

25th ANNUAL GENERAL ASSEMBLY

CHENNAI | INDIA

IAMU

AMET University
Chennai, India

AGA 25

16th – 17th OCTOBER 2025

DISRUPTIVE TECHNOLOGIES AND INNOVATIONS TOWARDS SUSTAINABLE MARITIME PRACTICES

Proceedings of the International Association of Maritime Universities (IAMU) Conference

THE NIPPON FOUNDATION

AMET UNIVERSITY
(Deemed to be University Under Section 3 of UGC Act 1956)

IAMU
International Association of Maritime Universities

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IAMU
International Association of Maritime Universities

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"A publication of the International Association of Maritime Universities"

For the Publisher

AMET University, India

ISSN: 2706-6746 (Electronic Version)

Preface

Welcome to the 2025 IAMU Conference
Disruptive Technologies and Innovations towards Sustainable Maritime Practices

It is my great honour, as the Chair of the International Program Committee and Program Editor for the International Association of Maritime Universities (IAMU) Annual General Assembly and Conference 2025 (AGA25), to welcome you to this year's distinguished gathering. The IAMU Conference continues its proud legacy of fostering global dialogue, collaboration and innovation in maritime education, training and research.

The 2025 theme, Disruptive Technologies and Innovations towards Sustainable Maritime Practices, captures the essence of the transformative wave redefining the global maritime landscape. It reflects our collective commitment to advancing digitalization, automation, artificial intelligence, clean energy transitions and smart technologies that will ensure a safer, more efficient and sustainable maritime future.

This year's conference stands as a powerful testament to the strength of academic scholarship and international collaboration within the global Maritime Education and Training (MET) community. It demonstrates how shared research and interdisciplinary engagement can accelerate the adoption of disruptive innovations and drive sustainability across the maritime sector.

The technical sessions pioneering research on sustainable shipping, digital innovation, maritime safety and forward-looking policy frameworks that will guide the industry toward decarbonisation and resilience. Through these scholarly exchanges, we aim to empower the next generation of maritime professionals with the skills, knowledge and foresight required to lead in an era of technological transformation.

A total of 124 Full Papers were submitted by scholars from IAMU member universities around the world, reflecting both the breadth and depth of global maritime research. Following a meticulous evaluation by an international panel of reviewers, 84 Full Papers are accepted successfully that passed the rigorous double-blind peer-review process, which included plagiarism and AI-content screening in strict adherence to IAMU publication standards. The final selection of 84 articles represents high-quality, original and thematically aligned contributions that advance knowledge in disruptive technologies, maritime innovation and sustainability.

On behalf of IAMU and the International Program Committee, I extend my heartfelt appreciation to all authors, reviewers, presenters and participants for your scholarly contributions and unwavering dedication to advancing sustainability in the maritime domain. My sincere gratitude also goes to the faculty and organizing team of the host institution AMET University and the IAMU Secretariat for their invaluable support and collaboration.

Together, we continue to champion innovation, knowledge exchange and global cooperation to ensure that disruptive technologies and sustainable practices steer the maritime industry smarter, greener and more resilient future.

Thank you and I wish you an inspiring and impactful conference experience.

Sincerely
Dr. Deepa Rajesh
Chair, International Program Committee & Program Editor for IAMUC 2025

Theme

Main Theme

Disruptive Technologies and Innovations towards Sustainable Maritime Practices

Sub Themes

- **Economic Aspect**
- **Environmental Aspect**
- **Policy Aspect**
- **Social Aspect**
- **Technology Aspect**

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IAMU ANNUAL GENERAL ASSEMBLY (AGA)

The Annual General Assembly (AGA) is a forum to allow the exchange of information, policy approvals, and the development and fostering of good relations and collaboration among IAMU member universities.

The Plenary Session, President's Forum, Project Presentations and IAMU Conference (IAMUC) are the main components of AGA. The IAMU Student Program (IAMUS) may be jointly organized by the host university.

PLENARY SESSION

The Plenary Session provides all staff of member universities with an opportunity to review activities of IAMU and to approve IAMU policies, programs and budget as recommended by the International Executive Board (IEB). The Chair of IAMU and the Executive Director, on behalf of IEB, report to the member universities on the decision of the IEB.

PRESIDENT'S FORUM

The President's Forum is a meeting in which the Presidents of IAMU member universities talk about issues especially on policy, direction, and activity of IAMU considering the academic relationship among member universities as well as the economic and technological developments in the international maritime community. The Local Executive Committee (LEC) of an AGA is responsible for organizing the President's Forum during the AGA.

PROJECT PRESENTATIONS

Each project coordinator/ representative of a research project shall make a project presentation in front of academic staff of member universities during the AGA, which is to improve the quality of the project.

IAMU CONFERENCE

IAMU Conference (IAMUC) provides academic staff of member universities with an opportunity to present the outcomes of their academic/ scientific research to the IAMU community. The LEC together with the International Program Committee (IPC) jointly organizes the IAMU Conference, including the selection of session topics and qualifying papers.

IAMU STUDENT PROGRAM

LEC of an AGA may organize the IAMU Student Program (IAMUS) during the AGA where students of member universities jointly participate in some events related to student's activities.

WELCOME TO AGA25

The Annual General Assembly (AGA) is the annual meeting of the International Association of Maritime Universities (IAMU). The International Association of Maritime Universities Conference (IAMUC), held annually as part of the AGA, brings together experts and official representatives of IAMU member universities from all over the world to discuss recent progress and future trends in Maritime education, training, research, and other matters within the scope of IAMU. AMET University is honored to host the 25th Annual General Assembly, IAMUC and IAMUS 2025.

This event aims to bring together global maritime leaders, academics, industry experts, and policymakers to exchange knowledge, share best practices, and foster international collaboration. The conference seeks to advance maritime education, training, research, and innovation, while strengthening partnerships that address emerging challenges and shape the future of the global maritime sector.

WELCOME TO AMET

The 25th Annual General Assembly will be a landmark event hosted by AMET University, India's first Maritime University, established in 1993. For over three decades, AMET has contributed to the maritime sector by producing skilled professionals, advancing research, and fostering innovations that serve not only India but the global maritime community.
Maersk A.P. Moller, Denmark, one of the renowned and leading shipping companies of the world, have established a Centre of Excellence in collaboration with AMET University which is the first model of Centre of Excellence in the world established by a leading shipping company. Likewise, other leading shipping companies like V Ships, PIL, Fleet Management etc., are having Memoranda of Understanding and established their Centre for Training in our Campus.

HISTORICAL BACKGROUND OF THE CITY

Discover India's rich cultural heritage through maritime museums, Centres of Excellence, and industry collaborations. Experience the unique blend of multilingual and multicultural traditions that define India's maritime legacy. Chennai, the Gateway to South India, is a city where tradition and modernity blend seamlessly. From the UNESCO World Heritage Site of Mahabalipuram, known for its ancient rock-cut temples and Dravidian architecture, to the iconic Marina Beach, the world's second-longest beach, the city offers diverse experiences. Heritage landmarks like the Santhome Church and Kapaleeshwarar Temple reflect Chennai's deep spiritual and cultural roots, while the Government Museum showcases India's rich history and art. For cultural immersion, Dakshina Chitra brings alive the traditions and architecture of South India, and for nature lovers, the Arignar Anna Zoological Park offers a glimpse of biodiversity. Adding to its spiritual vibrance, ISKCON Chennai provides a peaceful retreat of devotion and meditation. Together, these attractions make Chennai a destination of history, culture, spirituality, and coastal beauty.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Exploring digital solutions in maritime transport - challenges in supply chain management on training vessels

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Abstract: During the analysis of procurement routines aboard Dar Młodzieży, a training vessel operated by Gdynia Maritime University (GMU), recurring inefficiencies were observed in inventory verification and order forecasting. For instance, in 2023, nearly 18 kg of dairy products were discarded due to expired stock that had not been properly tracked. Interviews with the vessel's kitchen and technical staff confirmed that such cases were not isolated but reflected systemic gaps in cross-departmental coordination.

This paper investigates the current state of onboard provisioning practices and explores the feasibility of digital intervention using a custom-built prototype platform: DYLLI SHIP. The prototype adapts digital workflows originally tested in the HoReCa sector [6], combining role-based approvals, mandatory stock updates prior to ordering, and integrated food waste tracking.

The proposed system was conceptually tested through user feedback sessions and visual interface walkthroughs, conducted with crew members and shore-based logistics officers. While not yet deployed onboard, preliminary reactions suggest that the tool could streamline inventory coordination and increase order accuracy, particularly in high-turnover training environments. Participants especially valued the waste tracking dashboard and structured communication panel as enhancements over current ad-hoc paper-based methods.

This research highlights the challenges of digital transformation in maritime education and proposes a replicable system architecture to improve transparency, reduce waste, and support data-informed supply chain management. DYLLI SHIP, while still a prototype, provides a starting point for further testing and operational validation within the maritime training sector [1,2,3,7].

Keywords: ICT tools, digital transformation, supply chain management, training vessels

1. Introduction

Digital transformation is increasingly recognized as a driver of efficiency, transparency, and sustainability across the maritime industry [1,2]. While commercial shipping has widely embraced digital solutions in navigation, maintenance, and logistics, maritime education institutions, particularly those operating training vessels - often lag in modernizing critical operational domains such as supply chain management (SCM) [9,10].

Gdynia Maritime University (GMU), established in 1920, is one of the largest and most prestigious maritime academies in Central and Eastern Europe [3].With more than 5,000 students and a legacy of training officers and maritime professionals, GMU operates the full-rigged sailing ship Dar Młodzieży as its flagship training vessel [3,11].This 110-meter ship, designed for ocean-going cadet voyages, is not only a symbol of Polish maritime heritage but also a floating campus requiring comprehensive logistical support [11].

Each voyage necessitates careful planning of food, technical equipment, and consumables. Yet the current procurement processes onboard Dar Młodzieży remain largely analog and fragmented [9]. Orders are typically generated using static Excel files, transmitted via email, and processed without synchronized access to inventory data [1]. This often leads to inaccurate forecasting, excessive or duplicate orders, and wastage

of food and materials [7,8]. Communication between the ship and shore-based procurement offices is hindered by limited connectivity, reliance on asynchronous exchanges, and the absence of a shared documentation platform [12].

2. Theoretical framework: digital supply chain management in maritime sector

2.1 ICT and Operational Realities in Maritime Supply Chains

In recent years, the maritime supply chain has undergone a visible transformation, largely driven by advancements in Information and Communication Technologies (ICT) [12]. Traditional logistics, often reliant on fragmented paperwork and manual oversight, are being replaced with systems that prioritize responsiveness, automation, and better access to data. However, implementing these tools on training vessels, ships that double as educational platforms and operational units, introduces a unique set of opportunities and challenges [10,3].

One of the most prominent technologies in this shift is the Internet of Things (IoT). Onboard sensors installed in storage units or galleys, for example, can track temperature, humidity, and stock levels in real time. On GMU's training vessel Dar Młodzieży, IoT-enabled monitoring was cited as a factor in reducing spoilage, particularly during long voyages with irregular access to fresh supplies [13,17].



Figure 1. Dar Młodzieży in Gdynia port.
Source: Gdynia Maritime University

Commissioned in 1982 as the successor to Dar Pomorza, Dar Młodzieży remains one of the most iconic tall ships in European maritime education. Operated year-round by Gdynia Maritime University (GMU), the sailing vessel accommodates over a hundred cadets per voyage, offering hands-on instruction in navigation, mechanics, and seamanship. According to Capt. Dariusz Jellonnek, Director of GMU's Shipowner and Internship Department, "Dar Młodzieży continues to be more than just a school at sea, it's where cadets transition from theory to practice through teamwork, watchkeeping, and exposure to dynamic sailing conditions."

Each summer, the vessel participates in international events such as The Tall Ship Races and high-profile port visits across Europe. During the 2025 season, students will sail to Le Havre, Bremerhaven, and Amsterdam, where Dar Młodzieży will represent Poland at the 750th anniversary of the Dutch capital. These long-standing engagements reflect the vessel's dual mission: to preserve Poland's maritime heritage and prepare future officers for service in the global fleet.

Yet technology is only one side of the equation. In many maritime institutions, inventory tracking still relies on paper logs or basic spreadsheets [9,4]. These documents are rarely updated in real time, and often stored separately by different departments, engineering, procurement, deck operations, leading to

version conflicts and limited institutional oversight [1].

Blockchain, cloud platforms, and AI offer potential solutions. Blockchain creates secure, time-stamped records for requisitions and deliveries that cannot be modified retroactively, which is especially valuable when procurement decisions must be traceable [14,16]. Cloud-based systems and analytics help forecast consumption and coordinate supply cycles more efficiently [1,2]. However, in practice, few systems offer reliable functionality in offline or low-bandwidth environments, still common at sea [13].

The hybrid nature of training vessels also complicates demand planning. Unlike commercial ships with fixed routes, voyages are tied to academic calendars that may change due to weather, exams, or vessel availability [11]. As one logistics coordinator at GMU noted, “Sometimes we plan for a 10-day Baltic loop and end up rerouting to the North Sea, the provisioning can’t keep up.”

These operational shifts often clash with physical realities. Limited storage forces difficult decisions about what to carry. During a recent audit, crew reported that shelf space in the engine room was being repurposed for galley storage, highlighting the absence of a unified allocation model. Officers typically rely on intuition or experience, rather than centralized, data-driven processes [3].

Compliance also remains a constant pressure. Missing gaskets or expired fire extinguishers can trigger penalties or jeopardize a vessel's certification status [18]. Despite this, many inventory tasks fall to cadets or junior officers still learning maritime logistics. While this supports hands-on education, it also introduces inconsistency, particularly when no digital procedures are in place [10].

Finally, digital twins and automated systems may offer a way forward. At GMU, early-stage simulations model the effect of different procurement strategies on waste and delivery time. These are not yet operational tools, but they reflect a broader shift in training, from memorizing protocols to actively managing them using digital tools. This operational complexity is further compounded by the lack of streamlined communication between shipboard personnel and shore-based procurement offices, a challenge that directly undermines even the most advanced digital systems.

2.2 Communication between ship and shore-based procurement offices

Smooth coordination between onboard personnel and land-based procurement offices remains one of the most persistent challenges in maritime education logistics [1,12]. Communication inefficiencies are not just occasional, they are systemic, especially during long voyages or when sailing in poorly connected regions.

Multinational crews and procurement teams often operate with varying degrees of English proficiency. Misunderstandings over technical terminology or supply codes are frequent, especially when order templates or internal documentation differ by department [10]. One officer noted that the same type of gloves was ordered twice, once under the Polish term "rękawice" and again as "safety gloves."

Training vessels frequently operate beyond stable internet coverage. Even short email exchanges may be delayed by hours or days, especially in remote sea zones [12,13]. Moreover, many ships still rely on standalone systems not integrated with institutional databases [1], forcing procurement officers to cross-check documents manually. GMU’s Horyzont II, a small polar research vessel used for student practice and scientific expeditions, has operated in these areas for over two decades, including missions to the Antarctic and annual voyages to Hornsund in the Svalbard archipelago.



Figure 2. Horyzont II navigating icy waters near Svalbard
Source: Gdynia Maritime University

The traditional maritime chain of command often discourages junior officers or cadets from initiating communication with shore-based staff [18]. A logistics coordinator at GMU noted: "Some crew hesitate to report missing items early, fearing it might be seen as their mistake."

Without shared platforms or standardized protocols, information remains locked within departmental silos [4]. Inventory logs, order histories, and supplier communications are often kept in separate folders or personal drives, which hinders transparency and slows down decision-making [1,9].

This fragmentation impacts not only daily operations but also compliance. During one audit, mismatched records between the onboard inventory and the university's procurement system led to a full review of kitchen supplies, an unnecessary delay that could have been avoided with a centralized database.

This case illustrates how fragmented systems, institutional hierarchy, and limited connectivity converge to hinder efficient maritime logistics - a challenge that digital integration alone cannot solve without organizational reform.

3. Methodology

This research adopts a qualitative case study approach to investigate supply chain procedures and logistical inefficiencies aboard training vessels operated by Gdynia Maritime University (GMU) [19,3]. The case study framework was chosen intentionally. It reflects the operational and organizational specificities of maritime education, where logistical processes must serve a dual purpose, supporting both training goals and vessel operations [4,19].

Primary data came from semi-structured interviews conducted with crew members and GMU's maritime operations staff. These conversations were held in either Polish or English, depending on participant preference, and were transcribed manually. The questions explored everyday procurement routines, typical points of failure, and how communication currently flows between ship and shore.

To cross-check interview responses, institutional documents were also reviewed. These included requisition forms, inventory logs, and purchase approval records. Informal observations during onboard visits added another dimension. They helped identify gaps between how procedures are described on paper and how they actually play out in real conditions. As one logistics officer put it: "Sometimes the paperwork says one thing, but what's really on the shelf tells a different story."

Together, this triangulated evidence base shaped the development of the DYLLI SHIP prototype, a

digital solution tailored to the recurring issues identified by both onboard personnel and land-based administrators.

2.3 Qualitative interviews and process mapping

The core of the study is based on a series of in-depth interviews conducted between January and March 2024 with key stakeholders at GMU [4,20]. These interviews were semi-structured and conducted in person and online, focusing on understanding the end-to-end supply process, the typical communication flow between ship and office, pain points in inventory management, and procedural bottlenecks in procurement [4,19].

Based on the qualitative data collected, the research team developed a business process map representing the current state of SCM operations on training vessels [4]. This map served as the foundation for identifying digital intervention points and process optimization opportunities [1,2].

2.4 Prototyping and digital design using DYLLI

After identifying the key inefficiencies in onboard supply workflows and ship-to-shore communication, the research team moved on to designing a prototype of a digital tool tailored specifically for training vessels. This early-stage model was created using Figma, a collaborative interface design platform often used to visualize and test user journeys before development begins [6].

The concept builds on DYLLI, a mobile application originally developed under the Innovation Incubator 4.0 programme for the HoReCa and wholesale sectors [6]. Adapting the system for maritime education required several contextual adjustments, including offline access, simplified user inputs, and alignment with documentation routines onboard ships.

The prototype consists of four primary modules [6]:

- a digital requisition form structured around shipboard workflows,
- a real-time status panel indicating the progress of orders and approvals,
- a messaging feature that facilitates communication between onboard personnel and shore-side teams,
- and an administrative interface for monitoring inventory and supply cycles across departments. These functions were presented as clickable screens and demonstrated to selected staff members at GMU.

During feedback sessions, several participants remarked that the layout was intuitive and addressed their existing pain points, particularly the absence of visibility into procurement workflows. One participant commented that the status panel “makes it easier to follow what’s going on, even if you’re not part of every conversation.”

Although the prototype has not yet been tested in live onboard conditions, it was reviewed in detail against real-world operational procedures from previous voyages. Based on the feedback received, the system has been revised to better reflect the documentation habits, communication styles, and functional priorities of maritime training crews. The next phase will involve structured usability testing in controlled training environments.

2.5 Document review and data sources

In parallel with interviews and field observations, the study involved a structured analysis of internal documentation provided by Gdynia Maritime University (GMU). These records helped validate qualitative insights and offered a broader understanding of how supply chain processes unfold in daily operations [4,20].

Document analysis remains a well-established method in qualitative research, particularly when exploring institutional practices that are often not verbalized during interviews [4,20]. It enables researchers to uncover routine patterns, administrative constraints, and procedural norms embedded in the organization’s internal workflows.

The materials reviewed covered a wide range of formats and sources. Among them were archived procurement orders, sample invoices, inventory spreadsheets prepared manually on board, and ship-to-shore

communication reports. The team also examined maintenance logs, inspection checklists, and standard documentation templates used during voyage preparations and onboard audits [4,6].

One noteworthy example involved a set of requisition forms where the recorded stock levels did not match the quantities listed in corresponding delivery receipts. While this mismatch was small, two cases of tinned vegetables, it signaled a recurring issue reported in several interviews. These kinds of inconsistencies were critical in identifying weak points in the paper-based process.

Materials related to DYLLI's original development were also reviewed. This included early-stage design drafts, internal evaluations, and feedback logs from previous pilots. Together, these documents enriched the interview data and anchored the system design in actual operational needs [20].

2.6 Limitations and scope

This study draws on detailed input from staff members at Gdynia Maritime University, offering insight into how procurement and inventory systems operate aboard a specific training vessel. However, as the analysis was limited to a single institution, the findings should not be generalized to all maritime universities or shipboard environments. No data were gathered from other training ships, international academies, or commercial vessels, which restricts the comparative scope of the research.

Another limitation lies in the development stage of the proposed solution. The DYLLI SHIP prototype, while positively received during stakeholder walkthroughs, remains a conceptual model. It has not been tested in live sailing conditions, nor has it been integrated with existing onboard infrastructure. The system's resilience under practical constraints, like satellite signal loss, multitasking during drills, or limited digital literacy among rotating crews, still needs to be validated.

3. Findings

The analysis revealed several recurring problems in how procurement and inventory are managed aboard Dar Młodzieży, the main training vessel operated by Gdynia Maritime University (GMU) [3,11]. These issues came up repeatedly in interviews with logistics staff and officers and were confirmed through the review of internal documentation and process observations [4,20].

Among the most common concerns were duplicate orders, lack of real-time inventory visibility, and long approval cycles. One crew member mentioned during an interview, "Sometimes we end up requesting items we already have on board, simply because the last update wasn't recorded in time."

This pattern was also visible in procurement archives. For example, canned vegetables and dry goods appeared multiple times in separate orders filed only a few days apart. In some cases, items were listed under different names by different departments, making duplication harder to detect.

The formal procedure at GMU involves a three-step requisition process, but in practice, this is often bypassed. Especially during training voyages, crew members reported placing orders directly via phone or email to speed up the process. These informal workarounds were not always documented, which complicated inventory tracking.

Insights from these findings directly influenced the design of the DYLLI SHIP prototype. The tool includes modules for logging order history, monitoring stock levels, and working offline during limited internet access. While still in the testing phase, the prototype reflects the specific operational challenges identified during the study.

2.7 Inventory mismanagement

Inconsistent tracking of onboard inventory emerged as one of the most pressing issues highlighted by both ship crew and GMU administrative staff [9]. Inventory records were typically kept in separate Excel spreadsheets, often managed individually by department heads. These files were rarely updated and almost never synchronized across departments [1]. As a result, discrepancies between documented stock and actual items onboard were not uncommon.

Each department seemed to operate with its own version of the truth. For instance, one officer recalled a situation where two departments ordered the same dry goods without realizing they already had surplus stored in different compartments. "We were literally unpacking boxes of things we already had," he

said.

A more serious case occurred during a port return in early 2024. Over 250 expired yogurt containers were found in the galley refrigerator. These products had been reordered unnecessarily due to both spreadsheet misplacement and the lack of any physical stock check before submitting the new order [7,8]. According to the galley staff, no one had opened the lower shelf of the refrigerator in several weeks. The space was small, dimly lit, and often used as temporary storage during drills.

This incident underscored the absence of a unified system for managing supplies. The current paper and Excel-based methods not only reduce accountability but also make it difficult to avoid waste or plan resupply effectively. Interviews with multiple crew members confirmed that inventory updates were usually made retroactively, if at all, and often depended on the initiative of individual cadets or junior officers.

2.8 Lack of real-time communication and order tracking

Communication between the ship and the university's procurement office relies almost entirely on email exchanges [1,12]. While convenient on land, this method proves inefficient at sea. Messages are often delayed due to poor satellite connectivity, and replies can take days, especially when the vessel operates beyond Europe's coastal networks [13]. In practice, once a supply request is sent, the crew receives no status updates, unless someone follows up by phone. And even then, the person on the other end might not have access to the same file or context.

During interviews, multiple officers reported situations where they weren't sure whether an order had been placed, processed, or rejected. "You send an email, and then you wait. Sometimes it feels like shouting into the void," one crewmember remarked.

There is currently no shared platform or central dashboard to track the progress of requests [14]. Each team, galley, engineering, deck, uses its own system of folders and checklists, usually saved locally or on USB sticks. These disconnected practices result in delayed approvals, duplicate orders, and frequent misunderstandings, particularly when crew rotation occurs mid-voyage [9].

This lack of coordinated tools is most problematic during longer trips, especially when the vessel faces unpredictable weather or schedule changes. In such conditions, the absence of real-time information can force officers to make decisions based on outdated assumptions, increasing the risk of shortages or overstocking [11].

2.9 Overordering and waste

Overordering is not just a budgeting issue, it's a symptom of deeper problems in how information flows onboard and onshore. Without a unified inventory system or up-to-date stock validation, crew members often place orders "just to be safe" [7,8]. It's not uncommon for different departments to request the same items within days of each other, simply because no one has a full picture of what's already been delivered [1].

During field visits, several officers admitted they rarely check stockrooms before submitting requests. "Sometimes we're halfway through the voyage when we realize we've got double the sugar and no coffee," joked one galley assistant. The issue isn't carelessness, it's the lack of a shared overview.

Mismatch between documents stored in separate Excel files also plays a role. If one department updates their sheet but forgets to share it, another may place a redundant order. These errors are especially frequent during crew handovers, when working files are passed on hastily or skipped altogether [9].

The result? Waste. Not just of money, but of food, chemicals, and packing materials. Spoiled dairy, expired cleaning agents, or broken bulk containers aren't rare. Disposal requires time, space, and sometimes regulatory documentation, especially when chemicals are involved [7,21]. For an institution promoting sustainable development goals, these inefficiencies represent both a financial and ethical concern.

2.10 Procedural bottlenecks and fragmented responsibility

Another recurring theme in the data was the unclear division of responsibilities. Procurement tasks are split among captains, superintendents, and university administrative staff, yet no standardized protocol links their actions into a cohesive system [18]. In practice, this means key decisions are often based on

personal initiative or informal conversations, rather than structured workflows [4].

Administrative staff reported spending a disproportionate amount of time on routine reconciliations, merging conflicting inventory lists, checking incomplete order forms, or confirming basic supply quantities. “Sometimes we receive three different files for the same delivery,” noted one office assistant. These tasks, while necessary, add up quickly and could be handled more efficiently with automation [12].

Another concern is the absence of audit trails. There's no unified documentation structure to track who approved what and when. When inspections or financial audits occur, staff must search through scattered folders, both digital and physical, to piece together a paper trail [9]. The lack of version control adds to the risk of error and procedural delays.

