomings of the existing system for ENC updates is that the information contained in the T and P notices is not used. Figure 1 shows the status of the inclusion of T and P notices in the ENC updates by HO. PRIMAR and IC-ENC have collected information from the individual HO that distribute ENCs through the RENCs. The authors have collected and evaluated the available data on the inclusion of T and P notices submitted by individual countries to PRIMAR and IC-ENC in their 2019, 2021 and 2023 statements and summarized them in Figure 1.

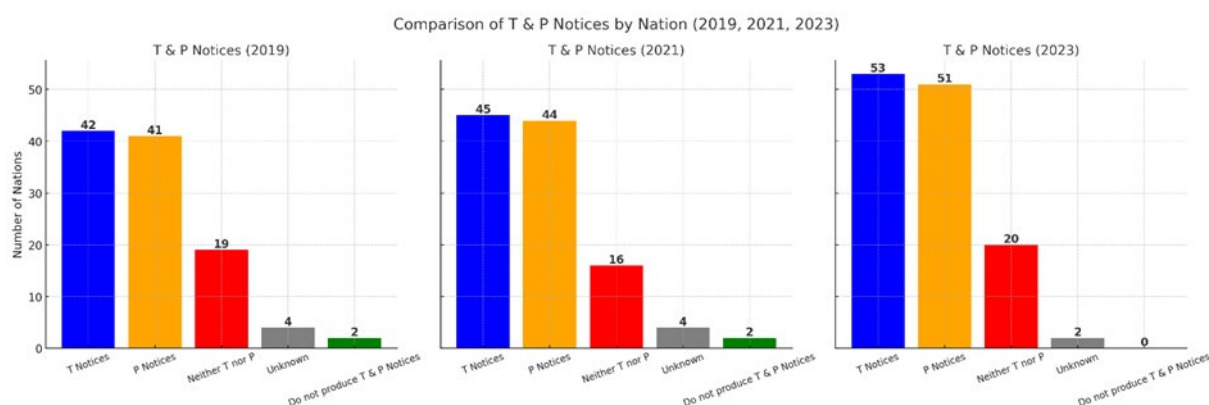


Figure 1. Inclusion of T and P notices in ENCs update by HO for 2019, 2021 and 2023. (Source: Admiralty, 2019; Admiralty, 2021; PRIMAR, 2025).

According to the data from 2019, 42 HO included T notices, 41 HO included P notices and 19 HO included neither T notices nor P notices in the ENC updates. Two HO stated that they do not issue T and P notices for either paper charts or ENC, while the situation was unknown for four HO (Admiralty, 2019).

According to data from 2021, the situation has changed as Russia, Ukraine and Iran have started to include T and P notices in the updates of ENCs, whereas previously they used the AIO UKHO service (Admiralty, 2021). It can therefore be said that in the cases where T and P notices were not included in the ENC, these notices were issued as part of the UKHO AIO service for all UKHO nautical charts. In cases where HO have included T and P notices in their ENCs, these have been retained so that no additional data information layers are required. PRIMAR RENC emphasizes that AIO is neither an official nor a mandatory service for ENC (PRIMAR, 2025). Otherwise, there was often unnecessary duplication of updates on the same cell.

According to the latest PRIMAR report from 2023 the number of HO producing ENC and T and P notices has generally increased, while the number of countries using the AIO service has remained relatively the same (PRIMAR, 2025). Only two HO did not indicate whether or not they include T and P notices in their updates, and no organization indicated that they do not including that notices, whether through the AIO service or by issuing their own updates.

4.2. ENC overlap in data coverage

In cases where ECDIS from the database uses two ENC cells from different HO for the same area and usage band, some difficulties have been reported in correctly displaying these cells when they overlap. For some ECDIS, this problem manifested itself in the duplication of certain objects or, even worse, in the deletion and non-display of certain objects on the ENC. The RENCs warn that some ENCs contain overlapping data

coverage, which may make them difficult to use in certain ECDISs that display both overlapping cells by default (PRIMAR, 2018; PRIMAR, 2025a). For this reason, the authors have compared the status and reporting of overlaps published as an integral part of each ENC package, using data from 2018 after the ECDIS application deadline and from 2025 before the transition to the new S-100 standard.

The identical instructions for 2018 and 2025, attached to the ENC ROOT file itself, state that discussions are underway between the individual HOs to address the potential lack of overlap of individual cells (PRIMAR, 2018; PRIMAR, 2025a). Data from 2018 and 2025 were collected and analyzed for all countries with overlapping ENC cells, which may lead to irregularities in the display of cells. The data on the overlapping areas of ENC cells in the 2018 edition of each HO are shown in Table 1.

Nation (HO)	ENC overlap in data coverage with following nations
AU (Australia)	ID (Indonesia), RU (Russia), C1 (China)
CA (Canada)	US (USA)
C1 (China)	AU (Australia), C1 (China), C2 (Hong Kong), CN (China), GB (Great Britain), IN (India), JP (Japan), KR (Korea), MY (Malaysia), PH (Philippines), US (USA)
CN (China)	C1 (China)
CN (SCC)	CN (SCC), C1 (China), JP (Japan), KR (Korea)
C2 (Hong Kong)	C1 (China)
DK (Denmark)	GB (Great Britain)
GE (Georgia)	RU (Russia), TR (Turkey)
GB (Great Britain)	IT (Italy), JP (Japan), C1 (China), IN (India), IR (Iran), DK (Denmark), ID
GR (Greece)	TR (Turkey), IT (Italy), HR (Croatia)
HR (Croatia)	GR (Greece), IT (Italy)
ID (Indonesia)	AU (Australia), ID (Indonesia), MS (Malacca and Singapore Straits), MY (Malaysia), SG (Singapore), GB (Great Britain)
IN (India)	GB (Great Britain), JP (Japan), KR (Korea), C1 (China), PK (Pakistan)
IR (Iran)	GB (Great Britain)
IT (Italy)	GB (Great Britain), GR (Greece), TR (Turkey), UA (Ukraine), HR (Croatia)
JP (Japan)	GB (Great Britain), KR (Korea), RU (Russia), US (USA), C1 (China), CN (SCC)
KR (Korea)	JP (Japan), RU (Russia), IN (India), C1 (China), CN (SCC)
MS (Malacca and Singapore Straits)	ID (Indonesia)
MY (Malaysia)	ID (Indonesia), MY (Malaysia), C1 (China)
PK (Pakistan)	IN (India)
PH (Philippines)	C1 (China)
RO (Romania)	UA (Ukraine)
RU (Russia)	US (USA), JP (Japan), KR (Korea), UA (Ukraine), TR (Turkey),
SG (Singapore)	ID (Indonesia)
TR (Turkey)	GE (Georgia), GR (Greece), IT (Italy), UA (Ukraine), RU (Russia)
UA (Ukraine)	RU (Russia), TR (Turkey), UA (Ukraine), IT (Italy), RO (Romania)
US (USA)	RU (Russia), JP (Japan), C1 (China), CA (Canada)

Table 1. List of hydrographic organization with ENC overlap in data coverage (Source: PRIMAR, 2018.)

To analyze the changes that have occurred compared to 2018, in terms of eliminating the overlap of ENC cells, the authors collected the latest data from 2025 and presented them in Table 2.

Nation (HO)	ENC overlap in data coverage with following nations
AL (Albania)	GR (Greece), ME (Montenegro)
AU (Australia)	ID (Indonesia), RU (Russia)
CA (Canada)	US (USA)
CN (PRD)	CN (SCC)
CN (SCC)	CN (SCC), CN (PRD), JP (Japan), KR (Korea), VN (Vietnam)
DK (Denmark)	GB (Great Britain)
GE (Georgia)	RU (Russia), TR (Turkey)
GB (Great Britain)	IT (Italy), JP (Japan), IN (India), DK (Denmark), ID (Indonesia), VN (Vietnam), RU (Russia)
GR (Greece)	TR (Turkey), IT (Italy), HR (Croatia), AL (Albania)
HR (Croatia)	IT (Italy), GR (Greece), ME (Montenegro)
ID (Indonesia)	AU (Australia), ID (Indonesia), MS (Malacca and Singapore Straits), MY (Malaysia), SG (Singapore), GB (Great Britain), JP (Japan), KR (Korea)
IN (India)	GB (Great Britain), JP (Japan), KR (Korea), PK (Pakistan)
IR (Iran)	GB (Great Britain), OM (Oman)
IT (Italy)	GB (Great Britain), GR (Greece), TR (Turkey), UA (Ukraine), HR (Croatia)
JP (Japan)	GB (Great Britain), KR (Korea), RU (Russia), US (USA), ID (Indonesia), CN
KR (Korea)	JP (Japan), RU (Russia), IN (India), ID (Indonesia), CN (SCC)
ME (Montenegro)	HR (Croatia), AL (Albania)
MS (Malacca and Singapore Straits)	ID (Indonesia)
MY (Malaysia)	ID (Indonesia), MY (Malaysia)
OM (Oman)	IR (Iran)
PK (Pakistan)	IN (India)
RO (Romania)	UA (Ukraine)
RU (Russia)	US (USA), JP (Japan), KR (Korea), UA (Ukraine), TR (Turkey), GE (Georgia), AU (Australia), RU (Russia), GB (Great Britain)
SG (Singapore)	ID (Indonesia)
TR (Turkey)	GE (Georgia), GR (Greece), IT (Italy), UA (Ukraine), RU (Russia)
UA (Ukraine)	RU (Russia), TR (Turkey), UA (Ukraine), IT (Italy), RO (Romania)
US (USA)	RU (Russia), JP (Japan), CA (Canada)
VN (Vietnam)	VN (Vietnam), CN (SCC), GB (Great Britain)

Table 2. List of hydrographic organization with ENC overlap in data coverage (Source: PRIMAR, 2025a)

From the RENC data and overlap reports from 2018 and 2025, it can be seen that the number of countries and overlaps between individual countries has increased and that only one HO has seen a decrease in cell overlaps. The reason for the increase in the total number of countries with overlaps is, on the one hand, that several HOs have emerged during this period and started producing ENCs. On the other hand, the fact that the number of overlaps of individual HO with other HOs has increased or remained unchanged cannot be explained. Despite the announcements and statements made in 2018 that discussions between the HOs will continue and that everything possible will be done to remedy this potential problem and shortcoming, it still exists. Consequently, it remains the responsibility of the OOW to regularly check and compare the data

displayed on the ECDIS with what they see from the bridge, as well as regularly cross-checking with other available navigational tools and equipment to maintain situational awareness. When planning the procurement of new cells for the navigation area, officers should also avoid purchasing cells of the same purpose and category from different HOs in order to avoid potential problems caused by overlapping ENC cells.

5. CONCLUSION

Based on the analysis of the status of ENC updates, it can be said that there are certain advantages and disadvantages. The advantages of the existing ENC update system are the fact that all steps of the process are standardized, well-defined and subject to quality control by RENCs and HOs. The fact that the inclusion of T and P notices in the updates is not standardized worldwide can be seen as a disadvantage.

Analysis of RENC data in 2018 and 2025 has shown that not much progress has been made in addressing the identified shortcomings in terms of overlapping data coverage, which may make it difficult to use in certain ECDIS systems. OOW is still advised to be cautious when using ENCs in cases of these overlaps, which certainly requires additional effort and knowledge to be applied by OOW when using such overlapping data on ECDIS.

These inconsistencies confirm that although a high degree of ENC standardization has been achieved, there are still shortcomings in the application of the standards. Although the IHO, RENCs and HOs have made extraordinary efforts to standardize ENCs to date, the analysis has shown that there are shortcomings that can only be remedied if individual HOs address the deficiencies independently and in collaboration with other HOs.

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Responsibilities of Maritime Transport Stakeholders for the Accuracy of Verified Container Gross Mass Data

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Resolution MSC.380 (94) of the International Maritime Organization, adopted in 2016, introduced an amendment to the SOLAS Convention requiring verification of the gross mass of packed containers. The verified gross mass data must be submitted before the container is loaded onto the ship at the port of loading. The obligation to determine the verified gross mass of the container and submit the data in a timely manner affects all parties in the shipping chain from the loading of the goods into the container to their loading onto the ship, so the participants have to cooperate to implement these rules in the best possible way. One of the objectives of this paper is therefore to review the role and responsibilities of each party involved, in particular the shipper and the ship master. In addition to the international regulations, the authors also analyze the legal regulation of the standard in the Croatian legal system. Particular attention is paid to the obligations of the recognized organization in the part relating to weighing equipment, as it must comply with the requirements of the country in which the equipment is used.

The paper also analyzes the court decision *Stournaras Stylianos Monoprosopi EPE -v- Maersk A/S (Maersk Klaipeda)* [2024] EWHC 2494 (Comm), which dealt with the issue of the carrier's responsibility for the accuracy of the data on the verified gross mass of a packed container.

The paper concludes with an assessment of the compliance of the Croatian legal system with international regulations on the obligation to provide data on the verified gross mass of containers, and the authors' views on the position of individual parties in the transport process.

KEYWORDS

Verification of the gross mass of a packed container (VGM); Safety; Shipper; Master responsibility.

1. INTRODUCTION

According to the International Maritime Organization, up to 90% of world trade is transported by sea (IMO). It is estimated that more than 1.7 billion tons of cargo are transported by containers around the world every year. Containerization has become an irreplaceable form of goods transport that combines maritime, road and rail transport into a complete transport chain. The increase in goods turnover results in the need to increase the fleet of container ships. If we look at the increase in the carrying capacity of container ships between 1980 and 2022, the carrying capacity has increased from 11 million metric tons to 293 million metric tons (Statista). The container fleet market size has grown strongly in recent years. It will grow from \$13.66 billion in 2024 to \$14.6 billion in 2025 at a compound annual growth rate (CAGR) of 6.8% (Business Research Company 2025).

The IMO points out that the consequences of declaring the gross mass of a full container incorrectly can be far-reaching (IMO). They can be divided into four categories: safety of seafarers and terminal operators (possible physical injuries), navigation safety (containers that have fallen into the sea pose a risk to other ships), economic effects (loss of goods, increased cargo handling costs, port congestion, disruptions in supply chains, rescue operation costs) and the impact on the marine environment (lost containers may contain dangerous substances that pose a threat to the marine ecosystem).

Since no significant scientific research has been conducted in the Republic of Croatia on the implementation of SOLAS Regulation VI/2 into the Croatian legal framework, the aim of this paper is focused on analyzing the relevant Croatian regulations and determining whether and to what extent the Croatian law is harmonized with the international standards. Special attention is paid to the analysis of the legal position of individual stakeholders in maritime transport and the supply chain when implementing the standard of verification of the gross mass of a full container.

2. SYNERGY OF LEGAL REGULATION ON CONTAINER TRANSPORTATION AND LOGISTIC SUPPLY CHAIN SUSTAINABILITY

The increase in maritime container traffic should be observed in the context of its impact on navigation safety, protection of the marine environment, impact on throughput in ports, security of terminals, etc. As a result, individual legal standards cannot be observed in isolation, but in the context of its network effect. As part of the realization of modern conditions for the safety of human life at sea, but also in ports, it is very important to take care of handling, stowage and transporting containers in a safe manner. It should be remembered that the 1972 International Convention for Safe Containers (CSC), which has been in force for over half a century, was adopted with the aim of establishing the necessary level of safety of human life during the transport and handling of containers and facilitating the international transport of containers with uniform safety regulations that apply to all modes of land transport (IMO, CSC).¹ It was established to avoid the proliferation of divergent national safety regulations for containers.

However, security threats can easily be realized by container transport. All over the world, initiatives are being taken to prevent suspicious flows of goods or shipments. The United States of America (USA) is certainly one of the leaders in this area, by establishing the Container Security Initiative (CSI) (U.S. Customs and Border Protection's). It is a security protocol designed to identify and preliminarily screen high-risk container shipments prior to their departure from foreign ports to United States destinations. The program originated from the need to secure the supply chain from potential threats, especially after the terrorist attacks of September 11, 2001.

¹ The Republic of Croatia is a party to the Convention based on the Decision on the publication of multilateral international agreements to which the Republic of Croatia is a party based on succession notification, Official Gazette No. IA 1/92.

The CSI program operates through a network of bilateral agreements between the United States and foreign port authorities. The advantages of CSI can be valorized through increased security, trade facilitation and positive economic effects. By identifying and mitigating threats at an early stage, CSI strengthens the global supply chain against potential terrorist activities (U.S. Customs and Border Protection's). Pre-inspected containers face fewer delays, allowing for the smooth flow of goods and minimizing disruption to international trade. Although CSI offers significant security advantages, it also incurs costs associated with the implementation of appropriate technologies in customs procedures, including increased staffing and training. Since its inception, CSI has expanded to include many ports around the world (U.S. Customs and Border Protection's). The Agreement between the European Community and the United States of America on the strengthening and expansion of the Customs Cooperation and Mutual Administrative Assistance Agreements to include cooperation in the area of container security and related issues is particularly significant (OJ L 304 of 30. 9. 2004). The Agreement ensures the rapid expansion of the Container Security Initiative to all EU ports that meet the prescribed requirements. Its goal is to improve cargo security on a reciprocal basis for both parties, while ensuring equal treatment of American and European ports and carriers. In order for the effects of cooperation to be as good as possible, in 2004 through the Joint Customs Co-operation Committee, the EU and the United States adopted recommendations on strengthening the security of containerized maritime transport based on the Agreement.²

The efforts to minimize the pollution of the marine environment by the loss of containers on the navigation route can also be achieved by establishing cooperation between individual countries that work together in retrieving sunken objects, including containers. In this sense, it is important to highlight the Protocol concerning cooperation in preventing pollution from ships and, in cases of emergencies, combating pollution of the Mediterranean Sea. Article 6 of the Protocol prescribes the following: "In case of release or loss overboard of hazardous and noxious substances in packaged form, including those in freight containers, portable tanks, road and rail vehicles and shipborne barges, the Parties shall cooperate as far as practicable in the salvage of these packages and the recovery of such substances so as to prevent or reduce the danger to the marine and coastal environment".³

The standard that unifies and contributes to the achievement of the highlighted goals (protection of human life at sea, safety of employees at the terminal, safety of ships and navigation, prevention of pollution of the marine environment, sustainability of supply chains, prevention of security incidents) is certainly the standard from SOLAS Regulation VI/2 on mandatory verification of the gross mass of packed containers. To ensure the effective and uniform application of SOLAS Regulation VI/2, the Maritime Safety Committee (MSC) adopted the MSC.1/Circ.1475 Guidelines regarding the verified gross mass of a container carrying cargo (IMO). Although the shipper is the main person responsible for the verification of the gross mass of a packed container, these Guidelines are also of great use to other stakeholders in the maritime supply chain. By adopting these Guidelines, the IMO further confirmed the importance of the gross mass verification standard for maritime transport and its sustainability.

² <https://eur-lex.europa.eu/EN/legal-content/summary/container-security-eu-us>

³ The Republic of Croatia adopted the Act on Confirmation of the Protocol concerning cooperation in preventing pollution from ships and, in cases of emergency, combating pollution of the Mediterranean Sea in 2003, Official Gazette no. 12/03. The Protocol entered into force in relation to the Republic of Croatia on 17 March 2004.

3. LEGAL POSITION OF INDIVIDUAL STAKEHOLDERS WHEN DELIVERING CONTAINERS FOR TRANSPORT

The conceptual definition of shippers and other stakeholders channels responsibility towards a specific person or group of persons. In the following chapters, an analysis of the relevant provisions of international regulations and the Croatian legal system will be conducted on the legal position of individual stakeholders when verifying the gross mass of containers and handing them over for transport in order to finally make a conclusion on the integrity of the legal system in the Republic of Croatia.

3.1. Who is the shipper?

MSC 1/Circ.1475 defines a shipper as a legal entity or person named on the bill of lading or a sea waybill or an equivalent multimodal transport document as shipper, and/or who (or in whose name or on whose behalf) has concluded a contract of carriage with a shipping company (IMO). International trade and the logistics supply chain represent a complex system, resulting in the fact that depending on the conditions of transportation, different persons may appear in the negotiating position with the carrier. The shipper can be a buyer or seller of cargo, a freight forwarder or a third party who appears in the role of a party that concludes a contract of carriage with the carrier (HZ Containers). In practice, the shipper is the person who establishes contact or communicates directly with the ship operator/carrier in order to carry out the necessary actions for loading and transporting a container by sea, including the timely delivery of cargo information necessary for planning the stowage and location of cargo on board and performing customs formalities (HZ Containers). In accordance with item 4. 1. MSC 1/Circ. 1475 the responsibility for obtaining and documenting the verified gross mass of a packed container lies with the shipper (IMO).

In the Croatian legal system, the provisions on persons in the maritime transport chain are dispersed in several regulations, starting with the Maritime Code. According to Article 445, paragraph 1, item 2 of the Maritime Code, the shipper is the charterer, or a person designated by him who, on the basis of the contract of carriage, hands over the goods to the carrier for transport. This conceptual definition should be interpreted in the context of defining the parties to the contract of carriage, namely the charterer and the carrier. Since the provisions on the mandatory determination of the gross mass of the container were not directly implemented in the Maritime Code but in the by-laws, the definition was not changed or adapted to the needs of the SOLAS Regulation VI/2. The Ordinance on Amendments to the Ordinance on handling dangerous goods, the conditions and method of transport in maritime traffic, loading and unloading of dangerous goods, bulk and other cargo in ports and the method of preventing the spreading of oil spills in ports from 2016 (hereinafter: Ordinance on handling dangerous goods) implemented the SOLAS Regulation VI/2 on the mandatory verification of the gross mass of containers, but the amendments did not include the revision of the definition of the shipper, so it remained the same. According to Article 2, paragraph 1, item 11 of the Ordinance on handling dangerous goods, the shipper is the charterer, or a person designated by him who hands over the goods to the carrier for the purpose of transportation. A certain adjustment was made in the Rules for Statutory Certification of Sea-Going Ships, Carriage of Cargo Annex 3, Appendix 3, subsection 2.2.2. in which the shipper is defined as a person with whom, or on whose behalf, or on whose authority the carrier concludes a contract of carriage by sea, or a person on whose behalf or on whose authority the goods are delivered to the carrier in connection with the contract of carriage.

The shipper's obligation to submit documents in a timely manner is also regulated by the provisions of Article 495 of the Maritime Code, which does not explicitly refer to the obligation of submitting a document on the verified gross mass of the container but refers to customs and other documents required for loading, transporting and unloading cargo. The document on the verified container gross mass is certainly included in

the list of documents required for the loading of cargo, so this provision *mutatis mutandis* applies to it as well. Untimely delivery of the document entails the responsibility of the shipper for damage that may occur due to the detention of the ship in the port, resulting demurrage, etc.

Here it is necessary to focus attention on the provision of Article 557 of the Maritime Code⁴, which emphasizes the responsibility of the charterer as the carrier's basic co-contractor from the contract, while the shipper operates only in his legal domain. The shipper hands over the goods for transport in the name and on behalf of the charterer and has no independent legal position in relation to the carrier. Regardless of who provided the above information (shipper or charterer), the charterer is always responsible to the carrier (Article 453 of the Maritime Code). Given that the Maritime Code does not contain express provisions on the liability of the shipper, the Civil Obligations Act applies according to the principle of subsidiarity (Bolanča, 2021).

3.2. Responsibility of ship-side stakeholders

Considering the responsibility of ship-side stakeholders in terms of meeting the standard on the verified gross mass of the container, it refers primarily to the ship master and the ship operator, i.e. the carrier. The legal systems of certain countries, including the Republic of Croatia, use two terms when fulfilling contracts of carriage by sea: ship operator and carrier, whereby the ship operator should be distinguished from the shipowner.⁵

In the Ordinance on handling dangerous goods, the term "ship operator" is used in the part that refers to the verification of container gross mass (it was previously pointed out that the Maritime Code refers to the obligations of the carrier regarding the receipt and transportation of cargo). Article 174a of the Ordinance on handling dangerous goods prescribes three main obligations of the ship operator: a) not to load containers with cargo onto the ship without data on the verified gross mass of the container with cargo, b) inform the shipper of the deadline for the delivery of data for the timely preparation of the Plan for stowage and securing the container, and c) provide the terminal with information on the verified gross mass of the packed container in the event that the verified gross mass of the container with cargo is determined outside the loading terminal of the container.

The "link" that connects the shipper and the ship operator in the delivery and acceptance of the container is the terminal. The terminal becomes the transmitter of data on the verified gross mass of the full container if such information is received from the shipper or in the case when the mass of the full container is determined at the terminal on behalf of the shipper (Article 174.a, paragraph 4. of the Ordinance on handling dangerous goods).

The position of the ship master is clearly determined by the basic principle from the Code of Safe Practice for Cargo Stowage and Securing, according to which the master should accept the loading of cargo onto the ship only if he is satisfied that he will be able to transport it safely. This principle is equally applicable in the case of accepting full containers on board. The master retains the discretionary right to decide whether to accept the container on board or not. The timely availability of data on the verified gross mass of the full container, which will be used to create the cargo stowage plan, is just one of the prerequisites for accepting the container for loading.

⁴ Article 557 of the Maritime Code: "The charterer is liable to the carrier for compensation for damage caused to him because the charterer or the shipper provided incorrect or incomplete information about the quantity, type and markings of the cargo."

⁵ The use of different terms can lead to certain ambiguities in application. On whether the term "ship operator" should be retained in Croatian law, see for example Grabovac, Ivo. Do we need the "ship operator" in the Maritime Code of the Republic of Croatia? *Naše more: International Journal of Maritime Science and Technology*, Vol. 44, no. 1-2, 1997.

3.3. The Role of the Croatian Register of Shipping

In accordance with SOLAS 74, Chapter VI, Regulation 2.4.2 and MSC.1/Circ.1475., if Method 2 is used to determine the gross mass of the container, it must be carried out by a certified company in accordance with the rules of the competent authority of the country on whose territory the packaging and closing of the container was carried out (IMO). Based on this provision, the Republic of Croatia had to take several steps in order to harmonize the legal framework with the international standards. The first standard refers to the appointment of the competent authority for issuing the certificate, which is the Croatian Register of Shipping (hereinafter: CRS). The second standard refers to the adoption of rules by the competent authority, in this case CRS, which prescribe the methods that can be used in determining the container gross mass, the general and special requirements that must be met by the service company to obtain the certificate, the validity period of the certificate, and the method and reasons for revoking the certificate. Both requirements were fulfilled by the adoption of the Rules for Statutory Certification of Sea-Going Ships, Carriage of Cargo in 2016, amended in 2018. Provisions on weighing the gross mass of containers are contained in Annex 3, Appendix 3, which relates to the securing and stowage of cargo. The provision on the appointment of CRS as an authorized body is contained in subsection 3.4.18.4. Rules for Statutory Certification of Sea-Going Ships, Carriage of Cargo.

In addition to the Rules for Statutory Certification of Sea-Going Ships, Carriage of Cargo, the Rules for Statutory Certification of Sea-Going Ships, General Requirements, Annex 4, Section IV from 2019 are also important, prescribing the requirements regarding the approval of service companies that, upon request and on behalf of the company or owner, provide services such as measurements and testing and maintenance of safety systems and equipment, and the results of which are used by a recognized organization (RO) when making decisions that affect the statutory certification of Croatian state-owned ships. Pursuant to item 2.2 of the Rules, the recognized organization is obliged to maintain a list of service companies and make it publicly available. CRS fulfilled this obligation by publishing the list on its official website.

The express prohibition of loading cargo transported in a container, whose gross mass has not been verified by the shipper, is determined by item 3.4.18. of the Rules for Statutory Certification of Sea-Going Ships, Carriage of Cargo. Both methods can be used to determine the verified gross mass of the container: Method 1 and Method 2.

The shipper is obliged to ensure that the document with the specified verified gross mass of the container is signed and certified by the shipper or his representative and delivered to the master of the ship or his representative as well as to the representative of the port where loading takes place sufficiently in advance to the satisfaction of the master or his representative, so that the ship plan for stowage and securing the container can be prepared. The CRS rules, as well as international rules, do not define the term "sufficiently in advance" because it depends on numerous factors: the size of the ship, the capacity of the cargo area, transshipment conditions in the port, etc. so it is determined on a case-by-case basis.

Regardless of which method of determining the verified gross mass of the container is applied, weighing may only be done with weighing instruments that meet the prescribed standards. They differ depending on whether non-automatic scales or automatic scales are used. In the case of using non-automatic scales, they must comply with the Ordinance on the metrological and essential requirements referring to non-automatic weighing instruments, implementing the Directive 2014/31/EU of the European Parliament and the Council on harmonization of the laws of the Member States relating to the making available on the market of non-automatic weighing instruments into Croatian legislation. If the verified gross mass of the container is determined using automatic scales, they must be in accordance with the Ordinance on technical and metrological requirements related to measuring instruments. With this Ordinance, Directive 2024/32/EU of the European Parliament and

the Council on the harmonization of the legislation of the member states in relation to the making available of measuring instruments on the market has been implemented into the legal system of the Republic of Croatia.

Based on the successfully completed approval procedure, the CRS issues a Certificate for Approval of the Service Supplier for determining the verified gross mass of the packed container. The Certificate is valid for three years. The approval process is based on the requirements of the Rules for Statutory Certification of Sea-Going Ships, Chapter 4 – Approval of Service Suppliers. In the process of issuing the certificate, the shipper must fulfill certain general and special requirements. The rules also stipulate the CRS has the right to revoke the Certificate. The cases are given by way of example. Exemplary enumeration may, in effect, lead to a misinterpretation of the application of the Rules in such a way that the Certificate is canceled only in the cases that are exemplarily listed. Cancellation of the Certificate may occur if the service is intentionally performed incorrectly, if the results of the verified gross mass are intentionally misrepresented, if the company does not inform the CRS about a change in the supplier's system, and if the CRS is notified of repeated complaints from the carrier and/or terminal operator about the wrongly determined verified gross mass of the packed container. The effectiveness of the application of these measures will depend on their implementation and the cooperation of the terminal and other stakeholders with CRS. The rules do not contain a provision on the legal remedy that would be available to the shipper in case he considers revoking the certificate to be unfounded or unlawful.

4. ANALYSIS OF JUDGEMENT IN THE CASE *STOURNARAS STYLIANOS MONOPROSOPI EPE -V- MAERSK A/S (MAERSK KLAIPEDA)*

The application of the rules on verification of the gross mass of a full container should certainly be considered in the context of the carrier's responsibility for cargo damage. The carrier is responsible for fulfilling two basic contractual obligations: to deliver the cargo to the recipient at the destination in the condition and quantity as received, and to deliver it without delay. One of the cases discussing the carrier's liability for cargo damage due to misdeclared container mass was the case *Stournaras Stylianos Monoprosopi EPE -v- Maersk A/S (Maersk Klaipeda)* (The National Archive).