2.11 High Institutional Interest in Digital Solutions

Despite these procedural inefficiencies, one of the more encouraging findings was the level of institutional interest in change. Interviews with GMU’s Maritime Operations Department revealed strong support for digital transformation, not as a distant ideal, but as an urgent operational need [3,10].

Stakeholders responded positively to the proposed DYLLI SHIP prototype, particularly features that addressed their day-to-day frustrations: real-time inventory validation, transparent tracking of orders, centralized documentation, and internal messaging tools designed with maritime workflows in mind [6].

Some voiced concern over unstable satellite connections during longer voyages. But these were framed as logistical hurdles, not objections to digitalization itself [13]. As one senior officer remarked: “The system doesn't need to be online all the time, it just needs to work when we do.” Overall, both crew and staff viewed the digital platform to streamline work, reduce waste, and regain clarity in supply coordination [7,8].

3. System visualizations

In response to the issues surfaced during fieldwork, the research team developed a functional prototype of a digital supply platform called DYLLI SHIP. Built in Figma and grounded in the logic of the original DYLLI system, used previously in HoReCa and wholesale logistics, the prototype was redesigned specifically for maritime training vessels.

At its foundation, DYLLI SHIP is meant to improve communication between three groups: onboard staff, captains, and university procurement officers. Rather than reinvent procedures, the tool mirrors what users already do, but adds structure, memory, and traceability.

Several core modules were introduced to reflect this approach:

- Mandatory inventory validation before an order can be submitted, ensuring that requests are grounded in actual stock data.
- Real-time order tracking with visualized order progress and messaging threads.
- Centralized document modules that separate editable forms from final, locked reports for auditability.
- Role-based access and approval hierarchies, enabling clear accountability while maintaining operational flexibility.

The visual assets presented in this chapter are not merely illustrative but serve as evidence-based system design artefacts, rooted in qualitative findings and verified pain points. The figures that follow correspond directly with functional modules developed for the proposed digital transformation of the university’s training vessel procurement workflows.

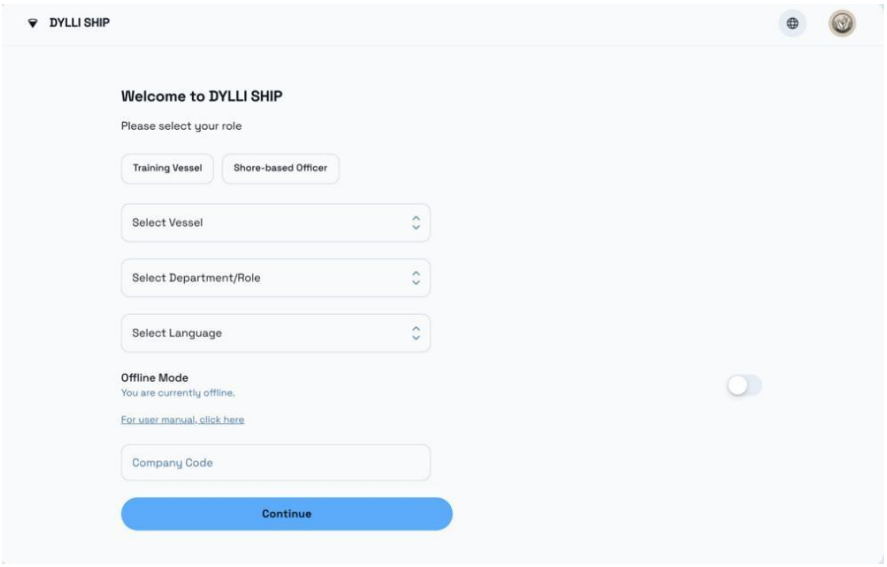


Figure 3. Role-Based Login Interface

Source: own elaboration.

The login interface of DYLLI SHIP is designed to accommodate two primary user groups involved in training vessel supply chains: shipboard personnel and shore-based officers. Upon selecting their role, users proceed to specify the vessel they are assigned to, their functional department or rank, and the preferred interface language. The inclusion of an offline mode toggle addresses connectivity limitations at sea, while the access to a digital user manual supports onboarding and usability. The minimal, responsive design ensures compatibility with varying screen sizes and maritime connectivity conditions.

This editable inventory table allows crew members to update real-time stock levels. Products are categorized, quantities can be edited, and expiry dates noted. Crucially, a “Save draft” option ensures input continuity in case of lost connectivity, while the “Send to Captain” action initiates the approval flow. Unlike many existing solutions, this system does not allow the crew to bypass this step, ensuring accountability and traceability.

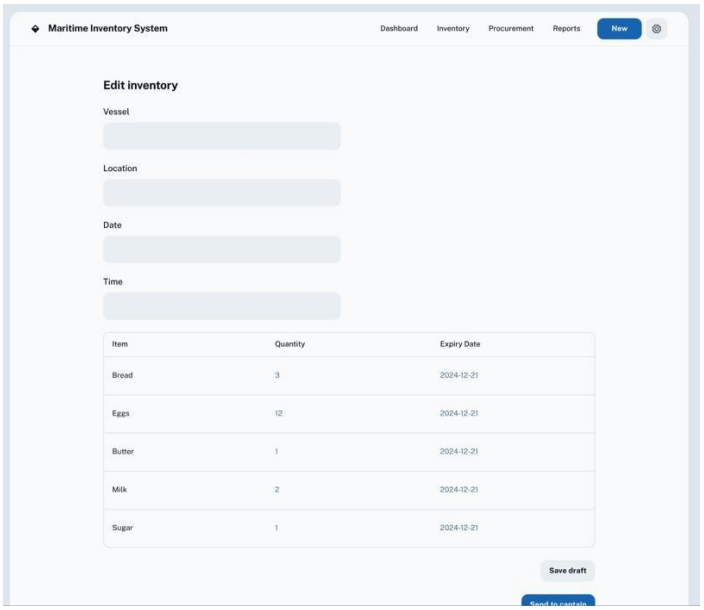


Figure 4. Inventory Update Panel (Shipboard User)

Source: own elaboration.

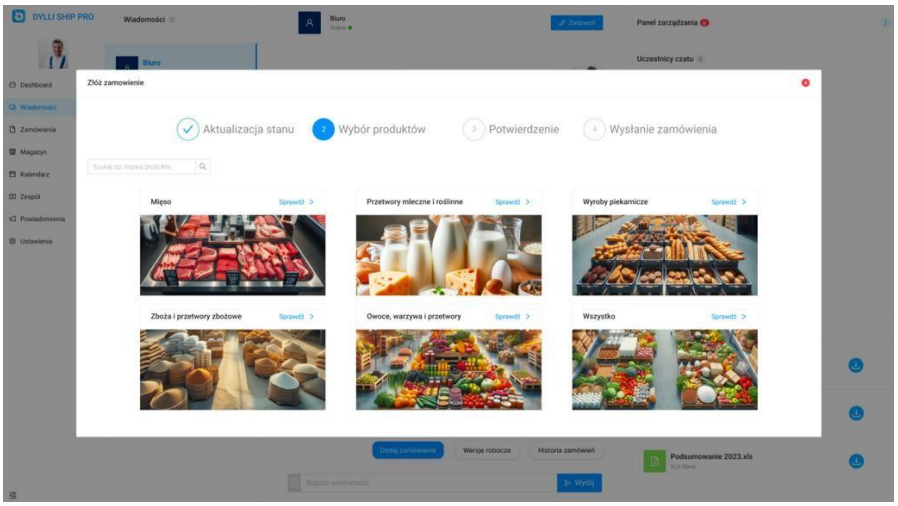


Figure 5. Order Creation Process with Visual Categories

Source: own elaboration.

This ordering interface introduces visual product categorization to minimize ambiguity. Users select from predefined categories (meat, dairy, bakery, vegetables, etc.), then choose specific products. This visual-first approach reduces cognitive load, especially for international crews with varying language skills. Notably, product search is embedded with inventory logic - a soft reminder appears if a similar product already exists in stock.

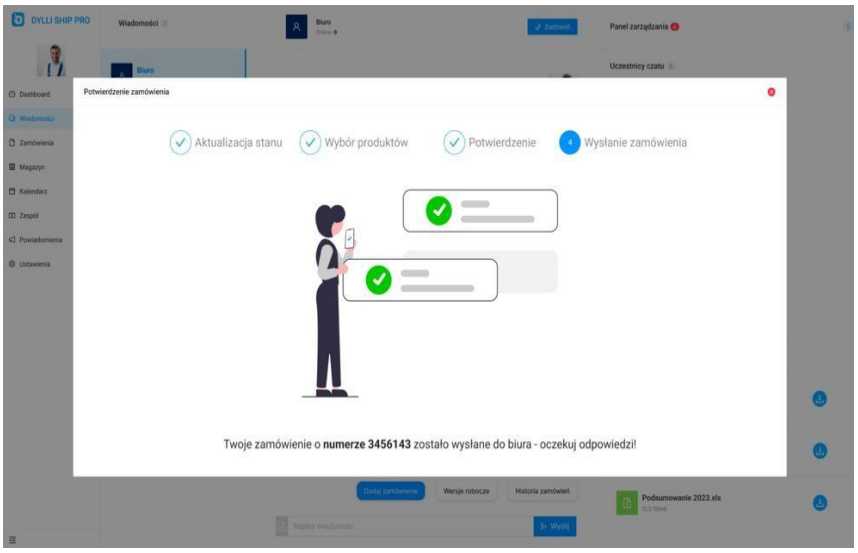


Figure 6. Order Confirmation Summary

Source: own elaboration.

The confirmation screen presents an animated summary of submitted orders. This stage functions both as user feedback and psychological closure, increasing trust in system responsiveness. The order ID is clearly visible for later tracking. This contrasts with previous Excel-based systems, where orders were often saved in separate local files and difficult to trace after submission.

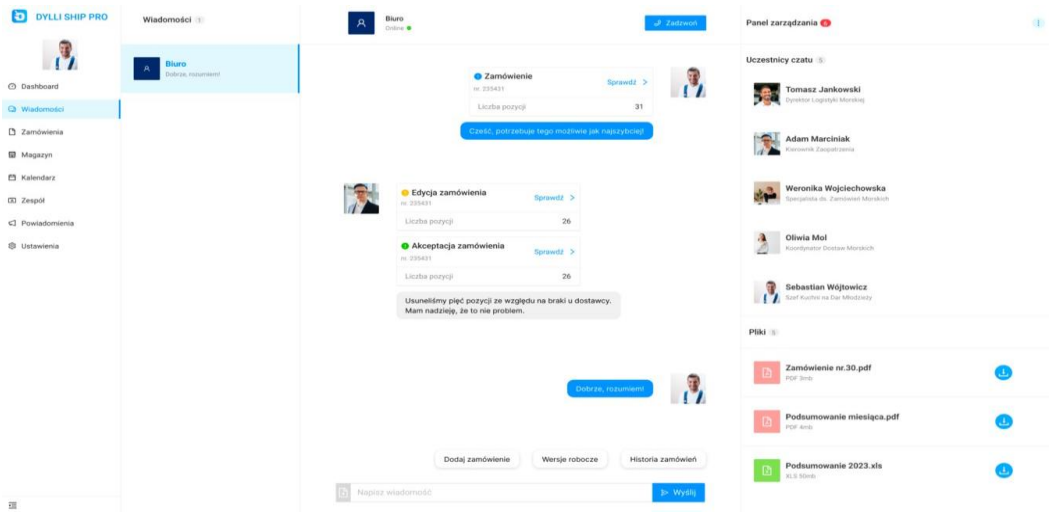


Figure 7. Shipboard-Office Communication Panel

Source: own elaboration.

This visualization presents the integrated communication interface developed within the DYLLI SHIP system to support structured, traceable interaction between onboard crew and shore-based maritime operations staff. The module was designed in direct response to challenges identified during interviews, particularly the lack of standardized communication protocols and fragmented correspondence related to order processing.

The panel enables synchronous and asynchronous dialogue that is contextually linked to specific procurement requests. Messages are organized in threads associated with individual orders, allowing for transparent editing, approval tracking, and comment-based clarification. The participant list - displayed in the management panel, ensures clear role identification, improving procedural accountability.

Critically, this communication space is not isolated from operational workflows. It incorporates direct access to order history, editable order drafts, supplier quotations, and automatically generated documentation (e.g., PDFs and spreadsheets). All attachments remain visible and accessible throughout the communication thread, eliminating issues related to version control and dispersed file storage.

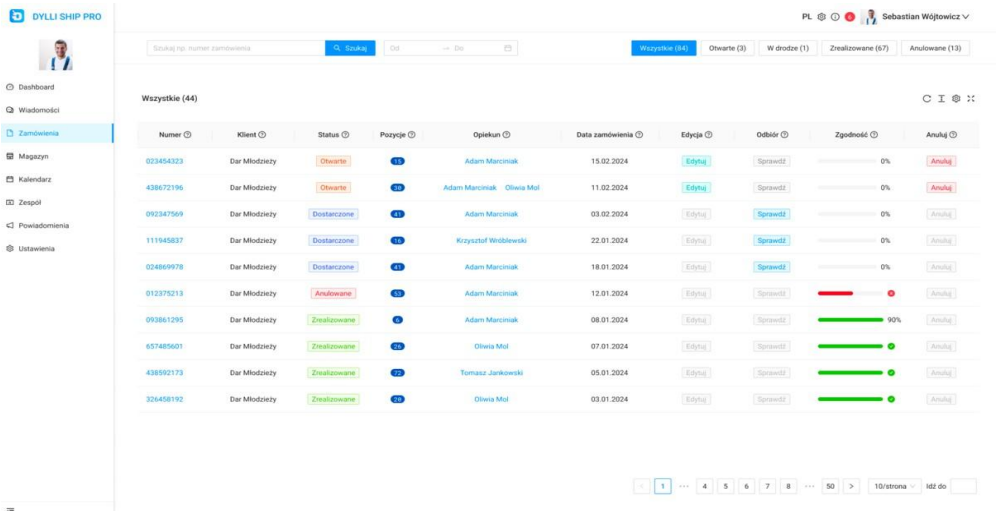


Figure 8. Procurement Dashboard (Office View)

Source: own elaboration.

By embedding document management, approval routing, and status notifications within a single interface, the module significantly enhances coordination efficiency. It mitigates the risk of miscommunication across departments and provides a scalable template for multi-role collaboration within

maritime educational logistics.

This screen allows procurement personnel to manage all incoming and processed orders. Filters for status, ship, and time range are integrated. Orders can be edited, cancelled, and exported to documentation. Notably, the system automatically generates matching PDF files (purchase order, invoice) for record-keeping - a step previously handled manually, leading to frequent discrepancies.



Figure 9. Sustainability Dashboard: Food Waste Monitoring

Source: own elaboration.

The screenshot illustrates a conceptual module within DYLLI SHIP designed for tracking food waste generated during a voyage. This dashboard presents aggregated data on discarded food, categorizing it by material type (e.g., food, paper, packaging) and linking it with key indicators such as the number of meals served or total voyage duration.

The upper section of the interface displays waste summary metrics, while the lower graph visualizes historical trends and waste projections over time. This functionality aims to support more sustainable and transparent food management on board training vessels, especially in contexts where overordering, poor inventory visibility, and inconsistent storage practices have previously led to unnecessary spoilage.

To make such a module operational, DYLLI SHIP assumes integration with smart kitchen infrastructure, such as food waste bins equipped with embedded scales and labeling systems. These devices, increasingly used in hospitality and cruise sectors, allow automatic quantification of discarded food at the point of disposal and enable detailed reporting on waste composition.

In the maritime educational context, implementing this component would require not only equipment acquisition but also kitchen workflow adjustments, including fixed-location storage, standardized labeling of ingredients, and routine training for galley staff. The primary objective of this module is not only to record waste but also to create behavioral feedback loops, whereby increased visibility of waste patterns leads to more conscious procurement and consumption practices.

The dashboard supports long-term monitoring of institutional sustainability goals and may be aligned with broader environmental compliance initiatives in the maritime sector. While the data shown is demonstrative, it reflects industry standards and benchmarks achieved in similar systems deployed in offshore and institutional environments.

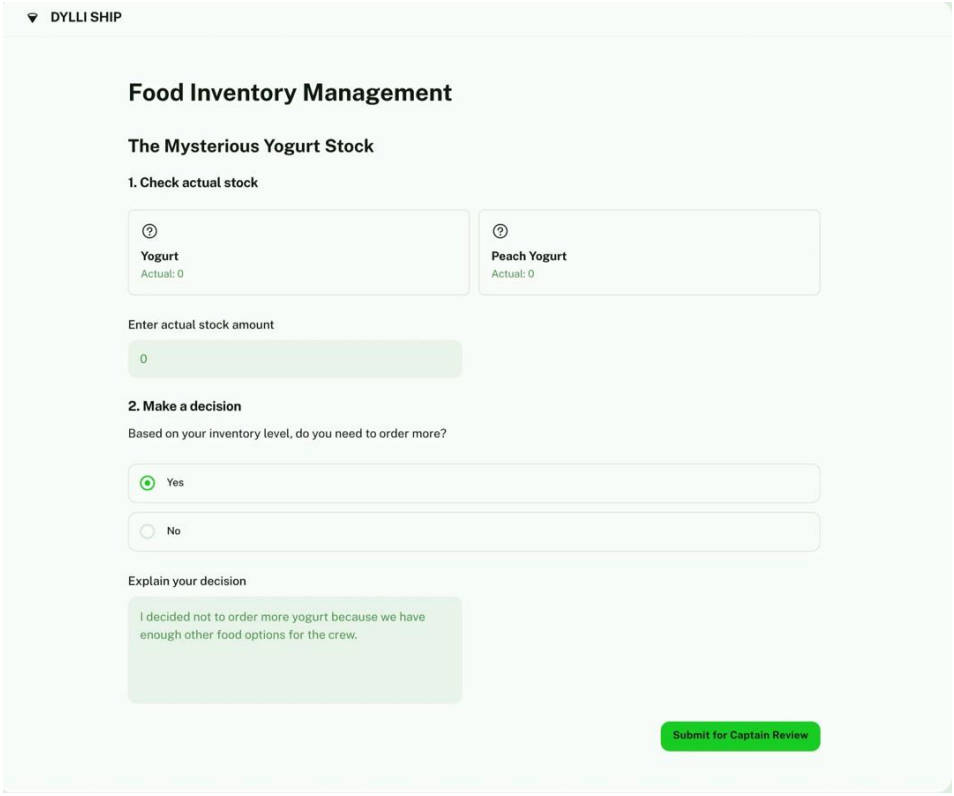


Figure 10. Microtraining Module: "The Mysterious Yogurt Stock"
Source: own elaboration.

This gamified simulation was developed to address a real-world anecdote from GMU crew, repeated over- ordering of yogurt due to lack of accurate stock tracking. The scenario walks the user through checking actual inventory, deciding on necessity, and receiving system feedback. It doubles as both an onboarding and awareness tool, reinforcing process logic before real operations.

3 Discussion

The DYLLI SHIP prototype, as presented in this study, builds upon the foundational design of the original DYLLI platform - an ICT tool first developed for the hospitality and wholesale sectors [6]. While the core functionalities such as digital ordering, inventory tracking, and communication remain central to both versions, the maritime adaptation introduces sector-specific features that address the unique constraints of shipboard operations [1,12].

The original DYLLI system was optimized for land-based environments with stable internet access, predictable delivery timelines, and professional inventory staff [6]. In contrast, training vessels such as Dar Młodzieży operate under conditions of intermittent connectivity, high personnel turnover, limited physical storage, and varied procurement cycles driven by voyage duration and weather [11]. These factors necessitated the development of offline functionalities, real-time crew-to-office communication modules, and simplified interfaces adaptable to a wide range of user competencies [10,13].

Furthermore, the inclusion of a smart food waste monitoring dashboard and structured order validation workflow represents an evolution beyond the HoReCa use case [7,8]. While food waste is an emerging priority in land-based sectors due to rising ESG reporting requirements, it is particularly critical in maritime contexts where space and disposal capacity are limited [2,27]. Here, the DYLLI SHIP design offers not only efficiency gains but also a platform for sustainable behavior change, informed by real-time data and supported by training features such as micro-simulations [10].

One of the less obvious but important distinctions of DYLLI SHIP lies in its educational design [3]. Unlike many commercial tools, this system wasn't developed solely for efficiency. It was shaped with training in mind. Integrated within the interface are microlearning prompts and real-time feedback loops, designed to reinforce supply chain logic for cadets and junior crew members [10,19].

In practice, this means that instead of simply filling out digital forms, users are prompted to reflect on stock levels, decision criteria, or timing, often with brief hints or process explanations built into the workflow. One of the instructors commented that "DYLLI doesn't just log the yogurt, it teaches you to think before ordering it."

This pedagogical layer didn't exist in the original DYLLI platform, which prioritized speed and logistics coordination in the HoReCa sector [6]. By contrast, the maritime adaptation treats the ordering process as a learning opportunity, not just a transaction.

4 Conclusions

This study shows that logistical operations aboard maritime training vessels remain deeply manual, despite their complexity and the growing availability of digital tools [1,9]. Inventory is still tracked in siloed spreadsheets. Communication between departments is fragmented. And costly mistakes, from food waste to missed approvals, are often the norm, not the exception.

Using a mix of qualitative research and low-fidelity prototyping, the DYLLI SHIP concept was developed to address these challenges in a direct, functional way [4,6]. The process wasn't about introducing another generic app. It focused on building something that matched the rhythm of life at sea, with its delays, multitasking, and need for offline access.

Three insights stand out from the project:

- Digital tools are only effective when paired with user training, accountability, and intuitive design [10]. A slick interface is useless if no one trusts it or understands why it's better than Excel.
- Breakdowns in communication and inventory visibility are not isolated bugs. They reflect deeper process flaws that require rethinking how procurement roles and approvals are structured [1,12].
- Sector-specific features matter. Offline functionality, compliance-ready reporting, and interfaces that work during a storm, not just in port, are critical to making tech usable at sea [13,3].

Looking ahead, DYLLI SHIP will move through several development phases [6]. Early mockups, shaped through user interviews and field observation, will form the base for controlled usability testing with onboard personnel. Short trial voyages will follow, allowing for data flow validation and behavior monitoring. With feedback from these early rounds, the system will be refined, enhanced, and finally prepared for a multi-month pilot deployment, complete with live support and embedded analytics [4,19]. This approach mirrors how things work in maritime education: test, adjust, repeat. The goal isn't just a smoother supply chain, it's a smarter one.

Future development phases will also explore integration with smart kitchen devices, external supplier databases, and regulatory compliance frameworks [7,8]. The long-term goal is to establish a scalable digital infrastructure that enhances maritime education, reduces waste, and aligns training vessels with the global transition toward sustainable, data-driven transport ecosystems [12].

This research contributes not only a proof of concept but also a methodological roadmap for how digital tools can be thoughtfully introduced in traditionally analog sectors, blending technology with pedagogy, and logistics with learning [10,15].

Acknowledgements

This research has been supported by Gdynia Maritime University within the framework of project No. WN/PZ/2025/10.

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International Association of Maritime Universities (IAMU)
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Predicting Aggregated Cargo Throughput of Major Indian Sea Ports with Bayesian Structural Time Series

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Abstract: One of the important indicators of port activity is Cargo Throughput. The port activity is important as port acts as nodal point of global supply chain of various commodities and to remain competitive globally, the ports are increasingly facing more pressure. Ports facilitate movement of diverse categories of cargo. This article considers the monthly overall Cargo Throughput of all major ports of India from January 2022 to December, 2024. The aggregated forecast exhibits more stability and has less volatility which is prominent in individual port level. The multivariate forecast model of aggregated Cargo Throughput of all major ports of India is developed. It is intended to explore the extent to which aggregated Cargo Throughput is influenced by Macroeconomic variables Consumer Price Index, Exchange Rate (Rupees/US Dollar) and Manufacturing Purchasing Managers' Index (Manufacturing PMI). The Bayesian Structural Time Series (BSTS) method has been adopted for forecasting. BSTS model with additive components is used for extraction of trend, seasonality of the time series of aggregated Cargo Throughput. The trend is linear with incremental upward slope which indicates small changes in Cargo Throughput over time, and the seasonality is very less. The regression component explains insignificant amount of variation in the Cargo Throughput.

Keywords: Cargo Throughput; Major Indian Port; Bayesian Structural Time Series

1. Introduction

India has long coastline of 11098.81 kms spanning over both the east coast and west coast (Circular, MoPSW, 2025). This long coastline acts as fillip for development of port infrastructure. At present there are 12 major ports and 213 minor ports in India (PIB Release, 2025). As majority of the international trade by volume is carried out through sea, the development of port infrastructure is of paramount importance for the economic development of the nation. Due to increase in globalisation, maritime trade is expected to increase in forthcoming years (Basic Port Statistics of India, 2022 - 23). Though the growth of maritime trade is dependent on several geopolitical factors like war, conflict, pandemic and type of cargoes, the containerized maritime trade is expected to grow by 3% in 2024 – 28 period. But it is lesser than long term growth of 7% which has been experienced in past three decades (Basic Port Statistics of India, 2022 - 23). In 2022, the volume of oil and gas trades witnessed highest growth among all cargo types (Basic Port Statistics of India, 2022 - 23). The port is an important nodal point in maritime supply chain and facilitates complex interconnection among several stakeholders. So, port infrastructure must be developed for decreasing the logistics cost which in turn has the potential to improve the competitiveness of the ports of a nation. The capacity augmentation reduces the logistics cost by the way of reducing waiting time and congestion in a port. Moreover, the development of hinterland of ports and industrialisation are also required for increasing the port attractiveness. The development of port entails huge capital cost which is irreversible in nature. In order to justify the capital fund allocation for port infrastructure development, the prediction of growth of cargo throughput is necessary. The cargo throughput prediction includes the quantity and type of cargo that are transacted through a nation's ports. However, this topic has received little attention in the literature (Rashed et al., 2018). The majority of published research articles analysed the cargo movements on individual port basis (Liu et al., 2023). A significant challenge in predicting cargo throughput at national ports lies in choosing the right forecasting method. The choice of method is primarily influenced by the type of

specific problem which is being addressed by the forecasting method. Eskafi et al. (2021) proposed a Bayesian Statistical framework to predict the cargo movement of a Iceland port on yearly basis. The model uncertainties were addressed by Bayesian framework, whereas parameter uncertainties were addressed by selection of macroeconomic variables based on mutual information. There were 06 (Six) macroeconomic variables like Gross Domestic Product (GDP) of the country, global GDP, the average annual Consumer Price Index (CPI), export, import and population of the country which were used for forecasting both containerized and non-containerized cargo throughput. Patil G.R. et al. (2016) applied dynamic regression modelling for forecasting cargo throughputs of all major ports of India up to 2019 – 20 based on the past data from period of 1980-81 to 2013-14. The study employed only one contemporaneous explanatory variable Gross Domestic Product (GDP) of India. The forecasting error was found to be within 10%. Gosasang et al. (2011) analyzed 12 years data from 1999 – 2010 for forecasting Bangkok Port, Thailand, cargo movement by Multilayer Perceptron and Linear Regression model with explanatory economic variables of GDP, fuel price, inflation rate, population etc.

This article primarily seeks to understand the overarching dynamics of the major port system of India, rather than focusing solely on trends specific to individual ports. It aims to analyze the collective impact of macroeconomic factors on the movement of cargo throughput of major ports of India. Multivariate forecasting model namely BSTS is employed to examine the impact of fluctuations in macroeconomic variables CPI, Exchange Rate (Rupees/US Dollar) and Manufacturing Purchasing Managers' Index (Manufacturing PMI), on the movement of cargo through major ports in India. The objective of the model is to provide projections for Indian major port cargo throughput in the forthcoming years, with the chosen variables serving as indicators.

2. Literature Review

Most of the models for forecasting cargo throughput is based on time series data which utilizes only longitudinal data ignoring the effect of external macroeconomic variables on forecast (Ramírez et al., 2025). In their 1996 study, Verbeke et al. applied an ordinary least square regression model based on the GDP of industrialized nations, positing an association between long term GDP growth in these countries and cargo volumes within the Hamburg-Le Havre range ports, alongside similar levels of containerization and market share. Rashed et al., (2017) identified significant relationship between level of economic activity and container cargo movement at Antwerp port, Belgium. It utilized single variable Autoregressive Integrated Moving Average (ARIMA) model for forecasting container cargo movement through port of Antwerp based on monthly container cargo throughput data from January, 1995 to March, 2015. Rashed et al., (2018) developed an empirical model which suggested that there was long term relationship between container cargo throughput at Hamburg-Le Havre (H-LH) range ports and number of economic indices based on time series data from 1995 – 2017. Seabrooke et al. (2003) employed Ordinary Least Square (OLS) regression model for predicting the different types of cargo throughput at the port of Hong Kong utilizing different economic indicators like import trade value, export trade value, population, GDP, Electricity demand, China's entry into the World Trade Organization. The model first estimated the statistical relationship between various categories of freight movement and external economic variables. The forecasting of throughput was then carried out by assuming the growth rate of different economic indicators based on historical trends using the annual data from the year of 1983 to 1999. Intihar et al. (2017) analyzed effect of inclusion of external indicators on the time series modelling of container movement using Dynamic Factor Analysis and AutoRegressive Integrated Moving Average Model (ARIMAX) and concluded that inclusion of external macroeconomic variables resulted in increased accuracy of model forecast. Haris (2019) analyzed the effect of several performance related factors of ports and external economic variables which includes maritime trade, exchange rates and GDP on growth of cargo movements at the Belawan International Container Terminal through a quarterly longitudinal data analysis from 2006 to 2018. Lejour (2003) presented four quantified economic scenarios for Europe, which served as a basis for forecasting port throughput in Netherlands for the years 2020 and 2040. Gu et al. (2023) investigated the effect of COVID 19 pandemic related factors on port operation using panel regression model utilizing the data from Singapore, Hongkong and Shenzhen. The proxy variable used to measure port operation was cargo throughput. The study exhibited the varying degree of loss of cargo throughput due to COVID 19 pandemic depending on the particular port and cargo type but it did not explore the long term consequences. Sahu et al. (2017) used both regression model with macroeconomic variables as causal variables and time series model for forecasting cargo throughput of all 12 major ports of India utilizing data from 2002-03 to 2016-17. The accuracy of prediction was found to be better in timeseries model. Tang et al. (2023) examined the time varying relationship between port development and hinterland economy in 9 port cities of Pearl River Delta between 2005 and 2019 and found a strong reinforcing relationship between development of physical facility of port and economic growth of port

cities. Lam et al. (2004) employed external economic and demographic variables, including number of people residing in the country, monetary values of imports and exports, demand for electrical power, GDP, and cost of construction, to project the cargo movement in Hong Kong for the period from the year of 2002 through 2011. Blauwens and Van Steelandt (1992) employed linear causal models to predict general freight and container movements in tonnes. Numerous studies have explored the correlation between economic activity and cargo movements through seas/oceans to project port traffic locally. Angelopoulos et al. (2021) demonstrated a measurable link between ports of Australia and their economic development, illustrating their role in reflecting economic activity. In a recent analysis performed for Port Metro in Vancouver to assess the investments in expanding its container terminal capacity by predicting container throughput up to 2050, based on the anticipated container demand in North America (Ocean, 2014). Gosasang et al. (2018) examined the trends in cargo movements and their correlation with external economic indicators to estimate container movements at Bangkok Port. Verbeke et al. (1996) estimated container movements for the port of Antwerp for the years 2000 to 2015 by analyzing various models from 1985 to 1995. The study employed univariate time-series methodologies.

3. Methodology

The methodology was based on BSTS analysis to extract the trend and seasonality of the time series of aggregated Cargo Throughput of all major ports of India. The employed BSTS model also explains the effect of fluctuations in macroeconomic variables Consumer Price Index, Exchange Rate (Rupees/US Dollar) and Manufacturing Purchasing Managers' Index (Manufacturing PMI), on the movement of major port cargo throughput in India. This category of time series models is extensively utilized and is referred to in different academic contexts as structural time series, state space models, among other terminologies. There are total 12 (twelve) major ports in India as defined by the Major Port Authorities Act, 2021 spanning both the eastern and western coast. The monthly data from January, 2022 to December, 2024 are utilized for structural time series analysis. The forecasting model consists of two elements. The time series element identifies general trend and seasonal variations within the dataset, while the regression element assesses the influence of explanatory macroeconomic variables on aggregated Cargo Throughput of all major ports of India. Both the elements are additive and the combined model is effectively estimated utilizing Bayesian techniques. The suggested research framework was evaluated utilizing the 'bsts' package, developed by Scott, S.L. and Varian, H.R. (2014), within the R statistical framework (R Core Team, 2020).

In the structural times series, c_t denotes the value of the observation at time t. The model is represented by a pair of equations

$$c_t = A_t^T \alpha_t + \varepsilon_t, \quad \varepsilon_t \sim \text{Normal}(0, U_t); \tag{1}$$

$$\alpha_{t+1} = P_t \alpha_t + S_t \eta_t, \quad \eta_t \sim \text{Normal}(0, V_t) \tag{2}$$

The expression (1) is classified as observation equation and expression 2 is classified as transition equation. A_t, P_t, and S_t consist of a mix of known values (often 0 and 1), and unknown parameters and α_t is unobserved latent state. A model represented by expressions above is considered as being in state space form. Large varieties of models, encompassing all Autoregressive Integrated Moving Average (ARIMA) and Vector AutoRegressive Moving Average (VARMA) models, can be described in the state space form (Scott, S.L. and Varian, H.R. (2014)). State space models are appealing primarily due to their modularity. Independent state components can be integrated by inclusion of their observation vectors A_t and organizing the remaining model matrices as components within a block diagonal matrix. The present BSTS model is derived by incorporating predictors in the basic structural model (1) as described below:

$$c_t = A_t^T \alpha_t + \beta \mathbf{x}_t + \varepsilon_t \tag{3}$$

The vector $\mathbf{x}_t$ in equation (3) is a contemporaneous set of explanatory macroeconomic variables. The spike and- slab prior distribution on predictor variables is employed to capture inclusion probability of predictors. A spike and slab prior is a type of prior for regression coefficients, wherein each coefficient is assigned a positive probability of being equal to zero. Following the observed data, Bayes' theorem revises the inclusion probability associated with each coefficient.

4. Results and Discussion

The Augmented Dickey-Fuller (ADF) test serves as a statistical method for assessing whether a time series exhibits a unit root, thereby signifying its non-stationary nature. Since the p-value is less than 0.05 as per Table 1 below, the null hypothesis is not accepted. It indicates that the time series of aggregated Cargo Throughput is Stationary.

Table 1. Result of Augmented Dickey-Fuller Test

Statistical Test	Variable	Result	Conclusion
Augmented Dickey-Fuller Test	Cargo Throughput	Dickey-Fuller = -3.8361, Lag order = 3, p-value = 0.02908	Alternative Hypothesis: Stationary

The time series of the model encompasses a local linear trend component as well as a semi-annual seasonal component.

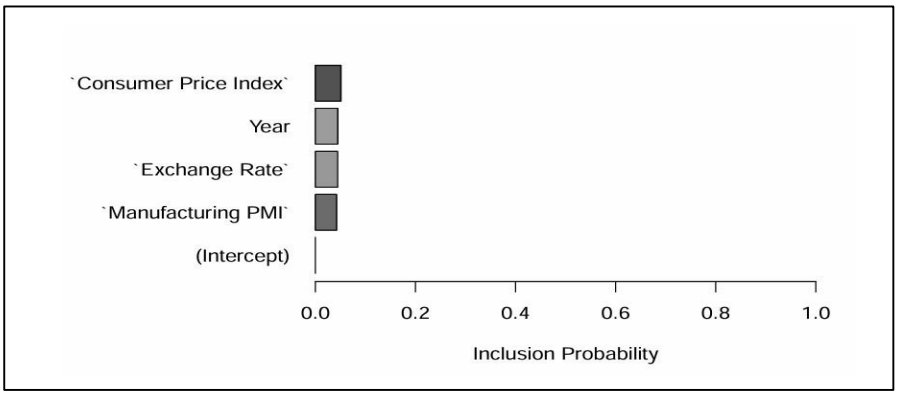


Figure 1. Inclusion probabilities of different predictors.

Figure 1 illustrates the explanatory variables to which the MCMC algorithm has allocated posterior inclusion probabilities. The three predictors are displayed with their respective posterior inclusion probabilities, the variation in these probabilities among the predictors is minimal.

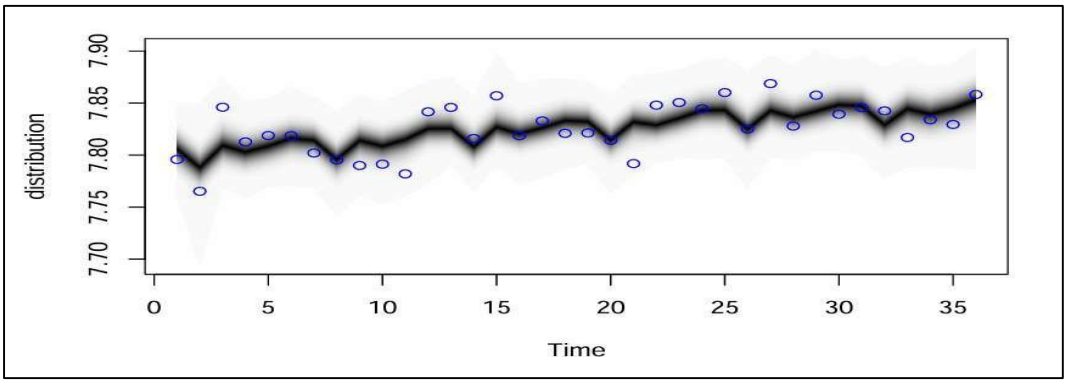


Figure 2. Posterior State of the model at different time periods.

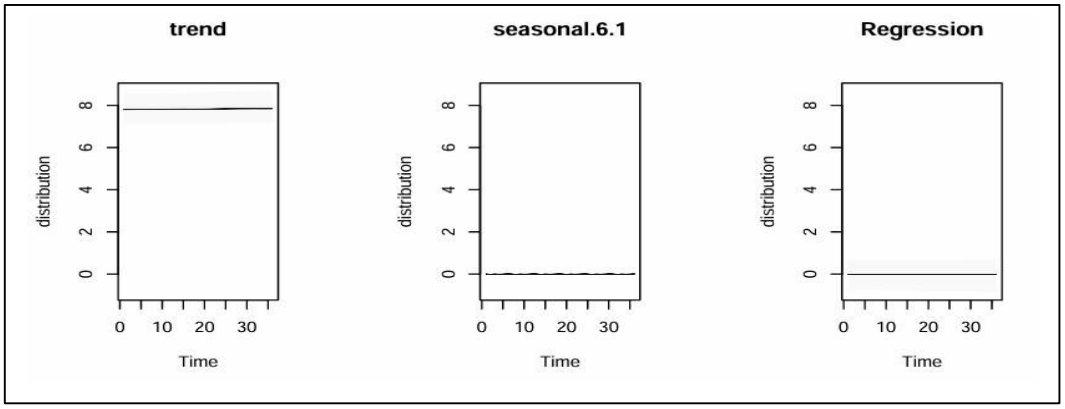


Figure 3. Contribution to State for aggregated Cargo Throughput.

Figures 2 and 3 illustrate the distribution of the hidden state across various time points. Figure 2 depicts the aggregated state ($A^T\alpha$), which signifies the adjusted series devoid of observational random components. In contrast, Figure 3 delineates the effect of each of individual states. Figure 3

illustrates the extent to which the trend component, seasonal component, and regression components account for the variation in aggregated Cargo Throughput.

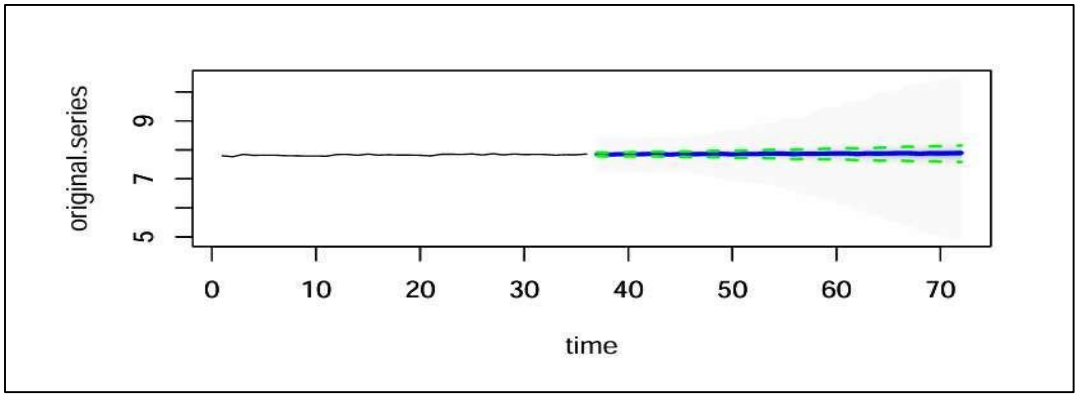


Figure 4. Posterior predictive distribution for future aggregated Cargo Throughput.

Figure 4 illustrates the posterior predictive distribution for future aggregated Cargo Throughput of all major ports of India.

5. Conclusion

A predictive system is presented for time series analysis utilizing the data of aggregated Cargo Throughput of all major ports of India. This system is a combination of Bayesian regression and state space model with spike-and-slab prior and computes average from a selected set of explanatory variables. The model averaging inherent in this type of particular prior and MCMC serves to mitigate the risk of choosing an inappropriate group of explanatory variables. Though the above mentioned method offers some defense against misleading explanatory variables, but no method offers complete protection.

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Settlement of Dispute Arising out of Blockchain-Based Smart Contract: A Revisit of Private International Laws in Maritime Convention Network

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Abstract: Blockchain technology is increasingly recognized for its potential to enhance transparency, security, and efficiency in the maritime industry, particularly in cargo tracking, freight payment systems, and the management of shipping documentation. However, its integration raises significant legal considerations, especially concerning the admissibility of blockchain records as evidence in maritime disputes. Taking smart contracts, which are self-executing contracts encoded on blockchain to automate processes, such as freight payments and cargo tracking, as a notable example, the author shall discuss current admiralty issues remaining in existing international maritime conventions, through which to assess whether it is necessary to establish a new theoretical concept of decentralized autonomous jurisprudence applicable to those disputes.

Keywords: DOA; on-chain dispute settlement; emerging PIL

1. Introduction

Maritime trade is long-lasting, considered the backbone of global trade, with approximately 80% of total cargoes circulated at sea for both manufacturing and consumption. Following this novelty, a wide range of actors involved in the whole supply chain may include sellers, buyers, carriers, insurance providers, terminal operators, commercial banks, and port state authorities. This operation was governed by a multitude of international and national standards, which made them incomprehensible to a neophyte. Paradoxically, though all these stakeholders are connected to each stage of the sales and carriage of goods process, they are isolated due to territory limitations and jurisdiction, making it especially difficult for the shipper and sea carrier to break the drought for the facilitation of documentation transferring. This is one of the main forces for the revolution of dematerialization of transport documents, such as Bill of Lading or charter party, in the maritime industry. So far, this long-term journey has witnessed the development from paper to electric form and now blockchain- based smart contracts, which accordingly revoke many legal issues to be solved, particularly when a dispute occurs. Frankly, technology development, even the smallest ones, is the hope of global trade. However, in the cutting-edge technical era, the unknown mostly becomes fear. By the same token, in the maritime industry, where stakeholders are rarely put in the same pool, blockchain is a novel example of a distributed ledger system. The only thread connecting parties involved (both in the blockchain and maritime network) is mutual trust. Nevertheless, a question worth mentioning is in which form trust does exist. In case this form is broken, how can the parties apply legal instruments to acquire justice? Deriving from the abovementioned matter, this paper shall seek findings on the following sections: (i) introduction to blockchain technology and smart contract; (ii) notable application of blockchain-based smart contract; (ii) the vulnerability of this digital record when comes a dispute; and (iii) how the dispute can be resolved in the light of international private law theories. All these matters shall be construed in accordance with traditional maritime conventions spectrum, through which to assess whether such existing instruments are efficient to deal with the emerging incorporation of technologies. Other umbrella international conventions are also interpreted to build up a comprehensive point of view on this matter. After that, the paper shall render an alternative approach to tackle such remaining difficulties that existing conventions have not yet ultimately addressed, especially when the rise of usage of and disputes from smart contracts in the maritime domain is

getting more visible and inevitable. Before unveiling each layer of smart contract application in the maritime domain, it is essential to dig deep into the root technology of this notion.

Because until the true nature of technology is revealed, principles of law can find a way to solve the dispute. Blockchain technology is generally categorized into three types: public, private, and consortium blockchains. Public blockchains are characterized by open access and decentralization, allowing anyone to read or write data without intermediaries, though modifications are technically infeasible (Tessier, 2019; Delahaye, 2015). Private blockchains, by contrast, restrict access to selected participants through permissions and cryptographic keys. Consortium blockchains combine elements of both, offering limited access to pre-approved users, often adopted in business contexts to enhance efficiency and security. Building upon this structure, smart contracts emerged as digital mechanisms to automate the execution of predefined obligations between parties (Szabo, 1996). These are not legal contracts in themselves but operate as self-executing code, essentially "if-then" logic hosted on distributed ledgers, facilitating the automated fulfillment of terms agreed upon in underlying legal documents (Olivier & Mamadou, 2022).

2. Case study of smart contract application in the maritime domain

From the above features of smart contracts, the business that can incorporate blockchain-based smart contracts must ensure its standards and consistency, such as the maritime industry. By the same token, for blockchain smart contracts, the maritime industry consists of a variety of partners, but based on distribution principles and trust among partners, working as an entry key granted to a selected user in the blockchain is the cornerstone of any transaction success. This typical example of this standard operation is Incoterms, which sets out traditional best practices in commerce so that parties can rely on and perform the carriage contract properly. The integration of Incoterms into blockchain technology, particularly through the implementation of smart contracts, could facilitate the automation of freight payment processes upon the fulfillment of specific delivery obligations. For instance, payment could be triggered when goods are positioned alongside the vessel under an FAS (Free Alongside Ship) agreement, loaded onto the vessel under an FOB (Free On Board) contract, or arrive at the designated port of destination under a CFR (Cost and Freight, with insurance and risk transferred to the buyer) arrangement. In this case, the code automating the term, for instance, FAS, might work as follows:

With respect to the traditional payment clause:

"*The Buyer shall pay the total contract price of [Amount of money] to the Buyer. The payment shall be made by Letter of Credit issued by [Bank of the Buyer] in favor of the Seller and to the account of the Seller opened in [Bank of the Seller" as long as the following any and all documents are provided: (i) commercial invoice; (ii) Packing list; (iii) Certificate of Origin; and (iii) Transport documents evidencing that goods were placed alongside the designated port of destination in accordance with FAS Incoterm 2020*".

In this traditional clause, at least three parties are involved, including the seller, the buyer, and the banks of both sides. The key interests that parties aim for are goods for the buyer, money for the seller, and a condition for money remittance (as a performance of the L/C contract) for the bank. However, the sale of goods, carriage of goods, and L/C are three separate contracts, which require separate implementation, though the result of this contract (i.e., the sales of goods contract) is the premise of implementation of the other contracts (carriage of goods contract and L/C contract). Therefore, following the traditional flow of work, business partners cost a lot of time and labor for contract management, not to mention the fact that manual processing can lead to errors. With respect to the smart contract payment clause, all partners can be within one table (equivalent to pre- selection of users in the blockchain domain), and the condition to pass each spot is set (no goods alongside the ship, no payment). Therefore, smart contract comes here to connect the seller, buyer, carrier, and banks in one pool and conduct the whole process by simple codes, such as (If goods arrive alongside the ship, L/C is kicked off" without intermediary intervention. This means that the carrier does not have to inform the seller/buyer about the status of cargoes, and the buyer does not have to inform the bank that cargoes are ready to load.

The application of smart contracts in the maritime sector can be spotted in Bills of Lading. B/L(s) are negotiable instruments, issued by the carrier of goods, which represent the right to claim the delivery of goods from the carrier. Paper B/L(s), as a matter of fact, are usually slowly transmitted and do not arrive at the port of destination until after the goods have arrived. As a result, cargoes are sometimes handed in without the presentation of B/L(s), which causes so many difficulties later. Before the intervention of

blockchain technology, a central registry of B/L(s) was the only conceivable architecture for digitalization. However, due to its private nature, this central registry of B/L(s) cannot work seamlessly except when all stakeholders become registered members (Koji Takahashi 2015). Later, a blockchain-based smart contracts B/L(s) initiative was proposed to tackle this problem. The model of smart contract B/L can be seen as follows:

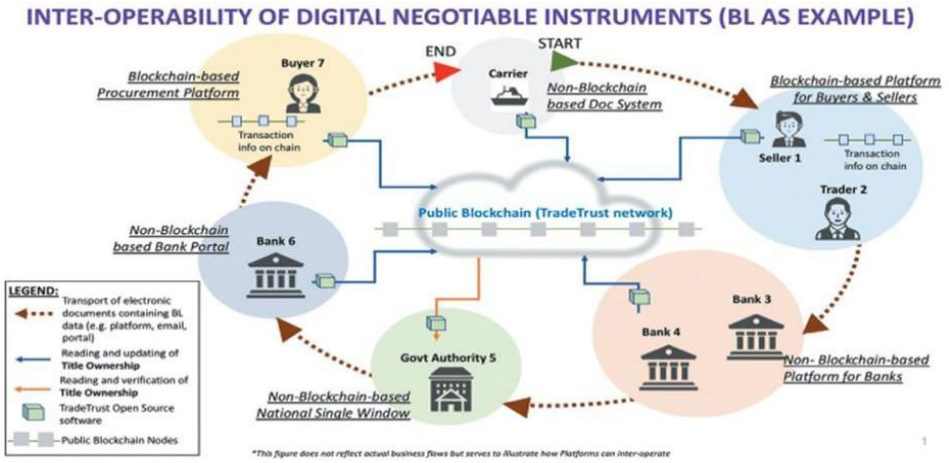


Figure 1. Interoperability of digital negotiable instruments

Figure 1 elucidates the heart of a public blockchain with permissioned users. Even if users are selected and access the domain, not all sources of data inside this network can be fully approached by all members. Instead, data is sorted and directed to users in accordance with the scope of their authorities. This is to ensure the date privacy and limit the risk of cyber-attack. It is noted that where an export transaction may require tons of paperwork, a smart contract can drastically reduce paperwork and save time by eliminating intermediaries and executing agreed-upon clauses (Mamunts, D. G. et al., 2018).

3. Disputes arising out of smart contracts

Despite bringing a lot of advantages, smart contract faces many challenges, especially when a dispute arises on the chain. In that case, the worthy-mentioning question shall be whether that dispute on the chain is accepted to be solved. To answer this, smart contract needs to be taken into account in light of the principle "recognition before adoption" within the spectrum of maritime conventions. Taking the notion of B/L(s) as an example, it is noted that so far only Articles 8, 50, 51.4 of the Rotterdam Rules embrace "negotiable electronic transport record". More importantly, the Rotterdam Rules uphold the approach of technology neutrality; therefore, an electronic record, despite being provided by law, is treated based on its technical essence in the broadest sense. Considering other national law approaches, an electronic record refers to a concentrated system that provides and manages both the environment of transaction and users in such an environment. This view is contrary to the decentralized nature of blockchain technology. In other words, the notion of "electronic record" does not exclude blockchain B/L(s) because, technically, blockchain technology belongs to the electronic category. Hence, following such requirements set out in Article 9 of the Rotterdam Rules, it is understood that as long as a digital record satisfying such requirements shall be qualified to be an "electronic record" and be amissible in the Rotterdam Rules. In short, within the Rotterdam Rules, smart contract B/L(s) can be considered as an independent electronic record that has the value of title and evidence of contract of carriage. In this case, smart contract B/L shall be equivalent to paper B/L(s), and the smart contract is not treated as a form to execute the traditional B/L.

By the same token, under the Rotterdam Rules, in 2017, the United Nations Commission on International Trade Law (UNCITRAL) adopted the Model Law on Electronic Transferable Records. This Convention lays down the attributes which an electronic record needs to possess for it to be treated as legally equivalent to the corresponding "transferable document". This notion was defined as a document that entitles the holder to claim the performance through its transfer (Article 2), which reasonably allows the interpretation that this instrument is broadly synonymous with a paper-based "negotiable instrument" such as B/L(s). Upholding the approach of technology neutrality, "electronic record" represents the function of "transferable

document". In other words, as long as the document satisfies the characteristics of transferability, it is recognized by the UN Model Law. Simply speaking, blockchain-based smart contract B/L(s) with the function of transferring claim or performance of the holder is deemed to be accepted and equivalent to paper B/L(s) (Koji Takahashi, 2020).