The consignee brought proceedings in an English court against the carrier claiming that the carrier had issued a clean bills of lading (B/Ls) despite a significant discrepancy between the shipper's declared weights and the verified gross container mass. The consignee received less cargo than contracted and requested compensation. The carrier claimed that its systems at the time did not cross-check the weights declared by the shipper with the VGM data provided by the terminal. He also argued that it is not the carrier's obligation to "supervise" every shipment, and the fraudulent behavior of the shippers could have been prevented if the shippers had arranged a supervisor when closing the container (England and Wales High Court, EWHC, 2024).

The court dismissed the claim because the consignee failed to prove that the carrier was aware that the shipper had given false information about the weight of the cargo. At that time, the obligation to submit data on the verified gross mass of the container was carried out for the safety of the ship and the creation of a cargo stowage plan and was not compared with the data on the declared weight. The bill of lading clearly states that the cargo information is stated "as declared by the shipper, but without responsibility or representation of the carrier." The obligation under Article III Rule 3(c) of the Hague Rules was for the carrier (Maersk) to assess the "apparent order and condition of the goods". The apparent order and condition of the cargo refers to its external condition so as to be apparent upon reasonable inspection. The weight of the container would not be visible by inspecting the external condition of the container (EWHC, 2024).

This case shows how important it is to understand the meaning of the limitation/exclusion of liability clauses that appear in the bill of lading and as such bind the shipper and consignee and benefit the carrier.

5. CONCLUDING REMARKS

After the analysis, the authors determined that Croatian law has successfully implemented the main requirements of SOLAS Regulation VI/2 on the verification of the gross mass of a packed container. There is potential for improvement, especially in terms of standardizing the conceptual definition of shippers. Thus, the Maritime Code and the Ordinance on handling dangerous goods give the same definition of shipper, but they differ from the one contained in the Guidelines MSC 1/Circ.1475. On the other hand, the Rules for Statutory Certification of Sea-Going Ships, Carriage of Cargo, provide a conceptual definition of the shipper closer to international regulations. As stated in the paper, the Ordinance on handling dangerous goods regulates the very complex and important issue of the delivery of data on the verified gross mass of containers in only one article (174.a). Minimalism in legal regulation can be criticized, but it should be taken into account that the provisions are dispersed in several laws and by-laws, depending on whether it is about technical requirements, property legal relations of stakeholders or the position of the regulatory body.

If we take into account the importance of maritime transport in the logistics supply chain and the importance of container flows in world transport flows, then the positive effects of the verification of data on the container gross mass are generated on the entire supply chain, i.e. on ship operators, agents, ports – container terminals, forwarders, land carriers and contribute to sustainable flows of container cargo in maritime transport. By verifying the gross mass of the container, negative environmental consequences such as the devastation of the sea and the marine environment are also reduced and eliminated.

Although the responsibility of individual stakeholders for damage caused by wrongly determined gross container mass is not explicitly prescribed in the Maritime Code, it can be derived from the general norms and principles of the responsibility of the shipper for the accuracy of data on the quantity and condition of the cargo, as well as the responsibility of the carrier for the orderly execution of the contract for the carriage of goods. The judgment in the case of *Stournaras Stylianos Monoprosopi EPE v. Maersk A/S (Maersk Klaipeda)* encourages the carrier's position that they cannot be held responsible for damage to the cargo caused by incorrect shipper information. According to the author's knowledge, at the time of writing this paper, the Croatian courts have not had the opportunity to decide on this issue, so the authors are not aware of its position of the Croatian courts.

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Analysis of the Application of Digitalization in Nautical Tourism

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Digitalization of business is taking place in various fields, including nautical tourism. Unlike classic apartment accommodation, boats are still rented out by charter companies resulting in the fragmentation of the market. Through digitalization and digital transformation, efforts are being made to reduce business costs and achieve overall business excellence. Digital transformation is a notion that can be encountered in various fields of human life today. Digital transformation is specifically directed towards numerous sectors within the economy itself, including tourism. Everything is directed towards the area of implementing various digital technologies in order to accomplish certain advantages such as improving the business itself, facilitating business operations, but above all achieving financial benefits. Today, digitalization is being implemented in all types of tourism, including nautical tourism. Digitalization as such is necessary in order to compete with global market trends. The purpose of the paper is to explain and analyze the existing trends that are changing the tourism market, pointing out the importance of digital business transformation, defining the key factors for the success of digital business transformation, and explaining the specific benefits of the digital business models.

KEYWORDS

Digitalization, Nautical tourism, Digital transformation, Charter companies

1. INTRODUCTION

The Republic of Croatia has been recognized worldwide as a tourist country providing various forms of tourism, but certainly among the most significant forms is nautical tourism. When defining nautical tourism, it is interpreted as a phenomenon that has specifically marked today's tourism. Nautical tourism therefore represents a special sub-type of tourism (Družić, 2003).

If we look at the etymological explanation, it can be pointed out that the very concept of nautical tourism derives from two terms, i.e. nautical and tourism. In this context, the term nautical, or boating / shipping in its broadest sense, refers to the very maritime affairs.

On the one hand, tourism is presented as a special activity that is actually recording constant expansion, the latter being essentially caused by continuous changes and development of new tourist needs, but on the other hand, it is also expanded by the development of the supply which inherently adapts to the new demands of the travelers themselves. Tourism is extremely important since it brings a significant income to local economies. This is on average about 30% of the total world consumption of services (Pirjevec, 2008).

Nautical tourism represents tourism in which the totality of all activities and all relationships as such are caused by the accommodation of boaters, either in nautical tourism ports or outside of them, i.e. it implies the use of watercraft but also other facilities that are related to nautical tourism activities, such as recreation, sports and other facilities (Luković; Gržetić, 2007).

Nautical tourism is tourism that includes the totality of various functional activities and relationships that are as such caused by the stay of boaters in or outside ports, or the procedures for using vessels and other facilities that are related to tourism activities (Luković, 2007).

Nautical tourism is also a commercial activity that has developed as such from the field of ordinary tourism and, on the other hand, maritime activities, while containing specific characteristics that make this form very unique (Kovačić and Bošković, 2006).

Nautical tourism can be categorized according to vessel ownership, sailing motivation, and sailing organization. In terms of vessel ownership, it is possible to distinguish between nautical tourism in one's own or club vessel, and the nautical tourism that takes place in a vessel rented for a certain period of time, i.e. charter.

The division can also be categorized according to the motive of sailing itself, where it is possible to distinguish between recreational nautical tourism, sports and fishing nautical tourism. As for the organization of sailing, we can talk about the division into nautical tourism of the individual type of organization and the group type of organization.

2. DIGITAL TRANSFORMATION

When talking about digital transformation, it is interpreted that the global environment as such brings numerous challenges to companies every day. Of course, in this situation, the emphasis is placed on the area of achieving concrete competitiveness in the market itself. The above item indicates that it is necessary to be subject to numerous changes so that ultimately the company itself could adapt to all the emerging market demands.

In order for a company to survive, it must continuously monitor all trends that occur in the market itself. It is interpreted that the changes that are taking place include changes that, as such, introduce numerous

technological aspects on which business ultimately depends. First of all, this is the area of information and communication technology. These technologies eventually result in the so-called digital transformation of the company itself.

2.1. Business digitalization

The field of business informatization is an area that has been undergoing a major revolution over the past twenty years. Namely, the focus is on business digitalization, which aims to improve the existing processes and the entire organizational structure so that all companies can successfully adapt to new times.

Digital transformation of a company is a special concept within which the elements for the digitalization of business are specifically combined. It is actually a special phenomenon thanks to which a certain readiness, or ability, to implement various changes in a company is presented.

Likewise, digitalization itself can be viewed as a separate concept that has the possibility of implementation in different sectors of society. Hence, digital transformation is a concept through which the implementation of information and communication technology is included in the field of business. In other words, the aim here is to digitalize business. Furthermore, in the above-mentioned way, efforts are made to focus on the use of smart devices, the Internet, applications and other tools that are intended to ensure the improvement of business itself.

Digitalization of business can also be described as the area of implementing information and telecommunications technology and the use of changes in the area of existing business processes, (Li; et al., 2016). This would also mean that the creation of new Internet or new mobile communication channels in this way enables the customers themselves to connect with other companies in a very easy way, thus changing the traditional interaction between the company itself and the customer on the other side (Ramaswamy; Ozcan, 2016).

As a result, it can be noticed that digitalization itself no longer focuses exclusively on the area of cost savings, but is directed towards the area that will ensure the improvement of the existing processes, which will ultimately contribute to the improvement of the customer experience itself.

It can be said at the same time that digital transformation as such is actually one of the most pervasive phases and for this reason it is described as a change in the entire organization whose goal is to lead towards the development of new business models (Zott and Amit, 2008).

2.2. Aspects of digital transformation

When talking about digitalization and digital transformation, it is very important to emphasize the impact on the entire company as well as on all effects and ways of doing business. Digital transformation goes beyond digitalization by changing simple organizational processes and tasks.

It can be said that the use of information and telecommunications technology enables a transformative possibility that leads to very thorough and radical changes in already existing business processes, but also in the capabilities of organizations, (Li; et al., 2018).

Through the use of digital technology, numerous possibilities are realized including, for example, cross-border interaction with customers, competitors, achieving a competitive advantage, and the like (Li; et al., 2018). Figure 1 shows the aspects of digitalization.



Figure 1. Presentation of the digitalization aspects (source: Teece, 2010)

The first aspect discussed is the organizational aspect of enterprise digitalization. This aspect specifically includes all organizational processes within the enterprise, also including the ideas directed towards the area of creating different values, but also towards the area related to creating different business models.

In this way, the aim is to achieve extended supply chains. It is very important to highlight the various organizational aspects. Their fundamental goal is specifically aimed at the improvement segment or the change segment of the aforementioned items. The fundamental goal of the organizational aspect is specifically aimed at achieving improvements and at the very change of the existing processes, all based on the application of the so-called digital technology.

As for the second aspect, it actually refers to the technological aspect. Here it is interpreted that the technological aspect as such includes a specific segment of implementing various innovations within technologies. Through this process, the use and possibility of improving the quality of the overall business is achieved. In other words, here the overall efficiency of the business is achieved, but at the same time there is an increase in the revenues themselves. When talking about the technological aspect of digitalization, it is very important to point out that most often we refer to business automation.

Finally, the social aspect includes the area related to networking and the creation of communication channels, all in order to create new experiences and thoughts among the stakeholders.

3. DIGITAL TRANSFORMATION IN NAUTICAL TOURISM

3.1. Digital transition of tourism

The very appearance of digital platforms has increased the volume and variety of tourism products, services and experiences. Digitalization has accelerated economic transaction and market availability, which has led to an increase in the visibility of both the product and the feedback from the clients themselves.

The aforementioned changes in the tourism market clearly did not happen overnight, but are the result of continuous development. It is particularly evident here that the period from innovation to implementation has been significantly shortened. Thus, traditional tourism has first entered the e-business phase, which is

specifically characterized by the adaptation of technology itself, in the segment of marketing and sales itself, i.e. the improvement of internal processes.

After this phase comes the phase related to e-commerce, that is, the phase in which technology specifically strengthens in the area of connectivity and collaboration. As for communication between different stakeholders within the destination, this results in concrete innovations along the entire supply chain.

In this case, it is precisely the application of artificial intelligence which makes it possible to respond to all user inquiries in a timely manner at any time of the day, which is not always the case when it comes to customer service employees themselves. As for the most common forms of application of artificial intelligence within the customer service of tourism and other companies, chatbots and direct messages are the right ones.

They are the ones who can give a direct answer to simple queries, while on the other hand, chatbots are developing independently because their development is actually based on learning through interaction with the users themselves. It is noticeable that trends within tourism are actually changing very quickly, making it increasingly difficult to respond to the demands and expectations of modern tourists.

It is therefore emphasized that digital transformation is an area that affects changes in organizational culture in order to provide new services, new products and also a new level of employee experience. Digitalization primarily refers to the automation of both business and operational processes. In other words, digitalization encompasses the process of converting analog processes into digital ones. When talking about digital business and its development, it is certain that the two terms are used interchangeably.

3.2. Digital transformation trends in tourism

Digital transformation trends in tourism include the following:

- guest personalization,
- cognitive computing,
- global mobile presence,
- data centricity,
- augmented and virtual reality.

3.2.1. Guest personalization

One of the trends in digital transformation in tourism is definitely the area of personalization for each guest. The very adaptation of packages and also the adaptation of offers based on user preferences represent a very important part in the field of innovative technologies. In this way, personalization represents a certain synonym for success.

As an example, micro trips can be cited, as they offer less busy routes that are therefore focused on the specific interests of the tourist himself and represent one of the perfect examples of personalization. Through digitalization and the introduction of *big data*, which helps in the segment of providing insight into the habits of travelers such as their favorite destination, their preferences related to the airline or their favorite dishes, today's travel companies use it to significantly increase the overall level of customization of the service itself.

This also enables mobile applications to send customized content to successfully attract tourists and also inform them about all the latest trends in the travel industry. What is expected is that personalization itself will play an even more important role in the tourism industry in the future, given that sending relevant information

and content serves to improve the overall user experience and thus becomes the center of the digital transformation strategy.

3.2.2. Cognitive computing

The field of cognitive computing is used in the segment of describing specific travel preferences for a particular *dream getaway* and to obtain certain further recommendations that are somehow tailored precisely based on the consumer's behavior in the past. For example, it is expected that in the near future a computer will actually be able to book an entire travel package, which also includes airline tickets, hotel accommodation, or in other words, trends will be based entirely on the characteristics of the traveler's profile and based on his past experiences.

It is considered that cognitive computing, or the self-learning system itself, functions in this way through the segment related to voice recognition, or through data mining and natural language processing, in order to replicate the human brain, which is expected in the future.

3.2.3. Global mobile presence

It is estimated that more than 1/3 of the world's population uses mobile devices to secure accommodation reservations. This would mean that free mobile connectivity is actually as essential for many users as Wi-Fi or 4G/5G networks. Some hotel chains therefore offer their users special devices that will be able to connect to the Wi-Fi connection during their entire stay in the hotel, and there is also the possibility of using portable batteries and selfie sticks for free.

Mobile connectivity is considered a basic requirement and is not considered a luxury. This means that users are the ones who expect a seamless mobile experience during their trip, from the moment of planning to the journey itself and during their stay in their chosen destination and accommodation.

3.2.4. Data centrality

A very important point in the field of digitalization in tourism is the focus on data. It is considered that data is the key to digital transformation. Tourism companies and platforms themselves are responsible for collecting and storing large amounts of data during travels. In this way, the collected data relate to the clients themselves, also including transactions.

A fundamental benefit of using the above data is primarily manifested in the ability to make informed decisions. In this way, it is also possible to learn about the clients themselves as well as about competitors. This improves the overall user experience and, as a result, increases income. If the data is used in a good and efficient way, this information can reveal which services users use the most and which are the least popular.

Also, in order to increase financial results, hotels are focused on selling the right product to the right customer at the right time. This segment is helped by internal data such as past attendance data, current reservations, all with the fundamental goal of planning the most precise offer.

3.2.5. Augmented and virtual reality

In the field of digitalization, virtual and augmented reality are also used, regardless of whether it is a tourist accommodation or a tourist destination. Through virtual reality, guests can view everything without

leaving their room. The basic goal here is to offer a specific overview of what the guests themselves will specifically experience and thus further stimulate their desire.

Numerous companies are therefore focused on creating tools related to travel search and booking, which allow potential travelers to, for example, visit a destination, choose a seat on a plane and review rental cars, and only then pay for the entire trip, all within the space of virtual reality.

3.3. The importance of applying digital transformation in nautical tourism

The importance of applying digital transformation in the field of nautical tourism is exceptional. First of all, the following points can be emphasized here:

- digital size of users,
- digital talent and entrepreneurship,
- readiness for technology,
- open innovation culture,
- adaptable policy and regulations.

First of all, it is emphasized that for the implementation of digital transformation in the field of nautical tourism, the scale of the market itself is extremely important. Hence, those countries that have an installed digital base and a very unique culture also have a very large competitive advantage. In the framework of digital talent and entrepreneurship, it is emphasized that science, technology, engineering, entrepreneurial and creative activities themselves are considered very necessary and even crucial for the realization of the possibilities of digital innovation. It is also of great importance for countries to focus on the aforementioned skills within educational priorities.

It is necessary to be ready for technology. The very status of technology and digital assets also includes the connection between investing in future generation technologies. It is necessary to have an open innovation culture. Innovations are those that are built into the business culture and the way the platform works.

This would mean that the number of those who rely on organizations in partnership with developers or services is growing. Large companies must move towards designing new open organizational structures, processes intended to manage open ecosystem platforms while at the same time embedding a culture of collaboration. Governments should also encourage innovation centers.

Only a quick change of requirements, preventive and perceptive policy creation by working together with employees on the platform contributes to the growth itself, which also ensures the so-called cyber security.

3.4. Examples of Digital Transformation in Nautical Tourism

It has already been highlighted that nautical tourism is a form of tourism in which cruises and tourists' stays on their own or someone else's vessel dominate, as well as various nautical activities carried out for recreational purposes (Vukonić and Čavlek, 2001). Similarly, it is stated that nautical tourism represents the totality of various multifunctional activities and relationships caused by the stay of tourists in nautical tourism ports or beyond, including the use of vessels and other facilities related to nautical tourism activities to provide recreation, sports, entertainment, and other needs (Luković and Gržetić, 2007).

When discussing the current level of development of nautical tourism, three fundamental groups of nautical-tourism demand can be highlighted (Gračan, 2011):

- Tourists focused on sailing individually or in small groups with various types of yachts and boats.
- Nautical tourists oriented towards mass cruises on various types of vessels.
- Nautical tourists focused on water sports, exploration, and experiencing the sea and its underwater world.

Given the fundamental purpose of utilizing numerous comparative advantages in both natural and social environments, it is clear that the goals of overall tourism development and policy must be emphasized.

The nautical industry is undergoing significant changes due to digitalization and the transition to more sustainable business practices. Digitalization in the nautical industry is evident in the use of software aimed at design, customer relationship management (CRM), social media marketing, and networking. It is noted that many digital solutions are emerging in the market, with the primary goal of improving the connectivity of ports, both locally and regionally, with the mainland. Ports thus become key drivers of socio-economic and sustainable growth in coastal areas of the entire program area.

One of the primary examples of hardware and software solutions is the design and promotion of personalized tourist experiences, as well as sustainable destination management, particularly through the platform Simpl, developed by the Slovenian tech company Art Rebel 9 Visual Communication d.o.o. from Ljubljana. This platform provides features such as connecting with smart sensors, direct experience sales, monitoring tourist habits, and enabling destinations to track movements and tourist flows in real-time. Based on available data, destinations can develop the necessary strategies. Since tourist destinations are largely faced with the issues related to "over-tourism," which not only diminishes the quality of the tourist experience but also the quality of life for the local community, the need for "smart" solutions to help manage destinations is becoming more evident. These solutions aim to achieve the outlined goals.

Another platform worth mentioning is "365 tours", the first Croatian marketplace connecting activity organizers and outdoor activity enthusiasts. This platform boasts over 100 partners and more than 600 activities, offering guests a wide range of experiences such as jet skiing, parasailing, quad biking, and more. The primary goal of this platform is to allow tourists to easily find, book, and pay for the experiences they want to enjoy, thus facilitating the search for active vacation options.

Considering that tourist destinations in Croatia face significant issues related to "over-tourism," which reduces not only the quality of the experience but also the quality of life for local communities, there is a growing need for "smart" solutions to help manage the destination with the goal of achieving these objectives.

It is evident that Croatia has been striving for a long time to keep pace with numerous European maritime projects. In this regard, the Ministry of the Sea, Transport, and Infrastructure, as the main holder of innovations and coordinator, plays a very important role.

As early as 2005, the first comprehensive web application, which connected three ministries and the economy, was launched. It played a crucial role in completely eliminating illegal charter operations in the Adriatic. This was the e-charter system, a pioneer of digital transformation in the maritime sector. The system introduced several innovations in an environment that was still underdeveloped in terms of digital technology. The system was later transformed into e-visitor, which handles payments for tourist fees, as well as the registration and deregistration of sailors.

4. CONCLUSION

With the fundamental purpose of utilizing numerous comparative advantages in both the natural and social environment, it is clear that the goals of overall tourism development and policy must be emphasized. The nautical industry as such is being shaken by digitalization itself and the concrete transition to more sustainable ways of doing business.

Therefore, digitalization in the nautical industry is digitalization that manifests itself in the form of the use of software intended for designing, that is, customer relationship management, marketing through social networks and networking. It can be seen that numerous digital solutions are being developed on the market with the basic goal of improving the connection of ports of local and regional significance with the mainland. Consequently, ports appear as a kind of drivers of socio-economic and sustainable growth of the coastal areas of the entire program area.

One of the fundamental examples of hardware and software solutions is certainly the design and promotion of individual tourist experiences, i.e. the sustainable management of the destination itself.

Given that tourist destinations in the Republic of Croatia are destinations that are largely faced with problems related to *excessive tourism*, there is a reduction not only in the quality of experience, but also in the quality of life of the local community, and accordingly, there is a need to find smart solutions that will facilitate destination management with the fundamental goal of achieving the aforementioned goals.

It is noticeable that the Republic of Croatia has been trying to keep up with numerous European maritime projects for a long time. It is in this segment that the Ministry of the Sea, Transport and Infrastructure, which is also the fundamental innovation carrier and coordinator, plays a very important role.

Given the popularity of the Republic of Croatia as a destination, it is clear that nautical tourism is of exceptional importance. Nautical tourism business is doing well, but the Republic of Croatia also has far greater predispositions for the development of this form of tourism.

The growing importance of digitalization in the nautical tourism industry is evident in its transformative impact on business operations and sustainable development. By leveraging a variety of digital tools, such as customer relationship management (CRM) software, social media marketing, and networking platforms, the sector is enhancing its connectivity and operational efficiency. The development of digital solutions is aimed at improving the integration of coastal ports, both locally and regionally, with the mainland, positioning these ports as key drivers of socio-economic growth in coastal areas.

One of the most significant digital advancements is the ability to design and promote personalized tourist experiences through technology, which also aids in the sustainable management of tourist destinations. In Croatia, a nation highly susceptible to the challenges of overtourism, digitalization offers innovative solutions that balance the quality of visitor experiences with the well-being of local communities. Smart destination management tools, powered by digitalization, are becoming crucial in mitigating the negative effects of mass tourism and achieving sustainable growth. Digital solutions emphasize technological innovations as a response to urban challenges, including the fight against climate change, the promotion of green policies, and sustainable development. This goes beyond mere technological implementations and encompasses social and ecological responsibility.

The Croatian government, particularly the Ministry of the Sea, Transport, and Infrastructure, plays a pivotal role in coordinating these initiatives and ensuring alignment with broader European maritime projects.

While nautical tourism in Croatia is thriving, the country possesses untapped potential for further growth, especially by embracing digital innovations that will bolster its competitive advantage in the global market.

In conclusion, digitalization is no longer a mere trend but a necessity in the nautical tourism sector. It fosters smarter, more efficient, and sustainable development, ensuring that Croatia remains at the forefront of this vital industry in the Mediterranean.

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Integration of Individual Systems in Maritime Industry - Standardization

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Standardization is pivotal in enhancing operational efficiency and reliability across various domains. In quality management, standards aim to improve productivity and reduce operational failures, while energy management standards focus on minimizing energy consumption. The rapid advancement of new technologies and the integration of information systems within the maritime industry have necessitated systematic monitoring and continuous investment by maritime companies to maintain competitiveness in an evolving market environment. Emerging research in digital twin technologies, increasingly adopted within the maritime sector, highlights the importance of standards such as ISO 23247 – Digital Twin Framework for Manufacturing. Furthermore, the adoption of Internet technologies emphasizes the relevance of ISO/IEC 27032:2023 – Guidelines for Internet Security, which has now entered its second publication. Standards like ISO 19030-1 – Ships and Marine Technology: Measurement of Changes in Hull and Propeller Performance are also instrumental in guiding the industry towards optimized energy efficiency and operational effectiveness solutions. The paper examines specific standardization systems and investigates the potential for integrating various systems to establish a cohesive framework. The analysis provides a foundation for recommendations aimed at advancing the integration and development of standardization practices within the maritime sector. Such integration has the potential to streamline operations, reduce costs, and improve compliance with regulatory requirements. Additionally, these efforts are critical in addressing environmental challenges by enabling the adoption of greener technologies and sustainable practices in maritime operations.

KEYWORDS

Maritime industry; Standardization; Energy efficiency; Information systems; Technological integration; Environmental challenges

1. INTRODUCTION

Shipping companies operate in highly volatile and unstable markets (such as freight markets, and markets for new, used, and scrap ships), which move in irregular cycles. This significantly complicates decision-making, especially when it comes to making strategic decisions.

The international nature of the maritime shipping market makes it more vulnerable to global economic trends. In order to survive, maritime companies are forced to constantly adapt to technological and market changes. Critical to the survival of shipping companies in the global market is the consideration and use of various methods and instruments to combat crises. The main goal of management information systems in maritime companies is to build information and communication infrastructure to enhance the safety and efficiency of maritime traffic, and ultimately, to increase the profit of the shipping company. Establishing a balance between the stability of the company and its adaptability to the environment and turbulent market changes (especially in the transport maritime market and the ship space market) is one of the key goals when structuring any company in the 21st century.

The application of new technologies in maritime systems, especially software technologies such as neural networks, expert systems, fuzzy logic, genetic algorithms, pattern recognition, information fusion, etc., provides new opportunities in signal processing, control, and diagnostics of maritime processes, thus enabling full monitoring, control, and navigation of the ship as a unified integrated system, i.e., the realization of the concept of an intelligent ship. The focus on new technologies and the integration of information systems within the maritime industry requires systematic monitoring and continuous investment by maritime companies in order to maintain competitiveness in the evolving market environment.

The integration of individual systems in the maritime industry through standardization brings multiple benefits, not only in operational but also in economic and ecological terms.

2. THE IMPORTANCE OF STANDARDIZATION IN THE MARITIME INDUSTRY

The maritime industry is a complex ecosystem that includes shipping companies, ports, shipyards, regulators, and various technologies (UNCTAD, 2023. Review of Maritime Transport 2023). Without unified standards, there is a risk of misalignment between different systems, which can lead to inefficiencies and increased costs. Standardization enables (Filatov, 2016):

- Increased interoperability between different software and hardware systems.
- Improvement of security protocols and data protection in digital systems.
- More efficient maintenance and monitoring of ships through predictive analytics and digital twins.

2.1. Administrative and technological aspects of standards developed through the application of new technologies

ISO 23247 Digital twin framework for manufacturing

The application of digital twin technology is becoming crucial in the modernization of the maritime industry. This technology enables detailed monitoring and simulation of vessel performance, which can optimize fuel consumption, reduce CO₂ emissions, and enhance navigational efficiency (Sejmour & Shaeen, 2011). The ISO 23247 Digital Twin Framework for Manufacturing is a series of standards that defines the framework for creating digital twins, with the goal of facilitating their implementation. Essentially, a digital twin is a virtual model of a physical entity or process that allows for the tracking, analysis, and optimization of performance in real-time (iso.org). The digital twin helps in identifying anomalies in manufacturing processes to achieve functional

objectives such as real-time control, predictive maintenance, process adjustments, big data analytics, and machine learning.

From an administrative perspective, the implementation of ISO 23247 requires the establishment of a strategy for the digitization and integration of digital twins into business processes. This includes defining roles and responsibilities, training staff, and ensuring alignment with existing standards and regulations.

From a technical perspective, this implementation involves the development and integration of sensors, data collection systems, and software platforms that enable the creation and management of digital twins. Additionally, it is necessary to ensure interoperability between different systems and guarantee the security and reliability of the data.

ISO/IEC 27032:2023- Guidelines for internet security

The growing digitalization and application of information systems increase the need for more secure protocols, which is why standards such as ISO/IEC 27032:2023 (Guidelines for Internet security) provide guidelines for Internet security by explaining the relationship between internet security, web security, network security, and cybersecurity. These standards address common internet security threats such as social engineering, privacy attacks, hacking, and the spread of malicious software (BIMCO et al., 2022).

From an administrative perspective, implementing this standard requires the development of policies and procedures for the secure use of the Internet, defining roles and responsibilities, and raising employee awareness of security practices. It also necessitates establishing incident response mechanisms and continuously improving security measures to stay ahead of emerging threats.

From a technical perspective, implementation involves security controls such as firewalls, intrusion detection systems, data encryption, and regular software updates. It is also essential to monitor and analyse network traffic to detect and prevent potential threats (Tarek, 2016).

ISO 19030-1:2016

Measurement of changes in hull and propeller performance defines general principles for measuring changes in the performance of a ship's hull and propeller and provides a set of performance indicators for the maintenance, repair, and retrofitting of hulls and propellers (DNV, 2020. Hull Performance & ISO 19030).

The administrative contribution to the implementation of this standard requires establishing procedures for regular monitoring and reporting of hull and propeller performance, as well as planning maintenance and repair activities based on the collected data.

From a technical perspective, the implementation involves the installation of measurement equipment, such as sensors for monitoring fuel consumption and ship speed, and the development of methods to analyse the collected data in order to identify changes in performance and determine appropriate measures.

Energy efficiency and environmental standards

Increased energy consumption and growing CO₂ emission regulations are encouraging shipping companies to implement energy-efficient solutions. The ISO 19030-1 standard, which relates to monitoring the performance of hulls and propellers, helps optimize fuel consumption and reduce the ship's resistance in water, directly impacting ecological sustainability.

Furthermore, the maritime industry is increasingly relying on greener technologies, including the use of LNG fuel, ship electrification, and the adoption of renewable energy sources. The standardization of these technologies enables their broader application and better control over the industry's ecological impact.

Economics and regulatory aspects

The integration of individual systems through standardization not only brings technical and ecological benefits but also financial savings. Standardized approaches to fleet maintenance and management reduce repair costs and the occurrence of unplanned breakdowns. Additionally, compliance with international regulations (e.g., IMO – International Maritime Organization emissions regulations) becomes easier when systems are compatible and aligned with applicable standards.

The integration and standardization of individual systems bring significant benefits to the maritime industry. By using internationally recognized standards, it is possible to improve operational efficiency, reduce costs, enhance cybersecurity, and support sustainable development. Future research and the implementation of innovative technologies, such as digital twins and energy-efficient systems, will further enhance the sector's competitiveness and ensure the long-term sustainability of maritime operations.

The implementation of these standards can significantly improve the efficiency and safety of operations through clearly defined administrative procedures and technical measures.

3. DIGITAL TWINS, INFORMATION SYSTEMS, AND ARTIFICIAL INTELLIGENCE (AI)

The connection between digital twins, information systems, and artificial intelligence (AI) is key to advanced automation and optimization in the maritime industry. These three concepts can be interconnected.

3.1. Digital twins and information systems

Digital twins are virtual replicas of physical systems – in this case, ships, port facilities, or entire logistics chains. These replicas use data from various sensors and information systems to simulate, analyse, and optimize the operation of real-world objects (International Organization for Standardization, 2021).