Tracing back to the International Convention for the Unification of Certain Rules of Law Relating to Bill of Lading (Hague Rules 1924), the Hague Rules amended by Brussels Protocol 1968 (the Hague-Visby Rules) and the United Nations Convention on the Carriage of Goods by Sea (the Hamburg Rules 1978), B/L is literally prescribed as a legal notion regardless of how this document presented. It is even very flexible when prescribing "any similar documents" or "other documents rather than B/L" because the conventions allow parties to choose the form of document either in a traditional sense (i.e., seaway bill) or technical sense (i.e., smart contract B/L) as long as it can prove the goods carriage. In other words, a smart contract or even any other electronic platform in which B/L(s) exist is not equivalent to traditional B/L(s) but an emerging tool to execute traditional B/L(s). The summary of the B/L perspective can be found below:

Table 1. Matrix of recognition and adoption of smart contracts in international instruments

	Hague Rules	Hague - Visby Rules	Hamburg Rules	Rotterdam Rules	UN Model Law
Recognition	Smart contract as a tool to execute tradition B/L(s)			Smart contract B/L(s) are equivalent to traditional B/L(s)	
Adoption	B/L(s) (Articles 5, 10 of the Hague Rules)	B/L(s) or any similar document (Article 1 of the Hague- Visby Rules)	B/L(s) and other documents rather than B/L (Articles 16, 18 of the Hamburg Rules)	Negotiable Electronic record	Transferable Electronic record

Deriving from the variety in approach and provision of B/L(s) in maritime conventions, therefore, it is essential to determine a smart contract in dispute as a legal-equivalent contract or as a form of contract/tool to execute a contract (hereinafter referred to as "form of contract"). Through which disputes can be properly classified and settled. Accordingly, disputes arising out of smart contracts shall be treated as two types, which are on-chain disputes and off-chain disputes, respectively. In particular, on-chain disputes refer to conflicts that emerge from actions or transactions occurring directly on a blockchain network (Jennifer Huang and Brendan Harrington, 2024), which is, in this research, a legal-equivalent smart contract. These types of disputes are inherently connected to the blockchain's defining traits: transparency, immutability, and decentralization. Every transaction recorded on a blockchain is permanently stored on a public ledger, making it impossible to modify or delete once it has been confirmed. As a result, on-chain disputes often center around issues such as the execution of smart contracts, the transfer of tokens or other digital assets, or the interpretation of automated rules encoded into the blockchain's protocol. Referring to the case study of B/L above, if a dispute arises out of such smart contract B/L(s) under the umbrella of the Rotterdam Rules or the UN Model Law, it is considered an on-chain dispute. In contrast, off-chain disputes arise outside the blockchain itself and pertain to matters that are not directly logged or settled through the blockchain network. These conflicts may stem from various sources, including disagreements over the terms of an agreement linked to a blockchain transaction but not formally embedded in a smart contract. They can also involve problems related to external services that interact with the blockchain. In a simple way, parties can have their own written legal contract with a choice of law, for example, from the Hague Rules, then issuing a B/L on blockchain to execute that contract partly or entirely. If a dispute arises, it is from and in connection with the written contract, but during its implementation in the chain.

4. Conflict of law

The notable research question of this part is whether different types of smart contracts need a different regulatory scheme to settle disputes arising from them. Within this research, it is humbly suggested that analogous regulation principles can be applied to resolve both types of disputes, no matter where they happen. The reason for this assertion is as follows. To begin with, legal-equivalent smart contracts are like a classical contract except for their technical advantages in performance or absence of intermediaries. Therefore, it is unreasonable if these superior features have to result in different rules rather than the ones

applicable to such laws governing the identical transactions. In addition, this research is of the view that "transactions made on or supported by blockchain technology are subject to the rules of the law that would apply to the equivalent acts outside the blockchain". Moreover, when considering the off-chain dispute, the legal contract executed by the blockchain base shall be the key element to determine the applicable law because that legal contract is the environment of the dispute. Therefore, technically, either for the case of on-chain or off-chain dispute, the determination of applicable laws must rely on the classical contract.

However, with the case of legal-equivalent smart contracts, the determination of law is a little bit more complicated due to geographically dependent factors in the environment of the distributed ledger (Mehdi El Harrak 2023). Based on the traditional rule of the *Lex Loci Contractus*, the law of the contract shall be the law where the contract was made, while distributed ledger technology ensures the anonymity not only of parties to the contract but also of the platform provider. Assuming that parties enter into a goods carriage transaction under the form of a smart contract B/L, equivalently performing legal function as a B/L issued under the Hague Rules, the question in this case is whether parties can rely on the Hague Rules to solve the on-chain dispute related to a legal-equivalent smart contract B/L. Taking Article 10 of the Hague Rules, saying that "this Convention shall apply to all bills of lading issued in any of the contracting States", coupled with the anonymity function of the distributed ledger, it is difficult to determine where the B/L was issued. Several assumptions can be made regarding this matter as follows: (i) the applicable law can be the law where the host ledger is, or (ii) the applicable law can be the law where the carrier who issues the B/L registers. However, even when assumptions can be made, the selection among them is not technically workable because the border in the light of the Hague Rules refers to a physical border, while blockchain is subject to a virtual border. In other words, the implementation of smart contracts (both types) is much closer to the parties than the location. Therefore, the *Lex Loci Contractus* is not suitable for the purpose of determining the applicable law in the context of smart contracts.

Deriving from the nature of the shipping industry, whereby the movement of things such as cargoes, ships, or fiat currency can be identified, the *Lex Situs* and the *Lex loci solutionis* can be applied to consider applicable law. These two principles will pose the challenge of where the properties are in the case of payment by digital assets. In that case, the following two proposals emerged (British Law Commission 2021). First, the place of performance is the place of the assets after it has been transferred. Second is the place where the transferor or the transferee is domiciled. However, this theory will not be able to work if the matter of anonymity remains.

In sum, the challenge of smart contracts' performance does not lie in laws but in technology. In order to apply smart contracts effectively, certain superior functions of it must be reduced.

5. Blockchain-based dispute resolution

Since smart contracts are fully made in code and their performance in a decentralized environment, state courts cannot reliably guarantee access to justice for such on-chain disputes. The need for a new dispute settlement mechanism is necessary and reasonable. A notable lesson for this matter can be seen from e-commerce, whereby some online platforms have installed a certain degree of technology to execute decisions, for example, the credit card chargebacks in eBay (Jia Wang and Lei Chen 2020). This model works based on the close connection between the marketplace, the payment method, and the online dispute resolution (ODR) service. In this context, the ODR system challenges the state's traditional monopoly on the enforcement of legal decisions by using technology to implement outcomes directly. Despite this, the state does not entirely relinquish its role in the justice system. Parties involved in an ODR case still have the option to bring the matter before a formal court if they wish to contest the private resolution. In such instances, a competent state court may issue a ruling that differs from the one reached through the private mechanism. Therefore, while disputes may initially be settled outside the state's direct oversight, state authority persists through the possibility of judicial review, ensuring that parties retain access to public justice if they perceive the outcome of the private process as unfair or unjust.

Modern ODR systems have been developed to address the unique challenges of contractual relationships within the blockchain ecosystem. These systems feature decentralized dispute resolution mechanisms tailored to the immutable nature of smart contracts and the pseudonymous identities of blockchain participants. That is blockchain dispute resolution (BDR) (Florence Guillaume and Sven Riva 2023). BDR mechanisms are uniquely suited to handle disputes within the blockchain ecosystem, as they are built directly into and operate through the same technological infrastructure. Because they function within the

blockchain environment, parties to a smart contract can authorize a BDR mechanism to assess and resolve any disputes regarding the contract's execution. Once a decision is made, it is automatically and immediately enforced through the blockchain. BDR systems operate independently, requiring no intervention or oversight from state institutions to administer justice or enforce outcomes. This independence is made possible through technology, as enforcement is carried out automatically by the smart contract itself. As a result, BDRs are self-sufficient, eliminating the need for external parties, since the smart contract inherently controls and manages the relevant contractual obligations.

The legal issue regarding the application of BDR is mutual consent, which establishes the juridical competence of the BDR mechanism. Parties involved must establish the agreement upon BDR mechanisms in the way as if parties enter into a choice of court clause. In this regard, parties can include the choice of the BDR clause in the smart contract parties are in, or they can discuss and formulate this clause in another smart contract. If the choice of the BDR mechanism clause is separately agreed, parties have to ensure that the two smart contracts must link to each other so that once a contract is breached, the BDR mechanism smart contract shall kick off immediately (Pietro Ortolani 2019).

The next legal question is whether the result of BDR needs to be enforced by a state, as in the case of classical arbitration findings. Within this research, the answer is that a state is unlikely to enforce the implementation of BDR. This is not because of maverick features of blockchain technology but because BDR is challenging to the traditional judicial competence of the state's court. Also, taking this premise, there is a reasonable concern about whether effective enforcement of BDR relies on the voluntariness of parties. Assuming this is correct, to what extent parties trust each other while their entity is unveiled on the chain and compared to the traditional case, justice cannot even execute, though the power of the state exists. This research is of the view that this challenge can be solved by technology, as long as parties on the chain must have property on the chain that can be temporarily frozen for dispute resolution.

6. Conclusion

In conclusion, while blockchain technology offers transformative benefits for the maritime industry, improving transparency, operational efficiency, and reliability, it also introduces complex legal challenges that current maritime frameworks are not fully equipped to address. The use of smart contracts for automating key processes like freight payments and cargo tracking highlights the growing disconnect between technological advancements and the limitations of existing international maritime conventions. As these self-executing digital agreements become more prevalent, questions surrounding the legal recognition and evidentiary status of blockchain records in maritime disputes become increasingly pressing. This calls for a re-evaluation of current legal doctrines and potentially the development of a new conceptual framework of decentralized autonomous jurisprudence that can more effectively govern and resolve disputes arising in a blockchain-integrated maritime environment. Such an evolution would ensure that legal systems remain adaptable and relevant in the face of rapid technological innovation.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Eco-activism and its Impact on Seaborne Economic Endeavours

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Abstract: In recent years, incidents involving eco-activist organisations have been brought to public attention. The main target of such attacks are endeavours, involved in oil drilling and transport of petrol and chemical products such as platforms, FPSOs and heavy lifting vessels, transporting the relevant equipment, as well as tanker vessels of different types. The conflict between environmental organisations and oil companies, as well as other corporations, has taken visible shape and popularity with the "Save the Arctic" campaign of the Greenpeace against companies developing their drilling activities in the Arctic region, with the main target being Shell. However, it is by far not the only endeavour of the environmental organisations. In the present article the authors try to explain the legal, security and safety aspects of such conflicts, as well as the influence similar activity has on these sectors of the shipping industry, directly involved in the process.

Keywords: environmentalism; eco-activism; seaborne economics; environmental awareness

1. Introduction

Environmental awareness is a key issue in the modern world. Nowadays people understand the importance of having responsible sustainable industry. We witness ever growing popularity and development of technology for green renewable energy and electric vehicles. As a result, drilling companies have been identified as a key party, responsible for the ever-growing production of greenhouse gasses, the major reason for the global warming problem. In the recent decade they have been under major pressure to maintain sustainability. Nevertheless, the modern world cannot reject its need of fossil fuels, they cannot disappear overnight from our industrial and public lives. There are, however, activist organisations, seeking a way to keep a closer look on how rich corporations keep up to their sustainability programs and how effectively they put them in place. This deep dedication has pushed environmentalists to undertake more and more aggressive campaigns in order to raise awareness of the risks of drilling, use of fossil fuels as well as other environmental issues. One of the most popular and widely known campaigns is "Save the Arctic" Campaign of the Greenpeace organisation. However, "Save the Arctic" is not the only endeavour Greenpeace has been developing in recent years. By analysing the collected data, the article is aiming to explore further the origins of this opposition as well as the legal aspects of similar incidents. The main purpose of the research is to reveal how probable is a major sea to happen as a result of environmentalists' actions accident and to examine the available precaution measures to sea practitioners at present.

2. Development of Environmental Activism

In order to evaluate the effect, the environmentalists' campaigns have on shipping industry, desktop research has been done to pinpoint their main objectives and strategy. Since Greenpeace has demonstrated a sound and well- planned activity, especially in recent years, for the purpose of this article their actions have become the main focus.

The origin of modern environmentalism can be identified in early 19th century. With the growing impact the technical revolution, more and more people saw the potential danger pollution was posing for future generations. Later, during the post-war period, the environmental idea got a clearer shape. The

American biologist Rachel Carson, in her book "Silent Spring" from 1962, was among the first scientists to raise concern regarding the use pesticides and how they affect both human and wildlife health. As a result of its influence, in 1970 the USA created the "United States Environmental Protection Agency". The direct impact of the book was the ban from use of the DDT pesticide in the USA, followed by other parts of the world. The awareness the book created gave the start of the first environmental organisations in the American continent, the most notable being the Greenpeace and the Friends of the Earth.

2.1 Greenpeace and "Save the Arctic"

Greenpeace is one of the most influential environmentalist organization worldwide. It was created in 1971 in Canada by the US activist Erwing Stowe (1915 – 1974) and his wife Dorothy (1920 – 2010). Nowadays, it contains 26 independent originations all over the world, which are funded entirely by individual supporters 'donations donation grants. They do not accept any government or corporate funding. The main goal of the Greenpeace organization (see https://en.wikipedia.org/wiki/Greenpeace) is raising public awareness concerning environmental issues, as well as influencing economy and society into taking steps to preserve the environment. However, during its existence, the organization has been criticized for some of its campaigns or some of their actions.

There have been other more extreme environmental organizations, with more aggressive actions regarding their goals. Some of them were created by ex-activists of the Greenpeace, such as Sea Shepherd Conservation Society. Other notable environmental extremists are Earth First!, Earth Liberation Front and Animal Liberation Front (Posluszna 2015). Due to some of their activities in the past, including arsons, bombing and other manners of sabotaging industrial endeavours, their activities were labelled by the FBI as "eco-terrorism" (Jarboe 2002). Regarding the shipping industry, the most aggressive approach in the past was against whaling ships as well as other fishing industry endeavours. It is important to pinpoint, however, that unlike the above-mentioned "eco-terrorists", Greenpeace has always been making its best to avoid such negative labelling, in order to gain positive public image. Its campaigns, as well as actions, have always been well organized, regarding legal and media coverage. Greenpeace has many ways to operate, it has a very elaborate and well managed structure and publicity. The actions of the organization are precisely measured thanks to the support of the substantial legal team the group has developed in the years of activity and legal proceedings.



Figure 1. Map of the Arctic Ocean Area.

"Save the Arctic" is a specific Greenpeace campaign, which aims at preservation of the Arctic by preventing oil drilling and unsustainable industrial fishing in the area (Figure 1). The campaign started in 2012 and calls for the establishment of a sanctuary in the uninhabited high seas area around the North Pole, following the model of the Protocol on Environmental Protection to the Antarctic Treaty (see https://en.wikipedia.org/wiki/Save_the_Arctic).

The campaign was a direct result from the 2010 Deep Water Horizon oil spill which caused a

disaster in the Mexican gulf the consequences of which are still visible in the area to this day. In order to explain how the campaign and other Greenpeace endeavours are carried out, the present article gives more profound information on some relevant activities.

In August 2012, six Greenpeace activists boarded the Prirazlomnaya rig, owned by the Russian energy giants Gazprom. The activists were prepared for a long stay onboard the platform in the Pechora Sea, carrying supplies and tents. However, the activists were forced to evacuate after pieces of metal were thrown at them, and water cannons were used by rig workers earlier that day. Despite the clash, the environmentalists were able to publish messages in social media and display a banner titled "Don't kill the Arctic". The actions of the members of the crew against protestors were regarded as negative by most of the consumers, since the eco-activists did not engage in any aggressive approach and their demonstration was entirely peaceful (AllmodeSS 2015).

A year before that, around eighteen Greenpeace activists boarded the Leiv Eiriksson semi-submersible drilling rig, operated by the Danish company Cairn Energy off the Greenland Coast. They demanded the drilling company to release their documentation regarding oil spill response. Three of them, tied themselves to the rig's structure with the intention to stay for at least 10 days (based on the supplies they brought with them). The Danish police eventually arrested the activists and issued substantial fines for interfering with rig's security protocol and carrying out protests on the platform. In the end, the activists' mission was a success, since it managed to make Cairn Energy release their oil spill plan in August, further increasing their credibility for upholding environmental rights.

In September 2013, 30 Greenpeace activists were arrested from their vessel, the Arctic Sunrise, detained by Russian Navy Commandos. They were kept in Russian jails for more than two months, on the accusation of piracy and at a later stage of hooliganism as well. The treatment of the Greenpeace activists by the Russians was later condemned by the media, but the incident again contributed in further gaining them publicity and highlighting the importance of the Arctic campaign.

In 2019, the attacks on Shell platforms off the coast of Scotland were impeded by a court decision ruled out by the Edinburgh Court. In it the Judge Lady Carmichael concluded that rigs are a private property and Shell has the right to prohibit the access of unauthorized personnel. Furthermore, any unauthorized boarding causes additional safety issues, as well as environmental hazard. This ruling may be a key stone for other drilling platforms to be able to protect their integrity from an unauthorized boarding (IMO 2009).

All of the above-mentioned examples gained a major media coverage and thus – a substantial public interest, however the most interesting cases regarding shipping industry are the ones which directly involve ships engaged in trading operations. Such cases are, as follows:

- In 2008 several ships were blocked from leaving the port of Dumai, Indonesia by Greenpeace activists (Reuters). The vessels were loaded with shipments of palm oil to China and Europe. The main reason behind these actions was the protest against production of palm oil which has a profoundly negative effect on the local environment in Indonesia, causes deforestation and severely diminishes the quality of air in the affected areas. The attack included protestors to approach the vessels with rubber boats and to attach themselves to the anchor chain and display protestors' banners;
- In May 2014, a joint endeavour by Greenpeace and other activists, calling themselves the "Arctic 30", organised a spectacular protest in order to prevent a shipment of Arctic oil, carried by a Russian tanker, to reach the port of Rotterdam. The 44 activists made an effort to block the vessel's road and to prevent the discharging of her cargo. They used some really spectacular methods, such as paragliders, climbers, a fleet of boats and inflatables in an attempt to block the path of the tanker. Some activists were arrested by the Dutch anti-terror forces, but were later released without any charges;
- In 2018 Greenpeace boarded the m/t Stolt Tenacity off the coast of Spain while underway to deliver her cargo of palm oil from Indonesia to the Netherlands. The vessel was approached and the protestors announced their intention to board the vessel for peaceful protest. Upon their boarding, their access to ship's structure was restricted and, according to master's testimony, they were briefed regarding security, offered a meal and safely taken to the authorities in the port of Cadiz, Spain. The event caused a delay and additional expenses to owners, but voyage was

resumed as soon as protestors were safely taken to shore (Pai 2018);

- In 2022 soon after the war between Russia and Ukraine started, several shipments of petrol with Russian origin were confronted in the Baltic Sea when protestors displayed banners stating "Oil Fuels War" and similar writing were made on the boards of vessels Clearly, apart from the environmental protest, there was also a political statement.

One of the latest incidents happened on 31 Jan 2023, when Environmental protesters boarded a heavy lifting vessel headed for the North Sea. This was the White Marlin, carrying the Shell Penguins Floating Production, Storage and Offloading unit (FPSO), which left China in December. The boarding, which took place near the Canary Island, was again organised by a Greenpeace as a part of their long-term protest against fossil fuels production. The FPSO was being transported to the North Sea onboard an owned by Boskalis vessel and was set to be deployed 150 miles north-east of Shetland. It was estimated to unlock 80 million barrels of oil. The idea was for the FPSO to be installed in the place of the Brent Charlie Hub, closed down since March 2021, with the intention to extract the remaining oil from the Penguins field. An extensive video footage from the boarding was published online. In it the activists demonstrate how they approach the vessel in small boats and climb aboard, after which they display a banner titled "Stop Drilling. Start Paying". The boats were launched from the Arctic Sunrise, one of the ships owned by the Greenpeace. According to The Guardian, one of the persons who attempted to board the vessel was Yeb Sano, Greenpeace's executive director for Southeast Asia.

In of the above-mentioned incidents share similar features and modus operandi. The usual strategy for boarding is from small ships or boats, launched and supported from an ocean-going mothership. In the past it used to be the m/v Esperanza, the former Vikir-4, a firefighting vessel. Since she was retired in 2022, the new Greenpeace mother vessel in most cases is m/v Arctic Sunrise.

When the activists reach the target vessel, they use sophisticated climbing equipment to scale the freeboard (many of Greenpeace activists, are professional or "extreme sports" climbers). The main climbing strategy is to identify a possible route to aid their ascent. Due to differences in design, some rigs prove to be easier to board than others. There are numerous videos demonstrating the ingenuity, skill, and determination displayed by activists in each new attempt to climb some of the inaccessible structures.

After boarding the vessel, the activists usually search for a sheltered and inaccessible space to settle their base. After that they begin to lift extra personnel and supplies from the smaller craft they arrived in. This way they have all they need in order to prolong their protest.

The above-mentioned scenarios for boarding by the Greenpeace activists demonstrate that the organisation aims at good preparation and success of one main mission rather than engaging in numerous endeavours. Missions which do not cause any harm to nature or crew members of the targeted structures are crucial for the positive publicity the organisation seeks. However, such endeavours, which disrupt the smooth operation of a platform, FPSO or a vessel may be a serious safety or security issue for all parties involved (McNicholas 2016, Bragdon 2008, Dimitrov, Alexandrov and Todorov 2021). Such delicate situation may be costly and may create additional risks.

Furthermore, regarding frequency of attacks, it seems that there is at least one notable case per year, followed by a number of smaller, more local campaigns. Following the frequency of the case studies, it seems that the activities during the period 2019 – 2021 were reduced which suggests the reason was the recent COVID-19 pandemic.

Regarding shipping industry practitioners' point of view, direct attacks towards commercial vessels carrying a cargo labelled as harmful or malicious by the environmental organisations, are the highest risk. Such attacks are time-consuming and cause additional expenses for the transport companies mostly. Thus, the attacks are directed towards parties which are basically independent sub-contractors of the targeted corporations. The result is causing delays and costs which do not impede in any way the targeted corporations' activity but merely the operating transport company.

3. Legal Situation of Greenpeace According to International Law of the Sea

It is important to pinpoint the legal status of the environmental activists in similar cases, to determine whether their actions, a type of unauthorised boarding, can or cannot be labelled as piracy, as it has happened in the past. Yet, their modern-days endeavours are much different and less aggressive than the ones negatively labelled in the 1990s and early 2000s.

According to the definition of the United Nations Convention on the Law of the Sea, piracy is "Any illegal acts of violence or (...), committed for private ends by (...) and directed, on the high seas, against another ship or aircraft or (...)" (IMO 2009). The five criteria which stand out from this definition, so that an act can be considered piracy are:

- An illegality requirement;
- Any act of violence;
- A private ends requirement;
- A geographic limitation (the high seas);
- A two-ships requirement.

Based on this definition it can be concluded, that in contrast to earlier cases, when more aggressive approach was adopted towards certain whaling and fishing boats, the modern-day Greenpeace activists cannot be qualified as pirates in their actions against Shell for at least these reasons:

- Firstly, Greenpeace's actions need to be illegal in some way, to classify as piratical. There is however the issue, that under some circumstances, environmental activism is considered a protected right – as it was defined by Article 19 of the International Covenant on Civil and Political Rights, a human rights treaty adopted in 1966. It is hard to arbitrate which is more important, the freedom of expression or a company's freedom of navigation (ECHR 2015). It is a difficult task to decide which actions of environmentalists – continuous or individual practices, are illegal. In its Jersild v. Denmark case of 1994, the European Court on Human Rights ruled, that freedom of expression protects "not only the substance of the ideas and information expressed, but also the form they are conveyed in". This decision made possible for direct protests to be considered legal if the demonstration is made in a manner acceptable for the public (Preston 2012). This precedent was also confirmed in several other cases, including the 2003 Eugen Schmidberger v. Austria case. In that situation, some environmentalists blocked one of the major transport roads through the Alps, the Brenner motorway. Their actions were a protest against the pollution caused by heavy trucks. The demonstration made such an impact since the Brenner motorway is one of the key connections between Italy and Austria. The Court's ruling was in favour of the Activists' right of free speech. The temporary infringement of transport was not seen as major breach of transport companies' right of movement. In reference to the latest incident described, the one from Jan 2023, it was considered that Greenpeace was not actively preventing Boskalis' vessel from executing its voyage, but only causing a temporary breach of its "freedom of movement". The act of boarding by the activists was seen only as exercising their "freedom of expression". The violation of Boskalis and Shell's rights was only temporary and as soon as Greenpeace's action and message were made public, they were able to continue with their endeavour;
- The second point is that for an act to be qualified as piracy there must be documented acts of violence. Greenpeace activists usually only board the vessel and deploy a banner, without showing signs of any violent behaviour or intent– which contrasts to earlier cases dealing with "environmental pirates". The term" pirates" was historically described with the Latin phrase "hostis humani generis", the 'enemies of all mankind', mainly due to the terror and violence in their actions. The peaceful actions of Greenpeace activists, however risky, cannot and should not be compared to theft, abduction, and murder as it would be criminal behaviour. In contrast, the activists' actions could be considered, more like a tort.

With the recent opposition between Greenpeace and different corporate endeavours, new debates may be triggered around "environmental pirates" after a relative period of silence (Schwartz 1998). This debate demonstrates the weak and maybe outdated legal definition of piracy. It is also obvious that Greenpeace's latest operations do not correspond to that definition either. "Piracy", as a term has the potential for application of universal jurisdiction. It is not correct for this term to be used as a label to obstacle citizens' right of access to relevant information and activists' freedom of expression. On the other hand, when analysing the attacks on motor vessels, it becomes clear that there is no procedural nor insurance remedy for affected companies to adhere to. This situation may be due to the fact that such cases have not been too often in the past, have not caused significant delay nor have intentionally posed a direct threat to human life. However, if they begin to intensify, a more serious and costly problem may arise, thus legislative ground may become necessary (Helmick 2021).

4. Effect on Shipping

The activities of Greenpeace and other environmentalists, which use mostly different forms of peaceful protest, can still cause severe damages and sometimes may even have the potential to present real danger for health, human life or safety protocol. The main impact is mostly financial, however, if not dealt with correctly, there is a significant risk of severe damage to reputation. All environmental organisations have significant legal and political background as well as professional media and PR support. They have the opportunity and options to take advantage of any situation, incident or comment.

Our research, however, shows that the number of security companies, involved in this particular area of expertise, is limited. This may be due to the fact that there aren't too many companies directly targeted by eco-activists, nor the environmentalists' actions pose a direct threat to the merchant endeavour or human life. If there was an incident involving injury or loss of life, it would be accidental and not intentional. There are, however, other not so obvious risks, which deserve attention. The main effects on shipping, some of which may seem hidden, include:

- Time delay and loss of revenue on a drilling campaign. It can qualify as costly expense when becoming involved with protesting environmentalists;
- Deliberate or (in most cases) involuntary vandalization to the rig's structure, which is a real probability during an activist boarding, that leads to extra costs form potential repair. Even when no apparent damage was caused during the incident, an inspection on the rig's systems' functionality will have to be done after the boarding in order to ensure safe operation to all systems. This usually includes a health, safety and Dropped Object Prevention Scheme survey, in the cases when protestors have been suspected to have had access to areas above the rig's working decks. Such safety protocol may cause additional delay and expenses;
- According to some local regulations, as soon as activists make contact with the rig's structure, since they are not invading the ship in an unlawful way (they indicate their intent and do not hide their identity), the protestors may be considered to be under the health and safety care of the company. It is in company's best interest to make every possible effort to ensure their safety (which includes preventing attempts on behalf of crew members to cause them harm);
- Health and Safety regulation is in compliance with the flag state legislation of the platform involved. The UK law for example, states in Section 3 of the Health and Safety At Work Act 1974 that the safety of anybody on the property is a responsibility of the employer. Similar provisions are stated in EU regulations as well, which makes them a law to any European flagged ship. The relevant law of the flag state must be carefully studied for similar provisions;
- The company Health and Safety policy always includes a commitment to mitigation of the impact of any foreseeable hazards in the relevant workplace. An environmentalist boarding can be considered in this context. There could be a protestor injuring him/herself on the facility. Such a case may have an impact of safety record, insurance, the client and the reputation of the company;
- According to SOLAS provisions, any protestors boarding a vessel or a rig, should have the right to lifesaving assistance in case they run into any misfortune before, during or after a (failed) boarding attempt. If the crew of the platform have any part into the cause of this distress, some severe consequences may be expected;
- As mentioned above, Greenpeace and other large environmental organizations usually have a well-developed legal support system, so legal actions are very likely if any harm comes to any of the protestors. Regardless of whether the potential case is strong in courthouse or not, most likely it will involve a lengthy, expensive court procedure with a number of opportunities for reputational damage to the targeted company;
- Most environmentalist organizations prefer to use different media to publicize their objectives and to attack the activity of their opponents. Most likely, a potential boarding will be carefully recorded in all possible medias. Any hints of aggressive behaviour or other acts that could be considered in a negative prospective are likely to be widely publicized and once more may be used for negative publicity of the targeted company;
- Usually, such events gain a significant media interest, which must lead to assessing the substantial

security risk that this may present. Such media coverage, when examined carefully, may highlight some security weaknesses. It may provide useful information for terrorist or pirates who wouldn't hesitate to exploit such weaknesses in some malicious endeavours like for piracy / robbery or a terrorist attack. An in-depth review of security measures must be done. Any publication of photos and / or videos showing boarding attempts must be prevented, because such publications, even if following different objectives, may give pirates and/or terrorists a precise inside information on how to conduct their own attacks.

It is obvious that in most cases acts of boarding conducted by environmentalists are not intended to be malicious or aggressive towards crew or structure. Even so, their occurrence is a problem for the company targeted, since they induce significant delays, expenses as well as substantial security risk. It is of major importance for crews to be instructed accordingly in order to minimize the negative impact of the incident. A risk assessment should be conducted in order to identify possible scenarios and relative actions. All the above-mentioned risks have been assessed according to their severity in Table 1 (AllmodeSS 2015).

The risk posed on shipping participants by environmentalists' boardings could be incorporated into the Ship Security Plan and the ISM shipboard Safety Management Manual (Petrig 2022). Since the nature of the environmentalist attacks is not a direct security issue but has the potential to quickly escalate into one, the crew and officers are to be dully instructed to act with caution, without showing any aggressive behaviour, avoiding any possible escalation of the situation. They must bear in mind the fact that there may be provocations and should focus mainly on avoiding negative publicity following the incident. For the purpose of this research, the advisory notes from Allmode Limited (a Ship Security advisor and provider) were examined. They contain precise procedure steps for owners in order to assist their onboard officers and crew into taking the right decisions for securing safety of all human life, technical procedures and last but not the least - the environment.

Table 1. Risk assessment elements regarding eco-activist boarding

Most Likely Course of Action	Most Dangerous Course of Action
1. Short term, high profile, peaceful occupation of targets such as drilling platforms, especially those linked with drilling operations in Arctic or Antarctic areas (or with any company, or drilling contractor operating in these areas).	1. Deliberate, accidental structural or mechanical damage, that can cause of Falling Object hazards.
2. Cause a loss time and / or of revenue due to interference with drilling campaign.	2. Direct cause of an accident, injury or dangerous occurrence, which can involve themselves or the crew, leading to legal ramifications
3. Direct cause of Falling Object hazards.	3. Negative media attention and damage to reputation as a result of poor handling of situation by rig's crew.
4. Generating Biological hazards.	4. Publication of security weaknesses that may inform and encourage criminal, pirate or terrorist organisations.
5. Direct cause of damage to reputation.	
6. Publication of security weaknesses that may inform and encourage other environmental groups.	

5. Conclusion

Based on all the information gathered and analysed in the present research, it becomes clear that, even though it is of a particular interest, the oil and drilling industry is not the only one to come in the spotlight for environmental groups. The records show that food and forestry industry may also be targeted. Such protests only happen when there is a legal right for them to be performed. However, for the vessels and their operators, who come under attack, there are neither standardised security measures, nor insurance coverage. On the other hand, the officers and crew cannot leave individuals, involved in unauthorized boarding, gain free and undisrupted access to all ships' structures since it may cause hazards, threatening the integrity of the vessel and endangering the life of the crew members. As demonstrated in the case of m/t Stolt Tenacity, one course of actions the vessel may undertake is to act in a manner similar to the procedure for finding stowaways onboard, with necessary lack of intend to hurt or disrespect any of the protestors involved. However, the deviation this incident caused, is costly and time-consuming. Additionally, the boarding environmentalists do not fit entirely into the definition of stowaways, since their boarding is not clandestine but fully announced. In this case, the owner hardly has the option to address any insurance coverage for the

relevant expenses.

The record of incidents shows that there were no boarding activities during the period 2020 – 2022 when the COVID-19 pandemic was present. Since the pandemic is now officially over, one may expect activity to enhance, further backed up by local legislation. One may expect the EU coast to be further scene of environmental protests onboard, based on the green policies and local rules in most EU countries.

The concern about the environment should be of major importance to every responsible human being. The Earth is by no doubt the only home the human race has. The global problems concerning climate change, global warming and pollution should not be addressed pro forma but with caution and responsibility (Burrows and Kinney 2016, Vestby 2019). The environmentalists' accusations that these issues are being addressed by major corporations more or less superficially or with the clear intention to be bypassed, have their solid ground. The eco-activists' determination is further backed by the green policy of the EU, the Tokyo protocol and many other international treaties, aiming at addressing the problem. However, one must take into consideration that a dramatic global change, in the use of renewable fuels, decarbonizing of production process, maintaining a residue-free life and making major corporations environmentally responsible is an objective that, unfortunately, cannot be obtained overnight. The right steps are being taken for this to happen in near future. As experience shows, it is more of a political strategy than an individual choice. We all feel our time will be the turning point of human development, but one must take it with the necessary patience. The aggressive approach does not contribute in a positive way, it adds additional threat both to life and the environment and causes unnecessary tension which may escalate also in political way and may, as a result, create new problems rather than solving those we already have. The attacks on fossil fuel production industry bring attention to the environmental dangers but also jeopardize the lives and jobs of both crew and additional personnel. Targeting tanker operating companies causes costs and trouble to the wrong subject while the main target remains unaffected. Most of the personnel of the targeted facilities work there to support their families. These attacks, aiming at major corporate giants, only result in harming their subcontractors' employees, people who are often convinced in the virtues of the environmental protection policy, then in affecting significantly the corporations themselves. Even with the large media coverage to the environmental campaigns and the highly polarized public opinion, one must always consider that "the road to hell is paved in good intentions". A wiser and more effective approach, even with more legislative and procedural changes, is needed in order to obtain the main goal of protecting the Earth for all its inhabitants and future generations.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Re-creating maritime incidents with engine room simulator

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Abstract: After a major maritime accident, affected parties conduct thorough investigations to find reasons which caused these incidents ranging from machinery failure, design faults to human error. In the process we always put the facts together and ask the questions: What if this was done in this situation? Why couldn't the engineers think of this as a solution to this disaster or to mitigate the consequences? A recent most example in this sphere of activities is the container ship MV Dali which struck Francis Scott Key bridge in Baltimore, Maryland, USA, in March 2024 after an electrical machinery failure. Unlike in the past, where the investigators cannot re-create an accident / incident to a certain acceptable degree with simulation, the modern-day investigators can re-create history with cutting edge technology available with new engine room simulators. The analysis of an incident by carefully re-creating it with available facts may lead to further possibilities that can be explored towards solutions to issues surrounding the incident. It further opens new avenues for students' learning of situational awareness to take timely action to strengthen safety of ships and people on-board.

Keywords: maritime incidents, engine simulator, situational awareness, Dali

1. Introduction

Maritime simulators are gaining ground and becoming a very sophisticated tool for teaching, training and assessment. To elaborate further, in the context of teaching, the modern engine room 3-D walkthrough simulators can be displayed in a pre-sea student classroom to show how an engine room looks like with location and orientation of all the virtual machinery, such as the Main Engine, Generators, Boilers, various pumps, purifiers, etc. This will immensely assist students to visualise the work environment in which they will be performing as future engineer officers.

In the context of training, we let the students do various simulator exercises designed carefully to either demonstrate how a particular machine works or familiarise them with their functions such as starting, running and trouble shooting.

Another aspect where the simulator can be employed very successfully is the assessment of competence. By carefully designing exercises that address the "intended learning outcomes" (ILO's), a simulator can be the best tool the examiners can have for assessment of competence. IMO STCW code emphasizes in its Competence tables (Column 3) that "approved simulator training" can be a method of demonstrating competence (STCW Convention and STCW Code).

Recently the authors discovered that the engine simulators can be used in certain instances to re-create an incident with a state-of-the -art simulator to have a second look at the incident after it happened. There are several benefits that comes along with a re-created incident. Recreated incident with an engine room simulator is like a testing ground for the incident. In the testing ground an investigator can tryout his/her assumptions and presumptions by feeding necessary data to the simulation and analysing the outcomes. Further, simulator re-creations can lead to new findings that has never been considered, but very much is the crux of the matter that had been overlooked during the investigation phase. The re-creation of a past incident with a simulator paves the way for students to get the opportunity to experience a similar situation, which

otherwise is limited to a power point presentation in a classroom. The use of the full mission simulator to re-create incidents with a simulated engine control room (which is very close to the real-life control room) and virtual reality engine room make the situational awareness necessary to make decisions incomparable.
After studying several maritime incidents, the authors re-created some of them quite successfully for teaching purposes. The re-creations are not necessarily replications of exact incident but mostly along a similar theme. There are several challenges we face when re-creating past incidents that needs careful consideration for authentic end results. The most important of them is that the ship we use in the simulation must have the same or very close physical dimensions / characteristics as the actual ship. Further, the ship type (tanker, container etc.) must be the same. In addition, if we cannot match the initial conditions necessary for the ship, we may draw inaccurate conclusions. In the case of the incident under consideration below, we noted that the inadequacy of some data of the real incident further hampers the findings and subsequently the conclusions. However, the authors wish to present the conclusions based on certain presumptions due to the lack of real data.

2. Re-creation of contact of Containership Dali with the Francis Scott Key Bridge and Subsequent bridge collapse

On March 26, 2024, about 0129 eastern daylight time (EDT), the 947-foot-long Singapore-flagged cargo vessel (containership) *Dali* was transiting out of Baltimore Harbor in Baltimore, Maryland, USA, when it experienced a loss of electrical power and propulsion and struck the southern pier supporting the central truss spans of the Francis Scott Key Bridge (Key Bridge). A portion of the bridge subsequently collapsed into the river, and portions of the deck and the truss spans collapsed onto the vessel's forward deck. A seven-person road maintenance crew employed by a company which was contracted by the Maryland Transportation Authority (MDTA)—and one inspector employed by another company on the bridge when the vessel struck it. The inspector escaped unharmed, and one of the construction crewmembers survived with serious injuries. The bodies of the six fatally injured construction crewmembers have been recovered. One of the 23 persons aboard the *Dali* was injured.

This recent maritime incident drew our attention for various reasons ranging from Safety of Life at Sea (SOLAS) regulations that govern the machinery such as the steering gear and emergency generator to the situational awareness of those on-board the ship. With the view to recreate the incident, we studied the incident at length together with SOLAS Regulations 29 and 30 on Steering Gear

We based the incident contents on the "Marine Investigation Preliminary Report dated 14th May 2024" by the National Transportation Safety Board (NTSB) and the Youtube video "(4405) Full video Francis Scott Key bridge collapse in Baltimore" (4405) Full video | Francis Scott Key bridge collapses in Baltimore - YouTube for the re- creation of the incident.

Below is the summary of incident timeline according to the video and relevant narrative from the NTSB Report

Table 1: Events Timeline as per the live video

Event	Eastern Daylight Time (EDT) in Baltimore	Time between events	Event Description	Distance to the Bridge	Speed of the ship	Ship's Heading
1	01:24:32	0	First Blackout. Main Engine stops. The fully lit forward main deck of the ship appears to be in total darkness.	0.6 Miles (3168 ft.) (approximately 3 ship lengths)	9.0 Knots	141.7
2	01:25:31 01:25:42	59 seconds 11 seconds	Lights appear on the ship. May be due to Emergency Generator. (It took 59 sec, to start and connect. The SOLAS requirement is 45 sec). The forward main deck lighting does not appear. Only the accommodation lights appear. There is black smoke from the		8.6 Knots	144.3

			funnel. No mention about the smoke in the NTSB report		
3	01:26:37	66 seconds	Second Blackout. However, the emergency lights remain lit. (Power lasted only 1 min 6sec.)	0.2 Miles (1056 ft.) (1 ship length)	
4	01:27:11	34 seconds	Lights appear on the ship again. May be due to Emergency Generator or the engineers manually closing HR2 and LR2. This power from Gen 2 lasted until the ship contacted the bridge.		
5	01:28:44		Water splashing from the bulbous bow appears on the video indicating that the bow is closing-in on the Pier 17.	Zero ft.	6.5 Knots
6	01:28:50	99 seconds	Dali Starboard bow hits the Pier 17 of the bridge. Bridge starting to Collapse		6.5 Knots
Total time from first Blackout to contact with the bridge = 258 seconds (4 mins. 18 secs.)					

We noted that some of the times of events differ slightly between the Youtube video and the NTSB narrative. In general, the officers on-board had just 4 mins 18 secs. to implement a plan to evade the disaster since the blackout.

3. Re-Creation Process

This involves selecting a suitable simulated ship with similar initial conditions. We selected Kongsberg container ship with RT Flex Main Engine. This is the most suitable simulator, and the comparison is given below.

Table 2. Comparison of Dali (real ship) with Simulated Dali (Kongsberg) with RT Flex engine

Parameter	MV Dali (Real Ship) May 14, 2024 NTSB Report	Simulated Dali (Kongsberg RT Flex)Ver: 3.6.037 (03)
1. Length OA	299.92 m	308 m
2. Breadth moulded	48.2	32.2 m
3. Depth moulded	24.8	21.8 m
4. Summer draft	15.03	12.8 m
5. Container capacity	9900	4800 TEU
6. Main Engine Total power	41.48 MW	51.28 MW
7. No. of TEU's carried. during the incident	4680 TEU (56675 MT)	4800 TEU
8. Service speed	22 knots	26 knots
9. Actual speed at first blackout	9.0 Knots (SOG)	9.0 Knots
10. Actual Course	141^0	141^0
11. Rudder position at the start	Mid-ships	Mid-ships
12. Speed of the ship when it struck the Bridge Pier # 17	6.5 Knots	5.95 Knots
13. Ship's heading when it reached the Pier # 17	Data not available	138 deg.

4. Discrepancies between Real Dali and simulated Dali which comply with SOLAS regulations.

From the NTSB narrative it appears that the real ship had a high voltage (6600V) system, and all the problems stemmed from the 6600V/440V transformer. Simulated ship has only the customary 440V system.

The NTSB report does not mention the time the emergency generator started after the first blackout. From the video it is evident that the emergency generator took 58 seconds, which is 13 seconds more than the SOLAS Regulation 44 requirement of 45 seconds maximum.

Further, the real Dali had two identical Steering Gear motors as per SOLAS Regulation 29 powered from the HV system stepped down to 440V LV Main busbar. It also had an Auxiliary Steering Gear directly fed from the Emergency 440V LV busbar. This arrangement complies with SOLAS Regulations; however, it becomes an issue in a situation like the present one. [SOLAS Regulation 29 Para4,5,6, Regulation 30 Para 2]. In the NTSB report it is mentioned that "…designated emergency steering pump (no.3) would have been available to turn the rudder at its low-speed setting." (When operated alone using emergency electrical power, steering pump no. 3 was designed to run at a lower speed, turning the rudder at a slower rate than with all pumps.)

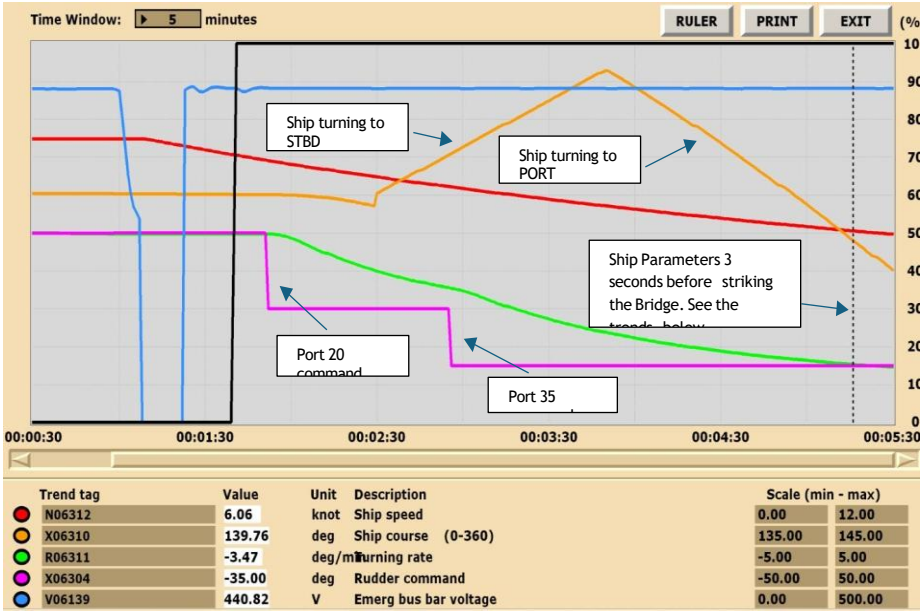
When re-creating the incident, the simulator we used had no HV distribution. The simulator is designed with a 440V system and two identical steering gear systems (which Complies with SOLAS Reg. 29/30) where the steering gear no.2 is powered by the emergency generator. However, even with the discrepancies the re-creation does not deviate from the actual machinery failures and the subsequent occurrences.

5. Situational Awareness and the Evasion of the disaster

After studying the NTSB report and while creating the simulation of the incident it was evident that the disaster could have been evaded if the officers involved had substantial awareness of the situation. The following facts may shed some light on the analysis of the real situation which will be further supported by the results of the simulation.

- When the ship had the first blackout, it was 3 ship lengths (approx. 3000 to 3168 ft) from the Scott Key Bridge.
- Ship's speed was 9 Knots (15.2 ft/sec) when the main engine stopped due to the blackout. This means the ship will reach the Key Bridge in approx. 200 – 210 seconds or 3.5 minutes if it maintained 9 Knots speed. If we assume that the ship will slow down to an average speed of 7 Knots, it will only take 262 seconds. Please refer to the actual time taken by the ship in Table 1 in the incident, which is 258 seconds. Therefore, we can assume that the average speed of the ship from the first blackout to striking the pier 17 of the bridge was about 6.9 Knots. The actual speed of the ship when it struck the bridge was 6.5 Knots. [NTSB Report]
- The point we need to raise here is that with a total time duration of 4 mins.18 secs. in hand, since the first blackout, what are the options the engineer officers on the ship had in the engine room and navigating officers on the bridge? For engineers, one precious minute was lost as the Emergency generator took 59 secs to start and connect to the emergency busbar. Assuming that a main generator was connected within next 1 minute, can the engineers start all the essential auxiliaries and start the main engine on Astern in the two remaining minutes to effectively stop the ship which had an average ahead speed of 6.9 knots? It is highly unlikely that this solution is possible
- On the other hand, what were the options the navigation officers on the ship had with a vessel that is moving at an average speed of 6.9 Knots towards the bridge and turning to starboard slowly during the run. The original heading of the ship at the blackout was 141^0 and when the emergency generator started and connected, the NTSB report mentions it as 144.3^0. and the course over the ground as 142.7^0. This is clear evidence that the ship is turning to starboard in the Fort McHenry channel as it is moving forward.
- The compulsory action of the officers on the bridge should have been to steady the ship by turning the rudder to Port to counter the starboard movement. Note that the emergency generator supplies power (440V) to the steering gear No.3, which acts as an auxiliary in this emergency as per SOLAS Regulation 29 Para 4 and Regulation 30 Para 1,2&3.
- The main purpose of having the requirements stipulated in the Regulations 29/30 are to provide means of controlling the ship when it has a headway without the propellor turning. Unfortunately, the first rudder command came only at 01:26:13 which was 20^0 to Port, 41 seconds after the auxiliary steering was available. It took further 70 seconds to make the rudder command 35^0 to Port which was too late to evade the disaster. Instead of using the SOLAS provisions for steering which is meant exactly for a situation like this, the officers on the ship's bridge failed to take the advantage of the auxiliary steering, which was powered by the emergency generator, running continuously since the first blackout.

6. Simulation results of 'what happened' compared with 'what could have done'



Simulator screen shot #1 Parameter Trends of the real incident just before striking the Bridge



Simulator screen shot # 2 Parameter Trends of the simulated incident just before the Bridge. Note the Ship's heading. There is a possibility that the ship could have avoided striking the Pier 17 of the Key Bridge.

7. Conclusions

7.1 It can be assumed beyond any reasonable doubt that the restoration of electrical power wouldn't have been a solution to the issue as the time available to run the main engine in Astern was not sufficient.

7.2 This leaves the task of avoiding the ship striking the bridge in the hands of the officers on the ship's bridge and their 'situational awareness'. The two factors that could have saved or mitigated the incident are:

(a) That the SOLAS regulation 43 stipulates that the emergency generator must start and connect to the emergency busbar within 45 seconds in case of a blackout.

(b) One of the steering gear systems must be powered from the emergency busbar. If it is identical to the Main Steering Gear Power unit it must not take more than 28 secs to go from 35^0 Port to 30^0 STBD and vice versa. If it is Auxiliary Steering Gear, it must not take more than 60 secs. to go 15^0 on Port to 15^0 on STBD and vice-versa

7.3 We created the incident without above requirements and the two screen shots of the 'real incident' and the 'simulated incident' was compared. In the Screen Shot # 1the ship was subjected to the first blackout at a simulator time of 00:01:00. The ship's emergency Gen was available at 00:01:30. During the blackout there

was no steering, and the ship started to turn to STBD. Senior Pilot ordered Port 20^0 at this point. However, that command was not sufficient to stop the ship turning and he ordered Port 35^0 one minute later. Finally, the ship ended up STBD Bow on the pier 17 with the ship heading 139.76^0

7.4 In the Screen Shot # 2 all the same initial conditions are used. However, we actioned a rudder command of 35^0 degree to Port 30 secs after the emergency gen was available and when turning to STBD was noted. This movement brought the ship one degree off the pier 17 of the Key bridge. Further, compare the rate of turning to port in the trend diagrams and the drop in speeds which could have contributed to avoiding the Pier 17 by the ship.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
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Automated Marine Sewage Treatment Plant (MSTP) Using Ultraviolet Lights for Domestic Ships in the Philippines

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Abstract: This prototype invention aimed to develop and design the Automated Marine Sewage Treatment Plant (AMSTP) to address the domestic ships which do not have a sewage treatment plant (STP). This AMSTP was designed based on acceptable value or standards of predetermined treated waste liquid quality as set in MARPOL (Marine Pollution) 73/78 Annex IV guidelines. This AMSTP used ultraviolet (UV) lights and a coliform sensor to monitor the waste liquid quality. The study was anchored in the theoretical frameworks of MARPOL (Marine Pollution) 73/78 Annex IV Regulation (Pollution Regulation for Sewage) and RA (Republic Act) 9275 (Clean Water Act). The study site was John B. Lacson Foundation Maritime University (JBLFMU)-Molo, Iloilo City, Philippines. The method of this study was a laboratory experiment using several samples from the AMSTP that were submitted for laboratory testing of the Engineering Department of Central Philippine University (CPU). This study was initially funded by the Department of Science and Technology (DOST)-PCIEERD for one year (2023-2024). The invention was submitted for several testing for its operation and application. Maritime and ship applications of this study will be used by domestic ships and sea-crafts in treating their disposal wastes plying Iloilo-Guimaras Strait. MARINA (Maritime Industry Authority) will use this study to make decisions about maritime policies and regulations in the Philippines.