Information systems are the foundation for the operation of digital twins, as they enable (Majić, 2018):

- data collection from sensors on ships (fuel, engine temperature, propeller performance, weather conditions, etc.),
- data transmission and processing through IoT (Internet of Things) technologies and cloud platforms,
- analysis and decision-making to optimize the ship's operation in real-time.

For example, a digital twin of a ship can use information from an information system to simulate different navigation scenarios and suggest an optimal route that reduces fuel consumption and CO₂ emissions.

3.2. The role of artificial intelligence (AI) in digital twins and information systems

Artificial intelligence enables automated data processing, predictive analysis, and decision-making based on large volumes of information. AI can contribute to the integration of digital twins and information systems in several ways (Parrott & Warshaw, 2017):

a) Predictive maintenance

AI can analyse data from digital twins to predict failures and reduce the number of unplanned downtimes. By using machine learning, patterns indicating potential problems can be identified, such as:

- increased propeller friction due to algae build-up,
- irregularities in engine performance,
- changes in hull performance due to sea conditions.

For example, ships using AI for predictive maintenance can reduce repair and maintenance costs and extend the lifespan of critical components.

b) Route and fuel consumption optimization

AI algorithms use data from information systems (GPS, weather forecasts, marine current data) to enable the digital twin to calculate the most efficient route with the least fuel consumption. For example, a ship using AI can avoid storms, choose a route with lower wind and sea current resistance, and thus reduce operational costs.

c) Automation of operations and autonomous ships

Artificial intelligence enables semi-autonomous and autonomous ships, where digital twins, combined with information systems, facilitate:

- automatic real-time ship control,
- safety analysis of navigation (collision avoidance, speed adjustment),
- communication between ships and ports through smart information systems.

For instance, autonomous ships use AI to analyse sensor data, adjust navigation, and communicate with port infrastructure without the need for human intervention.

3.3. How Does This Integration Change the Maritime Industry?

By connecting digital twins, information systems, and artificial intelligence, the maritime industry gains more efficient, safer, and environmentally sustainable operations. The benefits of such applications include (Mikelsten, Teigens & Skalfist, 2017):

- reduction of operational costs - lower fuel consumption and optimization of maintenance processes,
- increased safety - AI can analyse potential hazards in real-time,
- environmental benefits - reduced CO₂ emissions and improved energy efficiency of ships,
- automation and autonomy - ships become capable of intelligent management without human intervention.

For example, smart ports use AI to monitor the arrival and departure of ships, adjust port operations, and reduce waiting times, which increases the overall efficiency of maritime traffic.

The connection between digital twins, information systems, and artificial intelligence brings revolutionary changes to the maritime industry. By combining these technologies, ships become smarter, safer, and more efficient, while companies can achieve significant savings and reduce their negative impact on the environment (Agnusdei, Elia & Gnoni, 2021). The future of the maritime industry undoubtedly lies in digitalization and smart technologies that enable better predictability, automation, and sustainability.

Figure 1 shows the integration of digital twins, information systems, and artificial intelligence in the maritime industry. The diagram illustrates how data from sensors on ships is used through digital twins, processed by the information system, and decisions are made by AI for route optimization, predictive maintenance, and automation. The benefits, such as cost reduction, improved safety, and environmental advantages, are also highlighted.

The application of artificial intelligence (AI) implies significant changes in the organization, much more than the introduction of new information technologies.

Compliance with international regulations, especially those set by the International Maritime Organization (IMO), is crucial for the maritime industry as it ensures safety, navigation, pollution prevention, and efficiency of ship transport. All IMO member states are required to implement IMO regulations to ensure uniformity in the global maritime industry (OECD/ITF, 2020). One of the key areas in which the IMO plays a role is the regulation of greenhouse gas (GHG) emissions. Through various conventions and amendments, IMO has established standards for reducing pollution from shipping traffic. Some of the most important regulations are:

a) MARPOL Annex VI – Emissions Gas Limitation

The MARPOL (Marine Pollution Convention), particularly its Annex VI, sets limitations on the emissions of harmful gases from ship engines and requires the implementation of technologies that reduce the ecological footprint of the maritime sector (IMO, 2020. MARPOL Annex VI).

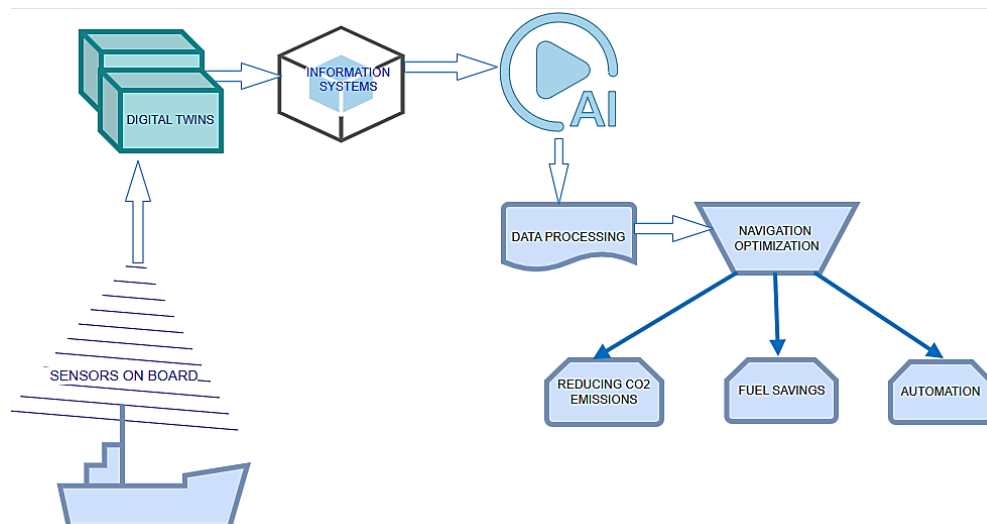


Figure 1. The connection between digital twins, information systems, and artificial intelligence

b) Energy Efficiency Design Index (EEDI) - Mandatory energy efficiency for new ships

IMO introduced the EEDI to encourage the design of more energy-efficient ships:

- New ships must meet fuel consumption standards per ton of cargo transported over a specific distance.
- The limits gradually tighten - ships built after 2025 must have a 30% reduction in CO₂ emissions compared to the 2010 reference values.

c) Carbon Intensity Indicator (CII) - Emission rating for existing ships

The CII applies to existing ships and tracks their operational efficiency regarding CO₂ emissions per unit of distance travelled. Ships are given a rate from A to E, where:

- Ships with a D or E rating must improve their performance or take corrective measures to continue operating without penalties.

d) IMO Strategy for Decarbonization by 2050

The IMO has set a goal to reduce gas emissions by 50% by 2050 compared to 2008 levels, with the long-term aim of complete decarbonization. This includes:

- the use of alternative fuels (LNG, hydrogen, ammonia, biofuels),
- development of hybrid and electric propulsion systems,
- improved ship designs for better aerodynamics and reduced fuel consumption.

3.4. How standardization helps ensure compliance with IMO regulations

Compliance with IMO regulations is a complex process that requires the implementation of international standards to ensure that ships and operations meet the required criteria. Standardization facilitates this process in the following ways:

1. Monitoring ship performance and optimizing emissions
The ISO 19030-1 standard helps monitor changes in the performance of hulls and propellers, enabling shipowners to identify increased fuel consumption and reduce emissions.
2. Safety and cybersecurity of digitalized systems
The digitization of ship systems introduces new security concerns, which is why the ISO/IEC 27032:2023 standard – Guidelines for internet security helps protect data and operations.
3. Introducing digital twins for emission monitoring
ISO 23247 enables the creation of digital twins that can simulate different fuel consumption and emission scenarios, helping to plan optimal routes and operating modes.
4. Standardization of alternative fuel bunkering
Standards for LNG bunkering (ISO 20519) and hydrogen technologies enable the safe and efficient transition to greener fuels in line with IMO goals.
5. Consequences of non-compliance with IMO regulations

If shipping companies fail to meet IMO requirements, they face:

- Fines and restricted access to ports that enforce strict environmental regulations.
- Higher operational costs, as older ships consume more fuel and have lower ratings according to CII standards.
- Loss of competitiveness, as ships with better ratings have an operational advantage and better reputation among clients.

- Possible ban on navigation, as certain regions (e.g., the European Union) plan to implement stricter measures for ships with high emissions.

International standardization and compliance with IMO regulations are inevitable steps for the maritime industry to meet ecological and economic objectives. The adoption of energy-efficient solutions, digital twins, artificial intelligence, and alternative fuels is crucial for reducing emissions and ensuring the sustainability of maritime transport.

4. EFFECTIVENESS OF THE QUALITY SYSTEM

The operation of the business must be continuously monitored and improved with the aim of achieving results and gaining a competitive advantage. In a quality system, everything begins with the requirements of stakeholders and should end with fulfilling those requirements through service characteristics. For the final service to have these characteristics, it is necessary to have a quality management system, consisting of quality structural elements. In the context of meeting the requirements of stakeholders, quality emerges as a resource that ensures satisfaction and helps secure the position of the maritime company through increased competitiveness in the maritime market.

Shipping companies use software packages that enable rapid assessments and a wide range of analyses. The development of a computer system allows the design of a suitable business strategy for maritime companies and effective communication among participants in the maritime market. A fundamental task of management is to select the most advantageous ways of using available resources with the use of technology. In maritime companies, one of the main requirements is the allocation of maritime personnel to appropriate positions based on their qualification structure, while meeting the efficiency requirements of the job positions and creating technological solutions (Pupovac & Zelenika, 2004).

STCW 95 - International Convention on Standards of Training and Certification (The STCW Convention) provided the basic guidelines for maritime education, addressing the growing demands for knowledge and skills among maritime employees in the context of ever-advancing technology and equipment. The core of the STCW 95 convention is to set and maintain adequate and harmonized operational standards, achieved through education and certification conducted at the national level or by maritime companies. Seafarers must be familiar with their specific duties to ensure quality work performance.

5. CONCLUSION

The introduction of new technologies, along with the modern demands for fast and secure transportation of people and goods, has made knowledge of nautical and marine engineering increasingly important, along with its integration into ship transport management, maritime management, and maritime informatics. Every company or business system has its own information system that collects, stores, preserves, processes, and delivers information. Information in the information system is stored in the form of data. Depending on the purpose of data processing, its layers differ: the transaction processing layer handles data during business

Processes, the management support layer prepares information for decision-making and management, and the communication and collaboration layer processes information necessary for communication among participants in the business system.

The goal of the management part of the information system is to provide decision-makers (managers, experts) with the necessary information. This decentralizes and democratizes decision-making by involving an increasing number of participants in the process. Although the management of the organization is tasked with

making business decisions, it cannot be ignored that decision-making occurs daily at all levels, individually or in groups. Decision-makers often make decisions under unfavourable circumstances, such as a lack of time or insufficient expertise, and their cognitive abilities are also limited. Therefore, they need assistance in identifying, finding, and analysing the necessary data or information, choosing methods or models for problem-solving, executing them, and analysing the obtained results, all for the purpose of making quality decisions.

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Cruise Tourism in Split-Dalmatia County from 2021 to 2024

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Considering the importance and economic, social, and environmental impact of cruise tourism, this paper aims to analyse data on foreign cruisers in Split-Dalmatia County from 2021 to 2024. The Croatian Bureau of Statistics publishes reports on foreign cruise ship arrivals in Croatian internal sea waters based on monitoring of the Croatian Integrated Maritime Information System (CIMIS). The beginning of international cruise tourism in Split dates back to 2002 when 82 ships carrying 20,616 passengers visited the City. In 2021, 36 foreign cruise ships made 208 voyages with 193,911 passengers, spending 568 days in Croatian waters. Of the journeys, 27.4% were recorded in Split-Dalmatia County. The Port of Split, with 124 visits, was the busiest port in the county and the second busiest in Croatia in 2021, while Hvar, with 41 calls, was the second busiest port in the county and the fifth busiest in Croatia. In 2022, 32.4% of the 632 cruise journeys in Croatia were recorded in the county. The Port of Split was the second busiest port in Croatia in 2022, with 272 visits, while Hvar ranked fourth with 98 visits. In 2023, 26.9% of the 646 journeys in Croatia were recorded in the county, while Split ranked second with 300 visits and Hvar fourth with 110 visits on the list of most visited Croatian ports. In 2024, the number of journeys increased further to 736, of which 24.2% were recorded in the county. Split was in second place on the list of the most visited Croatian ports, with 331 visits, and Hvar was in fourth place with 118 visits. These figures demonstrate the sector's great potential, but it must be managed sustainably to reach its full potential and benefit the community.

KEYWORDS

Cruise; Tourism; Sustainability; Split-Dalmatia county; Croatia

1. INTRODUCTION

Cruise tourism is an essential sub-sector of tourism as it contributes to the gross domestic product (GDP), creates jobs, and generates opportunities for local communities (EC, 2023). In 2023, the European cruise industry generated €55.3 billion and supported approximately 400,000 jobs (CLIA, 2025). Unfortunately, the cruise industry's negative environmental and cultural impacts are also well-documented, particularly in certain parts of the world (MacNeill and Wozniak, 2018; Špoljarić, 2020; Lloret et al., 2021; EC, 2023; Chou et al., 2024).

The Mediterranean is the most popular cruise destination in Europe and the second most popular worldwide (Kovačić and Silveira, 2020). The Adriatic is the fastest-growing cruise region in the Mediterranean, as shown by the number of passengers and port calls (Dorigatti et al., 2022). With 1.3 million passengers in 2018, Croatia was the second most visited country in the Mediterranean (Kovačić and Silveira, 2020).

Tourism is of paramount importance to the Croatian economy, as it is heavily reliant on tourism and accounts for 19.1% of the country's GDP (HTZ, 2025). In 2023, two essential documents were adopted in Croatia: a new Strategy for the Sustainable Development of Tourism until 2030 (Official Gazette 2/2023) and a new Tourism Act (Official Gazette 156/2023-2382), which provides local governments greater autonomy in decision-making (RCMTS, 2025).

Split-Dalmatia County is the largest Croatian county, spanning a total area of 14,106 km² and a sea area of approximately 9,576 km², which accounts for around 30% of the Croatian coastline (SDC, 2025). Its exceptional location and rich natural and cultural heritage (including UNESCO sites such as the Historical Complex of Split with the Palace of Diocletian, the Historic City of Trogir, and the Stari Grad Plain on the island of Hvar) have contributed to a tourist boom in recent decades.

The city of Split is the administrative second-largest city in Croatia. Due to its exceptional geographical position and maritime characteristics, as well as its rich cultural and natural heritage, the Port of Split has become a key destination for cruise ships. The beginning of international cruise tourism in Split dates back to 2002 when 82 ships carrying 20,616 passengers visited the Port (Split Port Authority, 2025). Since then, cruisers from all major cruise lines: Carnival Cruises, Royal Caribbean Cruises, MSC Cruises, Costa Crociere, Cunard Line, Radisson Cruises, Celebrity Cruise, Fred Olsen Cruise Line, Club Med Cruises, Thomson Cruises, P&O Cruises, Norwegian Cruises Line, Viking Ocean Cruises, Princess Cruises, and many others have visited the Port of Split.

Considering the importance and economic, social and environmental impact of cruise tourism, this paper aims to analyse data on foreign cruisers in Split-Dalmatia County for the period from 2021 to 2024 based on monitoring by the Croatian Integrated Maritime Information System (CIMIS). This analysis can provide an initial insight into the sector and serve as a starting point for further, more detailed trend analyses and the identification of the most significant challenges, as well as for investigations into the sector's sustainability in the county.

2. MATERIALS AND METHODS

The data was collected from the Croatian Bureau of Statistics, which publishes reports on the arrivals of foreign cruise ships in Croatian internal sea waters based on monitoring by the Croatian Integrated Maritime Information System (CIMIS). Ships submit information about the ship, journey, and passengers to this system via authorised shipping agents and shippers. At the same time, the accuracy of the data is verified by the harbour master's offices (DSZRH, 2022).

3. RESULTS

Table 1. shows the number of foreign ships on cruises, journeys, sojourns, and passengers on board in Croatia from 2019 to 2024 (DSZRH, 2021; DSZRH, 2022; DSZRH, 2023; DSZRH, 2024; DSZRH, 2025).

Year	Number of foreign ships on cruise	Journeys	Sojourns	Passengers on board
2019	75	726	1466	1120727
2020	10	26	124	4138
2021	36	208	568	193911
2022	82	632	1324	633697
2023	85	646	1474	868542
2024	86	736	1690	1048916

Table 1. Number of foreign vessels on cruises, cruises, sojourns, and passengers on board in Croatia from 2019 to 2024

In 2021, 36 foreign cruise ships made 208 journeys with 19,3911 passengers and spent 568 days in Croatian waters. In 2021, the number of journeys on cruise ships increased by 182, the number of sojourns increased by 444 days, and the number of passengers increased by 190,000 compared to 2020. Despite the increase in cruise activity in 2021 compared to 2020, the number of journeys decreased by 71.3%, the number of sojourns decreased by 61.3%, and the number of passengers decreased by 82.7% (DSZRH, 2022).

In June 2021, foreign cruise ships resumed sailing along the Croatian Adriatic Sea after cruise activities had been suspended for eight months, i.e., from October 2020. In 2022, they sailed all year round, indicating a certain recovery in cruise activities, which had come to a complete standstill from February 2020 (DSZRH, 2021) to June 2021 (DSZRH, 2022). In 2022, the number of foreign ships increased to 82, which made 632 journeys, covering 1,324 days and carrying 633,697 passengers. The number of journeys and the number of passengers on board tripled. In contrast, the number of sojourns doubled in 2022, compared to 2021, when strict epidemiological measures were introduced to limit the number of passengers on board cruise ships due to the COVID-19 pandemic. Despite the substantial increase in cruise activity in 2022 compared to 2021, the number of journeys decreased by 12.9%, the number of sojourns by 9.7%, and the number of passengers on board ships by 43.5% in 2022 compared to 2019 (DSZRH, 2023).

Following the strong growth in cruise activity in 2022, the number of foreign ships, journeys, sojourns, and passengers on board continues to increase in 2023 compared to 2022, albeit at a slower rate (85 cruise ships, 646 journeys – 2.2%, 1,474 sojourns – 11.3% and 8,68,542 passengers on board – 37.1%). Comparing cruise activity data from 2023 with data from 2019, the impact of the COVID-19 pandemic is still evident, as the number of journeys decreased by 11% and the number of passengers by 22.5%, while the number of sojourns increased by 0.5% (DSZRH, 2024).

In 2024, 86 ships made 736 journeys with 1690 sojourns and 1048916 passengers on board. The number of journeys increased by 13.9% in 2024 compared to 2023, the number of sojourns by 14.7%, and the number of passengers on board the ships by 20.8%. The number of journeys increased by 1.4%, and the number

of sojourns rose by 13.3%. However, the number of passengers on board ships declined by 6.4% in 2024 compared to 2019 (DSZRH, 2025).

Figure 1. shows the number of journeys per month in 2021, 2022, 2023, and 2024 (DSZRH, 2022; DSZRH, 2023; DSZRH, 2024; DSZRH, 2025). January was the month with the fewest journeys (1 in 2022, 1 in 2023, and 5 in 2024), and the number of journeys increased continuously from January to June. The peak season for cruises is from June to October, with most journeys usually taking place in August (113 in 2022, 107 in 2023) or September (119 in 2024). The highest number of cruises in 2021, 50, occurred in October, marking the first year after the COVID-19 pandemic. The number of sojourns fell from October to December.

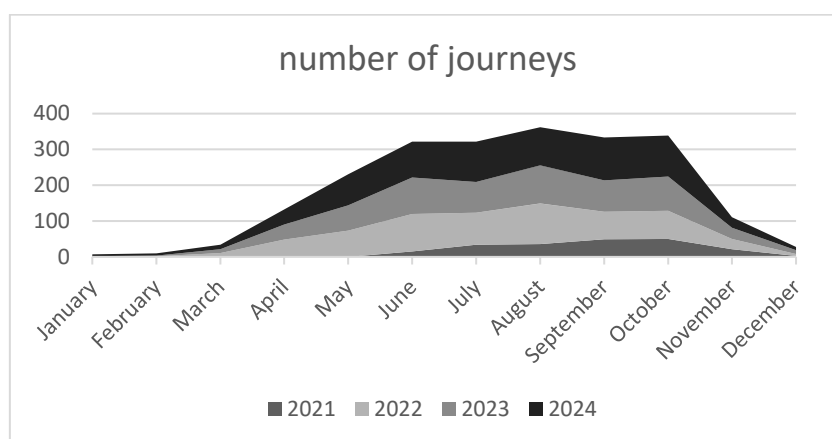


Figure 1. Number of journeys per month in 2021, 2022, 2023 and 2024

Figure 2. shows the number of sojourns per month in 2021, 2022, 2023, and 2024 (DSZRH, 2022; DSZRH, 2023; DSZRH, 2024; DSZRH, 2025). January was the month with the fewest sojourns (1 in 2022, 1 in 2023, and 16 in 2024), and the number of journeys increased continuously from January to June. The highest number of sojourns occurred in August (269 in 2022, 237 in 2023, and 237 in June 2023) or in September (135 in 2021 and 297 in 2024). The number of sojourns fell from October to December.

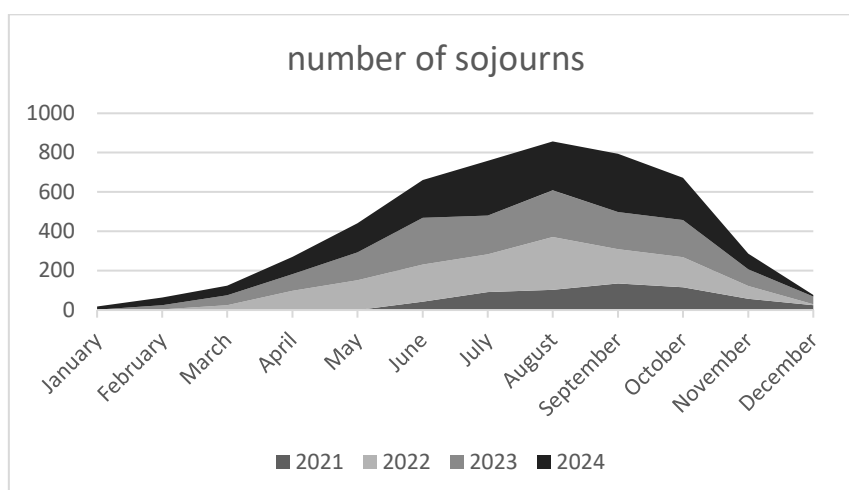


Figure 2. Number of journeys per month in 2021, 2022, 2023 and 2024

Figure 3. shows the number of passengers on board per month in 2021, 2022, 2023, and 2024 (DSZRH, 2022; DSZRH, 2023; DSZRH, 2024; DSZRH, 2025). January was the month with the fewest passengers on board

in 2022 (485), while February 2022 (94) and 2023 (1,152) had the lowest number of passengers. The number of passengers on board rose continuously from January/February to July. The highest passenger numbers were recorded in August 2022 (129,638) and 2023 (151,975), September 2021 (51,605), and October 2024 (182,313). The number of sojourns decreased from October to December.

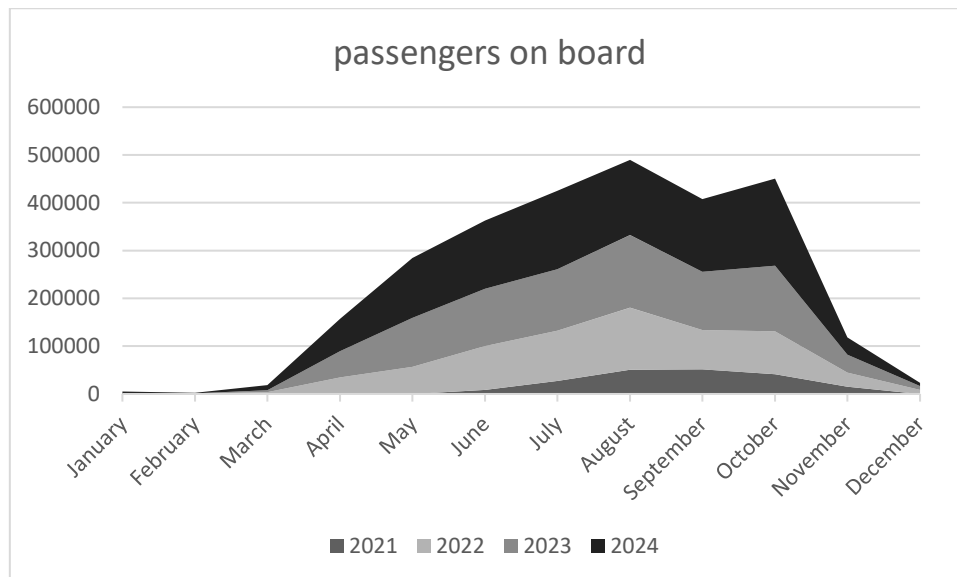


Figure 3. Number of passengers on board per month in 2021, 2022, 2023 and 2024

In Split-Dalmatia County, 57 out of 208 total journeys in Croatian waters (27.4%) were recorded in 2021 (DSZRH, 2022), 205 out of 632 journeys (32.4%) in 2022 (DSZRH, 2023), 174 out of 646 journeys (26.9%) in 2023 (DSZRH, 2024) and 178 out of 736 (24.2%) in 2024 (DSZRH, 2025). Thus, 2022 was a record year in terms of the highest share of journeys in Split-Dalmatia County in the total number of journeys in Croatia (32.4%), while 2024 was the year with the lowest share (24.2%).

Figure 4. shows the most visited seaports in Croatia from 2021 to 2024 (DSZRH, 2022; DSZRH, 2023; DSZRH, 2024; DSZRH, 2025).

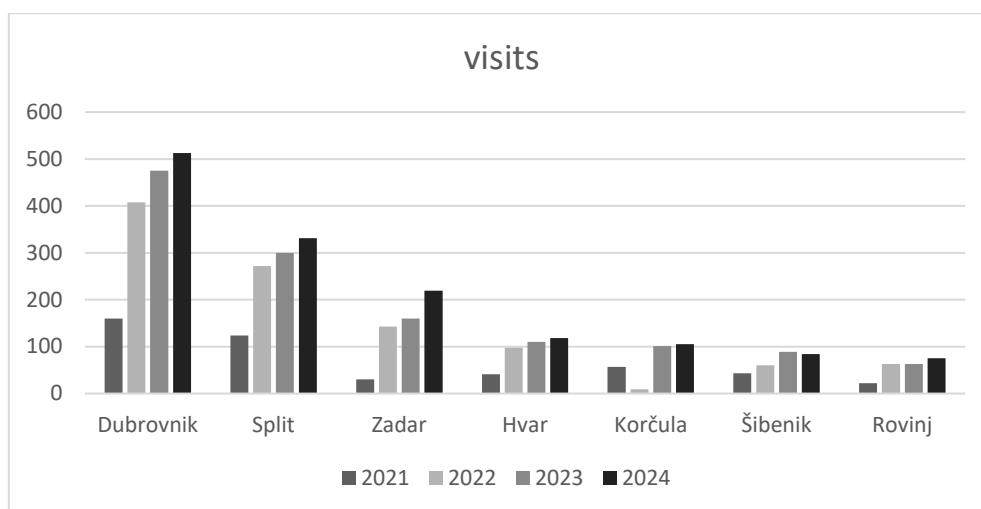


Figure 4. The most visited seaports in Croatia from 2021 to 2024

In 2021, Split (124 visits out of a total of 477 visits to Croatian ports or 26%) was the busiest port in Split-Dalmatia County and the second busiest in Croatia, and Hvar (41 visits or 8.6%) was the second busiest port in the county and the fifth busiest in Croatia (DSZRH, 2022). In 2022, Split was the second busiest port in Croatia, with 272 visits out of a total of 1,135 visits to Croatian ports (24%), and Hvar was the fourth busiest port, with 98 visits or 8.6% (DSZRH, 2023). In 2023, Split retained second place, with 300 visits out of a total of 1,197 visits to Croatian ports, or 25%. Hvar took fourth place, with 110 visits, or 9.2%, on the list of most visited Croatian ports (DSZRH, 2024). In 2024, Split ranked second on the list of most visited Croatian ports, with 331 visits out of a total of 1,445 visits to Croatian ports, or 22.9%. Hvar ranked fourth, with 118 visits, or 8.2% (DSZRH, 2025).

If the number of cruise ships, journeys, sojourns, and passengers continues to increase, constant monitoring and analysis of all risks, along with the implementation of appropriate measures, are necessary to maintain the sector's sustainability in all three dimensions: economic, environmental, and social. The new Croatian Tourism Act creates a framework for the systematic monitoring and development of the sector (RCMTS, 2025b). In addition to the Tourism Act and the Strategy for the Sustainable Development of Tourism until 2030, Croatia has also adopted a National Plan for the Sustainable Development of Tourism until 2027. Nevertheless, additional national regulations and/or guidelines are explicitly required for cruise tourism.

Every year, Split-Dalmatia County publishes an analysis of the tourist season, providing the most essential guidelines for the upcoming season. The county has published the Master Plan for the Development of Tourism in Split-Dalmatia County (2017 – 2027) with a Strategic and Operational Marketing Plan. The Master Plan outlines guidelines for both international and domestic cruises, emphasizing the importance of assessing, planning, and enhancing the infrastructure for international cruise ships in the Port of Split and the Port of Hvar while also involving all stakeholders in the planning process (TZSDŽ, 2018). In 2023, the UNESCO World Heritage Management Plan for the Historical Complex of Split, including the Palace of Diocletian, was adopted. Activity 8.3: The Introduction of a Sustainable Model for Cruise Ship Visitor Management has highlighted the need to regulate and optimise the number of cruise ships visiting the Port of Split in cooperation with the Split Port Authority. In this sense, it is essential to develop activities that diversify the tourist offer to minimise pressure on the Historical Complex of Split and maximise profits (Grad Split, 2023).

Cruise tourism has a strong impact on destinations, including economic, environmental and social impacts, which can be both positive (new business opportunities, additional income, better port and city infrastructure, increase in living standards, etc.) and negative (higher prices, change in lifestyle, lower quality of life, negative impact on the environment, etc.). Although the local population is generally positive towards cruise tourism, they are aware of the negative impacts of tourism on their quality of life (Brida et al., 2012).

Exploring awareness of the positive and negative aspects of cruise tourism among local stakeholders, such as business owners and residents, could provide important insights into their perspective and recommendations for future improvements in port-city relations (Vukić et al., 2021.). If stakeholders and especially the local population have a positive attitude towards cruise tourism, they will more easily tolerate the negative side effects of tourism development and be friendlier towards tourists (Sindik et al., 2017).

As Split is a relatively small Mediterranean city, overcrowding is very likely and the city's infrastructure cannot easily handle a large number of visitors at once, which challenges the locals' perception of the benefits of the cruise industry.