Keywords: marine sewage treatment plant; ultra-violet lights; domestic ships

1. Introduction

Disposal of wastewater has always been an environmental issue all over the world, its disposal is a major problem and a big challenge for a whole community as mentioned in the different studies in the field (Ayesha & Khan, 2023; Cheema, 2023). Furthermore, illegal sewage discharges are one of the few serious offenses onboard which should be taken utmost care of. Cases like these have a detrimental effect on the marine environment and ship owners are susceptible to heavy fines and sanctions if caught by the implementing body in domestic shipping. On the whole, seafarers' incompetence and credibility are questioned relative to their behavior. It is up to them to do something to keep their prestige and honor.

2. Theoretical Frameworks

The design of this automated marine sewage treatment plant was anchored on the following frameworks: RA 9275 (The Philippine Clean Water Act of 2004), MARINA (Maritime Industry Authority) Memorandum Circular No. SR-2020-02 in the Philippines, and IMO (International Maritime Organization)-MEPC (Marine Environment Protection Committee) of 2016. As mentioned by Pasaribu, Yamato, & Damoyanto (2023) marine regulation was promulgated to regulate pollution of the marine environment by ships as contained in Annex IV of MARPOL. this means that prevention of contamination by sewage by ships can be overcome by using auxiliary treatment plants by utilizing aerobic bacteria as waste decomposers and UV light as sterilizers or neutralizers of waste that is harmful to the environment.

3. General Objective

To design and develop an Automated Marine Sewage Treatment Plant (AMSTP) Using Ultraviolet

Lights with a Holding Tank and Shore Connection to Discharge Pipe for Domestic Vessels.

4. Methodology

The researchers of this project used quantitative research design by designing and developing the dimensions of the prototype automated marine sewage treatment plant (AMSTP) of the passenger ship. Specifically, this project entails the following:

System Design and Planning – the first step is data gathering and verification. This involves consultation with people in the maritime industry with regard to the standard requirements and the effectiveness of the existing sewage treatment plant in the domestic vessel corresponding to the MARPOL Annex IV. The revised standard used in the sewage discharge process and research for current issues concerning the impact of sewage pollution into the sea towards developing effective means of monitoring and treatment of sewage discharges.

System Development- after the system design and planning were established the inventors commenced the system development of a prototype sewage treatment plant, coliform sensor, new sterilization processes, and holding tank design. The purpose of the second step is to prevent the direct discharge of sewage whenever the fecal coliform level reaches its acceptable level. Also, it is designed to have a holding tank, the sewage volume equivalent to the total capacity of crew onboard of 20 to 25 persons. It included the task of developing the exact algorithm of program control for the sewage treatment plant. The procedure includes the following:to get samples of effluent from domestic ship sewage holding tanks, send samples to a laboratory for testing (Engineering Laboratory of Central Philippine University), finalize of design/drawing plan of AMSTP, to fabricate different AMSTP chambers, purchase and install UV lights, solenoid valves, coliform sensors, air blowers, compressors, pumps, 3-way control valves, install the control panel and its instrumentation, conduct the pilot testing and calibration, perform the testing of all available functionality of AMSTP, perform the actual testing and modification of parameters if needed at JBLFMU-Molo Campus, Iloilo City, Philippines, modify the parameters according to the needs, test the final product using Ultraviolet Lights (UVL) with a Holding Tank and Shore Connection to the Discharge Pipe.

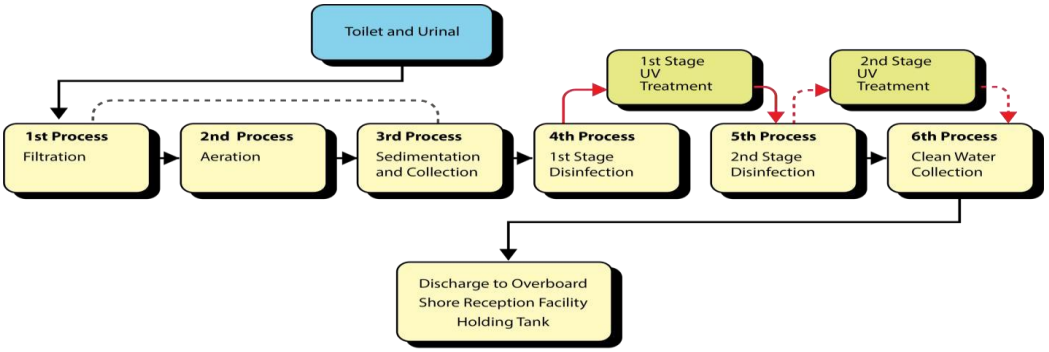
5. Results and Discussion

5.1 Dimension of AMSTP

This AMSTP is designed to have dimensions of 1.5M X 1.0M X 1.5M and a volume of 1.25 cubic meters. The voltage is 220/230 Volts, the wattage is 4500 Watts at 60 Hz. The weight of AMSTP is 2.5 Tons (2500kgs).

5.2 Marine Sewage Treatment Plant (MSTP) with MEC standards

The marine sewage treatment plant is used for treating the waste after the sedimentation and collection process using the first Ultraviolet (UV) lamp, which is the first disinfection stage, and then proceeds to the next stage- the "second disinfection stage," which is the 5th process. Again, it will be treated by the second Ultraviolet (UV) lamp. Then, the waste will proceed to the 6th stage water and it will go into the Facility Holding Tank. If the waste passes the quality standard, it will proceed directly to the 6th chamber without the treatment of the 2nd Ultraviolet (UV) lamp. See the figure below:



Marine Sewage Treatment Plant Process Flowchart

Figure 1. Flow of Treating the Sewage from Ship

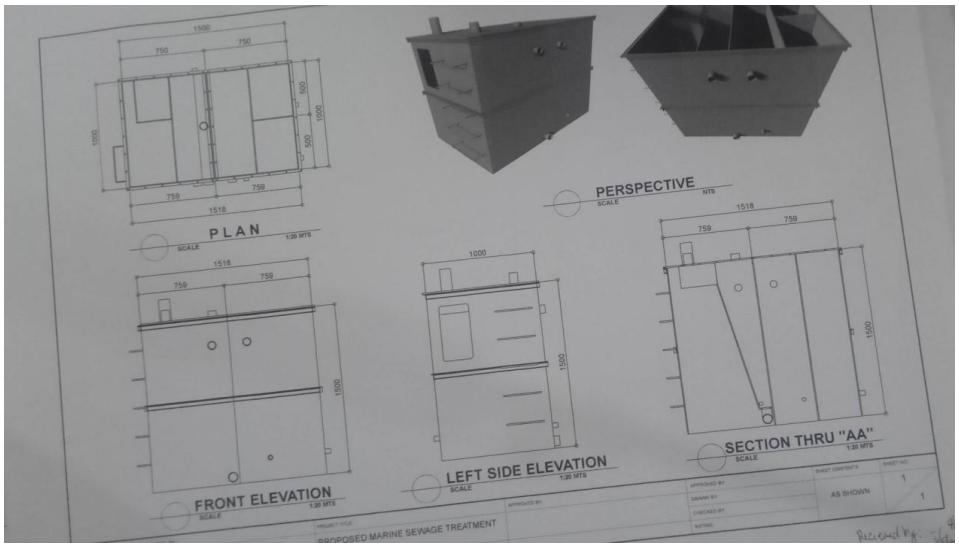


Figure 2. Dimension of the Prototype AMSTP

The modified design of the AMSTP with UV Lights, 3-way solenoid valve, and coliform sensor will ensure the continuous monitoring and measurement of the treated sewage from vessels, which will result to the conformance of the STP to the standard of MEPC 159 (55). The sewage from marine vessels that will be discharged overboard is safer for the marine environment.

5.3 Data Analysis of Influent and Effluent of AMSTP

The result of the analysis of the untreated and treated wastewater samples for the Automated Marine Sewage Treatment Plant (AMSTP) system. The result shows that the BOD5 of both untreated and treated with the values of 17.1 mg/L and 14.1 mg/L, respectively passed the DENR and MEPC 159 (55) guidelines. The total coliform and fecal coliform of the MSTP is reduced from >8.0 MPN/100 mL to 2.6 MPN/100 mL and >8.0 MPN/100 mL to 1.1 MPN/100 mL, respectively. This is way below DAO 2016-08 and DAO 2021-19 for Class C waters, and MEPC 159(55) of 10,000 MPN/100 mL and 400 MPN/100 mL, 100 thermotolerant coliform/100 mL for total and fecal coliform, respectively. Other parameters tested such as the pH have passed the set guidelines except for the total suspended solids (TSS) and chemical oxygen demand (COD). In this case, since actual domestic wastewater is being sampled and failed to pass the standard, the presence of the inert substances that come from the wastewater contributed to high values.

6. Conclusion

In conclusion, this invention of this AMSTP is one of the innovative approaches to address the issues on sewage treatment facilities of maritime vessels here in the Philippines. Therefore, this present invention deals with the use of environmental-friendly automated marine sewage treatment plant (AMSTP), specifically targeting wates in maritime vessels that are disposed into the sea, overboard, or to a shore reception facility. The automated sewage treatment apparatus comprises a multi-chamber body designed to process incoming sewage water and eliminate coliform and other bacteria before the discharge. Equipped with sensors to measure water levels and detect bacteria presence, the apparatus, controlled by a microcontroller, discharges water once contaminants are removed. If contaminants persist, the water is reprocessed until eventually suitable for discharge.

Recommendations

Based on the results and conclusions of this study, the following suggestions and recommendations were advanced:

The MARINA shall consider this project, environmentally friendly treatment of the wastes from the domestic ships as the basis of the ship waste management policy; the different LGUs shall invest in constructing this environmental-friendly treatment of wastewater so that the product water can be reused for other purposes and water can be saved. Local inventors shall be given support so that different potential inventions can emerge to help the government solve the problem of water pollutants. The administration of

maritime higher institutions (MHEIs) shall promote more inventions in relation to wastewater treatment, marine preservation, marine waste management, and marine environmental technology. The researchers and inventors of this project would like to encourage other researchers and inventors to explore other technologies that would have an environmental impact on the community and on the country at large.

Acknowledgements

The members of the Automated Marine Sewage Treatment Plant (AMSTP) comes into realization through the help, efforts, suggestions, and encouragement of the following people: Dr. Enrico C. Paringit, Executive Director of the Department of Science and Technology (DOST)-Philippine Council for Industry, Energy, and Emerging Technology Research and DFevelopment (PCIEERD) for granting the fund for the development of the prototype AMSTP, Dr. Carmel V. Ambut, WVCIEERD Executive Director for the knowledge and inputs to the project to improve its operation and functions, Engr. Rowen R. Gelonga, CESO II, Regional Director of DOST Region-6 for the support and inspiration given to the team, Dr. Ronald Raymond L. Sebastian, Chief Executive Officer (CEO) for the unwavering support to the inventors of this project, Mr. Robert O. Parcia, former Administrator for the encouragement and help towards the realization of this project, Engr. Neal Roberto Sobrejuanite, present administrator of John B. Lacson Foundation Maritime University (JBLMU)-Molo for the support of this study.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Sustainable Flow: Sustainable flow of goods and decreased CO_2 emissions of transportation

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Abstract: Although shipping is the most energy-efficient mode of transport, however in its current condition it produces about 3% of global CO_2 emissions. In response to demand for decarbonization and reduction of its greenhouse gas emissions, of maritime industries assigned digitalization as the signpost for the future development. Digitalization can provide unprecedented opportunities to develop sustainable and at the same time competitive business solutions for maritime industries. A key to sustainable digitalization is to maintain a balance between human well-being, environment, and economic interests of industries. Sustainable digitalization emphasizes on the development of digital tools to achieve environmental goals, i.e. technology as a leverage for positive environmental outcomes and sustainable development.

This paper reports on the outcomes of an EU funded project that aims to utilize sustainable digitalization to reduce the CO_2 emissions of seven ports in the Central Baltic area. The 'Sustainable Flow' project's goal is to develop a digital tool for stakeholders to gradually decrease their emission to the targeted level. The project also will create a framework for energy saving and production of renewable energy in the targeted ports. The paper will elaborate on the process and challenges involved with the development of the open-source digital tool which will be publicly available on the completion of the project.

Keywords: Digitalization, CO_2 emissions, Digital tool, Sustainability, MASS, Decarbonization

1. Introduction

Sustainable development is a current signpost across the industries including maritime logistics. One of the main challenges in sustainability is the reduction of greenhouse gas emissions. Although shipping is considered to be the most energy-efficient mode of transport, especially for transporting large volumes of freight, it counts for about 3% of the total CO_2 emission. It is estimated that if no changes are made and emissions continue to grow at current rates, by 2035 the carbon dioxide emissions of the shipping sector will increase by almost a quarter (International Maritime Organization 2023). To mitigate this alarming trend, the maritime industry must adopt innovative strategies to curb emissions and align with global sustainability goals. Increasing the use of digital solutions is one way to promote the green transition and reduce greenhouse gas emissions in maritime logistics- and thus support sustainable development. Technologies such as digital route optimization, predictive maintenance, and real-time emissions monitoring can enhance operational efficiency, reduce fuel consumption, and lower the sector's carbon footprint.

Aligning with UN sustainable developmental goal (UNSDG), the European Commission, adopted the digital technologies as a crucial element in achieving their environmental objectives with the goal of making the European Union climate neutral by 2050. For example, it is estimated that the Information and Communication Technologies (ICTs) has the potential to reduce the global greenhouse gas emissions by 15%. Technologies such as artificial intelligence (AI) and supercomputing can analyze vast amounts of data and thus provide intelligent suggestions to support environmentally informed decision-making solutions (European Commission 2020). Although such a digital solution is helping to create a greener and more sustainable future, it may create other environmental challenges. IT infrastructure consumes significant amounts of electricity that greatly contributes to the greenhouse gas emissions. This resulted in IT

technologies to be both part of the problem and solution at the same time (Murugesan 2008).

Sustainability is therefore to find a harmonious balance between environmental protection, economic viability, and social wellbeing (Murugesan 2008). The concept of sustainable digitalization address this balance by incorporating two complimentary perspectives; a goal-oriented approach and a design approach. The first perspective focuses on leveraging digital technologies as powerful enablers to achieve environmental objectives, such as reducing carbon emissions, optimizing resource use, or enhancing environmental monitoring through data analytics and IoT solutions. Conversely, the design-oriented perspective emphasizes refers to the principles of sustainable development into the creation of digital solutions (United Nations 2025). The utilization of these perspectives in sustainable digitalization not only harnesses technology to address pressing environmental challenges but also ensures that the design and deployment of digital systems are inherently sustainable.

2. Method

This paper reports on the outcome of the ongoing Sustainable Flow project. This project was developed based on the outcome of an earlier project; the EU funded Efficient Flow project. The Efficient Flow project was executed by Satakunta University of Applied Sciences (SAMK) in collaboration with ports of Rauma in Finland and Gävle in Sweden with Finnish Transport Agency and Swedish Maritime Administration as a lead partner. The findings of the Efficient Flow project that is published in 2019 resulted in the development of a digital tool with port and ship application. The digital tool is developed to enhance information exchange between different stakeholders including ports, ships, and hinterlands operators. As per the funding agency's condition the developed digital tool was open source and available for public recruitment. The digital tool has been utilized by different industries. For example, so far, the Unikie company from Finland developed "Port App". This digital platform improved efficiency and communication by providing real-time data between port users. Another stakeholder, the Fintraffic VTS, is using the tool as one of their corner stone in their digitalization strategy.

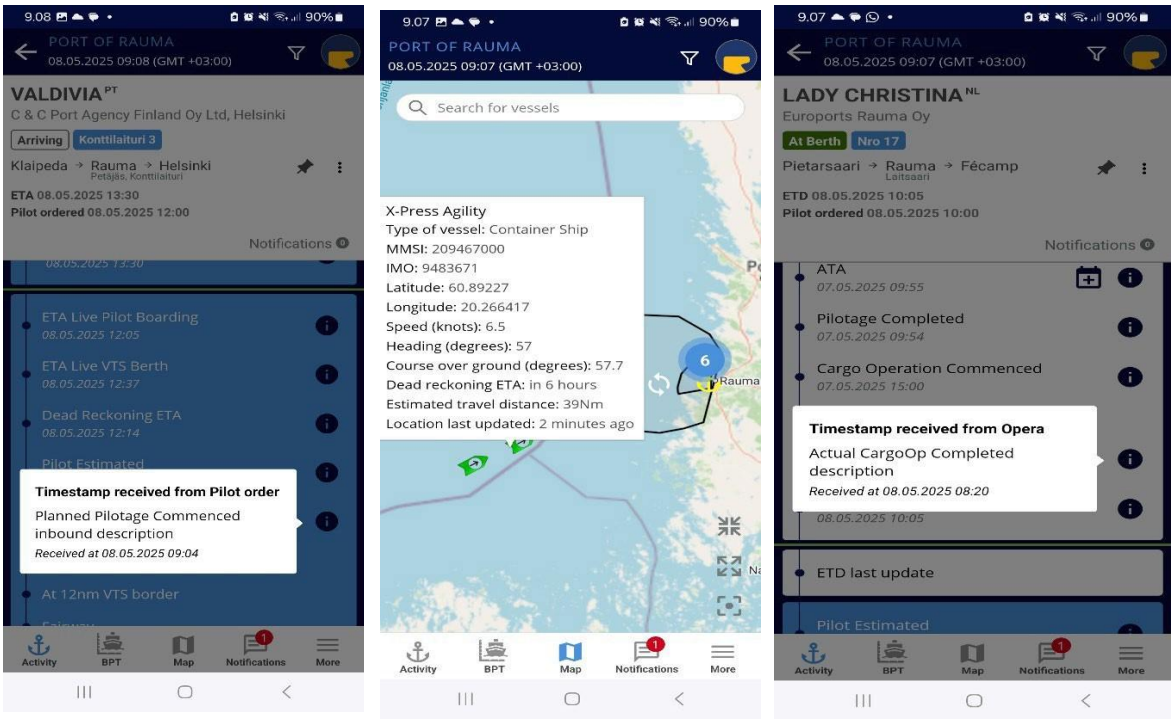


Figure 1. Three screenshots from Port of Rauma Port application of the digital tool. The left screen is showing M/S VALDIVIA inbound ordered pilot; Middle screen is the map in the tool showing ships and alarming areas and the right screen shows M/S LADY CHRISTINA outbound as its cargo operations completed.

Currently, there are more than 30 ports in Finland and Sweden that are utilizing the tool. As shown in Figure 1, the tool allows access to accurate and trustful data from port activities for example for ship captains with the Pilot Exemption Certificate (PEC).

The goal of the Sustainable Flow project is to provide a digital solution for the reduction of CO_2 emission from port operations. We experiment with digital tools in real world scenarios to investigate the applicability of the tool for enhancing the maritime operation. One of the objectives is for the digital tool to be able to automatically share essential information with all stakeholders in the port.

3. Sustainable Flow - Sustainable flow of goods and reduction of CO_2 emissions

The Sustainable Flow project is providing a solution for the reduction of CO_2 emissions in port areas. The project will develop and test the framework in seven pilot ports in the Central Baltic area as hubs of multimodal operations. The project's goal is not only to develop the knowledge and a framework for sustainable maritime industry for but to provide a practical solution and knowhow for stakeholders' application.

The goals and tangible outputs of the project are to develop:

1) a digital tool for reduction and measurement of CO_2 emission
2) a framework for managing energy consumption and production of renewable energy in ports.

There are seven partners involved in this project, Satakunta University of Applied Sciences as a lead, Åland University of Applied Sciences from Mariehamn, and Tallin Technical Universities. The Estonian Maritime Academy is the academic partners and Fintraffic VTS from Finland and Swedish Maritime Administration as national authorities. Other partners include International Transport Development Association (ITDA) from Latvia and Transport Föreningen (TPF) from Sweden. The project research team include mariners, environmental engineers, communication specialists, it-specialists, and UX/UI designers.

The project testing ports are Rauma and Pori in Finland, Mariehamn in Åland Islands, Norrköping and Oxelösund in Sweden, Riga in Latvia and Tallin in Estonia (Figure 2).

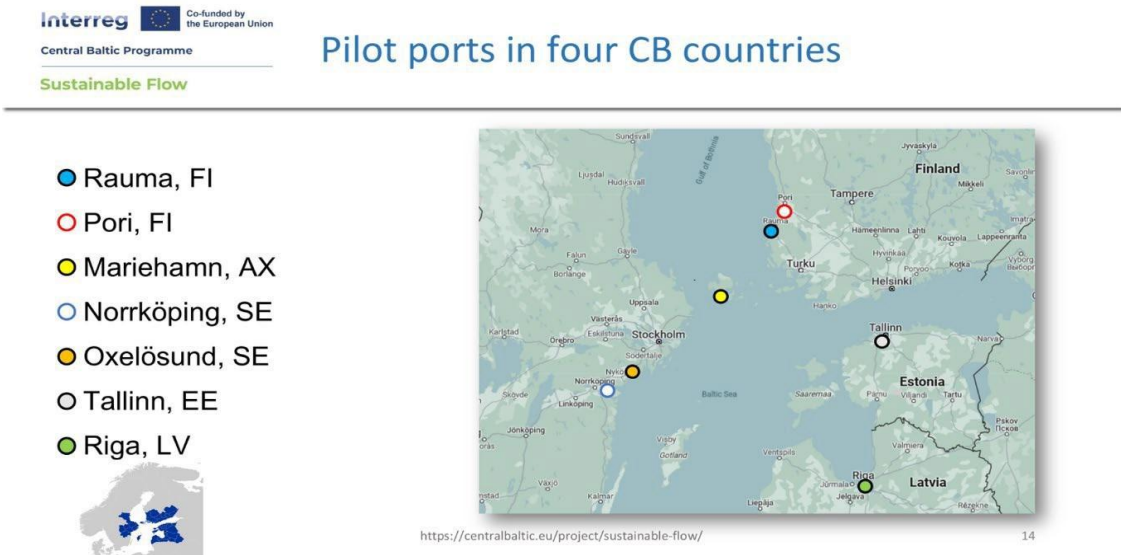


Figure 2. Sustainable Flow pilot ports

The project was initiated by the consultation with ports regarding their sustainability goals. The data collected from ports analyzed and the criteria for the digital tool was drafted. After a series of consultations with port operators and other stakeholders a tender was issued for development of the digital platform. These meetings gave opportunities to share the best practices in the pilot ports and one example is from the port of Rauma where onshore power can be used both for cranes when in operation and for ships during the nighttime to eliminate the need for ships' auxiliary engines. (Figure 3). An international tender bid has been announced and a Finnish company Awake.AI was selected to develop the tool. Awake is an optimization

platform company whose solutions are focused on developing customized AI/ML models to optimize cargo flow through the ports by reducing waiting times and emissions. Awake's AI-driven Logistics Platform developed to bring together all maritime stakeholders at sea, ports, and inland to make port operations more efficient, safe, and sustainable. The company delivers a holistic AI-driven software platform, ML, APIs, prediction and optimization models, Port Call Planning and Optimization Solutions and Smart Port Marketplace.



Figure 3. Port of Rauma. Onshore power can be used both for cranes when in operation and for ships during the nighttime to eliminate the need for ships' auxiliary engines.

After the initial version of the digital tool is developed it will be pilot tested in three of our partner ports Mariehamn, Norrköping, and Oxelösund. The data including feedback from stakeholders will be collected during the test period and will be analyzed and shared with the developer. Then the improved version of the software will be tested in all seven participating ports.

The projects such as Efficient Flow and Sustainable Flow show that digitalization has the potential to help maritime logistics industry to achieve emission reductions both at sea and on land. While shipping industry implement the Industry 4.0 technologies and more ships are becoming electrified and automated, ports operations are also embracing digitalization. However, the lack of harmony and unified timeframe means that industries come up with their own version of digitalization. As a result, the initial key challenge in our project was the fragmentation and variable quality of data along with the lack of comparability of data in both national and global contexts. Several studies also highlighted the need to harmonize data processing and reporting methods in the maritime sector in order to make progress in reducing carbon emissions and optimizing operations. The Sustainable Flow project will address this need by developing an emissions analytics tool that provides the accurate and timely information on emissions in port operations. The application will be a tool for informed decision making, allowing port operations to be conducted in a more environmentally friendly way.

The next phase after the development of the digital tool is the testing of the tool in the real-world environment. The seven partner ports will provide a unique test bed for the tool. During the test period we will collect data from all stakeholders. This will allow generation of complementary data that may be used for further development of the scope of the project. For example, in Efficient Flow project when the new "Port app" became available for testing some new ideas started to arise. Ordering the berth, fresh water, mooring men, and invoicing capabilities are among few that were requested by different stakeholders to be included in the app. When the Sustainable Flow digital tool passes next milestone and during the pilot testing in the three selected ports we are hoping that the collected data provide new additional features for the tool. The first software for all end users will take place in early fall 2025, giving access to web application provided for users specified by the customer ports. During the fall 2025 the digital tool will be approved by the project team and full documentation and training completed by the supplier. Very important is to ensure that all functionalities defined in technical digital tool requirements have been implemented and documented, and training material

has been provided to users and cyber security requirements are documented and fulfilled. Finally, at the end of the year 2025 review of customer feedback will take place and the digital tool will be in use in all seven pilot ports.

Sustainable Flow - project will finish at the end of April 2026 so there is time and resources to order additional features if evaluated important for the reduction of CO_2 emissions. In summer 2026 the developed code will be available to all interested partners as this digital tool is open-sourced and can be taken in use in different ports or other industries keen to reduce their CO_2 emissions.

4. Discussion

New digital tools is aimed at assisting maritime stakeholders to be more efficient, environmentally friendly, and sustainable. Continued collaboration and engagement with all stakeholders will be essential to realize the full benefits of the new Sustainable Flow tool. Our partner software developer, the Awake.AI has recently partnered with StormGeo, a global leader in weather intelligence and voyage optimization solutions, to deliver AI-powered port analytics to its clients. StormGeo will promote and deliver to its clients, our advanced port call analytics integrated solution, further enhancing its voyage optimization services. The digital tool will analyze a wide range of data, including historical traffic and emissions data, AIS data, and vessel data, to create safe and efficient port calls and avoid unnecessary idle time for ships. One way the digital tool will enable shipping companies to reduce fuel consumption and emissions is by making port calls more predictable and efficient – something that positively impacts both the bottom line and the planet.