In 2014, Ćosić & Favro (2016) surveyed 120 citizens of Split and 20 professionals on the impact of cruise tourism on the Split region. The respondents believed that cruise tourism had positive economic and mainly

negative impact on the environment and that there is no negative impact of cruising on the quality of life, tradition or cost of living. The authors attributed these results to citizens' lack of knowledge about the impact of cruise tourism (Ćosić & Favro, 2016). Vukić et al. (2021) conducted the study on the impact of cruise tourism on the local population (366 respondents) and business actors (17 respondents) in the port of Split in 2019 using questionnaires and personal interviews. Respondents recognised the economic and social benefits of cruise tourism, but at the same time were not fully aware of the negative impact of the sector and had a limited understanding of the concept of sustainability.

There is a very interesting survey by Knezović and Perić (2024) on the perception of 134 Split residents regarding the impact of cruise ships. The study found that 33% of respondents believed that cruise ships have an impact on them or their families in the form of negative impact on the environment (9.56% of respondents), increased workload and earnings (7.35% of respondents), negative social impact due to overcrowding (4.41% of respondents) and positive impact on the local economy (1.47% of respondents). In addition, 52% of respondents agreed that modern cruise ships have a negative impact on the environment, 36% were indifferent and 12% believed that modern cruise ships are environmentally friendly. When asked whether the number of cruise ships in the port of Split should be limited, 59% of respondents answered yes, 26% no and 15% indifferent. Respondents were also asked to suggest measures to reduce the negative impact of cruise ships on the environment. The suggestions were categorised as one of the following: *Cruise ship measures* – limit or completely ban cruise ship arrivals (33.1% of respondents) or more environmentally friendly ships (1.41%); *Port measures* – improve port infrastructure or build a new port outside the city centre (9.15% of respondents); *Measures relating to legislation and the way business is done* - improving regulations and controls (26.01% of respondents), introducing green taxes (4.93% of respondents) or investing in green initiatives (6.41% of respondents); and finally, *Social measures* such as raising awareness or changes in city governance (1.41%). The study concludes that the majority of respondents are aware of and concerned about the negative impact of cruise tourism on the quality of life in their city (Knezović and Perić, 2024).

Nonetheless, all cruise tourism stakeholders should be committed to the sustainability and innovative capacity of the sector in order to overcome the challenges in the cruise industry. The guidelines for the sustainability of cruises & recreational boating in the Mediterranean region (Plan Bleu, 2022) identify the main challenges facing the sector: eliminating air pollutant and greenhouse gas emissions, protecting ecosystems and biodiversity, eliminating water pollution, preventing waste generation and improving waste management, promoting knowledge and innovation and avoiding impacts on local socio-economic systems. In 2023, the European Commission published the Good Practices for Sustainable Cruise Tourism, in which the:

- high priority challenges in the cruise industry (greenhouse gas emissions, wastewater and certain forms of waste, hull biofouling, collisions/physical disturbance with marine life, light and dredging);
- medium priority challenges (noise in port, underwater noise and solid food waste) and
- low priority challenges (waste heat), (EC, 2023).

Potential environmentally friendly solutions were also analysed, such as: alternative fuels (LNG, biofuels, hydrogen and ammonia and synthetic carbon-based fuels) and alternative forms of power generation (auxiliary wind power), various systems (batteries, fuel cells, end-of-pipe technologies, air lubrication systems....), ship design changes (hull design optimisation, ship size...), shore-side solutions (onshore power supply) and voyage optimisation (speed and route optimisation, trim and draught optimisation, data analytics and automation, port call optimisation and smart docking systems), (EC, 2023). Although there are many environmentally friendly solutions, none of them are yet fully developed. Therefore, the support of all stakeholders remains the key factor in making cruising fully sustainable.

4. CONCLUSIONS

Cruise tourism has been an important part of the Split-Dalmatia County economy since 2002 and a driver of stabilisation and economic prosperity. Following the period from October 2020 to June 2021, when the COVID-19 pandemic brought cruise tourism to a complete standstill for eight months, the industry experienced a recovery in 2022. It is expected that the 2019 figures will be fully reached again in the Croatian Adriatic by 2025. The share of cruises recorded in Split-Dalmatia County among total cruises in Croatian waters was between 24.2% and 32.4% from 2021 to 2024. The Port of Split was the busiest port in Split-Dalmatia County and the second busiest in Croatia, with a share of 22.9% to 26% of total visits to Croatian ports. In comparison, Hvar was the second busiest port in the county, ranking fourth, with a share of 8.2% to 9.2% of total visits to Croatian ports. This paper highlights the significant potential of the sector for the county. However, as the number of cruise ships, journeys, sojourns, and passengers continues to increase, it must be managed sustainably to reach its full potential and benefit the community. The long-term success of cruise tourism depends to a large extent on the involvement and co-operation of all stakeholders in the planning and development of the sector. It is therefore important to continuously monitor the satisfaction of all stakeholders, especially the local communities, and to consider and support their wishes and suggestions. Split-Dalmatia County could further develop its brand as a destination with unspoiled nature, rich cultural heritage, warm hospitality, and good value for money, leveraging its proximity to the European tourist market. However, full attention should be paid to green and digital transformation for the sustainability of the sector.

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Sensor Technology and its Applications in Augmented Reality

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The integration of sensor technologies and augmented reality (AR) is transforming the maritime industry, particularly in the context of autonomous ships. This article explores the application of sensor technologies such as LiDAR, radar, and computer vision systems alongside AR interfaces to enhance the operational efficiency, safety, and autonomy of maritime vessels. The sensors enable real-time data acquisition, providing autonomous systems with situational awareness to navigate and respond to dynamic maritime environments. AR technology further supports these systems by overlaying critical data onto real-world visualizations, improving operator decision-making and remote monitoring capabilities. The article reviews the current state of sensor and AR technologies in autonomous shipping, presents case studies of their application, and discusses the challenges of data integration, reliability, cybersecurity, and regulatory frameworks. Future research directions are also identified, including advancements in AI, sensor robustness, and cybersecurity to address existing limitations. Ultimately, the article underscores the potential of sensor and AR technologies to revolutionize maritime operations, paving the way for safer, more efficient, and fully autonomous shipping systems. In maritime applications, AR is implemented primarily through, smartphones, heads-up displays (HUDs), AR glasses, or tablet-based interfaces. These devices allow operators to view vital navigational data, environmental conditions, and vessel performance metrics without looking away from the operational environment. This paper proposes innovative way to merge sensor technology with AR display to enhance security and safety in shipping.

KEYWORDS

Sensor technology, Augmented reality, Maritime industry, Remote monitoring

1. INTRODUCTION

The maritime industry is undergoing a technological revolution, with sensor technology and augmented reality (AR) at the forefront of this transformation. These technologies are reshaping how maritime operations are conducted, from navigation and safety to maintenance and training. This article aims to provide a comprehensive overview of sensor technology and its application in AR systems within the maritime context. Sensor technology forms the backbone of modern data collection and environmental interaction systems. In the maritime sector, sensors play a crucial role in gathering real-time data about vessel performance, environmental conditions, and navigational parameters. When combined with AR, this sensor data can be visualized in intuitive and actionable ways, enhancing situational awareness and decision-making capabilities for maritime professionals. Augmented reality, which overlays digital information onto the real world, has emerged as a powerful tool for presenting complex data in easily understandable formats. In maritime applications, AR can provide critical information directly in the user's field of view, reducing the need to consult multiple displays or instruments. This article will explore the theoretical foundations of sensor technology, its evolution, and its current state in maritime applications. It will then delve into how sensor data is integrated with AR systems to create powerful tools for maritime operations. Finally, it will examine practical examples of these technologies in use and discuss future directions for research and development.

1.1. Relevant research

Augmented reality (AR) technology is increasingly being explored for maritime navigation applications to enhance situational awareness and safety. Several recent studies have investigated the potential of AR to support navigation in compromised visibility conditions and improve data visualization for maritime operators. Ujkani et al. (2024) conducted in-situ testing of mixed reality systems for remote pilotage, finding that AR interfaces improved task accuracy by 23% compared to traditional setups, though VR scored higher in usability. Their study highlighted challenges like latency and cybersickness that need to be addressed. Laera et al. (2021) provided a systematic review of AR for maritime navigation data visualization, discussing issues and perspectives around implementing AR in maritime contexts. They emphasized the need for effective data representation to improve decision-making at sea. Templin et al. (2022) explored using AR and VR to support safe navigation on inland and coastal waterways. They developed prototype applications integrating bathymetric data, AIS information, and other sensor inputs to enhance situational awareness. Zhang et al. (2025) proposed an AR-based waterway traffic management system using multi-source data fusion of video, AIS, and hydrological information. Their approach aimed to improve ship detection and tracking in challenging visibility conditions. Nordby et al. (2024) presented a user interface design framework for AR-supported maritime navigation, outlining design requirements and evaluation methods developed through iterative prototyping and testing with end-users. Bandara et al. (2020) investigated using AR to generate artificial navigation light objects to aid navigation in low visibility. They conducted experiments to calibrate holographic signals and validate their effectiveness as navigational aids. van den Oever (2023.) gives a systematic review of augmented reality for maritime collaboration. All these studies collectively demonstrate the potential for AR to enhance maritime navigation and safety, while also highlighting technical and human factors challenges that need to be addressed as the technology matures. Ongoing research continues to refine AR applications for the maritime domain.

2. THEORETICAL FOUNDATIONS OF SENSOR TECHNOLOGY

2.1. Basic Principles of Sensor Functionality

Sensors are devices that detect changes in the environment and convert them into signals that can be measured and analyzed. The basic principle of sensor functionality involves detecting physical, chemical, or biological phenomena and translating them into electrical signals. This process typically involves three key components:

1. Energy conversion: Sensors convert one form of energy to another. For example, a photovoltaic sensor converts light energy into electrical energy
2. Signal conditioning: The raw signal from the sensor is often modified to make it suitable for further processing. This may involve amplification, filtering, or other forms of signal manipulation
3. Data processing: The conditioned signal is then analyzed to extract meaningful information

In maritime applications, sensors are used to measure a wide range of parameters, including temperature, pressure, motion, and chemical composition of air and water. Maritime operations utilize a variety of sensor types, each designed for specific applications. Figure 1. is showing main types of sensors used for maritime applications.

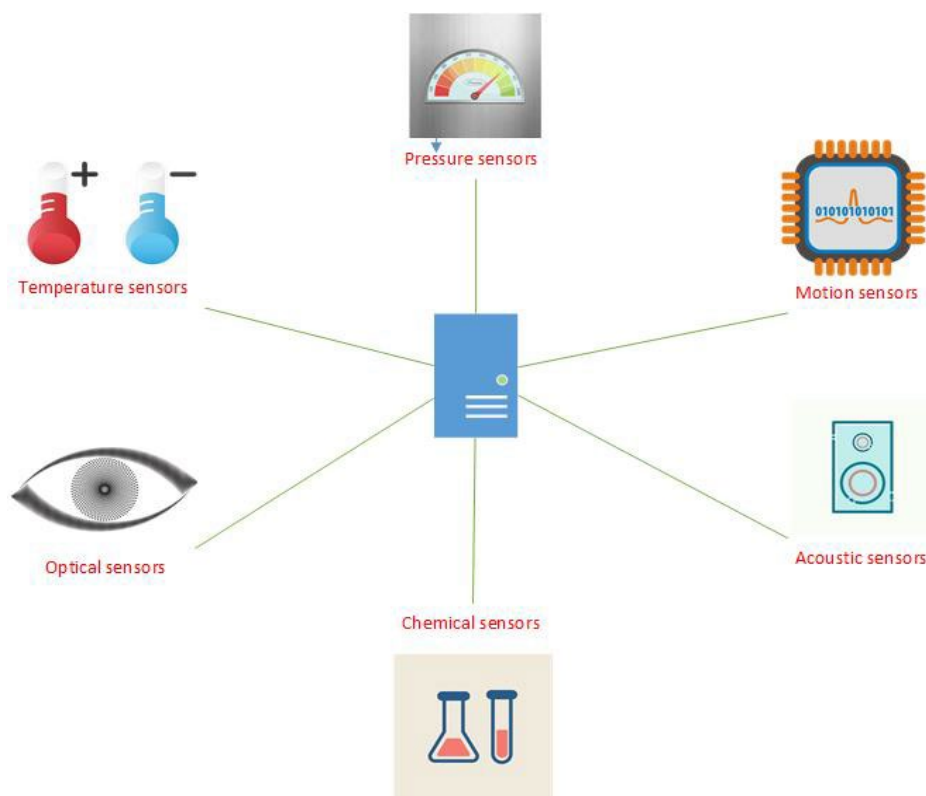


Figure 1. Types of Sensors in Maritime Applications

Maritime operations rely on a diverse range of sensors, each serving critical functions to ensure efficiency and safety. Temperature sensors are essential for monitoring engine performance and cargo conditions, while pressure sensors are used in systems like engine monitoring and depth measurement. Motion sensors, including accelerometers and gyroscopes, play a key role in navigation and stability control. Optical sensors are vital for imaging systems and obstacle detection, whereas chemical sensors monitor air and water

quality and detect potential pollutants. Finally, acoustic sensors are integral to sonar systems, enabling depth measurement and underwater obstacle detection. Together, these sensors form the backbone of modern maritime technology.

The development of sensor technology in the maritime industry has been characterized by significant advancements, including miniaturization, increased accuracy, wireless connectivity, and smart sensors. Miniaturization has led to smaller, more energy-efficient sensors that can be integrated into a wider range of maritime systems. Modern sensors offer higher precision and reliability compared to their predecessors. The advent of wireless sensor networks has revolutionized data collection and monitoring in maritime environments. Additionally, smart sensors with onboard processing capabilities have emerged, enabling real-time data analysis and decision-making. These advancements have collectively transformed the maritime industry, enhancing operational efficiency, safety, and environmental monitoring capabilities.

3. AUGMENTED REALITY IN MARITIME OPERATIONS

3.1 Principles of Augmented Reality

Augmented reality is a technology that superimposes digital information onto the user's view of the real world. In maritime applications, AR systems typically consist of the following components shown on Figure 2.

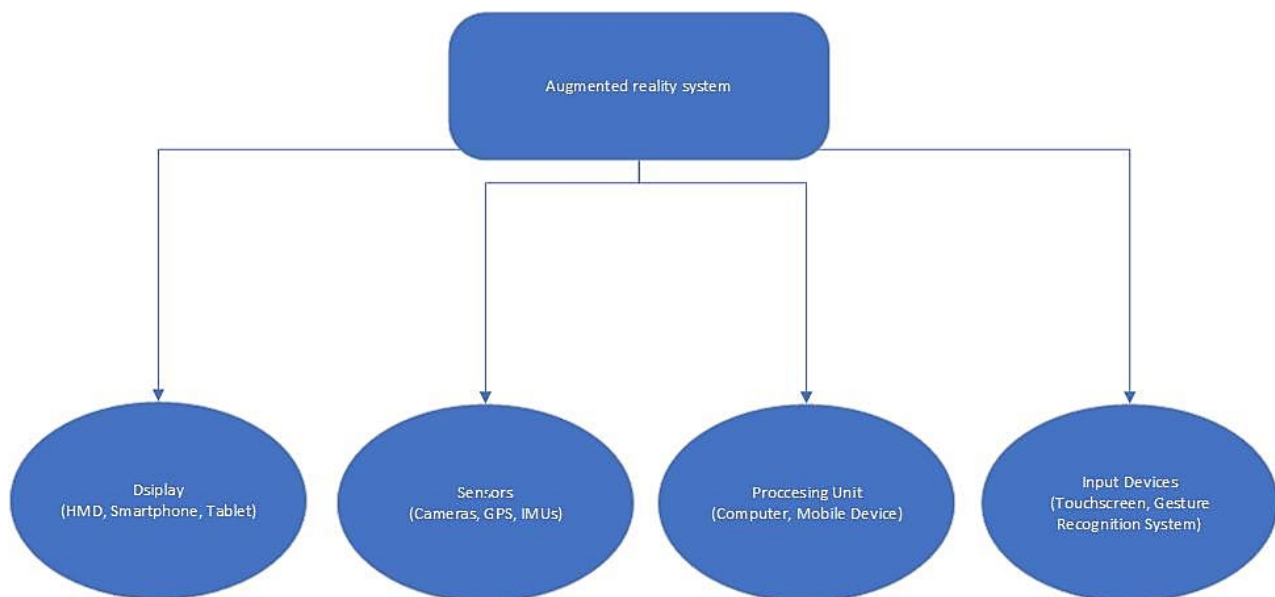


Figure 2. Augmented reality system components

The integration of sensor data with Augmented Reality (AR) systems represents a pivotal advancement in maritime operations, offering a sophisticated approach to enhancing safety, efficiency, and decision-making at sea. This integration process involves a series of intricate steps, beginning with the collection of real-time data from a variety of sensors deployed throughout the vessel and its surrounding environment. These sensors continuously gather crucial information on factors such as weather conditions, vessel performance, navigational data, and potential hazards.

Once collected, this vast array of data undergoes comprehensive processing and analysis. Advanced algorithms and machine learning techniques are employed to sift through the information, identifying patterns, anomalies, and critical insights that might otherwise go unnoticed. This processed data is then transformed into

visual elements that can be seamlessly integrated into the user's field of view through AR technology. The visualization step is particularly crucial, as it involves converting complex data sets into intuitive, easily understandable graphical representations. These might include color-coded overlays, 3D models, or dynamic icons that convey information at a glance. The challenge lies in presenting this information in a way that enhances rather than overwhelms the user's perception of their environment. Registration, the final step in this integration process, ensures that the virtual elements are precisely aligned with the real-world environment. This alignment is critical for maintaining the accuracy and reliability of the AR system, especially in the dynamic and often unpredictable maritime setting. Advanced tracking systems and spatial mapping technologies are utilized to achieve this seamless integration of virtual and real elements. The benefits of this integrated AR system in maritime operations are manifold and far-reaching. Perhaps most significantly, it dramatically enhances situational awareness among crew members. By overlaying critical information directly onto their view of the real world, AR systems enable maritime professionals to make quick, informed decisions based on a comprehensive understanding of their environment. This could include real-time updates on weather patterns, the positions of nearby vessels, or underwater topography – all visible without having to consult separate instruments or displays. The improvement in decision-making capabilities is another key advantage. By presenting complex data in intuitive, visual formats, AR systems make it easier for operators to process and act upon information quickly. This is particularly valuable in high-stress situations where split-second decisions can have significant consequences. Safety is paramount in maritime operations, and AR systems contribute substantially to this aspect. By highlighting potential hazards, providing clear navigation aids, and offering instant access to safety protocols, these systems can significantly reduce the risk of accidents. For instance, AR could visually mark safe navigation channels in challenging waters or highlight the location of safety equipment on board. Furthermore, the application of AR in maritime training has opened up new possibilities for efficient and effective skill development. Trainees can now engage with immersive, interactive learning experiences that simulate real-world scenarios without the associated risks. This not only accelerates the learning process but also allows for the practice of emergency procedures and rare events that would be difficult or dangerous to replicate in real life. As this technology continues to evolve, we can expect to see even more sophisticated applications in the maritime industry. Future developments might include more advanced predictive capabilities, integration with autonomous systems, and enhanced collaboration tools that allow for remote expertise to be seamlessly integrated into on-site operations. The ongoing refinement of sensor technology and AR systems promises to further revolutionize maritime operations, leading to safer, more efficient, and more sustainable practices across the industry.

4. PRACTICAL APPLICATIONS OF SENSOR-ENABLED AR IN MARITIME

4.1 Navigation and Collision Avoidance

One of the most significant applications of sensor-enabled AR in maritime operations is in navigation and collision avoidance. AR systems can integrate data from various sensors, including GPS, radar, and AIS (Automatic Identification System), to provide a comprehensive view of the vessel's surroundings. For example, the ARVCOP (Augmented Reality Vessel Conning and Pilotage) system developed by Technology Systems Inc. uses AR to overlay navigational information onto the real-worldview. This system creates virtual "rails" on both sides of the ship's track, helping with steering in low visibility conditions. The system integrates data from multiple sensors to provide real-time information about the vessel's position, speed, and heading, as well as the location of other vessels and potential obstacles. Another example is the use of AR for enhancing visibility in adverse weather conditions. The LYYN system, for instance, uses AR technology to enhance visibility in real-time in fog, dust, lowlight, snow, and smoke conditions. By extracting and enhancing barely visible features from sensor data, the system provides a clearer view of the environment, improving navigational safety.

4.2 Maintenance and Repair

Sensor-enabled AR systems are also proving valuable in maintenance and repair operations in the maritime industry. These systems can provide technicians with real-time information about equipment status, maintenance procedures, and repair instructions. For instance, AR systems can integrate data from various sensors embedded in ship machinery to provide a visual overlay of the equipment's current status. This can include information such as temperature, pressure, vibration levels, and operational hours. When a technician approaches a piece of equipment, the AR system can display this information directly in their field of view, along with any relevant maintenance alerts or historical data. Moreover, AR systems can provide step-by-step visual instructions for maintenance and repair procedures. By integrating sensor data with 3D models of equipment, these systems can guide technicians through complex tasks, highlighting specific components and providing real-time feedback on their actions.

4.2 Training and Simulation

Sensor-enabled AR systems are revolutionizing training in the maritime industry by providing immersive, interactive learning experiences. These systems can simulate a wide range of scenarios, allowing trainees to practice their skills in a safe, controlled environment. For example, AR-based training systems for bridge operations can integrate data from simulated sensors to create realistic scenarios. Trainees can interact with virtual instruments and displays, while the system responds in real-time based on their actions. This allows for the simulation of various weather conditions, traffic scenarios, and emergency situations. The Maritime Augmented Reality System (MARS) developed by Rolls-Royce is an excellent example of this application. MARS uses AR to create a virtual bridge environment, allowing operators to control and monitor a vessel from a remote location. The system integrates data from various sensors on the actual vessel, providing a realistic and responsive training environment.

4.3 Environmental Monitoring

Sensor-enabled AR systems are also being used for environmental monitoring in maritime operations. These systems can integrate data from various environmental sensors to provide real-time information about water quality, air pollution, and marine life. For instance, AR systems can visualize data from underwater sensors to provide information about water temperature, salinity, and pollutant levels. This information can be overlaid onto a real-time view of the water surface, allowing for easy identification of areas of concern. Similarly, AR systems can integrate data from air quality sensors to provide information about emissions and air pollution levels around ports and vessels. This can be particularly useful for ensuring compliance with environmental regulations and for planning more environmentally friendly shipping routes.

5. METHODOLOGY

The project focuses on developing an Android application to assist marines in navigating the sea safely and efficiently by providing real-time sensor data on a single, user-friendly display. The application will be designed to run across multiple platforms, including mobile phones and tablets, ensuring adaptability for various operational needs and environments. A key feature of this application is its integration with a centralized server that streams video data from a stationary camera installed at the entrance of a ferry. This camera monitors all vessels entering and leaving the port, providing critical visual information about maritime traffic. By incorporating this live video feed into the application, marines will have access to a dynamic view of their surroundings, enabling them to make informed decisions and avoid potential collisions. To achieve this functionality, the app will establish robust communication with the server's database, allowing for seamless and fast fetching, updating,

and synchronization of observed data. This ensures that users receive accurate and up-to-date information in real time, which is essential for safe navigation in busy port areas. The prototype will prioritize the development of a highly interactive graphical interface that overlays real-time sensor data onto the live video feed from the stationary camera or the device's camera when needed. By combining these elements, the application will provide marines with an all-in-one tool for enhanced situational awareness, enabling them to monitor vessel movements effectively and navigate complex maritime environments with greater ease. This innovative solution is designed to improve operational safety and efficiency while leveraging cutting-edge technology to address the unique challenges faced by marines in port areas and open seas.

6. RESULTS

Proposed system consists of surveillance camera mounted in ferry entrance, video input stream captured and used to detect vessels on video and android device on vessels that are getting real time data about situation on ferry entrance. System is shown on Figure 3.

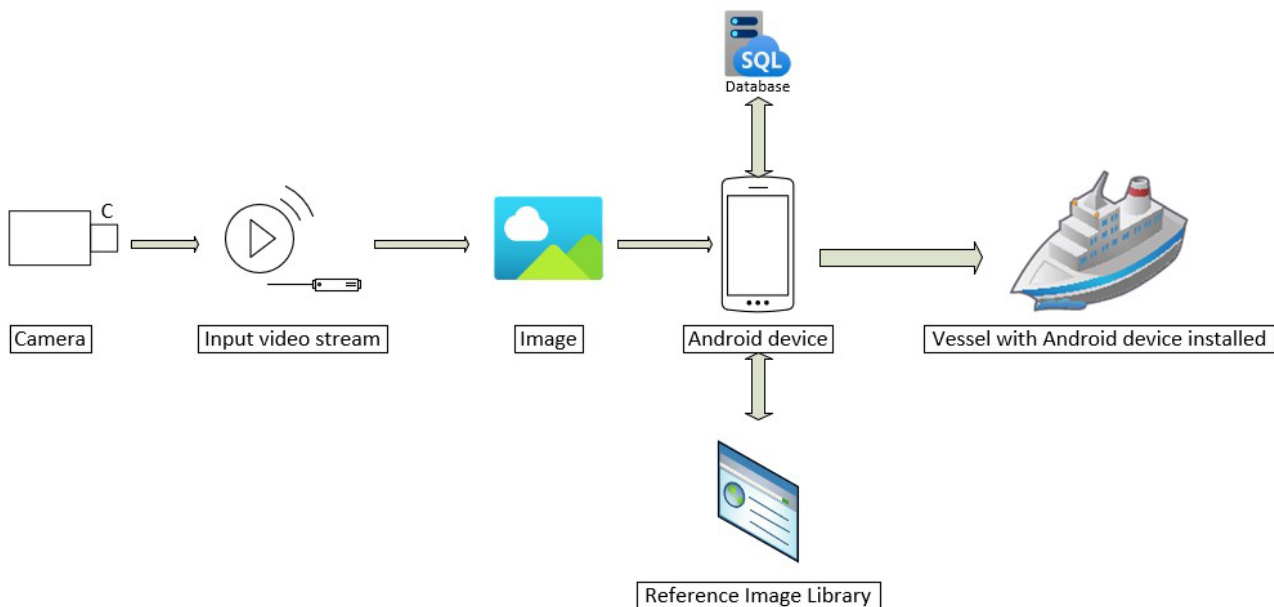


Figure 3. Proposed system

Developing of android app is done in Unity game engine version 2021.3.45f1 with the background of ARFoundation and ARCore algorithms. Reference Image Library is created using image samples of ships used to create YoloV9 model to recognize moving ships on surveillance camera video stream from ferry of Split. Library consists of samples from three classes: Motor boat, Sailing boat and Excursion boat. Figure 4. Is showing output that we have on mobile devices that encompasses detected vessels and augmented classes from image library.

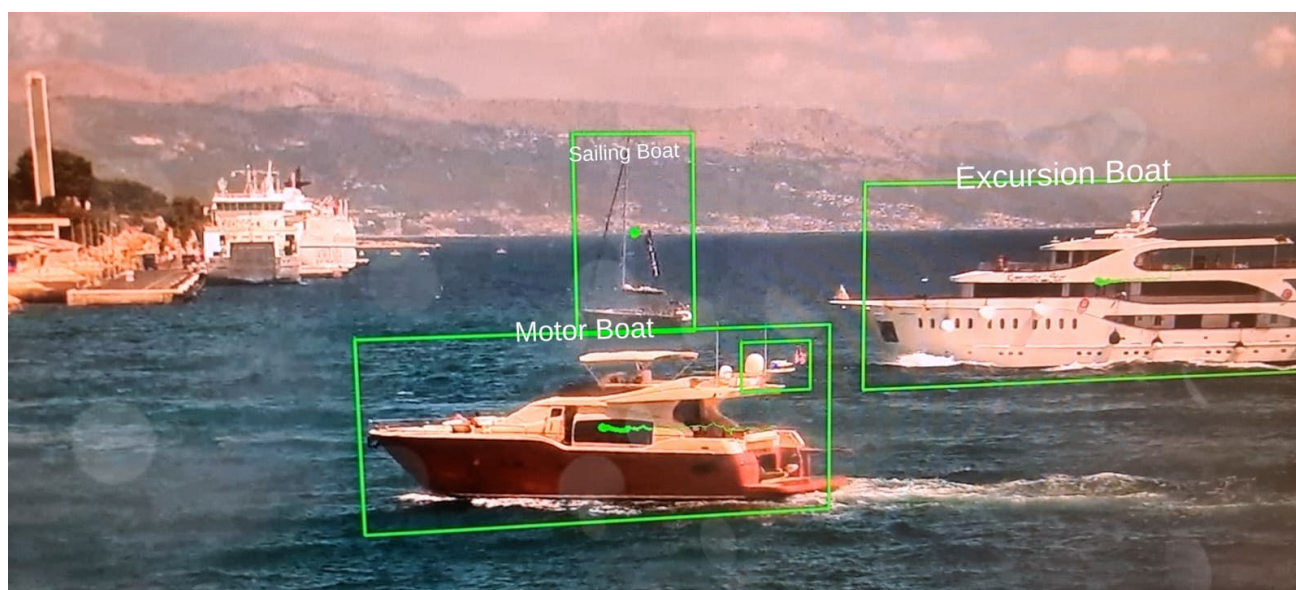


Figure 4. Augmented reality application for detection and classification of boats

The training, validation and performance evaluation of the developed DCNN model showed a high accuracy of over 98% in detecting ships on camera images. The Deep Sort algorithm was implemented to track detected objects while they are in the field of view of the surveillance camera. Figure 5 shows the evaluation metrics, including precision, recall, the accuracy of the model at a prediction threshold of 50% and at a more stringent prediction threshold between 50% and 95%.

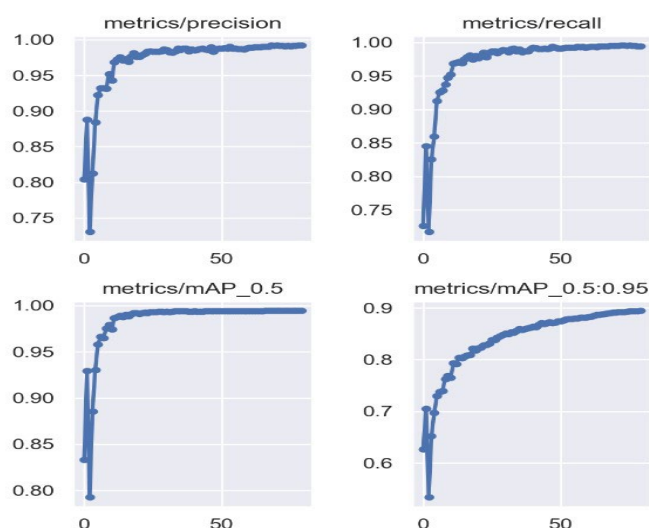


Figure 5. Evaluated metrics

Android devices are used to detect and recognize boats and finally classify them by reference defined in reference library. After successful recognition 3D object is spawned above them showing title of detected class. Points in center of rectangle surrounding recognized object are memories in last 3 second of video to create trajectory of movement. Trajectories can be used to determine speed of movement and line of movement. If lines of different boats cross that indicates possible risk of collision.

Also having display like this potentially can be expanded with all relevant information about ships like AIS, time of entering/leaving port etc.

7. CONCLUSION

The integration of sensor technology with Augmented Reality (AR) systems represents a significant leap forward in maritime operations, offering enhanced situational awareness, improved decision-making capabilities, and increased safety across a wide range of applications. While challenges such as ensuring robustness in harsh environments, standardizing data integration, fostering user acceptance, and addressing privacy concerns persist, ongoing research and development efforts are actively addressing these issues. Future advancements in this field are promising, with focus areas including the development of more resilient and miniaturized sensors, improved AR display technologies for bright outdoor conditions, advanced data fusion algorithms, standardized protocols for seamless data exchange, novel AR interfaces, and the integration of AI and machine learning techniques. These innovations are expected to further enhance the capabilities of AR systems in maritime settings. As these technologies continue to evolve and mature, we can anticipate a transformation in how maritime operations are conducted. The future of the industry is likely to be characterized by sophisticated sensor networks seamlessly integrated with intuitive AR interfaces, ushering in an era of smart, connected, and highly efficient maritime operations. This convergence of technologies has the potential to revolutionize various aspects of maritime activities, from navigation and collision avoidance to maintenance, training, and environmental monitoring. While challenges remain, the potential benefits of sensor-enabled AR systems in the maritime industry are substantial and far-reaching. As research progresses and these technologies become more refined and widely adopted, we can expect to see innovative applications that will continue to enhance operational efficiency, safety, and sustainability at sea. The maritime industry stands on the brink of a technological revolution that promises to reshape its future, making operations safer, more efficient, and more environmentally friendly than ever before.

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Implementation of Artificial Intelligence Solutions in Maritime Transport: An Overview

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Implementing artificial intelligence (AI) solutions in maritime transport brings numerous benefits, including improved safety, efficiency and sustainability. The development of such solutions requires an interdisciplinary approach involving the maritime industry, IT experts and regulatory authorities. AI can be used to analyze real-time data and improve navigation safety, optimize ship routes and fuel consumption, autonomously navigate and avoid obstacles, improve port efficiency, maintain and monitor ship condition, monitor and comply with regulations, and monitor and record environmental pollution. For example, Rolls Royce Marine is a company specialized in ship design, integration of complex ship systems and the development of propulsion vessel systems and their equipment. In partnership with Intel, they began testing the Intelligent Awareness System for ships, which consists of a large number of cameras, LiDAR (Light Detection and Ranging) and radars connected to central AI software, with the aim of developing fully autonomous ships. This paper provides an overview of AI solutions in maritime transport, with an emphasis on the advantages and challenges of implementing artificial intelligence in maritime transport.

KEYWORDS

Implementation; Artificial intelligence; Solutions; Maritime transport

1. INTRODUCTION

The development and application of Artificial Intelligence (AI) in maritime transport began with the automation of navigation systems and ship management. Today, AI in maritime transport is applied in autonomous ships, route optimization and fuel consumption, as well as in maintenance, predictive analysis, accident prevention, etc.

The term Artificial Intelligence was first used at the Dartmouth Conference in 1956 (Dartmouth, 1956). The development of electronic navigation systems, such as radar and early forms of autopilots, started in the 1960s, followed by the first computers in maritime navigation and route optimization systems, introduction of GPS, the Automatic Identification System (AIS) was introduced (Clear Seas, 2024).

In 2000, AIS becomes mandatory for large ships, as part of a revised chapter V of International Maritime Organization (IMO) SOLAS regulation V/19 – Carriage requirements for shipborne navigational systems and equipment (IMO, 2000). In 2005, advanced systems for optimizing fuel consumption based on data analysis were developed (World Fishing, 2005). In 2008, machine learning is introduced into predictive analysis of marine engine maintenance (BIX, 2008). Rolls-Royce launched its first autonomous ship project in 2012 (MMNZ, 2018). In 2017, the Norwegian company Kongsberg launched its first fully autonomous ship called YARA Birkeland (Kongsberg, 2018). In 2018, the IMO issues guidelines for autonomous ships and their regulation (IMO, 2018). In 2021, YARA Birkeland begins unmanned sea trials (The Maritime Executive, 2022). The tests of the first container ship with an AI automatic navigation system were completed in 2022, in Japan (Nippon Foundation, 2022). AI system for optimizing maritime routes reduced CO₂ emissions by 8-15% (Miller et al., 2024). In last five years, the use of big data and AI has been explored, to improve the safety and efficiency of maritime transport (Duan et al., 2019; Munim et al., 2020; Hlongwa, 2022).

The International Maritime Organization (IMO), as a specialized agency of the UN, is a key organization in defining global standards for maritime safety, environmental protection and shipping efficiency. The IMO Committee (Maritime Safety Committee – MSC) regularly issues guidelines related to the application of autonomous ships, including normative guidelines for artificial intelligence, sensors and autonomous systems (IMO, 2024).

The IMO is continuously researching and developing guidelines for Maritime Autonomous Surface Ships (MASS), which rely heavily on AI technologies. In 2018, IMO conducted a preliminary assessment of the regulatory framework to identify existing international conventions that should be adapted to integrate autonomous systems (IMO, 2018). One of the key challenges is adapting existing regulations, such as the International Regulations for Preventing Collisions at Sea (COLREGs) (IMO, 2025a) and the International Convention for the Safety of Life at Sea (SOLAS) (IMO, 2025b), to take into account the specific requirements and risks associated with autonomous ships. In 2019, IMO Interim Guidelines on Maritime Autonomous Surface Ships (MASS), i.e., the MSC.1/Circ. 1604, provide a framework for the development and application of autonomous ships and include details on safety, crew training, communication and integration with existing maritime legislation (IMO, 2019). The STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers) provides for new training for working with autonomous ships, including the safety aspects of working with new systems, although it does not specifically cover AI (IMO, 2025c).

The European Union (EU) is also actively developing legislation related to autonomous ships and the application of artificial intelligence in the maritime industry, ensuring compliance with global standards. The European Maritime Safety Agency (EMSA) provides guidance on autonomous navigation and the use of new technologies (EMSA, 2025). Several initiatives, plans and regulations have been adopted at EU level (EC, 2002;

EC, 2018a; EC, 2018b; Lee et al., 2024; EC, 2025a). The key legislative act regulating the use of AI is the Regulation on Artificial Intelligence (EU AI Act), which entered into force on 1 August 2024 (EC, 2025b).

Some countries are developing specific guidelines and laws for the implementation of AI and autonomous ships within their borders. For example, the Norwegian Maritime Authority (NMA, 2020), UK Society of Maritime Industries (SMI, 2024), and US Federal Maritime Administration (MARAD) agency (Safety4Sea, 2024).

The application of AI in maritime transport is still developing, and the future brings increasingly advanced autonomous systems and the optimization of global maritime transport. This paper provides an overview of AI solutions in maritime transport, with an emphasis on the advantages and challenges of implementing artificial intelligence in maritime transport.

2. ARTIFICIAL INTELLIGENCE IN MARITIME TRANSPORT

Artificial Intelligence (AI) is increasingly integrating into the maritime sector including autonomous ships and navigation, route and fuel optimization, safety and security, cargo management and logistics, predictive maintenance, port and traffic management, etc. (Durlik et al., 2024a; Durlik et al., 2024b; Nguyen et al., 2024).

Autonomous navigation is one of the most advanced areas of AI application in the maritime industry. These systems use computer vision, machine learning, and sensor data to enable autonomous ship control (Rudzińska et al., 2024). In the segment of route and fuel optimization, AI analyzes weather conditions, sea currents and traffic to suggest the most efficient routes, reducing fuel consumption and emissions. Maritime transport is responsible for about 3% of global CO₂ emissions, and AI can optimize fuel consumption and reduce the adverse environmental impact (Miller et al., 2024). In the maritime security and surveillance segment, real-time data analysis to identify potential security threats and improve ship surveillance is crucial (Şengönül et al., 2023). In the cargo management and logistics segment, IoT and AI analytics optimize cargo loading and unloading, improves tracking, and reduces time spent in ports (Tsolakis et al., 2021). In the predictive maintenance and data analytics segment, using sensors and data analytics algorithms, AI predicts equipment failures, enabling timely maintenance and reducing downtime (Ucar et al., 2024; Simion et al., 2024). In the port and traffic management segment, key technologies are AI-based ship arrival planning systems, automated port operations systems, and smart grid systems where AI connects all participants for better coordination (Datahub, 2024). In the fishing and marine resource monitoring segment, key technologies are fish species recognition systems, fishing optimization systems, and anti-illegal fishing surveillance systems (Kim et al., 2024).

The application of AI in maritime transport is already bringing significant benefits in terms of safety, sustainability, and efficiency. The development of autonomous ships, predictive analytics, and smart systems is expected to accelerate further in the coming years, making the maritime sector more advanced and environmentally friendly.

3. OVERVIEW OF THE ARTIFICIAL INTELLIGENCE SOLUTIONS IN MARITIME TRANSPORT

The application of AI in maritime transport includes the use of the following key technologies: computer vision for object and obstacle recognition (LiDAR data analysis and 3D mapping, You Only Look Once (YOLO), Point Cloud Analysis, Convolutional Neural Networks), route optimization systems for energy saving and safety (Machine Learning, Reinforcement Learning, Deep Neural Networks, Genetic Algorithms), predictive maintenance for analyzing the state of ship components (Deep Learning, Random Forests, Support Vector Machines), collision avoidance for ship safety (Kalman Filter, Recurrent Neural Networks, Monte Carlo

simulations), and data collection for research (Time Series Forecasting, Data Mining) (Zhang et al., 2022., Kalafatelis et al., 2024; Tang et al., 2024; Zhang et al., 2025). The following examples present several artificial intelligence solutions in maritime transport.

3.1. YARA Birkeland

In 2017, Yara International and Kongsberg Maritime announced a collaboration to build an autonomous ship (Kongsberg, 2017; Kongsberg, 2018). YARA Birkeland is the first fully electric and autonomous container ship built by Yara International (Norway) and Kongsberg Maritime. The ship was designed and built in 2018-2019. The first tests began at the Vard Brevik shipyard in 2020. The first unmanned test voyage was carried out in 2021, and it has been in operational use since 2022 (carrying transport between the ports of Herøya and Brevik in Norway). YARA Birkeland has a capacity of 120 TEU (container units), can reach a speed of 13 knots (24 km/h) and is 100% electrically powered (battery capacity 7 MWh). The application of AI is reflected in the use of computer vision and sensors for autonomous navigation, automated docking and departure, and weather analysis and route optimization in real time.

The advantages of YARA Birkeland are exceptional environmental benefits, as it reduces CO₂ emissions by 40,000 truck trips per year; as well as reduced operating costs due to the absence of fuel, crew and maintenance costs of traditional engines; integration with smart logistics systems for real-time route optimization; and increased safety by eliminating human error (Yara, 2024). The challenges are reflected in the regulatory framework, technical difficulties and high initial investments. In the future, full autonomy is expected (currently the system operates with limited human control), along with the integration with other autonomous systems (connection to smart ports), and expansion of autonomous freight transport (larger ships and international routes).



Figure 1. An autonomous container ship Yara Birkeland (Source: UAVPic, 2020).

3.2. Mayflower

The Mayflower (Mayflower Autonomous Ship – MAS) is a fully autonomous research vessel that uses AI to navigate and collect ocean data (IBM, 2025). In 2019, the launch of the project began, in 2020 artificial

intelligence system tests were performed, in 2021 the first attempt to cross the Atlantic Ocean was made (which was stopped due to technical problems), and in 2022 the Mayflower successfully crossed the Atlantic Ocean from Great Britain to the USA (Ship Technology, 2024). Mayflower applies AI to recognize other ships, waves, weather conditions and objects in the sea using computer vision. It automatically avoids obstacles and optimizes navigation and collects data on ocean pollution and marine flora and fauna.

Mayflower was built as part of the ProMare project and IBM AI. It is 15 meters long, weighs 5 tons, reaches a speed of 10 knots (18 km/h) and is powered by solar energy and batteries (IBM, 2025). Advantages include autonomous exploration, environmental benefits, the ability to collect data in real time, and reduced operating costs. Challenges are manifested in technical problems, navigation in complex conditions and limited data collection capacity (due to the smaller size of the ship).



Figure 2. An autonomous research ship Mayflower (Source: AI Business, 2020).

3.3. Fjord1 autonomous ferry

The Fjord1 autonomous ferry represents a significant step towards autonomous maritime navigation in the transportation industry. The ferry is part of a broader initiative to test autonomous ships in commercial maritime traffic, especially on short seas and in regions with high ferry traffic (such as Norway). Fjord1, in collaboration with the shipyard Havyard and technology partners, began the development of the autonomous ferry in 2020 (Marine Link, 2018). In 2021, the ferry successfully began test runs on routes between coastal destinations, with constant monitoring and tracking. In 2023, the Fjord1 autonomous ferry began commercial operations on selected routes, with the aim of further verifying its ability to safely transport passengers and cargo (Offshore Energy, 2024).

The advantages of the Fjord1 autonomous ferry are reduced operating costs; greater safety, increased precision in navigation where autonomous systems can better predict optimal routes, environmental benefits, and increased capacity (number of sailings). Challenges are: the need for highly sophisticated technology and adaptation of existing ship systems, adaptation of laws and regulations, the constant supervision, and distrust in the efficiency and reliability of autonomous systems. In the future, the ferry is planned to be connected to smart ports and other autonomous ships in the fleet, which will enable greater coordination, route optimization and increased transport efficiency. The ferry could become fully electric or use hybrid propulsion systems that reduce emissions and make transport more sustainable (Baird Maritime, 2024; Riviera, 2024).



Figure 3. Fjord1 fully autonomous ferry (Source: NES, 2024).

3.4. Rolls-Royce Marine Intelligent Awareness System

Rolls-Royce Marine, in collaboration with Intel and many other partners, is developing innovative technologies for smart ships and autonomous navigation, and one of their key systems is the Intelligent Awareness System (IAS) (Rolls-Royce, 2018). This system uses artificial intelligence (AI) and advanced sensors such as LiDAR (Light Detection and Ranging), cameras, radar and other technologies to increase situational awareness on ships (Alamouh and Ölçer, 2025). The main goal of IAS is to enable ships to navigate autonomously and improve safety at sea. In 2014, Rolls-Royce began investigating the possibilities for the development of autonomous ships, to improve the safety and efficiency of navigation. In 2016, the concept was officially presented at the Norwegian Maritime Authority (NMA) conference, and in 2017, pilot testing began in real conditions on ships. In 2020, the testing was conducted with an autonomous ship equipped with the IAS system (Design Boom, 2025). The tests have shown that the system enables ships to operate in fully autonomous conditions, using advanced real-time data analysis.

The benefits of the IAS system are reflected in increased safety, optimized navigation, reduced human error, increased efficiency and reduced fuel consumption and emissions, thereby contributing to the sustainability of maritime transport. There are still certain challenges in implementation, technical complexity of the system, the incompatibility of maritime laws and regulations, etc. In the coming years, ships equipped with IAS systems are expected to become the standard in the autonomous ship market.



Figure 4. Rolls-Royce Marine Intelligent Awareness System – IAS (Source: Port Technology, 2018).

3.5. Smart Port of Rotterdam

The Smart Port of Rotterdam represents a key point for the development of future maritime infrastructure. The use of advanced technologies such as AI, IoT, big data and blockchain makes Rotterdam a pioneering port that sets standards for automation, optimization and sustainability in maritime transport (Martide, 2024). In 2014, Rotterdam began a project for the development of smart ports, with the aim of creating a smart infrastructure that will enable more efficient management of the navigation route, increase safety and reduce the adverse environmental impact (Port of Rotterdam, 2025). In 2016, the implementation of IoT and big data technologies for monitoring and managing ship traffic, container movement, and weather conditions in real time begins. The project was aimed at connecting all parts of the port into one digital ecosystem. In 2017, a system for automatic recognition and data analysis of ships arriving and departing from the port was tested in Rotterdam. This launched an AI and ship automation project, where artificial intelligence was used to optimize ship docking times and reduce operating costs. In 2023, Rotterdam becomes the first major port to use blockchain to track and authenticate ship cargo, enabling transparency and security in data management within the ecosystem.

The benefits include optimized traffic monitoring, optimizing ship routes, automatic container tracking, and automated data recognition and processing systems; reducing emissions and environmental impact through the use of energy-efficient technology, optimizing ship routes to reduce CO₂ emissions and fuel consumption, and using alternative energy sources (such as solar power); reducing operating costs; and data transparency and security. Although it faces challenges in terms of integration of new technologies, data security and regulations, future developments include improved management of maritime operations, expanding the application of blockchain technology, advanced AI predictive systems, reducing the environmental impact (using electric and hybrid ships) and the global connectivity of maritime routes in order to reduce the waiting time for ships to unload and load cargo.



Figure 5. Communicating assets and autonomous navigation at the Smart Port of Rotterdam (Source: Port of Rotterdam, 2025).

This paper chose few key examples to show AI implementation in maritime sector. There are many other examples of the implementation of AI solutions in maritime transport. For example, there is Wärtsilä's AI Navigation System that optimizes routes and integrates real-time data which improves fuel efficiency and ensures timely arrivals; Navis AI App helps smaller vessels and yachts navigate safely and efficiently; MarineTraffic uses real-time AIS data for vessel tracking and route planning; SeaDrive provides smart navigation and route optimization for yachts and smaller vessels; Caterpillar Marine's AI-Powered Predictive Maintenance uses sensor data to forecast equipment issues and schedule timely maintenance; Nautilus Labs optimizes fleet performance and sustainability through AI insights; Cruise Planners' AI App simplifies booking and itinerary planning and offers tailored travel suggestions; MSC Cruises' Virtual assistant called "Zoe" answers questions and assists with planning activities; Sealma AI provides personalized booking and itinerary planning for yacht charters; Windward's Environmental Monitoring System monitors real-time pollution levels and marine biodiversity; IBM's Green Horizons uses AI to predict and manage air pollution in port cities; Seadog solution integrates marine and fisheries data with AI to support both recreational and commercial fishers; Knowit's AI solution predicts fish locations which improves efficiency and promotes sustainability; Ai.Fish's CatchVision Software and Ai.Fish API provide AI-powered electronic monitoring solutions to streamline fisheries management; and many others.

4. ADVANTAGES AND CHALLENGES

Advanced AI systems bring numerous benefits to maritime transport, including increased safety, optimized navigation, reduced risk of human error, greater efficiency, and lower fuel consumption and emissions, contributing to environmental sustainability. Autonomous navigation enables a more environmentally friendly approach by using electric or solar power, collecting real-time data, reducing operating costs by eliminating the need for fuel and crew, and integrating with smart logistics systems for dynamic route optimization. Smart ports improve operational efficiency by monitoring traffic, optimizing ship routes, automated

data tracking and processing systems, and container recognition, while simultaneously reducing emissions and operating costs.

The application of AI solutions in maritime transport faces challenges such as regulatory constraints, technical barriers and high initial investments. Current international and national regulations are not yet fully adapted to autonomous navigation. On the technical side, the integration of sensors, LiDAR, radars and computer vision in complex navigation conditions is challenging, with limitations in data collection. Although they reduce costs in the long term, the initial investments in the development and implementation of AI systems are very high. In addition, there is still resistance among manufacturers, regulators and the public, mainly due to concerns about trust in autonomous systems and their reliability.

5. CONCLUSION

This paper presented an overview of AI solutions in maritime transport, with an emphasis on the advantages and challenges. Overview of the artificial intelligence solutions in maritime transport included examples of current application of AI, such as YARA Birkeland (the first fully electric and autonomous container ship), Mayflower or MAS (a fully autonomous research vessel), Fjord1 (the first autonomous ferry), Rolls-Royce Marine IAS system (AI-based system to navigate ships autonomously and improve safety at sea), and the Smart Port of Rotterdam (the first major port to use advanced technologies such as AI, IoT, big data and blockchain to optimize port operations).

Advantages and challenges of AI solutions in maritime transport have been emphasized. AI solutions in maritime transport contribute in reducing fuel consumption and emissions, timely detection of faults, reducing downtime and repair costs, reducing the risk of human error, improving navigation, optimizing the ship performance, and reducing operating costs. The challenges of AI solutions in maritime transport are manifested in high implementation costs because the development and introduction of AI technology requires significant investments, inaccurate or incomplete data that can reduce the effectiveness of AI systems, vulnerabilities of AI systems that can become targets for hackers, which threatens navigation safety, and in the regulatory aspect of the application of AI systems in maritime transport which is still incomplete.

Future developments are focused on further advancing autonomous navigation, integration with smart ports, and improved management of maritime operations. The expansion of advanced technologies will enable greater transparency and security, while advanced AI systems for data analysis will enable accurate prediction of challenges such as traffic congestion and adverse weather conditions. The development objectives also include reducing negative environmental impact and strengthening global connectivity of maritime routes.

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A Bibliometric Analysis of the Underwater Hull Inspection Using ROV

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The reason for the underwater hull inspection could be threefold: firstly, it is an obligatory process to assess any possible damage and fatigue to the ship's hull, and therefore, it is done for safety reasons and classification societies prescribe it; secondly, it could serve as a detection process for biofouling serving as a vector for spreading marine invasive species; and thirdly, it could serve for security and anti-terrorism purposes, because underwater part of the ship's hull could serve as a hideout for various contraband, even weapons and explosives. Until recently, underwater hull inspections were done by professional divers in full, while lately, more and more inspections have been performed using remote-operated underwater vehicles (ROV) or autonomous underwater vehicles (AUV). However, technological advancements and related scientific research are not the same worldwide; some ports and areas use and study ROVs more than others. Therefore, it is important to identify research gaps and enable future studies to deal with emerging identified problems. With that aim, the authors used a bibliometric analysis to assess research trends, knowledge gaps, and collaboration patterns. Data was collected from the Web of Science (WoS) database, and publication trends, citation networks, key authors, and thematic developments were analysed using the VOSviewer software. Research gaps identified in this paper include the necessity for standardised training for ROV operators, the establishment of legal and regulatory standards concerning underwater hull inspection using ROV, and limited international collaboration. By addressing these gaps, future research can enhance ROV-based underwater hull inspections' efficiency, accuracy, and regulatory acceptance, ensuring safer and more sustainable maritime operations.

KEYWORDS

VoSviewer; Maritime safety and security; Sustainability; Marine robots; Bibliometric analysis; Underwater hull inspection

1. INTRODUCTION

Maritime transportation has far-reaching effects on globalisation, international trade and the world economy. Over 80% of the world trade by volume and over 50% by value was carried by sea (UNCTAD, 2021; Ferrari et al., 2023). It is evident that the world economy would not be the same without maritime transportation. In addition, as the maritime industry grows, the probability of maritime accidents is increasing. Such unwanted events can cause catastrophic consequences for human lives, the environment and the economy. Structural failure is considered one of the identified causes of maritime accidents (Dong et al., 2022; Vukelić and Vizentin, 2017), as was the case with the container ship MOL Comfort (BMA, 2015). Such accidents are usually affected by fatigue cracks, buckling, indents, corrosion, or a combination of these factors. In addition, structural overloading, ship design errors, substandard materials usage, inadequate weldings, coating breakdown and vibrations induced by hydrodynamic loads or the machinery further enhances structural failures (Lin and Dong, 2023). In order to avoid structural failure accidents and prevent or reduce the effect of the aforementioned factors, ships are designed and built following stringent safety and environmental protection standards. Furthermore, ships and offshore structures are constantly exposed to rough and aggressive marine environment conditions that can cause biofouling besides already mentioned failures like cracks and corrosion on the surface of the hull, affecting the safety of maritime operations (Hong et al., 2018). Part of the ship's hull below the seawater surface is subjected to various levels of fouling by marine or aquatic organisms (Cioanta and McGhin, 2017; Song and Cui, 2020). The base of the fouling mechanism for ships and offshore structures is formed by biofilms, which constitute the connection between marine organisms and the structure itself (Hua et al. 2018). The biofilms and fouling organisms attach to all ship's underwater structures, such as propellers, rudders, speedlogs, and echo sounders housings. Since the fouling causes frictional resistance, it increases fuel consumption and, in addition, increases CO₂ emissions. Thus, the effect of ship fouling is twofold negative: fouling affects economic loss and increases environmental pollution (Cardaillac et al., 2024). Ship underwater hull fouling, besides an increase in fuel consumption, can lead to the spread of invasive marine species, affecting local marine habitats and causing substantial economic and environmental damage. Therefore, ships are subjected to comprehensive inspections during the building period and while in service (Nair et al., 2017). During the building period, any overlooked hull defects, such as paint cracks, inadequate weldings or usage of substandard materials, could be detected and, repaired and maintained before costly ship defects occur. Furthermore, during service, it is important to adequately carry out an inspection to uncover possible defects and identify potential biofouling. In that way, the ship's hull structure is kept in a satisfactory condition and the risk of structural failure is reduced (Davies et al., 2021; Lin and Dong, 2023).

Besides inspections related to hull condition and the biofouling process, security inspections of the underwater hull part of the ship became necessary. Security threats have increased during the last decades, and it is of the utmost importance that secure and safe ports and cargo transfer are enabled. For example, explosive devices or some other kind of contraband could be attached to a ship's hull and transferred from one port to another (Davis and Lugsdin, 2005; Faulkner et al., 2009). Besides explosive devices, drug smuggling is a serious threat, and many ports worldwide are struggling to prevent drug trafficking through their terminals (Faulkner et al., 2009). Ship's crew is usually unaware of contraband attached to the underwater part of the ship's hull, but we are witnessing many masters prosecuted and jailed due to drugs attached to their ships, which were found during inspections.

Underwater hull inspections have largely depended on visual assessments performed by human divers commonly. Nevertheless, this method presents considerable hazards, is labour-intensive, and requires a substantial time investment, leading to limited operational efficiency and suboptimal quality of the survey results (Davis and Lugsdin, 2005; Hong et al., 2019). Recent advancements in technology have enabled inspectors to reduce costs and enhance efficiency. Remotely Operated Underwater Vehicles (ROVs) are used to perform visual inspections proficiently and gather evidence while minimising risks to human safety. Despite the effective

operation of ROVs, they necessitate the presence of skilled operators and continuous oversight. Furthermore, the quality of the documentation may vary considerably based on human performance during the execution of these tasks (Cardaillac et al., 2024).

In contrast to inspections where human divers are physically involved, remote inspection technologies leverage mobile digital devices and collaborative software platforms, allowing inspections to occur without the inspector needing to be physically present on the vessel. Automatic inspection technologies take it further by employing robots (to examine the hull independently, without human involvement. These technologies enable inspectors to assess the structural condition from a secure, stationary position, decreasing operational interference and minimising downtime for ship owners while allowing for greater flexibility during survey operations. Nevertheless, adopting these technologies introduces additional challenges (Lin and Dong, 2023).

However, as mentioned earlier, using ROVs (or autonomous underwater vehicles – AUVs) requires proficient and skilful operators. In that light, there is a need to have formal education or training through which such operators will acquire the necessary knowledge and skills. National Ocean Service defines AUV as an Autonomous Unmanned Underwater Vehicle used for underwater survey missions such as detecting and mapping submerged wrecks, rocks and obstacles that may be hazardous to navigation. The AUV conducts the survey without operator intervention. At the end of the survey, the AUV will return to a pre-programmed location where data is downloaded and then processed. A remotely operated vehicle (ROV) refers to an underwater robot that is connected to a ship by a cable. Commands and control signals between the operator and the ROV are transmitted by cables and enable vehicle remote navigation. The ROV can be equipped with a video camera, a light, a sonar system, and a movable arm that can be used to extract small objects such as sediments, cutting ropes, and similar (NOAA).

According to the aforementioned, some of the main existing solutions in underwater hull inspection using ROV include:

- 1) Manual ROV-Based Inspections where human operators remotely control ROVs using tethered connections. These are equipped with high-resolution cameras, sonar, and other equipment for visual inspections and minor interventions. Some examples are Saab Seaeye Falcon (hull and offshore infrastructure inspections) (SAAB, a) and VideoRay Defender (security and maintenance inspections) (VideoRay).
- 2) Semi-autonomous ROVs with SLAM & AI-assisted navigation, which are enhanced with Simultaneous Localization and Mapping (SLAM) and AI-based object recognition. Some of the examples include BlueROV2 (AI-assisted control for stability and manoeuvrability) (Blue Robotics).
- 3) Fully Autonomous AUVs for Large-Scale Hull Inspections which operate without human intervention, by pre-programmed missions and AI-driven decision-making. They are usually equipped with sonar, LiDAR, and advanced imaging for detailed mapping. Some of the examples include HUGIN AUV (hull and seabed mapping) (Kongsberg) and Eelume AUV (autonomous robot designed for continuous inspections) (Eelume); and
- 4) Hybrid Solutions (ROV-AUV Convergence) combine ROV manoeuvrability with AUV autonomy for adaptive and real-time decision-making (SAAB, b).

Furthermore, in some ports or sea areas, the usage of underwater robots is already well-developed and regulated, while in others, human divers still perform underwater hull inspections and cleaning. Some countries and academic institutions conduct research and improve and develop the use of ROVs, and therefore, it could be expected that such countries and regions have more developed and implemented the usage of robots for underwater inspections.

This paper evaluates underwater hull inspection studies using ROVs through a bibliometric analysis of Web of Science (WoS) publications. Bibliometric analysis provides a systematic method for evaluating scientific literature's growth, impact, and structure on a specific topic. By analysing published papers, citation patterns, and collaboration networks, bibliometric studies help identify research trends and gaps. Despite significant progress in underwater hull inspections with ROVs, comprehensive studies quantitatively mapping this research area are still limited.

The analysis will examine key aspects such as the evolution of research output, the most productive authors and institutions, citation impact, co-authorship networks, and thematic trends.

The study has outlined the following specific objectives to reach its aim:

- a) Analyse the trends in publications regarding underwater hull inspections using ROVs over time, pinpointing significant periods of growth.
- b) Determine the most productive authors, institutions, and countries contributing to the field.
- c) Investigate co-authorship networks among scholars and countries to assess levels of collaboration.
- d) Identify the most influential journals, conferences, and papers based on citation analysis.
- e) Analyse frequently occurring keywords and topics to understand dominant themes and research directions.
- f) Highlight underexplored areas.

To the best of our knowledge, this study is the first to provide a bibliometric analysis of underwater hull inspection using ROVs. It offers valuable insights into research growth, collaboration, and impact while highlighting important research gaps: limited international collaboration and a lack of standardised ROV operator training programmes. The findings support future research planning, industry adoption, and regulatory standardisation, establishing it as a significant reference for researchers, policymakers, and industry professionals.