The development of the Digital Tool is progressing according to the schedule, despite an initial delay caused by a legal appeal in the procurement process. So, progress is being made in improving logistics operations and lowering CO_2 emissions in ports. Effective collaboration with Awake.AI and pilot ports has been instrumental in developing the MVP. The tool will be developed on the Awake.AI cloud platform, incorporates essential features such as emission calculations, data entry, and reporting. Additionally, significant effort has been dedicated to the Decision-making Tool, which will be an integral component of the overall system. However, limited availability of APIs from ports has been a significant challenge, necessitating the use of preformatted Excel sheets for data collection. Additionally, varying levels of engagement from ports have impacted the speed of information exchange and project timelines. The tool is still under development, and real- world testing has not yet commenced. Testing of the MVP at the ports of Mariehamn, Norrköping, and Oxelösund is planned to start soon, with feedback informing further enhancements. Following the MVP testing phase, the Digital Tool is scheduled for release to all pilot ports by fall 2025, with ongoing user training and documentation.

Acknowledgements

Sustainable Flow project is co-funded by Interreg Central Baltic programme for the duration of 1.5.2023 to 30.4.2026 with a budget of 3.4 M€. All project partners have invested their own funding and seven pilot ports their priceless knowledge and working days.

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The 25th IAMUC

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Proceedings of the
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Rare procurements related to green energy sale in Vietnam shipping companies: explanations from street level bureaucracy theory

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Abstract: The green energy transition is considered globally as evident development in maritime industry. Furthermore, Vietnam engaged that toward 2050, the carbon dioxide must be cut to zero emission. Under the circumstances that the actual procurement law code has been applicable for all manners of procurement, the authors try to explain why there are rare green energy procurements in Vietnamese fleet by using the analytic framework from M. Lipsky. Therefore, the role of officers, personnel in the relationship with their shipping companies and the other stakeholders will be focused on.

Keywords: Vietnam; green energy; procurement; street level bureaucracy

1. Problematic

There are different types of companies or institutions which have marine fuel demand such as shipping companies, pilot companies, tug boat companies, maritime safety corporations, maritime universities, research and rescue coordination centers. The purchase of fuel is regulated as a regular expense in the maritime industry. Using clean energy has been evident in the future for the maritime sector. In the period of 2025-2030, warm-up phase, the carbon dioxide emitted fuels will be admissible up to 2050 (COP26, 2021). Nevertheless, the non-carbon dioxide emitted fuel is appreciated as an alternative fuel. The IMO regulation, EEXI and CII are currently in effect. In the light of Vietnam Procurement Law 2023, in force since the 1st January 2024, there is any distinction between clean energy and the actual DO- 0.05 SII in terms of procurement preparation, organization and termination. Especially in the case of green energy, as a facultative environmental factor, the bid solicitors must give a higher note to green energy contractors. Nevertheless, the number of LNG vessels and the consumption of LNG by shipping have been moderate in Vietnam. Furthermore, in the global market, there are various types of green energy with lower cost than the one of VLSO as indicated in the figure. Therefore, this article aims to answer the question why managers in shipping companies don't choose green energy as main fuel for their company apart from legal and political unanimity.

2. Analytic framework

In 1980, Professor M. Lipsky from Massachusetts Institute of Technology created a bottom-up policy framework which focused on the Street- level bureaucrats (Lipsky, 2010). In contrast with the public sectors, private shipping companies didn't work for fairness, neutrality or justice; what they care about is KPI, lucrative goals for their companies. Nevertheless, in many researches on public policy management, many scholars mentioned that a public unit in order to maximize the public value and to gain more productivity should function as a private company (Acemoglu & Robinson, 2013) (Hill, 2015). Besides, the Street - level bureaucrats is a bottom-up model which focuses on analyzing the behavior and working habits of the staff, personnel when they make decisions. Despite different missions

from the public sector, private companies have various goals, missions which lead to a sustainable development for the company, maritime clusters and the wealth of society. *Grossomodo*, this point of view has the same achievement with the public value. That's why the Lipsky model
can be applied in the case of green energy procurement. The distinction between public and private stakeholders in the maritime industry should not be observed as a research limitation. The contribution of Lipsky was that by concentrating on the role of staffs, executives, the bottom-up implementation model indicated 03 factors that had a dominant impact on the behavior of the executives as: Inadequate resources; Threat and challenge to authority; Expectations about job performance.

The threat and challenge to authority in the typical model of Lipsky will not be examined because as defined in his research, these two terms referred to distinct physical and psychological threats. The authority takes an important role in the public sector where "*the greater the degree of authority can be imposed, the less the threat*". Limiting and controlling the authority is evident in cases of public power where the resources are favorable. In contrast, the private sector doesn't have this kind of authority limitation due to the nature of private ownership which is more moderate than that of the public sector.

To answer the question why there is moderately rare purchase on green energy for vessels in Vietnam, the Lipsky model is chosen. The circumstances of maritime industry permit to deeply research on inadequate resources, expectations of job performance in a narrow link with routinization, and the simplification.

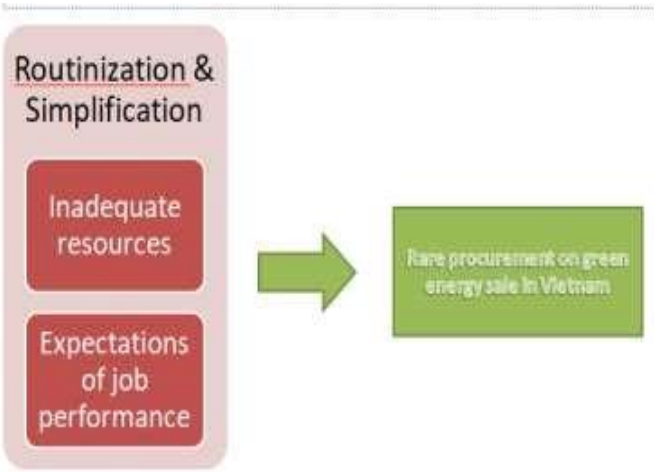


Figure 1. Scheme of four factors impacted on rare procurement decisions made by shipping managers related to green energy

3. Literature review

In the subject of green energy, there are many academic researches which provide an outline of all actual green, renewable and/or clean energy. The pros and cons of various types of energy are clearly analyzed (Mi, Wang, Zhang, Zhang, & Ge, 2024) (Peter Nuttall, 2023).

In the subject of green energy policy, many recommendations from official sources such as IMO, BIMCO, and UNCTAD are highly appreciated. Nevertheless, the implementation details for a country in term of marine green energy have been limited (DNV, 2024) (Nations, 2024).

The research combining procurement and green energy for shipping for a concrete country as Vietnam has witnessed a moderate number of papers. In the case of Vietnam, the article "*Analyzing the legal roles of contract for the sale of clean fuel in marine procurement*" from our group has indicated that the maritime industry followed strictly this green energy transition due to its high demand on fuel. The contract for sale of clean fuel is an agreement, stipulating the obligation and right of the vendor and the buyer. According to the Law of Procurement 2023, the contract for sale, is considered as a manner to select the contractor; a process in order to select the contractor and a manner to evaluate the contractor's competence. Besides, according to the Law of Commerce 2005, the contract for sale is a legal agreement to implement the demands from procurement dossiers and a manner to limit risks. Our research has listed the

legal framework applicable to bidding for the procurement of clean fuel for the maritime industry in Vietnam. The 2023 Bidding Law allows the inviting party to choose many forms and methods of selecting contractors but these selections must ensure competitiveness, efficiency, fairness, transparency and accountability. International bidding is conducted if the price of clean fuel does not meet the requirements on price, technology and quality. Although the world price is better, Vietnam currently has only 01 LNG distribution point at Cai Mep - Thi Vai, which is a policy suggestion on construction, leasing, and coexistence of fossil fuel and clean fuel points in the context of encouraging energy transition. From there, it lays the foundation for the process of using mixed energy and reaching the ultimate goal of reducing greenhouse gas emissions.

4. Methodology

To resolve the problem, there are principally three research methods which have been applied. Firstly, collecting data is important to have the most possible panoramic situation. The data is collected via various

appreciated sources such as the Vimawa, Vietnam maritime and waterway administration (Vinamarine in the past); IMO; BIMCO, UNCTAD. Secondly, the comparison method will help to analyze the data from these sources mentioned above. Thirdly, synthesize is applied to have a systematic outline and to get concrete solutions for the rare purchase related to green energy.

5. Inadequate resources and routinization

In this part, the inadequate external resources are analyzed in the response of the routinization as reaction in the internal side.

5.1. Lack of uptake materialization

High potential frequent expenditure in the market

These years have witnessed the significant development of non-carbon dioxide fuel. The number of non- carbon dioxide ships augmented increasingly year after year according to the statistic of Argus media (Figure 1)

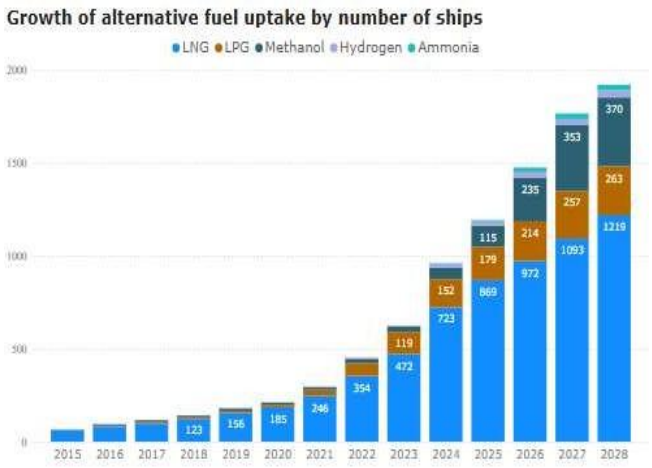


Figure 2. Growth of alternative fuel uptake by number of ships

Vietnam is ranked in the 21st position in the leading flags of registration by dead weight tons, as of the 1st January 2024. The Vietnamese fleet is ranked 31st position by commercial value with a 0.5% of the global share of value. In the subject of deliveries of new built vessels in 2023, the number of oil tankers flagged Vietnam is at the 3rd position after the one of the Republic of Korea (1st position) and China (2nd position). Therefore, the fuel demand of Vietnam fleet is perpetually high. The demand will be constantly high with insignificant change predicted through year, according to the study of UNCTAD.

Year	Total seaborne trade in tons	Containerized trade in TEU
2024	2.0	3.5
2025	2.5	2.9
2026	2.5	2.9
2027	2.4	2.6
2028	2.3	2.5
2029	2.3	2.5

Figure 3. Percentage of growth in global maritime trade from 2024 to 2029

Moderate uptake methods at a moderate infrastructure

In contrast with the positive indicators, there is only 01 LNG distribution center in the South of Vietnam.

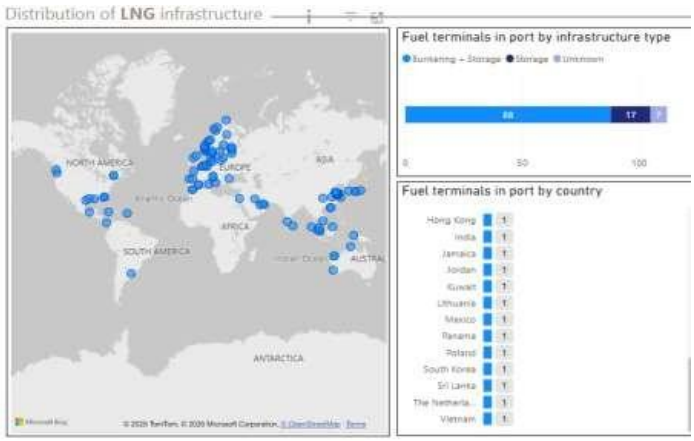


Figure 4. Distribution of LNG infrastructure in the world

This moderate number of distribution points is considered as inadequate external materials. Besides, the fleet has developed a remarkable quantity of offshore supply new built vessels (31.352 vessels) which is higher than Japan, and situated at the 4th position after China, Republic of Korea and Europe. Nevertheless, the average vessel size of the Vietnam fleet is at small and medium size (approximately 6777DWT according to UNCTAD) and the average age of the Vietnam fleet is about 15.5 years (according to the Vietnam ship owners' association).

The small size of the offshore vessel and old ages of the fleet can be considered as hindrance for the shipping managers to choose green energy for their companies even though at many moments, the price of green energy is lower than the one of fossil fuel.

5.2. Routinization and simplification – challenge to green energy

Routines are defined as regular instruction and habit that helps to perform the tasks. Routines under the circumstances of this article are determined in the relationship with resource inadequacy, threat perception and shape the performance of tasks. Therefore, the trade-off incurred in and its consequences.

At the beginning of the decarbonization issue, the change or demand of green transition should be considered correctly as a sustainable manner to survive and develop rather than a "troublemakers", an external requirement from higher hierarchies. At this moment, the warm-up phase, the legal framework harmonizes the manner, procedure and deletes the difference between various fuels, the stakeholder participated. Nevertheless, green energy is sold rarely for shipping operations in Vietnam because "*Routinize as much as possible*" has been a good solution for doing actual marine business.

Year	Number of parties	% change rate	Total amount (VND)	% change rate
2024	14	12.5	199,443,114,511	8.3
2023	16	33.3	184,216,180,640	24.1
2022	12	-	242,785,965,900	-

Figure 5. Short term trade receivables of Vietnam ocean shipping joint stock company from 2022-2024

Vosco, a big shipowner in Vietnam, has annual audited consolidated financial statements which indicated an amount around 180-200 billion VND received in the short term by clients. The number of clients did not change so much from these 03 years (Company, 2024).

Routines provide more information about potential difficulties and project an image of shipping companies. In the case of Vietnam shipping companies, the routinization is preferred as they don't have inadequate resources for using green energy. Simplification is a routine that permits the staffs to make quick decisions, especially in case of instrument inefficiency.

A long-term green energy project should be planned to systematically resolve the infrastructure issues. Furthermore, the performance of jobs by shipping managers also provokes problems.

6. Expectation of shipping manager performance at warm-up phase

6.1 Potential expectations for purchasing green fuel

The shipping managers must perform their tasks in response to ambiguous and contradictory expectations. The cargo-owner and the ship-owner share the same ambition of on time and safe voyage to maximize the profits. This could be contradictory in case of damages of goods carried, heavy weather. Nevertheless, the social and environmental responsibility of shipping companies has increased significantly these days. As a manager, the origin of role expectations in three places is located at:

- in peers and others who occupy the complementary role positions. This category depends on the internal organizational structure of each shipping company.
- in the reference group (in comparison with the other ship-owner at the same dimension). Actually, according to the Vinamarine, there are 500 ship-owners in Vietnam, 38 foreign container shipping companies and 10/38 exploiting the domestic market.
- in public expectations, in particular, compulsory obligation from the Government and the expectations from the society. In 2023, for the first time, the VCCI (Vietnam Chamber of Commercial and Industry) had launched the PGI (Provincial Green Index) (Industry, 2025). In terms of marine provinces, there are 03 main cities in Vietnam playing a major role in maritime industry as Haiphong (in the North) and Ba Ria - Vung Tau, Ho-Chi Minh city (in the South). The result of PGI of these three cities in comparison with the one of other 60 provinces is very positive as indicated below:

City	2022 Ranking position	2023 Ranking position	2024 Ranking position
Haiphong	16	7	4
Ba Ria Vung Tau	19	8	14
Ho Chi Minh	49	5	24

Figure 6. Provincial Green Index of major port cities in Vietnam from 2022-2024

As at this moment, all the index and figures are optimal and positive, it's not believed that green energy procurement will be taken place in in short term. The vision of Vietnam shipping companies have just stayed at a sustainable corporation such as "*solid partner – reliable carrier*" (Vosco); "*comprehensive solution, driven by trust*" (PTSC); "*We ship in your process*" (PV Trans); "*Customer's satisfaction is our success"* (Hai An transport and stevedoring)

Redefining the job performance needs more pressure from the cargo-owner and directly from consumers who must have a green demand as "client-centered interests".

6.2 Using simplification to satisfy different stakeholders

Simplification refers to the symbolic construct to make the actual situation easier to manage. When exercising a simplification mindset, the shipping manager may be biased. That is reinforced by the need of the executives to improve the KPI of the company or at least to have a deal with other big cargo owner, traders by focusing totally on fossil fuel. Maintaining the neutral mechanism with simplification is necessary to satisfy different parties in maritime carriage of goods. From May 2025, the liner shipping company, CMA CMG has launched the first e-barge with NIKE in the Mekong Delta River, at Cai Mep Port (Ba Ria - Vung tau City). This launch did not affect the operation of fossil fuel fleet of CMA CMG in Asian market (Group, 2025). Furthermore, the green energy as in this illustration does not need to be purchased, the shipping companies themselves can produce clean, renewable energy by setting solar powered charging station at their office.

7. Conclusion

In an actual VUCA world (Volatility, Uncertainty, Complexity, and Ambiguity), collecting relevant information, hoarding as much information as possible on maritime energy is primarily necessary. Vietnam committed to zero GHG emission. Therefore, the period 2025-2030 is considered as warm-up phase which requires the legal harmonization and perception from marine stakeholders. In summary, after analyzing the behavior of shipping managers by the bottom-up model of Lipsky, there is a new scheme that illustrates more details to explain the rare number of procurement related to green energy sale in Vietnam, different from the 1st precedent scheme in the section 3.

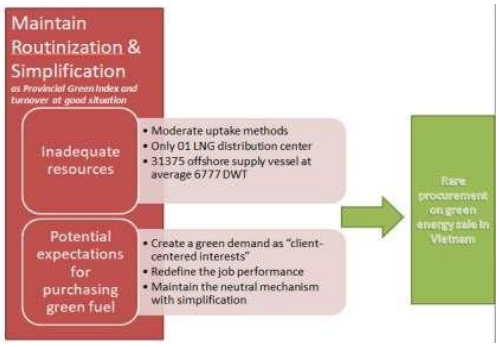


Figure 7. Concluded scheme of four factors impacted on rare procurement decisions made by shipping managers related to green energy

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Analyzing the Eco-Benefits of Innovative Hydrogen Production Methods

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Abstract: As a carbon-free fuel for a range of industrial and energy uses, hydrogen has emerged as a possible solution to the growing demand for clean energy. This study offers a thorough analysis of the environmental effects of cutting-edge hydrogen generating techniques. It starts with a summary of the technologies used to produce hydrogen today, contrasting more recent, environmentally friendly approaches like water electrolysis, biomass gasification, and photo catalysis with more traditional ones like Steam Methane Reforming (SMR). Since the widespread use of hydrogen technology needs to be in line with international sustainability targets, the significance of evaluating environmental effects is underlined. The methods of Environmental Impact Assessments (EIAs) and Life Cycle Assessments (LCAs), which are essential instruments for assessing the sustainability of various hydrogen production processes from the extraction of raw materials to end-use, are a major emphasis of this article. The study illustrates the trade-offs of traditional and novel approaches in terms of resource use, cost-effectiveness, carbon emissions and energy efficiency. In order to demonstrate the practical effectiveness and ecological impact of novel approaches, case examples are incorporated. Notwithstanding the advancements, a number of obstacles and constraints are noted, such as high energy requirements, problems with scaling, and economic feasibility. In order to guarantee the long-term sustainability of hydrogen as a crucial part of the global energy transition, the paper concludes by examining future directions for developing hydrogen production technologies and highlighting the necessity of integrated solutions that combine technological advancements and renewable energy sources.

Keywords: Energy storage and decarbonization, hydrogen production, advanced technologies, eco-sustainability and environmental impact assessment. Green hydrogen and sustainable energy are used for comparative evaluation along with LCA and carbon footprint analysis.

1. Introduction

Leading the way in sustainable energy solutions, hydrogen provides a cost-effective, environmentally responsible, and energy-efficient substitute to meet the growing need for clean energy worldwide. The necessity of moving away from hydrogen's role in addressing environmental challenges, especially global warming, has become even more crucial as a result of the switch from conventional fossil fuels to renewable sources (Dutta, 2014). In order to guarantee long-term sustainability and resilience in the energy environment, recent studies highlight the necessity of quickening this transition . Hydrogen plays a significant role in this shift, highlighting its significance in the development of global energy systems and opening the door for clean energy (Zhang et al., 2016).

Recent studies have shown that the adaptability of hydrogen in energy systems can support eight essential uses during this transition (Dincer and Acar, 2016). Large-scale renewable energy integration, the provision of clean energy across several industries, the creation of adaptable and durable systems, the encouragement of multigenerational energy solutions, and the lessening of monopoly influence are some examples of these uses. Furthermore, hydrogen encourages increased effectiveness and supports greener ways offers a sustainable energy source for both domestic and business contexts: transportation. From fueling

industrial processes to driving vehicles, hydrogen has the possibility to completely change everything.Energy use by mixing sustainability with economic and environmental advantages (Kalinci et al.,2015).According to projections for 2050, hydrogen may cover up to 18% of world energy needs. generate around thirty million employment, reduce yearly CO2 emissions by six gigatons (Uyar and Besikci, 2017). Data training up to October 2023.promise of hydrogen also covers the transportation sector, where hydrogen and fuel cell technologiesBy middle of 400 million cars, powered engines might transform the sector.Mostafaeipour et al., 2016, the century Hydrogen is also expected to have higher operating efficiencies. energy systems; hence, they are a vital component of the battle for sustainable development and against climate change (Nakamura et al., 2015). Apart from its environmental advantages, hydrogen can be easily integrated into current energy infrastructure.Through use of the already in place natural gas distribution network, especially in structures (Gong et al., 2016).This enables hydrogen to satisfy roughly 10% of the world need for construction heating by 2050.

Valente et al., 2018. For medium to high temperature, hydrogen provides a better efficient replacement for power.Maroufmashat et al., 2016 demand heat in manufacturing environments. Hydrogen generation breakthroughs have It further improved its cost, efficiency, and environmental sustainability, therefore lowering reliance on fossil fuels and strengthening its status as a renewable energy source (Salvi and Subramanian, 2015).

In order to produce, distribute, and store hydrogen, infrastructure must be substantially invested into move toward a hydrogen economy. Emphasizing the Source, System, and Service ofHydrogen provides a thorough framework to enable this transformation (Dincer and Acar, 2015). TheFighting climate change calls for the creation of a big hydrogen economy, which provides significant benefits.Social, financial, and ecological benefits for a sustainable future (Göllei et al., 2016).Less particle matter, sulfur, nitrogen oxide emissions along with greenhouse gases, therefore lowering the damaging health consequences of smog (Owierkowicz and Malinowska, 2017). Furthermore, air pollution Reducing noise pollution, hydrogen-based systems help create cleaner, more peaceful cities by replacing Burning techniques (Marchenko and Solomin, 2015).

The ability of hydrogen to provide energy security using local, safe, and dependable means Another significant benefit is that guarantees future use of sustainable production, distribution, and storage. (De Santoli et al., 2017). More research and development is required to make hydrogen if one wants to fully realize this objective.systems inexpensive, workable, and flexible enough to be utilized in several of applications. Foundation Governmental, industrial,as well as public acceptance (Joshi et al., 2016).Use of hydrogen in transportation helps to decarbonize air, maritime, and land transportation.Particularly in internal combustion engines and fuel cells, which provide a more environmentally friendly alternative to electric cars (Maleki)et al. 2016). Hydrogen lowers the environmental footprint of in addition to encouraging sustainable practices.fields including ammonia manufacture, steel production, and methanol plants (Mehrpooya et al., 2017). AsMore cities investigate hydrogen for heating and cooling; it could be crucial for longdistance power.Renewable energy storage and transportation (Beheshti et al., 2016). This research will focus on hydrogen. The possibility of generation as a long-term sustainable answer for several energy uses must be assessed in terms of environmental advantages of this technology.

2. Overview of hydrogen production methods

Both renewable and non-renewable resources can be used to manufacture hydrogen, and many techniques have been developed to increase output and efficiency. Steam methane reforming (SMR), biomass gasification, electrolysis, and thermochemical water splitting are significant industrial processes.. The most popular approach, SMR, is economically feasible but uses fossil fuels, which increases CO2 emissions unless combined with carbon capture technology. When fueled by renewable energy sources, electrolysis— which uses electricity to divide water into hydrogen and oxygen—is cleaner, although it is frequently more expensive? These many approaches offer a mechanism to incorporate hydrogen into energy systems, assisting in the global transition to clean, renewable energy sources and advancing sustainability goals.

2.1 Conventional Hydrogen Production Methods

2.1.1 Steam Methane Reforming (SMR)

Approximately 48% of the hydrogen produced worldwide comes from the most popular traditional method, steam methane reforming (SMR). In order to create hydrogen and carbon monoxide, methane (CH_4) and steam (H_2O) are reacted at high temperatures (700–1,000°C) and pressures, usually with the aid of a nickel catalyst. Although SMR is very economical and efficient, it uses natural gas, a fossil fuel, and emits a lot of $CO2$. Despite being commercially feasible, SMR is not environmentally sustainable in the absence of

carbon capture and storage (CCS) technology because to its significant CO_2 emissions.

The reactions involved in SMR are:

Primary Reaction (Methane Reforming): CH4 + H2O → CO + 3H2 Secondary Reaction (Water-Gas Shift): CO + H2O → CO2 + H2

2.1.2 Partial Oxidation of Hydrocarbons

When other hydrocarbons (such as coal or oil) are available in place of methane, another traditional technique is partial oxidation (POX). In POX, a hydrocarbon fuel and a little quantity of oxygen react at temperatures between 1,200 and 1,500°C to produce a mixture of hydrogen, carbon monoxide, and some leftover hydrocarbons. Even while POX produces hydrogen, it is not as effective as SMR and still emits CO2. However, it continues to be a feasible alternative in areas where natural gas supplies are scarce.

The key reaction in partial oxidation is:

CH4 + 1 O2 → CO + 2H2

2.1.3 Coal Gasification

In the past, coal gasification has been used to create hydrogen from coal. This process creates hydrogen, carbon monoxide, and other byproducts when coal, steam, and a regulated amount of oxygen react. The process uses a lot of energy and runs at very high temperatures (around 1,500°C), which results in considerable CO2 emissions. In regions with large coal deposits, coal gasification is still used despite its negative environmental effects. Similar to SMR, this technique can reduce CO2 emissions by utilizing CCS technologies.