The paper is organised as follows: the first section provides an introduction to underwater hull inspection using ROVs. The second section outlines the study's methodology. The third section presents the results and discusses the findings. The fourth (and final) section offers conclusions, including the study's limitations and suggestions for future work.

2. METHODOLOGY

Bibliometric analysis provides an overarching perspective on extensive academic literature. It uses quantitative techniques to evaluate publication histories, helping researchers grasp the characteristics and development of scientific output in particular fields (Li and Hale, 2016). These techniques assess the performance and trends in research for authors, journals, countries, and institutions while also identifying collaboration patterns among them (Li and Zhao, 2015). This analysis can highlight key authors, significant publications, essential journals, and leading countries and institutions on specific topics. Exploring the variety of journals within a topic and the subject categories of their publications showcases the diversity of research themes and the multidisciplinary aspect of a field. Additionally, bibliometrics can reveal emerging breakthroughs, ongoing research directions, research gaps and principal themes within a discipline (Wang et al., 2014). Therefore, this study utilised bibliometric analysis to explore research trends and gaps related to ship underwater hull inspection by employing ROVs (or AUVs). The authors used the Boolean operator "OR" to include synonyms of the terms. The following terms connected with the Boolean operator "OR" were used for screening: "underwater hull inspection Remotely Operated Underwater Vehicle", "underwater hull inspection ROV", "underwater hull inspection Autonomous Underwater Vehicle", "underwater hull inspection AUV". This indicates that these terms appear in the title, abstract, and/or keywords of the reviewed publications. Web of

Science (WoS) database was used to search for publications related to the theme of the paper since it is the "most widely used and authoritative database of research publications and citations" (Birkle et al., 2020). The software VOSviewer (van Eck and Waltman, 2010), which is freely available, was utilised to analyse and visualise the relationships among authors, journals, countries, co-citations, and terms.

3. RESULTS AND DISCUSSION

The number of peer-reviewed publications indicates the growth trend in research regarding underwater hull inspection with ROVs. As shown in Figure 1, this number has risen more significantly since 2015.

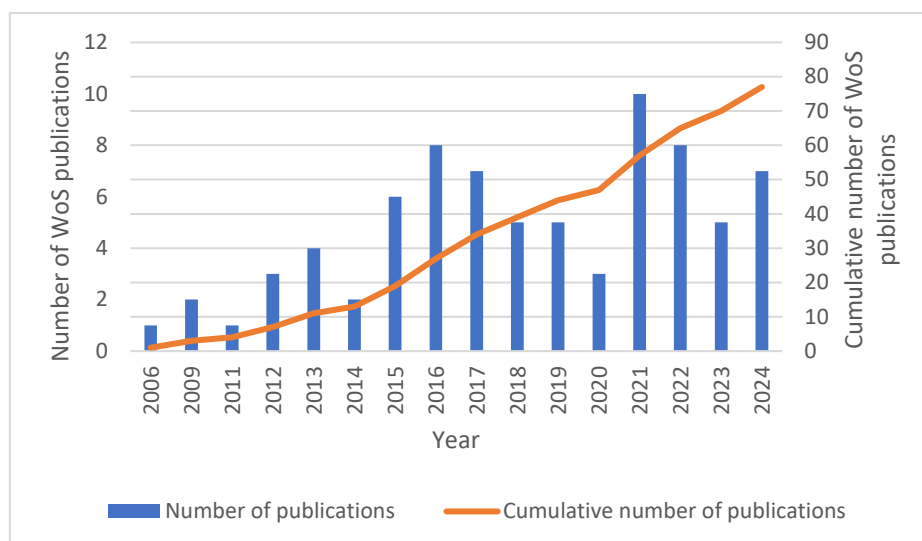


Figure 1. The number of WoS publications regarding underwater hull inspection using ROVs.

From 2006 to 2024, the WoS database contained 77 publications (excluding review papers) on the research subject. However, the continuity of published papers on this study's research topic only began in 2011.

Regarding authorship, 195 authors were identified for 77 publications. Table 1 shows the five most productive authors.

No.	Author	No. of publications
1	Kim, Jin Whan	12
2	Eustice, Ryan M.	11
3	Hong, Seonghun	8
4	Ozog, Paul	7
5	Chung, Dongha	5

Table 1. The five most productive authors.

The cooperation pattern, or co-authorship, among authors publishing studies on underwater hull inspections using ROVs was examined using VOSviewer. Only authors who published at least two papers on this topic, each receiving at least two citations, were included in the network analysis. Authors not connected to others in the network were excluded. The results of this co-authorship network are depicted in Figure 2. The

size of the circles indicates the number of publications, while the lines connecting authors illustrate their collaborations. Different colours signify various collaboration clusters, revealing three clusters of authors within the network.

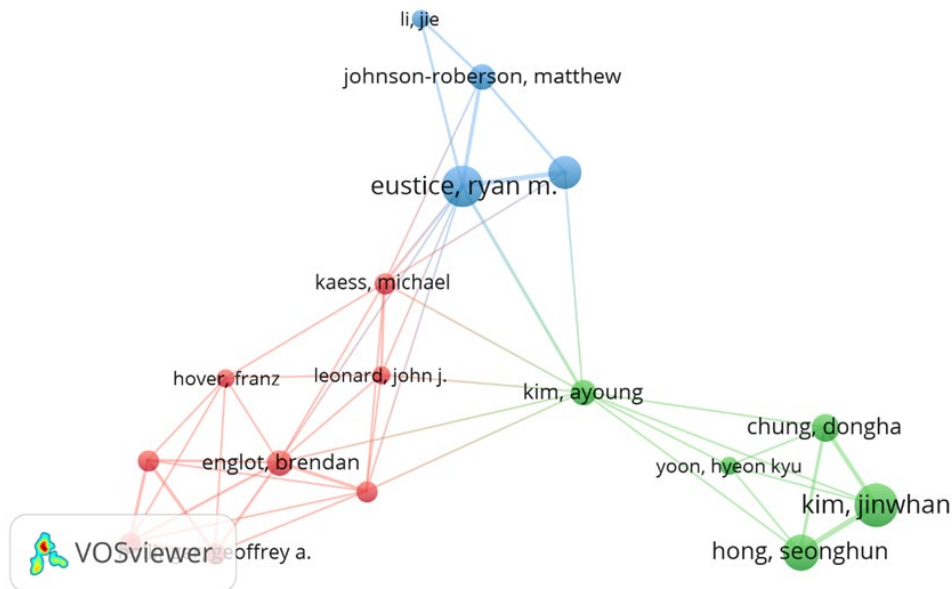


Figure 2. Authors' cooperation network regarding studies on underwater hull inspection using ROVs.

Out of 77 screened publications, 34 were published in 22 journals, while the remaining 43 were published in conference proceedings indexed in WoS. The largest number of published papers with the theme of this research in one journal was three, and four journals were found, each with three publications (Table 2).

No.	Journal name	No. of publications
1	Autonomous Robots	3
2	IEEE Journal of Ocean Engineering	3
3	The International Journal of Robotics Research	3
4	Journal of Marine Science and Engineering	3

Table 2. Most active journals publishing on underwater hull inspection using ROVs.

The most active conference was Oceans IEEE, with eight publications on the theme of this research. In addition, the bibliographic coupling of sources was analysed using VOSviewer. Two publications are considered bibliographically coupled when they both cite a common third publication. Essentially, bibliographic coupling refers to the shared references between publications. The minimum number of documents of a source was set at two and the minimum number of citations of a source was set at two. Of the 54 sources, 16 met the threshold set (Figure 3).

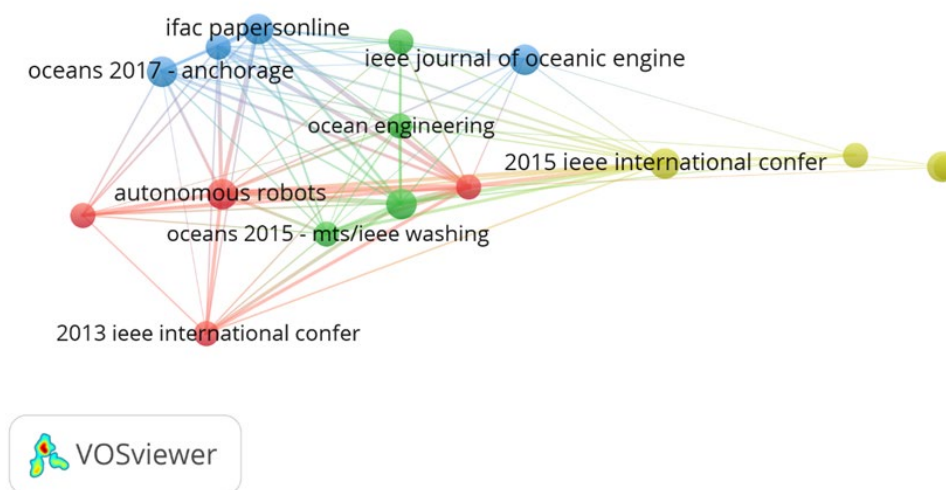


Figure 3. Bibliographic coupling of sources.

Twenty countries participated in the underwater hull inspections using ROV research. Table 3 presents the five most productive countries.

No.	Country	No. of publications
1	USA	26
2	South Korea	16
3	People's Republic of China	6
4*	India	5
4*	Italy	5
5*	Australia	3
5*	Germany	3
5*	Malaysia	3
5*	Norway	3

*Countries with the same number of publications have the same ranking number.

Table 3. The five most productive countries.

From Table 3, it can be seen that Asia is the continent with the highest number of publications, followed by North America, Europe and Australia. The co-authorship network among countries researching underwater hull inspection with ROV was analysed using VOSviewer. Only countries with a minimum of two publications on this subject and two citations were included. Countries without connections to others in the network were excluded from the analysis. The cooperation results are illustrated in Figure 4. In this figure, the size of each circle reflects the volume of publications, while the thickness of the links signifies the strength of collaborative efforts. Different colours indicate distinct collaboration clusters. Three main clusters emerge: the USA and South Korea (blue), Australia and Malaysia (green), and Italy and Germany (red).

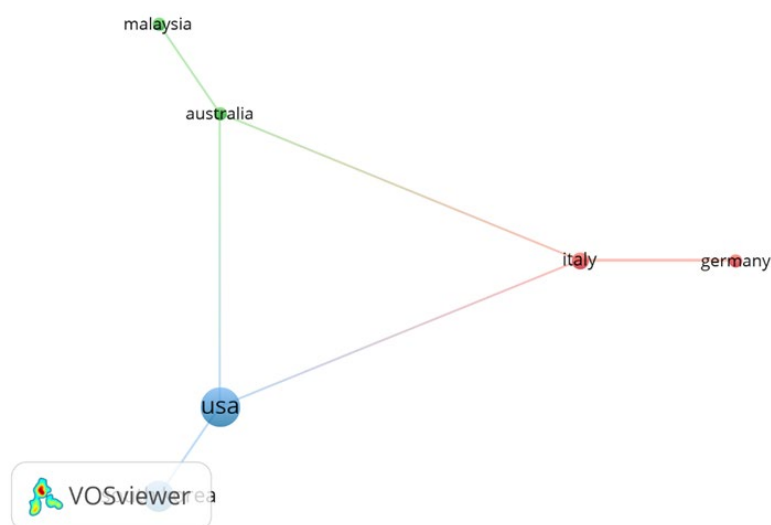


Figure 4. Co-authorship between countries.

Figure 4 shows that collaboration between countries studying the use of ROVs for underwater hull inspection is still scarce and needs improvement. In addition, a blue cluster published 54.5% of publications.

A total of 79 institutions were involved in publishing 77 papers identified. Table 4 presents the three most productive institutions. Out of 77 publications, these three institutions (academia) alone participated in 54.5% of published papers found in the WoS database (again from the USA and South Korea).

No.	Institution	Country	No. of publications
1	University of Michigan	USA	22
2	Korea Advanced Institute of Science Technology KAIST	South Korea	13
3	Massachusetts Institute of Technology MIT	USA	7

Table 4. Three most productive institutions.

The cited analysis indicates how often other works in the WoS database have cited publications on underwater hull inspections with ROVs. It is generally assumed that the number of citations indicates a publication's influence, reputation, and quality. However, some authors argue that citation counts reflect visibility rather than quality (van Nunen et al., 2018; Aksnes et al., 2019). The five most cited publications are presented in Table 5, together with the authors, year of publication and journal.

No.	Authors	Year	Title	Journal	Citations
1	Hover, F.S.; Eustice, R.M.; Kim, A.; et al.	2012	Advanced perception, navigation and planning for autonomous in-water ship hull inspection	The International Journal of Robotics Research	177
2	Hollinger, G.A.; Englot, B.; Hover, F.S.; Mitra, U.; Sukhatme, G.S.	2013	Active planning for underwater inspection and the benefit of adaptivity	The International Journal of Robotics Research	111
3	Negahdaripour, S.; Firoozfam, P.	2006	An ROV Stereovision System for Ship-Hull Inspection	IEEE Journal of Oceanic Engineering	98
4	Ozog, P.; Carlevaris- Bianco, N.; Kim, A.; Eustice, R.M.	2015	Journal of Field Robotics	Long-term Mapping Techniques for Ship Hull Inspection and Surveillance using an Autonomous Underwater Vehicle	52
5	Kim, A.; Eustice, R.M.	2013	IEEE International Conference on Robotics and Automation	Perception-Driven Navigation: Active Visual SLAM for Robotic Area Coverage	37

Table 5. The five most cited publications on underwater hull inspection using ROV.

Co-citation analysis examines the connection between two publications by showing how often they are cited together in other works. If two publications are frequently cited together, it likely indicates they share similarities (van Nunen et al., 2018). For the sake of the analysis, the minimum number of citations was set to five, meaning that a specific reference had to be cited five times in any of the 77 publications analysed. There were 1751 referenced publications, but only 34 met the threshold limitation and were divided into three clusters (Figure 5).

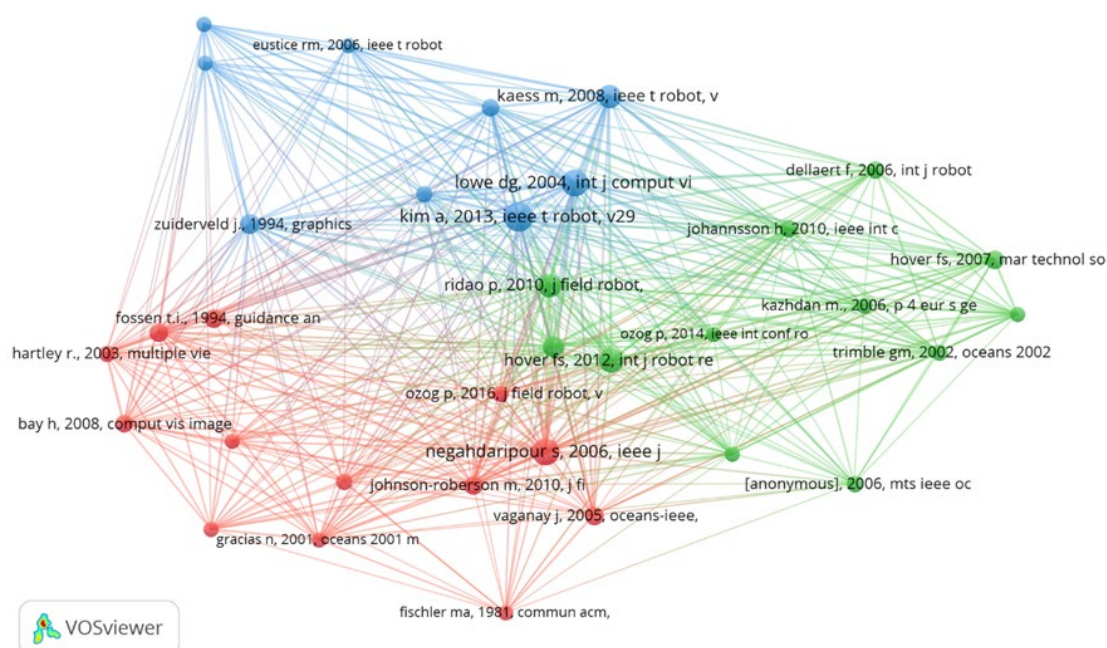


Figure 5. Co-citation analysis of referenced publications.

Analysing the terminology in the titles and abstracts of publications related to underwater hull inspection using ROVs can reveal key topics and research trends within this study's topic. VOSviewer was used for the terms analysis, and 2155 terms were found in the publications' abstracts and titles. The minimum number of occurrences was set to five, and 83 terms met the threshold set. Only the most relevant terms were included in the network (60% of the terms meeting the threshold). Figure 6 presents a terms analysis of WoS publications.

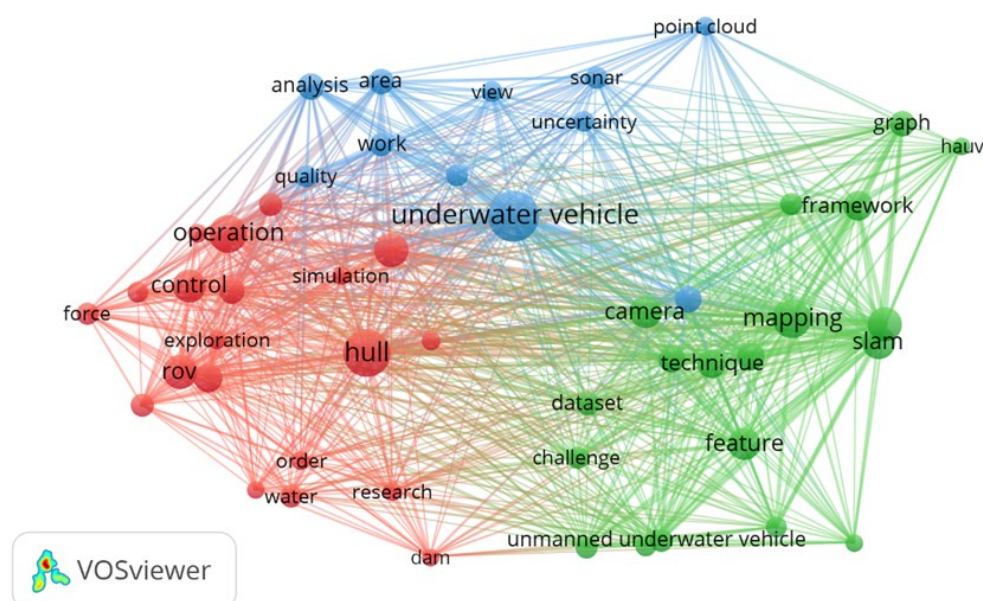


Figure 6. Terms analysis of WoS publications dealing with the underwater hull inspection using ROV.

The circles' size indicates how often a term appears; a larger circle means greater frequency in the abstracts and titles of publications about underwater hull inspection using ROVs. The distance between terms reflects their relatedness: closer terms indicate a stronger relationship. This relationship is assessed by counting how frequently terms co-occur in the titles and abstracts (van Nunen et al., 2018).

As seen from Figure 6, there are three clusters of terms, while the ten most occurring terms were underwater vehicle (40), hull (35), mapping (24), operation (22), ROV (19), simultaneous localisation (18), control (17), SLAM (simultaneous localisation and mapping) (17), camera (16) and feature (16). However, although there is a need to have adequately trained and educated ROV operators for underwater hull inspections, one of the important findings of this study is that the terms education or training appear only four times: "training inspection class mini ROV operator ", "short course ", "high school education "and "day course". To identify these terms, the authors manually screened all 2155 terms. That means that important topics such as ROV operators' training have not been adequately studied, and future studies should deal with this issue more intensively. In addition, while manually screening terms, phrases related to maritime law and regulations thematic were not identified. Therefore, as this is also one of the important issues, there is a need for studies on this topic.

Based on these findings, five key research gaps have been identified:

- ROV operator training and education – There is a need for standardised and structured training programs.
- Legal and regulatory frameworks – Lack of standardised regulations for underwater hull inspection using ROVs.
- International collaboration – Weak research cooperation between countries.
- Long-term data management – Better tools are needed to analyse and store hull inspection data.

Filling these gaps can significantly advance the field, ensuring safer, more efficient, and standardised ROV-based hull inspections.

4. CONCLUSIONS

Underwater hull inspection is an important and necessary action to keep the ship in safe and seaworthy condition and for security reasons. Human divers have traditionally performed this work, which was considered hazardous. The introduction of autonomous underwater vehicles (AUV) enabled hazard-free operations and facilitated the process. However, humans are still involved in the operation (as operators), and adequate training is needed.

The paper provides a bibliometric overview of research on underwater hull inspections using ROVs. While publication trends indicate a growing interest, collaboration between researchers and countries remains limited. A relatively small number of publications related to the research topic was found in the WoS database. The analysis showed that researchers from three countries have published over 60% of publications: USA, South Korea and China. Hence, there is a need for other countries to include more and contribute to research. For example, Croatia contributed with only one WoS publication, and as a maritime country with shipyards and rich maritime history, there is a need for more studies on this topic. The study also highlights gaps in ROV operator training and legal aspects, suggesting areas for future research.

The analysis results should be observed in light of the research's limitations. Only the WoS database was taken to examine existing literature on the research topic, while other databases (like Scopus, for example) probably contain valuable publications worth reviewing. Therefore, future research will include all relevant databases to obtain comprehensive and more accurate results. Furthermore, the authors used specific terms

as explained in the Methodology section, and the results might differ if other terms were used. Nonetheless, the authors find the results of this study valuable and suggest directions for future research to fill the gap identified.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

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Analysis of the Operation of the ME-GI Two-Stroke Slow-Speed Diesel Engine in the LNG Tanker

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The development of technologies aimed at finding advanced solutions with the highest degree of fuel energy efficiency and minimal environmental pollution has resulted in the development of modern electronically controlled marine slow-speed diesel engines that use dual fuel systems, e.g. liquified natural gas *LNG* or compressed natural gas *CNG*, low sulphur heavy fuel oil *LSHFO*, heavy fuel oil *HFO*, marine diesel oil *MDO* or low sulphur marine gas oil *LSMGO*. The company *MAN Diesel & Turbo* has developed the *ME-GI* (*M-type, Electronically Controlled, Gas Injection*) type of marine engines, which operates according to the diesel process, where the liquified gas boil-off is compressed through the fuel gas supply system *FGSS* and injected into the cylinders at 300 bar and 45 °C, directly combusted in the cylinders. The main purpose of the *FGSS* is to supply fuel gas to the engine at the correct pressure, depending on the engine load. The operation of a dual-fuel engine first requires the injection of the pilot fuel, i.e. a small amount fuel oil which is self-ignited. As the combustion process starts, the secondary fuel (i.e. gas) is injected into the combustion chambers. Initially, the engine is always started on fuel oil. Once the engine operation on fuel oil is stabilised, the fuel supply can be switched to fuel gas. The engine runs both on fuel gas and fuel oil with equal efficiency. This paper analyses and discusses the *ME-GI* two-stroke slow-speed engine *MAN B&W 5G70ME-C9.5-GI*, installed on modern *LNG* carriers.

KEYWORDS

ME-GI, LNG, dual fuel, combustion, fuel gas supply system

1. INTRODUCTION

Liquefied natural gas LNG is a transparent, colourless, and odourless liquid. It is typically transported and stored near its boiling point at atmospheric pressure, which is around -162°C . Its density-less than half that of water-along with its heating value and other characteristics, varies based on its composition. The actual composition of *LNG* varies depending on its source and liquefaction process, but the main ingredient is always methane. Natural gas is mostly methane CH_4 , which has a higher energy content than other fuels and therefore emits less carbon dioxide when burned (Vorkapić, 2020; Damjanović, 2024; Zore, 2024).

Liquefied Natural Gas *LNG* is emerging as a competitive marine fuel due to stricter environmental regulations on marine emissions. The market for *LNG*-powered ships is projected to expand beyond local short-sea routes to deep-sea shipping on a global scale.

The latest *MARPOL* Annex VI establishes limits on NO_x and SO_x emissions from exhaust gases, distinguishing between open sea and designated *Emission Control Areas ECA*. In this context, *LNG* is considered a viable alternative to conventional, more polluting fuels like *Marine Diesel Oil* and *Heavy Fuel Oil*, gaining traction across various shipping segments. (MAN Diesel & Turbo, 2016; Vorkapić, 2020).

Until now, emissions have been limited by the *International Convention for the Prevention of Pollution from Ships MARPOL*. However, new, even tighter limits have now been set, with the *Marine Environment Protection Committee MEPC* of the *International Maritime Organization IMO* adopting a decision to include a new Chapter 4 into *MARPOL*, Annex VI, referring to the *Energy Efficiency of Ships Regulations*, and introducing the *Energy Efficiency Design Index EEDI*. The *EEDI* is an important technical measure aimed at promoting more energy-efficient and therefore more environmentally friendly ships. The *EEDI* is a measure that represents the amount of carbon dioxide CO_2 emitted when transporting one tonne of cargo per nautical mile (*tonne mile*). The *EEDI* requires the lowest possible energy consumption per tonne mile for different types of ships. In 2025, new ships, compared to those built in 2014, will be 30% more energy efficient (Vorkapić, 2020).

MAN Diesel & Turbo is a global leader in manufacturing large, low-speed gas diesel engines for ship propulsion. Their *ME-GI* engines, characterized as 2-stroke, *dual-fuel*, *electronically controlled*, *gas-injected systems*, are widely recognized in the industry.

Fuel oil is considered the basic fuel type on the engine since the start, loading, low load operation and stop of the of the engine is always carried out using only fuel oil (MAN Diesel & Turbo, 2016). When operating the engine on fuel gas a small amount of fuel oil is always necessary. This amount of fuel oil is used as pilot fuel to control the ignition of both fuel oil and fuel gas in the combustion chamber.

The secondary fuel, fuel gas, serves as an alternative to fuel oil. The fuel gas supply system delivers compressed gas to the engine's fuel gas injection system, allowing the engine to operate in dual-fuel mode using compressed gas rather than liquid gas (MAN Diesel & Turbo, 2016). The engine can operate with up to 95% fuel gas, while 2-5% fuel oil is always required as pilot fuel to regulate the ignition of both fuel oil and fuel gas in the combustion chamber.

A key distinction of these engines compared to other dual-fuel engines is their consistent operation on a standard Diesel cycle. The high-pressure gas injection at the end of the compression stroke offers several advantages, including the elimination of knocking and misfiring limits, the ability to operate at full power, and maintaining maximum *Brake Mean Effective Pressure* without de-rating (Juliussen, Kryger, & Andreasen, 2011; Jelić & Mage, 2013; MAN Diesel & Turbo, 2016).

2. FGS SYSTEM

Heat transfer to liquefied natural gas in cargo tanks during cargo handling or during navigation leads to the formation of *boil-off gas*, the rate of cargo evaporation being in the range of 0,08 to 0,135% per day during the navigation of a loaded ship with tanks initially filled to 98,5% of their total capacity (MAN Diesel & Turbo, 2016; Vorkapić, 2020).

Under normal conditions the *boil-off gas* is used as a means of fuel in the ship's main engines *ME-GI* and/or main generator engines. During normal operations the pressure in the tank is controlled by the use of the *boil-off gas* in the *ME-GI* engines or *DFDG* as fuel or in the gas combustion unit *GCU* (Jelić and Mage, 2013; MAN Diesel & Turbo, 2016).

The gas vapour is taken from the vapour header and passed through the partial re-liquefaction unit and then on to the *BOG* compressor before going to the ship's main engines *ME-GI* and/or *DFDG* where it is burnt as fuel (MAN Diesel & Turbo, 2016). The *FGSS* must supply fuel to all engines taking into consideration all gas supply variables.

The engine requirements to gas supply pressure and temperature when operating on *LNG* are:

- for the *ME-GI* engine: *HP* gas at 300 bar, 45°C,
- for the dual-fuel gensets: low-pressure *LP* gas at 6 bar, 45°C.

The amount of gas used in dual fuel mode depends on the amount which is available from the fuel gas supply system (MAN Diesel & Turbo, 2016). The *ECS Engine control system* receives information from the fuel gas supply system of the available amount of fuel gas and calculates the needed amount of fuel oil based on this.

2.1. BOG Compressor

High-pressure *HP* compressors are more complex and expensive than *HP* cryogenic pumps; however, they provide a direct solution for managing boil-off gas *BOG*. *Burckhardt Compression* and *MAN* are developing a *BOG HP* compressor system for *LNG* carriers equipped with *ME-GI* propulsion. This system integrates the *HP Fuel Gas Supply System* with re-liquefaction processes, enhancing efficiency in *LNG* carrier operations (Burckhardt Compression, 2017; Burckhardt Compression, 2018; Daewoo Shipbuilding & Marine Engineering, 2018).

The compressor, commercially named *Laby-GI*, is a five-stage reciprocating machine, designed with labyrinth oil-free piston sealing in the first three stages and conventional lubricated piston ring sealing in the final two stages. It is identified by the model *5LP250-5B-1*, as illustrated in Figure 1. (Hager, 2018; Hess, 2018; Daewoo Shipbuilding & Marine Engineering, 2018).

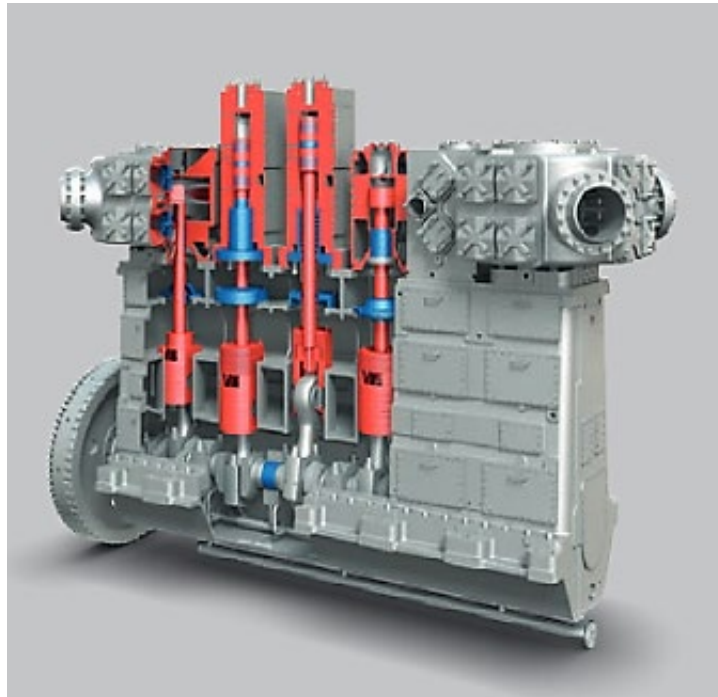


Figure 1. Burckhardt Compression (Source: Burckhardt Compression, 2018)

The main purpose of the high pressure compressor *FGSS* is to provide fuel gas to the two-stroke main engines according to engine load and to serve *DFGE* and partial re-liquefaction plant.

The compressor unit is used to handle *boil-off gas* with a design inlet flow of approx. 4700 kg/h and will compress the gas over five stages from a suction pressure varying between 106 to 170 kPa at variable suction temperature between -120/40°C to a delivery pressure of about 30600 kPa at 45°C (MAN Diesel & Turbo, 2016; Daewoo Shipbuilding & Marine Engineering, 2018).

The compressor may run at full or at partial load condition. The compressor can work at a different capacity, by activation of valve unloaders (100%, 75%, 50%) (Daewoo Shipbuilding & Marine Engineering, 2018). Discharge pressure is controlled by a bypass (a recycle) valve over the first stage. Depending on the gas demand of the *ME-GI* the by-pass over 1st stage opens and closes.

In case of low pressure at compressor inlet the by-pass valve over 1st stage will be forced to open to avoid vacuum in tank. The intermediate pressures are controlled with additional bypass valves over 1-3 stage and 3-5 stage (Ruetzel & Hager, 2017; Hager, 2018; Hess, 2018). In the third stage a supply line is provided for supplying gas to the *Dual fuel Generators* and *GCU*. The line pressure is controlled by a pressure control valve.

The compressors, the unit vessels and piping systems are protected from unexpected overpressure conditions by means of mechanical safety valves installed in the piping system and at the compressor frame (Jelić and Mage, 2013; Daewoo Shipbuilding & Marine Engineering, 2018).

3. FUEL GAS INJECTION SYSTEM

Fuel gas injection system is the common denomination for the fuel gas components installed on the engine, see Figure 2.

The main components are:

- fuel gas pipes,
- fuel gas adapter block (connected to the fuel gas control block),
- fuel gas control block (located next to the cylinder cover),
- fuel gas injection valve (in the cylinder cover) (Jelić and Mage, 2013; MAN Diesel & Turbo, 2016).



Figure 2. Fuel gas components (Source: Authors, 2023)

3.1. Fuel gas pipes

There are two strings or lines of interconnected fuel gas pipes on the engine, an inlet line and an outlet line, see Figure 3.



Figure 3. Fuel gas pipes (Source: Authors, 2023)

The fuel gas pipes are built with double walls, with the outer shielding pipe designed to contain any gas leakage and prevent it from entering the machinery spaces in case of a rupture or leak in the inner fuel gas pipe. The space around the outer pipe, including areas around valves, flanges, and other fittings, is ventilated by the outer pipe ventilation system (MAN Diesel & Turbo, 2016).

The outer pipe ventilation system is designed to ensure continuous air circulation within the outer volume of the double-wall fuel gas pipe system. This ventilation is facilitated by an electrically powered extractor fan located above the deck.

The fan operates independently of any other ventilation systems in the engine room, with its start and stop controlled by the *ECS*. It is installed to draw air through the outer volume of the double-wall fuel gas pipe, creating a pressure in the outer volume that is below atmospheric pressure during fan operation (Juliussen, Kryger, and Andreasen, 2011; Jelić and Mage, 2013; MAN Diesel & Turbo, 2016).

In the event of gas leakage, the gas will be directed to the ventilated section of the double-wall piping system and detected by hydrocarbon *HC* sensors. If the leakage reaches a high level, the engine will continue to operate, but it will switch to fuel oil mode, discontinuing fuel gas operation. All fuel gas pipes will then be purged with inert gas. The inert gas system is used to purge the entire fuel gas piping in the installation, with typical purging pressure values ranging around 10 ± 2 bar, depending on the engine. The first inlet pipe is a vibration compensator (helix) pipe, which is connected at one end to the fuel gas supply pipe and at the other end to an adapter block via a second pipe, as shown in Figure 4.



Figure 4. Helix pipe – compensator (Source: Authors, 2023)

The adapter block features a bore that allows the fuel gas to flow freely into the next pipe in the line, as illustrated in Figure 5. (MAN Diesel & Turbo, 2016).

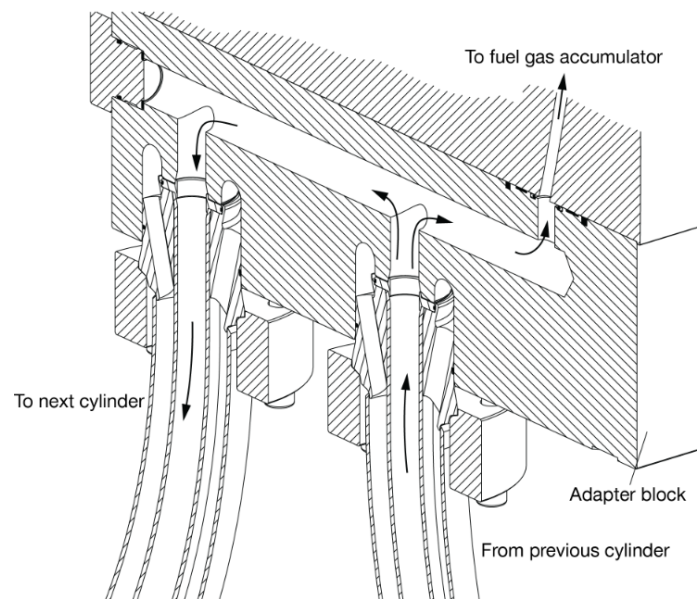


Figure 5. Fuel gas flow from the inlet pipe through the adapter block (Source: MAN Diesel & Turbo, 2016)

The subsequent pipes are interconnecting the adapter blocks between two cylinder units. In this way the fuel gas is distributed to all adapter blocks on all cylinder units. The inlet line is the one closest to the cylinders, the outlet line is the one farthest away from the cylinders. The interconnecting pipes are connected to the adapter blocks similarly to the inlet line pipes. The adapter blocks have similar bores which allows the fuel gas to flow freely to the next pipe in the line (MAN Diesel & Turbo, 2016).

The outlet line on the engine ends, in a compensator (helix) pipe which is connected to an outlet pipe leading to a non-return valve and a silencer which emit exhaust in a safe area in free open space. From the adapter blocks the gas flows to the connected gas control blocks, through control valves in the block and through bores in the cylinder covers to the fuel gas injection valves, see Figure 6. (MAN Diesel & Turbo, 2016).

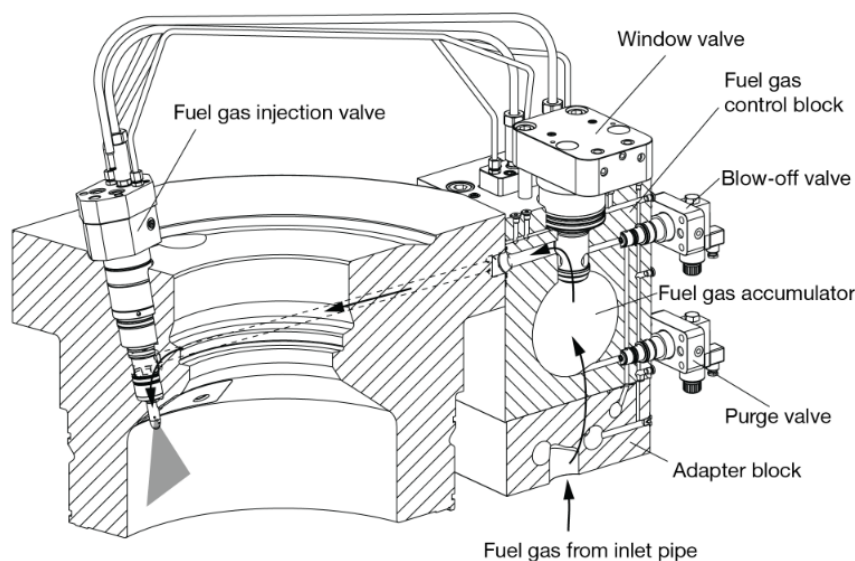


Figure 6. Fuel gas flow from adapter block through the control block to the fuel gas injection valve (Source: MAN Diesel & Turbo, 2016)

3.2. Fuel gas adapter block

The adapter blocks are separate blocks but connected/bolted to the fuel gas control blocks with seals and guide pins between the blocks flanges. The mediums/systems are connected to the fuel gas control block through bores with seals at the blocks flanges (MAN Diesel & Turbo, 2016).

The medium/systems are:

- gas inlet (fuel gas inner pipe),
- gas outlet (fuel gas inner pipe),
- outer pipe ventilation system (fuel gas outer pipe),
- hydraulic oil high pressure line,
- hydraulic oil low pressure supply *LPS* line,
- hydraulic oil drain from the top of the control block (the drip pan), connected to the sludge/waste tank,
- sealing oil,
- hydraulic oil drain pipes, connected to the hydraulic oil drain in the *HCU*.

All adapter blocks except one type are similar, the special type is marked *End Block*, the *End Block* has extra bores for the outer pipe ventilation system, it connects the inlet side to the outlet side in order for the ventilation air to pass (Juliussen, Kryger and Andreassen, 2011; Jelić and Mage, 2013; MAN Diesel & Turbo, 2016).

3.3. Fuel gas control block

The fuel gas control block contains all components necessary to control the fuel gas injection except for the fuel gas injection valves which are mounted in the cylinder cover. All the valves in the block are controlled by the *ECS*. The fuel gas control block also contains a fuel gas accumulator volume which ensures a stable fuel gas injection pressure. The fuel gas enters the control block through a bore in the flange between the adapter block and the control block, see Figure 7. From there the fuel gas enters the accumulator through a non-return valve (MAN Diesel & Turbo, 2016).

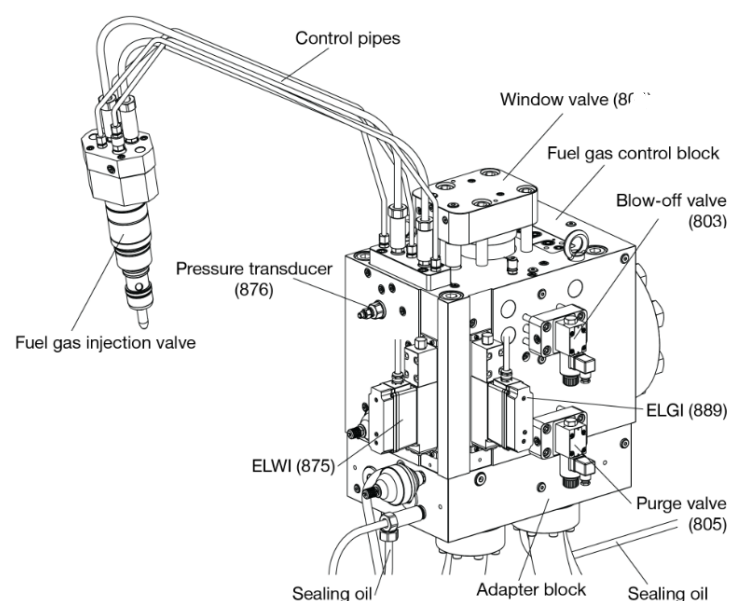


Figure 7. Fuel gas control block and fuel gas injection valve (Source: MAN Diesel & Turbo, 2016)

The fuel gas injection is regulated by two valves in series. The first valve, known as the window valve, is normally closed. It creates a timing window (a predetermined number of crankshaft degrees) based on the crankshaft position, during which it opens and allows fuel gas to flow from the accumulator. The gas then passes through bores in the control block and cylinder cover to the fuel gas injection valves, which are the second valves in the series.

The purpose of the window valve is to function as a safety valve, it prevents that a fuel gas injection can take place outside the allowed timing window, thereby preventing an *un-timed combustion* (MAN Diesel & Turbo, 2016). Due to the maximum allowed open time/degrees the window valve limits the maximum possible amount of injected fuel gas. The fuel gas injection valve controls the precise timing and gas injection amount.

The window valve and the fuel gas injection valves are activated hydraulically by two electrically controlled 3/2-way valves which are controlled by the ECS. The window valve hydraulic activation is performed by an *ELWI* valve - *Electronic Window valve* mounted on the foremost side of the control block (MAN Diesel & Turbo, 2016).

The hydraulic activation of the fuel gas injection valve is performed by an *ELGI* valve *Electronic Gas Injection valve*, supplying high-pressure hydraulic oil to the fuel gas injection valve, thereby controlling the timing and opening area of the fuel gas valve. The *ELGI* valve cannot operate unless the *ELWI* valve is open/active. The *ELGI* is mounted on the control block on the manoeuvring side, see Figure 8.

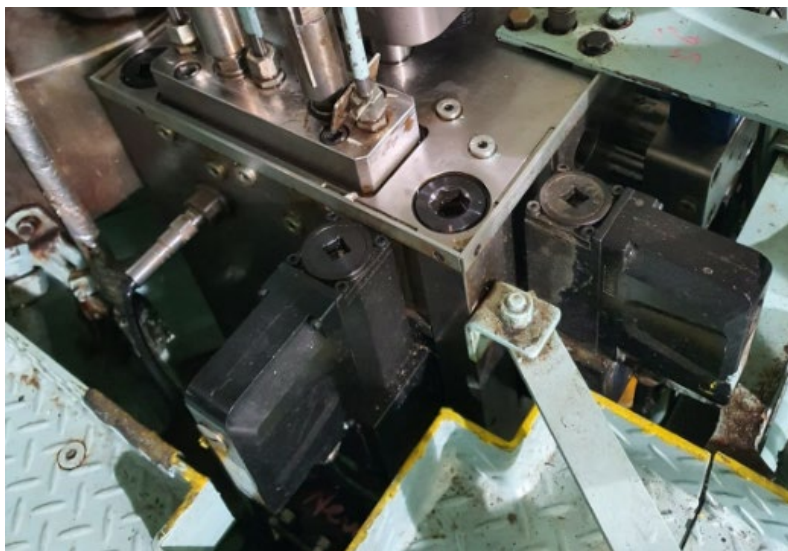


Figure 8. *ELWI* valve *Electronic Window valve* and *ELGI* valve *Electronic Gas Injection valve* (Source: Authors, 2023)

The hydraulic oil used for activation of the valves comes from the hydraulic system's high pressure line. In order to avoid that fuel gas pollutes the hydraulic oil, sealing oil is applied in the window valve and the fuel gas injection valves (MAN Diesel & Turbo, 2016). The sealing oil seals the area between the fuel gas and the hydraulic oil used for activation of the valves. The sealing oil pressure is kept at a constant differential pressure above the gas pressure.

Fuel gas injection is controlled by two valves in series. The first valve, called the window valve, is typically closed. It defines a timing window (a set number of crankshaft degrees) based on the crankshaft position, during which it opens to allow fuel gas to flow from the accumulator. The gas then travels through bores in the control block and cylinder cover to the fuel gas injection valves, which act as the second valves in the series.

Two solenoid controlled hydraulic directional valves, *purge* valve and *blow-off* valve, are mounted on the manoeuvring side of the block, see Figure 9. The valves are operated during purge and blow-off operations. If the *purge* valve opens it will empty the gas in the accumulator into the outlet pipe. If the *blow-off* valve opens, it will empty the gas in the area from the window valve to the fuel gas injection valves into the outlet pipe (MAN Diesel & Turbo, 2016).



Figure 9. *Blow-off* valve and *Purge* valve (Source: Authors, 2023)

A pressure transducer connected to the *ECS* measures the fuel gas pressure in the control block bore between the window valve and fuel gas injection valves. The transducer output is used for monitoring by the *ECS Engine control system*, see Figure 10.

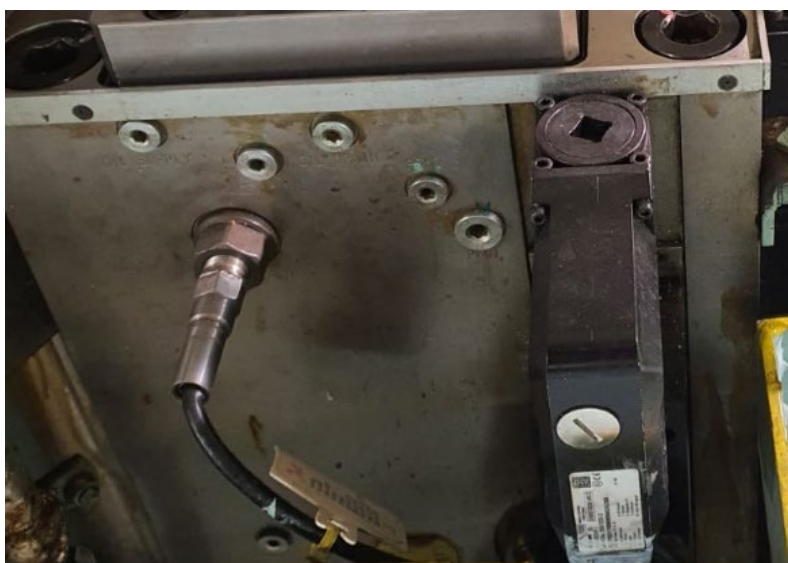


Figure 10. Pressure transducer (Source: Authors, 2023)

3.4. Fuel gas injection valve

Three fuel gas injection valves are mounted in the cylinder cover, see Figures 11.,12.



Figure 11. Fuel gas injection valve (Source: Authors, 2023)



Figure 12. Fuel gas injection valve are mounted in the cylinder cover (Source: Authors, 2023)

The fuel gas flows from the control block to the fuel gas injection valves through bores in the cylinder cover. Five pipes with common flanges in both ends connects each fuel gas injection valve with the control block, see Figure 13.



Figure 13. Five the control pipes (Source: Authors, 2023)

The hydraulic system on the *ME-GI* engine is an electronically controlled mechanical hydraulic system used for actuation of fuel oil injection, fuel gas injection and exhaust valves. The *engine control system ECS*, controls and monitors the system (Juliussen, Kryger and Andreasen, 2011; MAN Diesel & Turbo, 2016).

The control pipes are used for:

- high-pressure hydraulic oil for activation of the fuel gas injection valve, thereby controlling the timing and opening area of the fuel gas valve, control pressure approx. 273 bar,
- sealing oil, in order to avoid that fuel gas pollutes the hydraulic oil, sealing oil is applied to the fuel gas injection valves. The sealing oil seals the area between the fuel gas and the hydraulic oil used for activation of the valves. The sealing oil pressure is kept at a constant differential pressure above the gas pressure, control pressure approx. 338 bar,
- hydraulic oil low pressure supply *LPS*, control pressure 4 bar, oil from the hydraulic oil low pressure supply *LPS* line is applied to the fuel gas injection valve in order to bleed the hydraulic system from air,
- hydraulic oil drain, drain oil from the valve activation and *LPS* supply is connected to the hydraulic oil drain in the *HCU* (MAN Diesel & Turbo, 2016),
- gas detection, sealed areas in the fuel gas injection valve have fuel gas detection bores used for leak detection which are connected to the outer pipe ventilation system. Any gas leakage will be led to the ventilated part of the double-wall piping system and will be detected by hydrocarbon *HC* sensors. The detection of leakages is to be carried out when the fuel gas supply system is pressurised with nitrogen.

If a leakage in the fuel gas pipe system occurs, the *ECS* will detect that there is a leakage in the system, but will not determine the location. In order to detect the exact location of a leakage, the 10-300/400 bar nitrogen supply or the nitrogen booster unit is used for leakage troubleshooting.

4. CONCLUSION

The environmentally advantageous *ME-GI* concept sets a new industry benchmark for two-stroke propulsion engines in liquefied natural gas carriers *LNGCs* and other commercial shipping applications. The distinctive diesel-type combustion of the *ME-GI* engine, combined with the reliable high-pressure *HP* gas supply

system, gives *MAN B&W* two-stroke engines remarkable flexibility. They can operate with virtually any quality of fuel gas, maintaining efficiency with little to no reduction, regardless of the gas's calorific value.

Whenever the vessel enters a harbor or an emission-controlled zone, the multi-fuel *ME-GI* engine seamlessly and reliably transitions between operating on fuel gas and compliant fuel, ensuring adherence to regulations. Modern electronically controlled marine low-speed diesel engines using dual fuel show a significant advantage in optimizing the combustion process and represent a major step forward in efficiency and reducing harmful exhaust emissions.

In addition to safe and reliable operation on gas, the *ME-GI* (*M-type, Electronically Controlled, Gas Injection*) marine engine has significantly reduced CO_2 emissions by 20-25%, NO_x by up to 80%, and significantly lower methane emissions compared to standard *ME* engines running on conventional fuels.

The NO_x emission control level according to regulations 13.3, 13.4, Annex VI of the *MARPOL Convention* is 17,0 and 14,4 g/kWh. The high-pressure natural gas injection system used in the *ME-GI* engine designed by *MAN Diesel & Turbo* has the advantage of being insensitive to the type or variations in the composition of the gas mixture.

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Analysing the Application of the Leadership and Managerial Skills on Board Ships

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Nowadays, systems on ships are highly technologically advanced, but accidents at sea are still frequent. About 80% of accidents occur due to human factor, so there is a need to act on it and reduce the number of accidents caused by the human factor. According to the International Maritime Organization (IMO) requirements and the amendments to the STCW Convention A-II/2 and A III-3 from Manila in 2010, all deck or engine officers must be trained to use leadership and personnel management skills. This course enables crew members to develop the skills to manage a ship's crew successfully. Being a good leader means mastering the course guidelines, which include but are not limited to (i) skills and knowledge in the field of ship personnel management, (ii) understanding of international conventions, recommendations and national legislation, (iii) the ability to apply task and workload management, (iv) knowledge and ability to make decisions and (v) development, introduction and supervision of standard operating procedures. A good organisational culture means facing clear goals, having a strategy, and being open to new ideas. It also means adopting a trusting relationship among crewmembers to create a culture of belonging through the company's vision and mission. All this leads to development and responsibility among crewmembers at the support, operational, and management levels. This paper aims to determine how and to what extent seafarers use the knowledge they have acquired during training and identify the characteristics and effects of shipboard leaders. With that aim, a survey was developed, and the opinions of 71 experienced seafarers were collected and analysed. The study findings revealed that seafarers apply leadership and teamwork skills on board ships and consider their leaders competent with desirable characteristics and effects.

KEYWORDS

Leadership; Teamwork; Crew manning; Designated person; Communication

1. INTRODUCTION

Ship's crewmembers need to function adequately as a good team (or teams if we consider different shipboard departments separately) because the safety of persons, ships, transported goods and the environment are in the first place. In addition, crewmembers need to cooperate to carry out all jobs safely and effectively. Therefore, it is of the utmost importance for shipboard team (or teams) to have a competent leader (or leaders). Onboard ships, team leaders are usually the officers, and the overall team leader is the captain (ship master). The leader of each team needs to guide his crewmembers towards the safe performance of the given job. Master, as leader of all shipboard teams, should monitor crewmembers' performance and take responsibility for their actions and safety (Theotokas et al., 2014).

However, human factors significantly affect marine safety because human error is a cause of around 80-85% of marine accidents (Hanzu-Pazara et al., 2014; Hasanspahić et al., 2021a). In shipping, adequate leadership, teamwork, and crewmember relations must be achieved to reduce human error and promote marine safety. Consequently, the International Maritime Organization (IMO) introduced model courses, which are "meant to suggest and help professors, lecturers and instructors in their teaching" (Horck, 2003). Crewmembers in charge of the shipboard teams should take IMO model courses to train themselves for efficient crew management. However, just taking leadership and crew management courses is not a prerequisite for a safe working environment on board a ship (Vujičić et al., 2018). The company's safety managers should implement measures to achieve healthy human relations and teamwork at all levels of the ship hierarchy. Captains must ensure compliance throughout all levels of the shipboard hierarchy. Notwithstanding the ship's officers taking leadership and crew management courses, marine accidents caused by improper and poor leadership and teamwork still occur (MAIB, 2014a; MAIB, 2014b).

The leadership skills of a shipboard leader in marine emergencies are instrumental for realising the specific job. However, it must be stated that it is highly improbable that crewmembers and their leaders will be prepared in detail for every emergency that might take place at sea (Clarke, 1999). Good leadership skills enable better management, decision-making, instructing and cooperation between crewmembers (Boin et al., 2013). As a prominent team leader and decision-maker, the captain manages crewmembers and makes decisions during emergencies. IMO Model Course 1.39 states, "Leadership is a process in which another individual influences one group of individuals and tries to achieve a common goal".

Multiculturality and communication problems onboard ships are challenges in modern shipping. It is essential that crewmembers assigned with duties during emergencies on large and modern cruise ships can properly utilise communication. In addition, they should clearly understand emergency instructions to prevent passengers from panicking and adequately perform safety duties. A good understanding of their duties, experience and engagement are the most critical factors for making good decisions (Horck, 2004). The ability to supervise team member activities safely and be respected by followers defines a good leader. Leading team members during crises, including communication and interaction with them, are desirable abilities for a good leader (Hanzu-Pazara et al., 2014). A high safety level onboard a ship cannot be achieved without instilling effective teamwork. However, the traditional shipboard hierarchy must be reinstated, and leadership must instil a safety culture to achieve that. The captain must balance his authority and the team member's initiative to do that. He should always utilise just culture and motivate crewmembers to report any near-misses they may notice without fearing punishment (Bielić et al., 2017).

Teamwork should be a key to success in emergencies at sea, whereas leadership characteristics such as human relations (interaction with crewmembers) and competence of leaders are crucial. Some studies pointed out that poor inter and intra-communication, disagreement with COLREGs, and the influence of fatigue on timely decisions caused (among other causal factors) collisions at sea (Vujičić et al., 2017).

To this end, the IMO has a major role in improving safety at sea. During the 2010 Manila Conference, assertiveness training for seafarers was also included in the IMO Model Course 1.39 Leadership and Teamwork and IMO Model Course 1.40 Use of leadership and managerial skills, given its importance not only for those who have to direct operations but also for those in lower ranks and ratings who may have to communicate on safety matters with senior officers and captains (Hanzu-Pazara et al., 2012). The training is not about technical marine knowledge but focuses on the non-technical leadership skills and qualities required in a modern-day teamwork environment.

All crewmembers in the capacity of deck or engine officer, master and chief engineer are required to be trained to use leadership and human management skills and teamwork. Leadership style refers to the way the leader establishes relationships with crewmembers, specifically how subordinates' behavior is directed and the methods used to achieve this. Every leader has their way of approaching work and communicating with subordinates. The leadership style is created as a result of a combination of one's traits, skills, experiences, and knowledge; over time, it becomes a unique signature of the leader. In addition to the above, management style also includes a visual component, i.e. the very appearance of a person and the way crewmembers perceive him. For this reason, it is not unusual that each style affects interpersonal relationships and the atmosphere on board a ship, which are a prerequisite for achieving desired goals and results (Karlić and Hadelan, 2000).

With the amendment of the STCW Convention in 2010, it became possible to renew and acquire certificates of the highest qualifications at both the management and operational levels after completing supplementary education programs. Among these programs, we highlight courses that are typically based on the IMO Model Course 1.39 and 1.40, which focus on leadership, managerial skills, and teamwork (IMO, 2014; 2018). The primary purpose of the courses is to acquire competencies for successful leadership and people management at all levels. Therefore, this paper aims to identify the extent of teamwork and leadership abilities present on board ships after implementing the 2010 Manila Amendments as a part of additional requirements for CoC certification and determine the application of the skills acquired in these courses onboard ships.

2. LEADERSHIP STYLES

It is generally known that three styles are used to manage people (Harms et al., 2018):

- Autocratic
- Democratic
- Laissez-faire

There must be a hierarchy on board ships, and it is essential to clearly establish who is responsible for each task and who reports to whom. The autocratic style, by its very name, implies a strict and unquestioning respect for authority (Harms et al., 2018). This leadership style is characterised by one-way communication, as there are no sub-questions regarding the assignment of jobs and tasks (Chukwusa, 2018).

In contrast to the autocratic style, the democratic style on board is much more accessible and flexible. The leader brings softness to his business, which is characteristic of those who have developed high emotional intelligence. This style is characterised by two-way communication that involves the cooperation of crewmembers and the leader, who are not considered subordinates. Their opinions and ideas are respected, and thus, they participate in decision-making. In this way, creativity and innovation are also encouraged. From the above, many commanders opt for this leadership style. A positive atmosphere and communication are prerequisites for a successful business, which every leader desires and strives for. All of the above can be observed and realised depending on the composition of the crew on board because they can have different attitudes, personalities, cultures, etc. Because of the above, the leader must use a combination of democratic and autocratic style (Tudor et al., 2008).

Unlike the previous two leadership styles, the Laissez-faire style involves the leader very little in the work of the crewmembers. In this style, the assumption is that each crew member is an expert in his job, and they independently determine the outcomes. The leader gets involved a little; that is, he is ignored, which indicates great autonomy and the reason for the freedom that might lead to chaos on board (Ciprić, 2022).

Whatever leadership style the leader uses, the leader is responsible for planning, devising strategies, setting goals, and making decisions. In addition, according to Hasanspahić et al. (2021b), subordinates expect the leader to possess good knowledge to react adequately in emergencies.

3. METHODOLOGY

The authors prepared a survey on leadership and management skills on board ships. The survey consisted of 12 closed-end questions. The first seven questions focused on demographic information, including respondents' age, gender, nationality, highest degree level, current shipboard rank or rating, sea time experience, and maritime sector. The other five (questions 8 to 12) dealt with the seafarers' opinions on leadership and management skills and their usage on board ships. The survey was distributed to active seafarers and was available online (via Google Forms). It was active for three months, and during that period, 71 respondents accessed it and responded to questions. Additionally, the authors conducted informal interviews with instructors of leadership and managerial courses to gather their insights on the courses they teach.

To analyse participants' responses, we used the median and standard deviation as the primary descriptive statistics. The median is a measure of central tendency that is resistant to skewed data and outliers, making it particularly suitable for ordinal data, such as Likert responses. It represents the most common sentiment among the respondents. Standard deviation reflects the variability or dispersion of responses, providing insight into the consistency or diversity of respondents' opinions. These measures were chosen because they offer a balanced perspective on both the overall trend (median) and the level of consensus or disagreement (standard deviation) among the sample. One limitation of the median is that, while it effectively represents the central tendency in ordinal data, it does not consider the entire distribution of values. Likert scale's standard deviation assumes interval properties, potentially overlooking nuances of ordinal data interpretation.

4. RESULTS

According to the answers to the demographic questions, 56% of respondents were between 30 and 49 years of age, 24% were older than 50 and 20% were younger than 29. Most respondents were male (93%), and most had undergraduate education (Bachelor's degree, 52%). Regarding sea experience, 58% of respondents had more than ten years of experience at sea, 20% had between 5 and 10 years, and 22% had less than five years of sea experience. The maritime industry sectors where respondents are employed are presented in Figure 1. As shown in Figure 1, most respondents are engaged in the cruise sector, followed by LNG and bulk carriers.

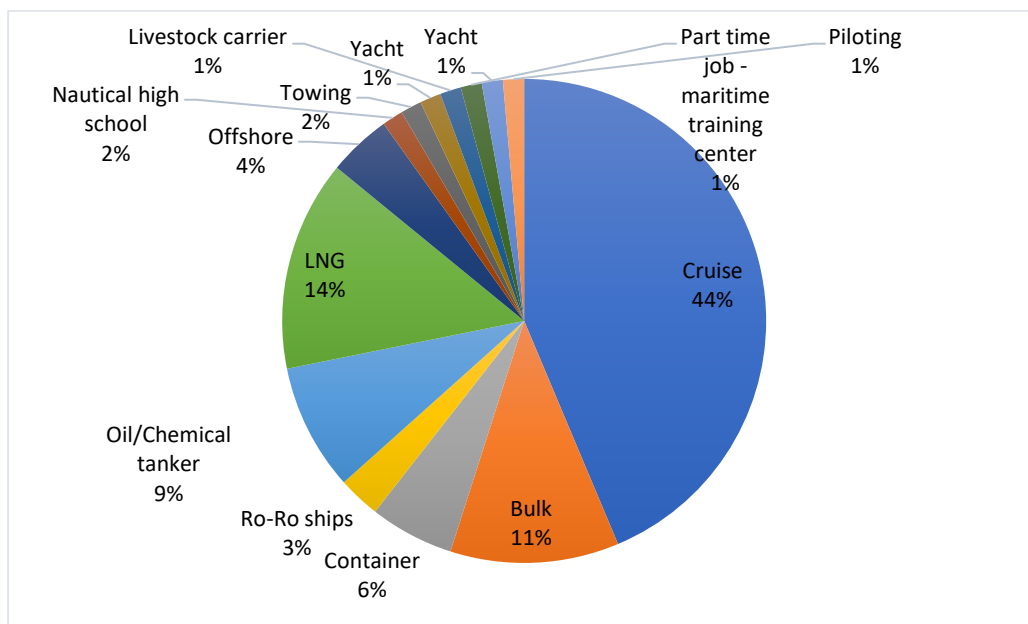


Figure 1. Respondents' sector of the maritime industry.

Question 8 dealt with the extent to which Task and workload management skills are applied on ships: (i) workload, (ii) planning and coordination, and (iii) rest hours and fatigue. The respondents could assign a value from 1 to 5, where 1 is the lowest and 5 is the highest. The results are presented in Table 1.

Question 8. Considering the course concept (course objective), the instructor should define specific requirements for the use of leadership and managerial skills to the trainees. We would like to know to what extent Task and workload management skills are applied on ships.	Median	Standard Deviation
Workload	4	0.71179
Planning and coordination	4	0.82150
Rest hours and fatigue	4	0.98571

Scale: 1 is the lowest, and 5 is the highest rate.

Table 1. Respondents' opinions on different requirements for the use of task and workload management skills on board ships.

According to the results presented in Table 1, respondents have high opinions on using task and workload management skills on board ships and think that instructors equipped them with adequate knowledge on the subject.

Next, question 9 dealt with seafarers' opinions on effective resource management knowledge application on ships. Respondents' views are presented in Table 2.

Question 9. Considering the course concept (course objective), the instructor should provide different requirements for the trainees' use of leadership and managerial skills. We would like to know to what extent Effective resource management skills are applied on ships.	Median	Standard Deviation
Effective communication	4	0.94419
Intercultural respect	4	0.92423
Formal and Informal learning	4	0.78697
Supervising	4	0.84648
Mentoring	4	0.98933
Delegating and coaching	4	0.90361
Assertiveness	4	0.96002
Leadership style	4	0.89589
Motivation	4	0.96415

Scale: 1 is the lowest, and 5 is the highest rate.

Table 2. Respondents' opinions on different requirements for the use of effective resource management skills on board ships.

As presented in Table 2, the respondents' opinions on subjects are relatively high (median rate 4), and there are no differences between respondents' opinions. From the responses, it can be concluded that all effective resource management skills are equally needed and applied on board ships.

Question 10 dealt with respondents' opinions on using and applying decision-making techniques (Table 3).

Question 10. Considering the course concept (course objective), the instructor should provide different requirements for the trainees' use of leadership and managerial skills. We would like to know to what extent decision-making techniques are applied on board ships.	Median	Standard Deviation
Situation awareness	5	0.68509
Team decision-making	4	0.92165
Risk assessment	4	0.88093
Sharing vision	4	0.80442
Evaluation of outcome	4	0.80491

Scale: 1 is the lowest, and 5 is the highest rate.

Table 3. Respondents' opinions on different requirements for using and applying decision-making techniques on board ships.

As shown in Table 3, respondents' opinions on decision-making techniques are equally high (median rate 4, except for situation awareness, which is 5). As situation awareness is recognised as a cause of numerous marine accidents, seafarers perceive it as extremely important.

The last two questions in the survey dealt with the perceived characteristics and effects of shipboard leaders. In question 11, seafarers were asked to characterise their leaders using the offered characteristics. Respondents could choose multiple answers, and the results are presented in Figure 2.



Figure 2. Perceived characteristics of shipboard leaders as seen by the respondents.

The first three characteristics that respondents characterised their leaders with were good and effective communication (54 answers), acceptance of challenges (40 answers), and a strong leader in crisis (36 answers). According to the answers, seafarers perceive their leaders as competent and desirable since they show characteristics needed in emergencies and routine operations. In question 12, seafarers were asked to characterise their shipboard leaders in the offered effects. The results are presented in Figure 3.



Figure 3. Perceived effects of shipboard leaders as seen by the respondents.

The first three effects that respondents characterised their leaders with were that team members are motivated (39 answers), professional standards are very high (34 answers), and the team is confident (33 answers).

5. DISCUSSION AND CONCLUSIONS

Decision-making is one of the most important characteristics of a captain (leader). On the ship, it is understood that the selection of an action should be taken, or one of the strategies should be applied to reach the goal. Decision-making, or the ability to make correct decisions, is a quality every master must have. It is the most difficult, most challenging process that the master must perform while managing the ship and the crew (Wang and Ruhe, 2007).

As the lecturers of the leadership and managerial courses stated, seafarers with many years of experience at the management level on board ships are keen to listen to topics about crew management and often recognise themselves in various situations they had while working on board ships. However, through communication with seafarers attending the course, they also point out that with some companies, it is challenging to initiate disciplinary proceedings for a crewmember who does not follow the regulations and instructions. This makes it difficult for them to play the role of leader, and at the same time, they lose their authority. The only thing left for them is to try to complete the contract or get off the ship themselves. During the course, they actively participate in the discussion, solve tests on how to communicate on board, teamwork, and a test on leadership style on board. Very often, they express their opinion about the possible more frequent

attendance (listening) of the course on the mentioned issues, either at training centres or on the ship, to cope more easily with the increasing challenges of managing the crew.

The respondents' answers confirmed the importance of leadership and teamwork skills and their application on board ships. Managing crewmembers by creating a positive working atmosphere and instilling a just culture improves safety at sea and creates a sense of satisfaction among seafarers on board ships. For the future research the authors plan to investigate whether leadership challenges differ significantly across maritime sectors such as bulkers, tankers, cruise ships and others.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

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The Impact of Teaching the Course Medicine for Seafarers on the Attitudes and Knowledge About Vaccination of Students of Nautical Science at the Faculty of Maritime Studies, University of Split

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Maintaining health while traveling requires adherence to medical guidelines, including risk prevention measures and vaccinations against infectious diseases. Yellow fever vaccination is mandatory under international regulations, while others, like meningococcal meningitis, depend on the destination country's requirements. To support disease control, health authorities issue an International Certificate of Vaccination in accordance with global vaccination regulations, serving as a crucial tool in controlling the cross-border transmission of infectious diseases. This study aims to investigate the attitudes and knowledge of Nautical Studies students regarding vaccination. Additionally, it seeks to determine whether there are differences in attitudes and knowledge between students who receive education on onboard healthcare and those without. For the purposes of the study, we developed a questionnaire consisting of three sections: knowledge about vaccination, attitudes, fear and anxiety related to other health conditions. The participants were undergraduate students of Nautical Studies at the Maritime Faculty of the University of Split. The results confirmed our initial hypotheses. Overall, students demonstrated a positive attitude toward vaccination, with an even more favourable outlook after completing the course Medicine for seafarers. Additionally, students' attitudes and knowledge about vaccination were not correlated with anxiety or fear related to other health conditions. By classifying their duties on board, a ship, seafarers spend part of their working life as second officers of the deck. The second officer or the master is the person responsible for the health of people on board, which includes access to the documentation and vaccinations. The negative attitude towards preventive medical interventions is not proportional to the quality performance of the set work tasks. The difference in attitudes toward vaccination based on education highlights the role of scientific understanding, trust in institutions, and informed decision-making in healthcare.

KEYWORDS

Vaccination; Attitudes; Knowledge; Education

1. INTRODUCTION

The knowledge and attitudes of seafarers regarding vaccination significantly impact their health, safety at sea, and global public health situation. Seafarers are a specific population working in an international environment, frequently traveling between countries with different epidemiological profiles and health regulations. Their awareness of vaccines is crucial for the prevention of infectious diseases. Maintaining health while traveling involves following medical advice on risk avoidance and vaccination against specific infectious diseases (Teaching Institute for Public Health, Split - Dalmatia County, 2025).

Seafarer vaccinations include:

- Compulsory vaccinations according to international and local regulations: against yellow fever, and depending on the regulations of the destination country, against meningococcal meningitis,
- Vaccinations based on epidemiological indications or employer requirements,
- Vaccinations required for issuing certificates for documents (visa, etc.) (Teaching Institute for Public Health, Split - Dalmatia County, 2025; National Institute of Public Health, 2019).

The relevant authority issues an International Certificate of Vaccination (the Yellow Card) or other certificates according to international regulations (National Institute of Public Health, 2019; WHO, 2005). In accordance with the International Health Regulations (IHR 2005) of the World Health Organization, travellers to certain areas are required to have an International Certificate of Vaccination as one of the important means of controlling cross-border importation and spread of certain infectious diseases (WHO, 2005). According to the aforementioned regulations, no one can be a crew member on a ship without an International Certificate of Vaccination with recorded compulsory vaccinations according to international and local regulations (National Institute of Public Health, 2019).

A ship's crew member must have an International Certificate of Vaccination with documented mandatory vaccinations, including yellow fever and, if necessary, meningococcal meningitis vaccination, depending on the health regulations of the destination country (Pomorac.hr, 2025).

Naval ranks determine the hierarchical level of seafarers employed on board and their positions train them to perform specific duties. The need to maintain strict discipline and morale on ships, where people live under difficult conditions, to prevent epidemics that previously plagued ships, and to use the knowledge and experience of senior and more capable seafarers for the common good, has determined the right and duty of certain individuals to perform the jobs entrusted to them by rank and function (Ministry of Maritime Affairs, Transport and Infrastructure, 2013; Učur Đ.M., 2014). The second deck officer is responsible for the health of people on board, which includes oversight of the necessary documentation and vaccinations. In certain circumstances, the captain may also perform this role (Učur Đ.M., 2014).

A negative attitude toward proven preventive medical interventions is not proportional to the quality performing assigned work tasks. Raising the level of knowledge and positive attitudes is crucial for personal safety and public health. Education and raising awareness about vaccination can increase vaccination rates among seafarers, reduce the risk of epidemics on ships, and ensure the continuity of the global maritime industry.

In this context, the primary goal of this study was to examine whether students of Nautical Studies who have taken the course Medicine for seafarers' have a more positive attitude toward vaccination compared to those who have not. The secondary goal was to assess vaccination knowledge among students who have attended the course Medicine for Seafarers and those who have not, as well as to investigate whether students' attitudes and knowledge are linked to anxiety and fear caused by other disorders.

2. PARTICIPANTS AND METHODS

2.1. Structure and Description of the Study

This study was conducted in accordance with the principles of the Declaration of Helsinki. This paper presents a cross-sectional study conducted at the Faculty of Maritime Studies, University of Split. The participants were undergraduate students of Nautical Studies who were in the first year of study (they did not take the course Medicine for seafarers') and the second and third year of study (who had the course Medicine for seafarers'). In order to assess the students' attitudes and knowledge, a special questionnaire was created. We also examined symptoms of anxiety and fear that may be related to another disorder. In addition to demographic data, which included sex, age, program, and year of study, the questionnaire consisted of three parts: the first part assesses knowledge about vaccination, the second part evaluates attitudes, and the third part tests anxiety and fear related to other disorders. Initially, the participants were provided with information about the study. If they agreed to participate, they were given the questionnaire to complete.

2.2. Measurement Instrument

For the purpose of this study, a vaccination knowledge questionnaire was used. The purpose of the questionnaire was defined as a method to assess vaccination knowledge among the student population. The questionnaire includes items that assess misconceptions about potential vaccination risks. Based on these concepts, the questionnaire included 8 true/false questions with an option for "I don't know"; a nominal scale (true/false/I don't know) was provided to make it easier for participants to reveal their answers. Knowledge scores ranged from 1 to 8, with correct answers being scored (Cvjetković S.J. et al., 2014). The Knowledge set had 8 variables. The *Attitude Scale toward Vaccination* consisted of 14 items (five for and eight against) on a five-point Likert scale (from 1 "Strongly disagree" to 5 "Strongly agree"). For negatively worded statements, reverse coding was applied (Cvjetković S.J. et al., 2014). The Experience set included 14 variables.

The third part of the questionnaire assesses feelings of anxiety and fear related to other disorders (Freeman D. et al., 2019). The participants were asked to rate their experiences in the past month for the provided statements. The response options for each statement were: never, rarely, sometimes, often, and always. Each response option was assigned a numerical value. The Anxiety and Fear set had 5 variables.

Due to the lengthy text of the questions in the variables, and to improve readability, abbreviations were used for all variables in the following sections of the paper. In the results section, descriptive statistics for each variable in all variable sets were provided, with the abbreviation corresponding to the numerical order of the variables in the set.

The abbreviation for the Knowledge set was K, for the Experience set AT, and for the Anxiety and Fear set ANF.

2.3. Participants

The study involved students of the undergraduate program in Nautical Studies at the Faculty of Maritime Studies, University of Split, who completed the Vaccination Knowledge and Attitudes Questionnaire.

Before starting the study, the minimum sample size was calculated. According to the information from the minimal sample size calculator, we needed 164 or more participants to achieve a 95% confidence level that the true value would be within $\pm 5\%$ of the measured study value. A total of 64 first-year students completed the questionnaire out of 108 enrolled students. From the 73 second-year students, 58 completed the questionnaire, while from the 105 third-year students, 70 completed the questionnaire. In total, 192 students participated in the study. The course Medicine for seafarers', which is typically taken during the third semester of the second year,

was attended by students from both the second and third years. So, in total, 128 students participated in the course, while 64 first-year students did not attend.

2.4. Inclusion and Exclusion Criteria

The inclusion criterion for this study was that the participants were students of the undergraduate program in Nautical Studies at the Faculty of Maritime Studies, University of Split. Excluded from the study were all students who did not belong to this program and those who did not correctly complete the questionnaire. Also, participants who were in their second or third year and did not enroll in the course Medicine for seafarers were also excluded. To ensure the validity of the collected data, a thorough review of the completed questionnaires was carried out. This approach ensured that only data reflecting careful and thoughtful responses from the participants were used in the subsequent analysis, thus increasing the validity of the results interpretation.

2.5. Statistical Methods

The Shapiro-Wilk test was used to assess whether the data followed a normal distribution or deviated from normality. Based on the results of the Shapiro-Wilk test, descriptive statistics were calculated along with the corresponding measures of central tendency. To test the first two objectives, either the independent samples T-test or the Mann-Whitney U test was applied, depending on the normality of distribution. For testing the third objective canonical correlation analysis was used. Canonical correlation analysis is a multivariate technique employed to determine the relationship between two sets of variables. All analyses were conducted using the statistical software STATISTICA 14.0.0.15, (Statsoft, 2020) with a *p-value* of <0.05 considered statistically significant.

3. RESULTS

In this study, 192 participants took part. To assess the normality of distribution, the Shapiro-Wilk test was used. The results indicated a deviation from normality for all sets of variables ($p < .001$). Descriptive statistics showed the medians and interquartile ranges (IQR) of the variables in all sets (Table 1).

The set of variables Knowledge	Acronym	N	Median	IQR	Shapiro-Wilk	p of Shapiro-Wilk
Contemporary scientific evidence confirms the association of vaccines with chronic diseases such as autism, diabetes, and multiple sclerosis.	1K	192	2.000	2.000	0.775	$< .001$
Vaccines are 100% effective.	2K	192	2.000	0.000	0.759	$< .001$
In the Republic of Croatia, there is a legal obligation to vaccinate children.	3K	192	3.000	1.250	0.661	$< .001$
Administering multiple vaccines at the same time may overwhelm the immune system.	4K	192	3.000	2.000	0.646	$< .001$
Mumps virus infection can lead to serious complications such as hearing loss and meningitis.	5K	192	1.000	2.000	0.604	$< .001$
Thanks to the systematic implementation of vaccination, polio and diphtheria have practically disappeared from the European continent.	6K	192	3.000	2.000	0.676	$< .001$
Reduced vaccination rates in certain regions of Europe and the US have caused a significant increase in the incidence of measles and whooping cough in those regions.	7K	192	1.000	2.000	0.689	$< .001$

A child with an ear infection who is on antibiotic therapy should not receive a vaccine.	8K	192	1.000	2.000	0.648	< .001

The set of variables Attitudes

Media reports about the connection between vaccines and chronic diseases, such as autism and multiple sclerosis, have led me to question vaccination as a safe method.	1AT	192	3.000	2.000	0.910	< .001
It is important to maintain high vaccination rates in the population to avoid the emergence of new epidemics.	2AT	192	4.000	1.000	0.878	< .001
Educating parents about vaccines is an important way to ensure higher vaccination coverage in the population.	3AT	192	4.000	1.250	0.830	< .001
Doctors play an important role in educating parents about the importance of childhood vaccination.	4AT	192	4.000	2.000	0.843	< .001
It is no longer necessary to vaccinate children because these diseases are now very rare.	5AT	191	2.000	1.000	0.878	< .001
Vaccination against a specific infectious disease is a safe protection against contracting that disease.	6AT	192	3.000	2.000	0.905	< .001
Vaccines contain substances that have been proven to be harmful to children's health.	7AT	192	3.000	1.000	0.840	< .001
The diseases started disappearing before compulsory vaccinations were introduced, due to better hygiene and sanitary conditions.	8AT	192	3.000	1.000	0.894	< .001
The state has no right to impose vaccination obligations on children; parents should be the ones to decide.	9AT	189	3.000	1.000	0.897	< .001
There is not enough evidence to prove that immunization prevents the occurrence of infectious diseases.	10AT	188	3.000	1.000	0.895	< .001
Pharmaceutical companies promote childhood vaccination for profit, despite being aware of its harmful effects.	11AT	190	3.000	1.000	0.901	< .001
I would vaccinate my child according to the prescribed immunization program.	12AT	192	3.000	1.000	0.845	< .001
I would advise a friend to vaccinate the child according to the prescribed immunization program.	13AT	192	3.000	1.000	0.902	< .001
If vaccines against HIV and hepatitis C were available, I would definitely get vaccinated.	14AT	192	3.000	1.000	0.890	< .001

The set of variables Anxiety and Fear

I have been worried about someone trying to harm me.	1ANF	192	1.000	1.000	0.740	< .001
Various thoughts about people trying to upset me have crossed my mind.	2ANF	192	2.000	2.000	0.821	< .001

It has been difficult for me to clear my mind from doubts.	3ANF	192	2.000	2.000	0.846	< .001
The worry that someone is trying to harm me is very hard to control.	4ANF	192	1.000	1.000	0.648	< .001
Thinking about possible attacks on me makes me feel stressed.	5ANF	192	1.000	1.000	0.500	< .001

Legend: N – number of participants, IQR – Interquartile Range (IQR) and p- value for significance testing

Table 1 Descriptive statistics for all sets of variables

To examine whether students of Nautical Studies who have attended the course have a more positive attitude toward vaccination compared to those who have not, the non-parametric Mann-Whitney U test was conducted (Table 2). The results of the test indicated no significant differences between students who completed the course and those who did not, in terms of their attitude toward vaccination (all $p > 0.05$).

	U	P
1AT	3440.000	0.060
2AT	4448.000	0.307
3AT	4501.500	0.231
4AT	4598.000	0.142
5AT	3458.000	0.091
6AT	173.500	0.826
7AT	553.500	0.095
8AT	4722.500	0.070
9AT	4470.000	0.169
10AT	3460.000	0.150
11AT	4281.500	0.356
12AT	4729.500	0.059
13AT	3873.000	0.522
14AT	4007.000	0.800

Legend: U – test value, p – significance level

Table 2 Mann Whitney U test (AT)

To test the differences in knowledge about vaccination between students the Mann Whitney U test was also applied (Table 3). No statistically significant differences were found between students in higher years compared to those in lower years who did not attend the course from 2K-8K, whereas in the first question (1K), there was a difference ($p=0.016$). The group that did not attend course had higher values in the response according to the Likert scale for the 1K variable.

Var.	U	p
1K	3276.000	0.016
2K	3600.000	0.107
3K	3628.000	0.134
4K	3684.500	0.191
5K	3605.500	0.099
6K	4108.500	0.970
7K	4090.500	0.988
8K	4060.500	0.990

Legend: U – test value, p – significance level

Table 3 Mann Whitney U test (K)

To determine whether students' attitudes and knowledge are related to anxiety and fear resulting from another disorder, canonical correlation analysis was used. Table 4 presents the results of the canonical correlation analysis between the knowledge variable set and the anxiety and fear variable set. The correlation between the variable sets was statistically significant, as the empirical significance level for the canonical correlation coefficient was $p < 0.05$. The first two extracted canonical factors were statistically significant ($p < 0.000$ & $p = 0.039$), while other canonical factors were not statistically significant ($p > 0.05$). For the first significant canonical factor, question 2K from the knowledge variable set most highly correlates with question 5AN from the anxiety and fear variable set, contributing to the canonical factor (-0.852 and 0.734), while for the second significant canonical factor, question 5K highly correlates with 2AN (-0.688 and -0.937) (Table 5). The results of the canonical correlation analysis between the attitudes variable set and the anxiety and fear variable set extracted only the first significant factor ($p < 0.001$) (Table 6). From the attitudes variable set, 9AT correlates with 1AN from the anxiety and fear variable set ($p = 0.623$ & $p = 0.229$) (Table 7).

Root	Canonical R	Canonical R-sqr.	Chi-sqr.	df	p	Lambda Prime
0	0,472	0,223	88,873	40	<0,001	0,617
1	0,398	0,158	42,471	28	0,039	0,794
2	0,175	0,031	10,784	18	0,903	0,943
3	0,150	0,023	5,068	10	0,887	0,973
4	0,068	0,005	0,859	4	0,930	0,995

Table 4 Testing of the extracted canonical factors using the Chi-square test for the sets of variables Knowledge and Anxiety and Fear

The set of variables Knowledge	Root1	Root2	Root3	Root4	Root5
1K	0,127	0,318	-0,532	0,678	-0,150
2K	-0,852	0,090	-0,147	-0,259	-0,246
3K	0,306	-0,290	-0,443	-0,257	-0,165
4K	0,039	-0,078	0,316	0,181	0,881
5K	0,219	-0,688	-0,282	0,384	-0,057
6K	0,127	0,629	0,322	0,133	-0,049
7K	0,210	-0,293	0,184	-0,236	0,289
8K	0,019	0,476	-0,475	-0,466	0,320
The set of variables Anxiety and Fear	Root1	Root2	Root3	Root4	Root5
1ANF	-0,057	-0,003	0,019	0,291	-1,243
2ANF	-0,703	-0,937	0,621	-0,582	-0,085
3ANF	-0,172	0,195	-0,992	0,822	0,608
4ANF	0,461	0,192	-0,993	-1,198	-0,038
5ANF	0,734	-0,502	0,775	0,922	0,489

Table 5 Correlation matrix of canonical factors – the set of variables Knowledge with the set of variables Anxiety and Fear

Root	Canonical R	Canonical R-sqr.	Chi-sqr.	df	p	Lambda Prime
0	0,514	0,264	118,446	70	<0,001	0,500
1	0,415	0,173	66,026	52	0,092	0,680
2	0,310	0,096	33,643	36	0,581	0,821
3	0,238	0,057	16,420	22	0,794	0,908
4	0,192	0,037	6,410	10	0,780	0,963

Table 6 Testing of extracted canonical factors using the chi-square test for the sets of variables Attitudes and Anxiety and Fear

The set of variables	Root1	Root2	Root3	Root4	Root5
Attitudes					
1AT	0,129	0,390	-0,365	0,650	0,418
2AT	-0,341	-0,220	0,249	-0,196	-0,153
3AT	-0,184	0,387	-0,108	-0,434	0,180
4AT	0,150	0,280	-0,537	0,424	0,268
5AT	-0,188	0,030	-0,303	0,470	-0,566
6AT	0,017	-0,287	0,074	0,399	-0,572
7AT	0,300	0,113	-0,089	-0,347	-0,612
8AT	-0,402	-0,445	-0,193	0,106	0,062
9AT	0,623	-0,279	-0,112	-0,593	-0,260
10AT	0,099	-0,329	-0,360	0,161	0,759
11AT	0,252	0,153	0,400	0,177	-0,002
12AT	-0,420	0,010	-0,379	0,001	-0,112
13AT	0,615	0,389	-0,407	0,041	-0,310
14AT	-0,129	0,389	-0,365	0,650	0,418
The set of variables	Root1	Root2	Root3	Root4	Root5
Anxiety and Fear					
1ANF	0,229	-0,299	-0,330	-0,169	-0,030
2ANF	-0,033	0,029	0,647	-0,395	0,646
3ANF	0,119	0,738	0,242	0,394	0,065
4ANF	0,071	-0,324	-0,123	0,679	0,931
5ANF	0,216	-0,681	0,102	0,230	-0,823

Table 7 Correlation matrix of canonical factors - the set of variables Attitude with the set of variables Anxiety and Fear

The results show that students who have attended the course Medicine for seafarers' do not have more positive attitudes towards vaccination compared to those who have not attended the course. Furthermore, those who have not attended the course tend to agree more with the statement that modern scientific evidence confirms the connection between vaccines and chronic diseases such as autism, diabetes, and multiple sclerosis. Based on the results of the canonical correlation analysis, we can argue that participants who lack trust in the effectiveness of vaccines exhibit higher levels of anxiety compared to those who trust in the effectiveness of vaccines.

4. DISCUSSION

The survey of students of the Nautical Studies and statistical analysis of the obtained data did not show a higher level of knowledge, nor differences in attitudes towards vaccination between higher-year students who attend the course 'Medicine for seafarers' and those who did not attend the course.

Vaccine knowledge among seafarers is multifaceted. It is effect on the protection of both, personal and collective health. Seafarers are often exposed to infectious diseases such as the flu, hepatitis, COVID-19, and other diseases that spread easily in the confined spaces of a ship (Vranic S.M. et al., 2023). Well-informed seafarers can make better decisions about vaccination and protecting their health. The second effect is the reduction of the risk of outbreaks on board. Regular vaccination reduces the risk of epidemics that can threaten the crew and the ship's operations. The third significant effect is the reduction in the need for medical intervention at sea. Access to medical services on board is limited, and more serious infections may require urgent evacuation, which poses logistical and financial problems (Senbursa N. et al., 2024). Prevention through vaccination mitigates these risks.

The influence of education on the formation of attitudes toward vaccination is multidimensional, which reflects the complexity of human risk perception and trust in science, highlighting how education shapes attitudes, though it is not the only factor. Individuals with higher levels of education often have a better understanding of scientific principles and methods (Di Napoli F. et al., 2023). This may make them more likely to accept scientific consensus regarding the effectiveness and safety of vaccines. Those with lower levels of education may be more susceptible to misinformation due to a lack of familiarity with scientific terminology or critical thinking skills. Educated individuals are more likely to rely on reliable information sources, such as medical journals and official health websites, whereas those with lower education levels often turn to social media and word of mouth, where misinformation circulates more rapidly.

The attitudes of seafarers towards vaccine uptake are influenced by their trust in vaccines and the healthcare system (Alfano V. et al., 2022). Seafarers' views on vaccines are often shaped by experiences, media information, and recommendations from health professionals. Education affects openness to scientific findings, but cultural and personal factors, such as religious beliefs or mistrust of pharmaceutical companies, can play an important role regardless of educational level. One study discovered a substantial association between knowledge and the semester of medical studies (Sanftenberg L. et al., 2020). A systematic review revealed 1795 cases of vaccine-preventable infections on ships, the bulk of which were varicella cases among crew members. The review emphasized the importance of improving seafarers' immunization practices in order to minimize disease transmission across borders (Mouchtouri V.A. et al., 2019). Studies have stressed the need of immunizing seafarers against COVID-19, given their involvement in international travel and the possibility of disease transmission. Partnerships between ports and healthcare institutions have been formed to provide onboard immunization programs for seafarers (Mungmunpuntipantip R. & Wiwanitkit V., 2021; Taylor, T. L., Maguire, D., & Johansson, M., 2022; Battineni, G., 2021). This lack of regulation poses challenges for controlling vaccine-preventable diseases in maritime industry, and in order to act according to the principle of primary prevention, it is necessary to start from the education of future seafarers.

Furthermore, if seafarers have a negative attitude toward vaccination, they may face employment and travel restrictions, which can significantly affect their quality of life. Cultural and religious factors play an important role in shaping attitudes. Individuals may have negative views about vaccination due to personal beliefs or cultural barriers, which can affect their willingness to accept vaccines (Cvjetković S.J. et al., 2014). Knowledge is just one factor influencing attitudes toward vaccination, but it is one we can influence. Personality traits or cultural factors are more difficult to change, so education and information remain the most significant interventions we can apply to preserve a positive attitude toward vaccination. The difference in vaccination attitudes based on

education reflects its impact on understanding scientific information obtained from verified data source, trust in institutions, and decision-making about health.

5. STRENGTHS AND LIMITATIONS OF THE STUDY

The limitation of the study includes sample limitations, as it was conducted on a single study group at the faculty. Out of 192 participants, 3 did not provide answers to all questions. Given the open scientific practice, transparency, and integrity of the study, these participants were not excluded from the study, but some variables have a slightly smaller sample size. Additionally, a minimal limitation could be the subjectivity of self-reported information and the lack of longitudinal follow-up. Also, the study faced a limitation due to the uneven distribution of participants, with 128 students attending the course Medicine for seafarers' and 64 not attending. This imbalance stems from the course's scheduling within the academic calendar, which naturally draws students from both the second and third years. Despite this, the study still provides valuable insights into student engagement and outcomes.

6. CONCLUSION

The study aimed to determine the differences in knowledge and attitudes towards vaccination between students of the Maritime Faculty who attended the course Medicine for seafarers' and those who did not, as well as the association with anxiety and fear.

There were no statistically significant differences between students in higher years compared to those in lower years who did not attend the course, which may suggest that the curriculum does not allocate enough attention to this topic or has not presented it to students in an acceptable manner.

CONFLICT OF INTEREST: Professor Andrea Russo is a member of the congress's scientific committee.

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