The chemical reactions for coal gasification are as follows:

Carbon Reaction with Steam: C + H2O → CO + H2 Water-Gas Shift Reaction: CO + H2O → CO2 + H2

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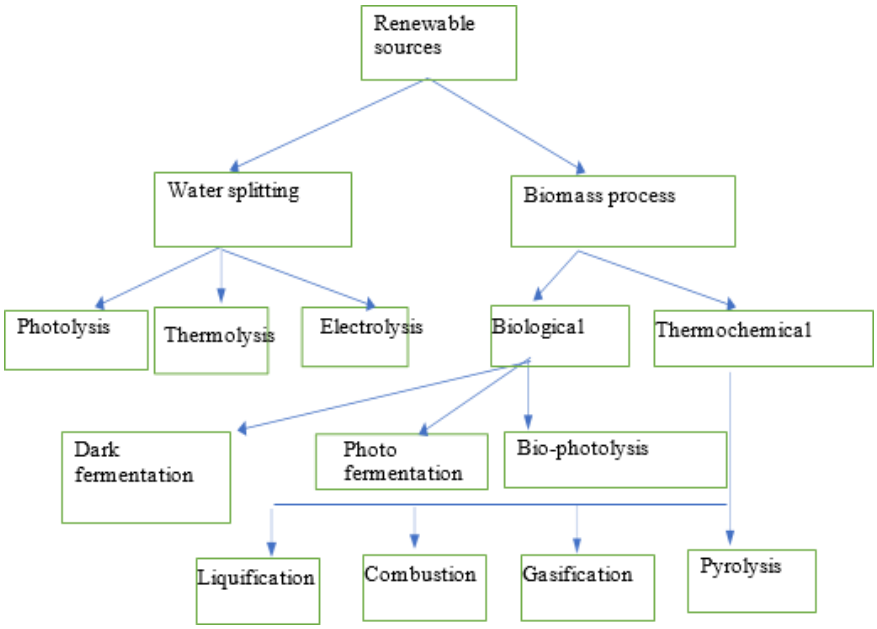


Figure 1. Hydrogen production methods

2.2 Innovative Hydrogen Production Methods

2.2.1 Electrolysis of Water

Using electricity, the electrochemical process of electrolysis separates water (H2O) into hydrogen (H_2) and oxygen (O_2). Alkaline electrolysis, proton exchange membrane (PEM) electrolysis, and solid oxide electrolysis are the three primary forms of electrolysis; each has different operating conditions, technological requirements, and levels of efficiency. The basic reaction for water electrolysis is: 2H2O → 2H2 + O2

Alkaline electrolysis works at moderate temperatures and use an alkaline electrolyte, usually potassium hydroxide. Faster reaction rates are possible with PEM electrolysis since it uses a solid polymer electrolyte, although more expensive ingredients are frequently needed. The high temperatures (700–1,000°C) at which solid oxide electrolysis operates increase efficiency but necessitate sophisticated thermal control. Electrolysis, particularly when powered by renewable energy sources like solar or wind, is one of the cleanest methods of producing hydrogen.

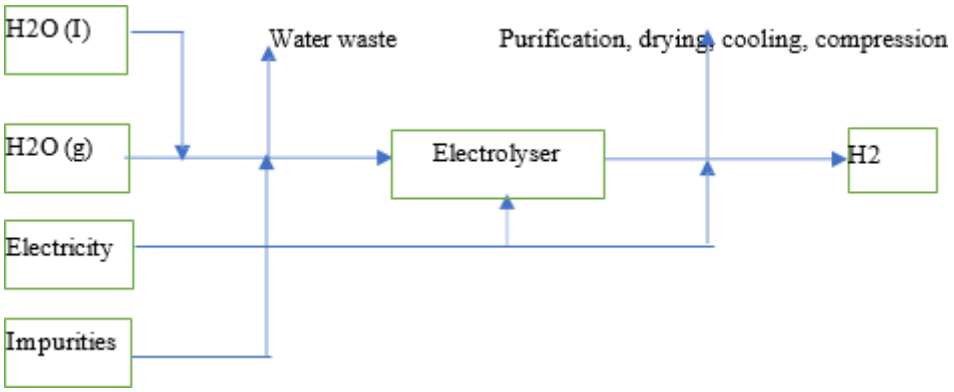


Figure 2. Flowchart of hydrogen production using electrolysis

2.2.2 Biomass Gasification

Biomass gasification employs organic materials like wood, agricultural trash, or other biomass sources to make hydrogen. Under regulated heating, biomass decomposes thermally to produce a mix of hydrogen,

Carbon monoxide and carbon dioxide. An ecologically friendly replacement called biomass gasification can Based on the biomass source, be carbonneutral or even carbonnegative.

Main reactions in biomass gasification include:

Decomposition of Biomass: Biomass → CO + CO2 + H2 + CH4 Subsequent Reactions with Steam and Oxygen: C + H2O → CO + H2

Because of its great promise, studies on improving the efficiency and yield of biomass gasification are still in progress.

2.2.3 Thermochemical Water Splitting

It can be difficult to scale and optimize sustainability.

Through hightemperature, thermochemical water splitting breaks water into hydrogen and oxygen. reactions. This technique comprises cycles including intermediate processes enabling the use of nuclear or solar heat sources include the hybrid sulfur cycles and the sulfuriodine (SI).

The following is the typical reaction for thermochemical water splitting:

H2O → H2 + O2 Sulphur-Iodine Cycle: H2SO4 → SO2 + O2 + H2O Hybrid Sulphur Cycle: SO2 + 2H2O → 2H2 + H2SO4

Despite ongoing development, this method offers low emissions and high efficiency when paired with renewable heat sources.

2.2.*4 Photo electrochemical (PEC) Water Splitting*

Using solar energy, photo electrochemical water splitting produces hydrogen directly. Electron-hole pairs produced when semiconductor materials absorb sunlight power water-splitting processes. Although PEC water splitting has the advantage of using a lot of water and sunlight, it also has disadvantages, including low efficiency and high costs due to the sophisticated materials required.

Electrolysis and PEC water splitting share a similar simplified reaction:

$$\text{Light energy} + 2H_2O \rightarrow 2H_2 + O_2$$

3. Environmental Impact assessment

An environmental impact assessment of hydrogen generation evaluates the ecological effects of

various production techniques. Coal gasification and steam methane reforming (SMR), two traditional methods of producing hydrogen, emit a lot of carbon dioxide (CO_2) and other greenhouse gases, which significantly contribute to global warming. These methods usually require large amounts of fossil fuels, which worsens the degradation of the environment and the depletion of fossil fuels.

Advanced hydrogen production technologies include electrolysis, biomass gasification, and normally more environmentally friendly are thermochemical water splitting. With electrolysis comes hydrogen. Little direct emissions, especially powered by renewable energy. CO2 can be released via biomass gasification.

Though it is renewable, but not as much as systems driven by fossil fuels. Thermochemical decomposition of water provides great efficiency and lowers greenhouse gas by using extra heat from nuclear or solar thermal sources.

Emissions other factors include examination of land footprint, water usage, and ecological disturbance possibility. of evaluating ecological effects. Although it is cleaner, modern technology can still have an influence on sources like water for electrolysis. Ultimately, achieving a future based on sustainable energy could need reducing enhanced hydrogen creation lessens environmental consequences and greenhouse gas emissions.

3.1 Life Cycle Assessment (LCA) Methodology:

One of the most important means of assessing the environmental effects of hydrogen is life cycle assessment, or LCA. From birth to death, manufacturing technologies. Life cycle assessment (LCA) counts the environmental effects. Including raw material extraction, manufacturing, warehousing, and of every stage of the hydrogen production life cycle. Use, transportation, and disposal. This approach enables a just assessment of traditional and novel methods by giving a thorough picture of the ecological, social, and financial components of hydrogen manufacturing.

3.1.1 Goal and Scope Definition

The first phase in the LCA methodology is to set out the goals and scope of the study. The main objective in Understanding the environmental effects of several manufacturing processes usually helps one to grasp hydrogen's generation. (such as steam methane reforming, electrolysis, and biomass gasification). Whether one should include upstream processes such raw material extraction or downstream processes such hydrogen storage, in the analysis by defining of system boundaries. Since it affects the results and guarantees that the Analysis is still relevant for actual uses; thus, choosing the appropriate system limitations is critical.

3.1.2 Inventory Analysis

Inventory analysis gathers information on outputs like as well as on inputs like energy, water, and raw materials. Emission levels for every step of the hydrogen production process. Trash levels for each phase. Steam methane reforming (SMR) Unlike water electrolysis, which requires methane and produces carbon dioxide (CO2) as a byproduct, Often generates less direct emissions when powered by renewable sources; electricity is needed here. The Collected throughout this stage is data including energy consumption, water usage, greenhouse gas. Provides a thorough examination of resource use and emissions, air contaminants, and other emissions. environmental output over all procedures.

3.1.3 Impact Assessment

The phase of impact assessment quantifies potential environmental effects by means of analysis of the inventory analysis data. influences. - Eutrophication, acidification potential, resource depletion, and global warming potential (GWP) Certain of the impact areas investigated in this phase. Regarding hydrogen generation, GWP is often the Main emphasis is on renewable since conventional technologies such SMR generate carbon dioxide and other greenhouse gases. On the other hand, powered electrolysis often has less of an impact even if it still adds to resources. Water shortages and depletion in some areas. LCA finds the places where by studying every effect group. Every hydrogen generating technique has maximum environmental consequences.

3.1.4 Interpretation and Improvement

The last stage in a life cycle assessment requires data synthesis and conversion to reasonable goals and action items. This step gauges the trustworthiness and the value of the information convened as well as

points out which specific phases should be updated. For instance, in case of high CO2 emissions by European industry, there might be a recommendation to move away from SMR and instead begin to utilize carbon capture technologies. Improving water accessibility or complementing renewable energy with electrolysis are the two main methods to mitigate the environmental effects of electrolysis in general, especially in places where water is scarce. For completeness, sensitivity analysis has been included in interpretation to predict the effect of different assumptions such as power and vert kilometrage**.**

3.1.5 Application of LCA in Hydrogen Production

With life cycle assessment (LCA) in the production of hydrogen, the entrepreneurs and producers manage to do this procedure by reviewing the environmental effects of the move towards new types of production on a long-term basis. SMEs can employ the information garnered from such analysis to devise effective strategies capable of utilizing further resources efficiently or even mitigating negative effects to some extent; for example, instead of using outmoded technologies with high ratios of GWP like SMR, it is rational to opt for using renewable powered electrolysis - and instead of downgrading the level of GWP as in the prior case, employing biomass gasification would engender a wider range of actions. In conclusion, the LCA method entails a calculated evaluation of the environmental ramifications in the production of hydrogen. Therefore, it assists in realizing sustainable development, as it clearly pinpoints the areas of concern allowing for the necessary adjustments to be made concerning enhancing productivity, resource management, and environmental conservation

3.2 Comparative Impact of Methods

The most common measures of the environmental effects of a process within life cycle assessments are eutrophication potential (EP), Human Toxicity Potential (HTP), Abiotic Depletion Potential (ADP), Acidification Potential (AP), and Global Warming Potential(GWP). This study’s primary focus is GWP due to his concern on the greenhouse gas emissions resulting from hydrogen production which is an important issue concerning the environment. ADP (fossil) and AP are included in the evaluation to analyze the emissions related to the use of fossil fuels.

The ranges emanating from these parameters tend to differ significantly from one study to the other, more so in the case of hydrogen produced through the sustainable energy route. The discrepancy is created due to the difficulty in trying to standardize the parameters for technologies at a very low industrial focus.

4. Case Studies of Innovative Methods

4.1 Electrolysis

Overview: Electrolysis is the process of using electricity to separate water into hydrogen and oxygen. Green hydrogen with a low carbon footprint is produced when this process is powered by renewable energy sources like solar or wind.

Example: For instance, the Hywind project in Norway generates hydrogen for industrial and transportation uses by using offshore wind energy to power electrolysis units.

Result: Compared to conventional methods, this program has significantly reduced greenhouse gas emissions while demonstrating the viability of large-scale green hydrogen production.

4.2 Biomass Gasification

Overview: Using thermal processes in a low-oxygen environment, biomass gasification transforms organic materials into hydrogen and other gases.

For instance, the Biofuels Research Centre in Canada turns agricultural waste into hydrogen using biomass gasification techniques. This technology solves waste management problems in addition to producing clean hydrogen.

Result: By encouraging a circular economy model where waste is converted into valuable energy resources, the center's programs have decreased the amount of waste that ends up in landfills and the overall carbon footprint.

4.3 Photoelectrochemical Water Splitting

Overview: This novel method directly synthesizes hydrogen from solar energy without the use of external electrical sources by using sunlight to aid chemical reactions for water splitting.

As an illustration, research at the California Institute of Technology has produced innovations in photo electrochemical cells that effectively convert solar energy into hydrogen.

Result: By offering an effective method of producing clean fuel from solar energy, the labor acquired in building these cells has the potential to completely transform the production of hydrogen..

4.4 Results of Innovative Methods

The case studies demonstrate how new hydrogen generation systems could promote sustainable energy practices and drastically cut greenhouse gas emissions. By boosting efficiency and using renewable resources, these technologies help the environment.

Table: 1 Technology costs for producing hydrogen

Methods	Cost of production (USD)	Source
H_2O splitting by photo catalysis	5.0	Solar
Reforming steam	0.75	Methane
Centralized gasification of biomass	1.2 to 2.4	Biomass
Without CO_2 sequestration, gasification H_2Osplitting Electrolysis	0.92	Coal
H_2O splitting by photo catalysis	2.6 to 3.0	Nuclear
Reforming steam	1.4 to 2.3	Nuclear

5. Challenges and Limitations

Novel hydrogen generation systems have great potential, but several obstacles and limitations keep them from being widely adopted.

5.1 Barriers to the Economy

Cost Competitiveness: Green hydrogen is generally pricier than grey hydrogen, which comes from fossil fuels. The main reason is that producing green hydrogen requires more expensive renewable energy and technology. While grey hydrogen can be made for around $1 per kilogram, green hydrogen costs between $2.50 and $6 per kilogram.

Uncertain Market Demand: It's tough for investors to decide on new technologies when the future
demand for hydrogen is unclear. If there aren’t strong signs that green hydrogen will be in demand, they might hesitate to invest.

Policy and Regulatory Issues: Right now, the rules about carbon pricing and renewable energy support aren't clear. This makes it tough for investors and developers to navigate. We really need better regulations to help shift towards cleaner hydrogen production.

5.2 Technological Barriers

Technology Maturity: Right now, many new hydrogen production methods are still in the testing phase, which holds back their potential for wider use. To be competitive with traditional fossil fuels, electrolysis systems really need to work on becoming cheaper and more efficient.

Infrastructure Requirements: Building the infrastructure for producing, storing, and delivering hydrogen comes with a lot of challenges. Most current systems are set up for traditional fuels, which makes it hard for new technologies to get a foothold.

Energy Input Costs: The cost of making green hydrogen largely depends on how much renewable energy costs. Since the price of renewable energy can change, it also affects how affordable it is to produce hydrogen.

6. Conclusion

This study looks closely at different ways to produce hydrogen and how each method affects the environment. It also considers how doable, scalable, and affordable these methods are. One of the key takeaways is that there isn’t a single "best" method for hydrogen production because each one comes with its own set of pros and cons. For instance, steam methane reforming (SMR) can produce hydrogen efficiently and at a low cost, but it uses a lot of fossil fuel and emits a considerable amount of carbon dioxide. Without carbon capture and storage (CCS) technology, it's not a sustainable long-term option. On the other hand, electrolysis stands out as a cleaner option when it's powered by renewable energy sources. However, its higher costs and significant energy needs make it less accessible for widespread use. Biomass gasification can be a low-carbon option, but it usually doesn't perform as efficiently as SMR or electrolysis. Nonetheless, it can be useful, especially if the biomass is sourced sustainably. A key finding from this research is that incorporating renewable energy like solar and wind into hydrogen production could lower carbon emissions and boost

overall efficiency. To make eco-friendly hydrogen production more viable, several important recommendations come into play. First, we need to invest heavily in research and development to improve the efficiency, scalability, and cost-effectiveness of these hydrogen production methods. Innovating catalysts, reactor designs, and energy management systems should be top priorities, especially for thermochemical processes, biomass gasification, and electrolysis. Second, we need solid laws and financial incentives to promote the use of renewable energy in producing hydrogen. This might involve offering subsidies for renewable-powered electrolysis and biomass gasification, along with tax breaks for companies using low-carbon hydrogen technologies. Collaboration between businesses, academia, and private sectors is also crucial for advancing innovative hydrogen production methods. Running thorough life cycle assessments (LCA) will help us understand the environmental impacts of different hydrogen generation methods and find ways to improve supply chains. Finally, strong policy frameworks should support the transition to a cleaner hydrogen economy. These frameworks can include industry-specific incentives, research funding, and carbon pricing strategies. By following these strategies, the hydrogen industry can significantly contribute to reducing greenhouse gas emissions, combating climate change, and paving the way towards a sustainable, low-carbon energy future.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Facilitating greener education and cleaner shipping through the development of Novel bespoke micro textured metals to combat bioFOULing in niche areas on vessels

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Abstract: Biofouling, the unwanted biological growth on ships, causes increase of fuel costs, emissions, corrosion, and transfers non-native invasive species. As a result of updated international regulations, biofouling guidelines were improved, while training for maritime personal and students became essential. The aim of the project was to determine the antifouling efficacy of novel textures and plasma in different marine environments while engaged with knowledge exchange between project partners, outside the project with a Biofouling Network and knowledge transfer to maritime education and teaching (MET). Participatory field research in the project formed the tools for the case study demonstrating training and knowledge transfer in the fields of biofouling and antifouling. The first step was a 2-day workshop using an interactive approach to gauge the average understanding, to deepen the topic and exchange knowledge between all partners. The second step was site-specific training by a specialist at the partner sites. Finally, the partners were able to transfer their knowledge to members of the Biofouling Network and to students at one of their institutions. The positive outcomes of training and knowledge exchange between partners may facilitate an opportunity to expand the approach beyond the project partners.

Keywords: Biofouling, Environmentally Friendly Antifouling, Maritime Education and Training (MET), Participatory Research

1. Introduction

Any surface in seawater will be biofouled first by biofilm and then by algae and invertebrates (Wahl 1989, Dürr and Thomason 2010, IOC-UNESCO and GEF-UNDP-IMO GloFouling Partnerships 2024). These cause corrosion, material fatigue, increased drag, transfer of non-native invasive species, increased fuel consumption, and emissions, thereby contributing to Global Climate Change (Poloczanska and Butler 2010). Indeed, Schultz et al. (2011) estimated that the economic impact of biofouling for the US DDG-51 fleet was $56M per year at the time. Recently, progress has been made with the updated and amended guidelines on the control and management of ship biofouling by International Maritime Organisation Resolution MEPC.378(80), 2023. This includes training and education for maritime personal such as ship masters and crew, on impacts of invasive aquatic species from ship biofouling (Chapter 13.1, Point 2), benefits to the ship of managing biofouling (Chapter 13, Point 3), and biofouling management measures (Chapter 13, Point 3), and marine training organisations need to include these in their syllabi as appropriate. Still, biofouling is neglected in maritime training and education. Reasons for this may include lack of knowledge and confidence on the topic of biofouling, and the importance of the topic may not be accepted in maritime organisations, industry or educational institutions.

In the IAMU/Nippon Foundation-funded project NOFOUL, the research aim was to develop environmentally friendly bespoke novel antifouling laser machined textures on metals for diverse maritime

environments and niche vessel areas. This antifouling solution was field tested at an international scale and was used as a model training approach on biofouling and antifouling for non-specialist trainees, in this case engineers, and specialist trainers. The non-specialist trainees were the project partners from Constanta Maritime University (CMU, Romania), Istanbul Technical University (ITU, Turkey), Ordu University (ODU, Turkey) and the University Academy of Maritime Education and Training (AMET, India). The specialist trainers and facilitators were biofouling and antifouling researchers from the lead institution Liverpool John Moores University (LJMU, United Kingdom).

In NOFOUL, a number of teaching and learning tools were combined (training, knowledge transfer and exchange, coaching, participatory research, networks, higher education (HE) teaching) and split into activities (2-day training workshop, site-specific training at the partners/trainees, training through coaching during the experiment, IAMU Biofouling Network organisation with webinar presentations, HE maritime teaching on biofouling). Training by demonstration and by doing while focussing on real-life experience was used in the 2-day training workshop and site-specific visits. Coaching during the field experiment, i.e. guidance of the trainee, was applied partly at site-specific training as well. Knowledge transfer was introduced from the first activity onwards, the workshop, and the last activity, the webinar presentations, and HE maritime teaching. When the knowledge transfer was completed by the specialist trainers, the non-specialist trainees, became trained non-specialists able to train other non-specialists by contributing to webinars in the network (connections between people with shared interests), and HE maritime teaching at their institutions. All partners participated in wide discussions and knowledge exchange facilitating the two-way knowledge transfer, from the start of the project.

In NOFOUL, participatory planned international research, network organisation, and HE teaching by non- specialists were enabled by training, knowledge transfer and exchange, and coaching. Participatory research methodologies emphasized collaboration between researchers, practitioners, and end-users throughout all stages of the research process, from problem definition to solution implementation (Cornwall and Jewkes 1995; Roque et al. 2022). Thus, careful coordination, mutual respect, and shared commitment to co-learning, supported by an agreement, is needed to integrate expertise within participatory frameworks (Nguyen et al. 2020).

The NOFOUL training and education aim was to develop a novel model training approach in the field biofouling and antifouling, combining learning and participatory research.

2. Biofouling Training

2.1 Biofouling Workshop

The aim of the Biofouling Workshop (Phase 1) was to inform and develop biofouling knowledge, background, skills, antifouling field trial approaches, biofouling assessment requirements and standardisation for the planned participatory and collaborative research (international experiment in 2025). The workshop was interdisciplinary and intercultural. An informal agreement was presented and accepted which included to: 1) get to know other partners; 2) appreciate mutual knowledge, background and contribution; 3) discuss openly, with respect. Non-specialist NOFOUL partners from India, Turkey and Romania took part in the Biofouling Workshop at LJMU (United Kingdom) on the 23rd and 24th July 2024 to receive training from LJMU biofouling specialists on biofouling and antifouling. The five visitors from Constanta Maritime University (CMU; 2 persons), Istanbul Technical University (ITU; 1 person), Ordu University (ODU; 1 person) and the University Academy of Maritime Education and Training (AMET; 1 person) engaged actively with the training. Additionally, partners from CMU (1 person) and ODU (1 person) engaged virtually. The tools included short lectures (15 to 20 mins) followed by group discussions (15 to 20 mins). Practical sessions (hands-on learning) were conducted in the laboratories (photonics laboratory, marine biosciences laboratory) and at the field site for antifouling testing (Liverpool South Docks, United Kingdom). These tools facilitated knowledge transfer and exchange on methodologies on biofouling and antifouling as well as activity breaks from the intense discussions. Participants experienced practical sessions on biofouling identification using microscopes, on adhesion strength of biofouling using a force gauge, and using image analysis for assessment. At the end of each day, feedback sessions were included to discuss activities design and content and establish actions on key points. Trainees reported that they learned many new aspects of biofouling and how it changed their understanding and perspective of biofouling. Trainees were inspired by the practical work.

As a result of the Workshop, it was agreed to offer the Workshop as a NOFOUL group to IAMU members to benefit their HE teaching. The trial workshop was approved as a template for future Biofouling

Workshops, particularly for IAMU scientists, engineers, and mariners.

2.2 Site-specific Training

The aim of the site-specific training was to develop biofouling skills specific for the site to facilitate the standardized antifouling field trial, and identify specific biofouling assessment requirements for the planned participatory and collaborative research (international experiment in 2025). Trainees were engineers and had not conducted any prior field experiments, with the exception of one trainee who worked on antifouling coating experiments from an engineering perspective. This lack of site knowledge required site-specific training for the field experiment itself and the data collection.

Two separate training parts were considered that are site-specific and cannot be addressed by the trainer and coach when not on site. Thus, the trainer was required to complete a site visit to work with the trainee. The trainee needs to complete work following experimental protocols and virtual coaching prior to the visit. The visit to each partner site was conducted by the trainer in January 2025. Training Part 1 was designed around the field trial with the tasks to: 1) obtain the materials; 2) build the experimental frame; 3) identify the field site; 4) attach the test samples on the frame; 5) deploy the frame and the samples; 6) select and undertake environmental measurements during exposure of the samples; 7) determine the point of time for removal of samples; and 8) remove, code and preserve samples. Trainees were required to complete Tasks 1, 2, and 3 based on a protocol and virtual coaching provided by the trainer. Tasks 1 to 3 were then corrected and validated during the site visit. Tasks 4 to 8 were carried out during the site visit with the trainer and trainee using knowledge transfer, and coaching. After the visit the trainee was supported by virtual coaching and guidance on attachment of samples and their order. Training Part 2 was designed around the treatment of the preserved samples with the tasks to:
1) identify a dissecting microscope with suitable magnification; 2) take photographs; 3) send photographs to LJMU for assessment; 4) assess photographs for percentage coverage of biofilm using a standard image analysis method. Task 1 was required to be completed by the trainee prior to the visit by the trainer based on guidance. Tasks 2 and 3 were taught by knowledge transfer and guidance during the visit, and after the visit via a protocol and virtual coaching by the trainer. Task 4 was included as an optional task for the trainee but was not expected because of the shortness of NOFOUL and the time needs of the assessment. This task was supported by training during the visit, a protocol, and virtual coaching.

Most of the tasks for Training Part 1 were completed. Tasks 1 and 2 were only completed upon the visit of the trainer. Task 3 was completed as potential sites were identified. These were then validated by the trainer. Task 4 was demonstrated by the trainer during the visit, while the coding was supported with a coding map for standardization at all sites and virtual coaching. Tasks 4, 5 and 6 were then completed. Tasks 7 and 8 were completed late at some sites with removal late, but coding and preservation of samples completed. Training Part 2 demonstrated the difficulty for non-specialists to achieve specialist tasks successfully. Particularly, Task 1 slowed down the start of the data collection. At no site was it possible to determine the correct microscope prior to the visit. The variations in microscopes were underestimated by the non-specialists. Availability of microscopes were not sufficiently explored prior to the training visit. When dissecting microscopes were identified just before photography was done, there were then uncertainties on magnification and thus, if standard size of area was photographed. This led to the development of a calibration tool for the microscope. A square (650x450µm) was engraved by laser on a small panel. This square had to be filling the field of view in the microscope, and thus, this magnification would be used for photography of subsamples. The standardization of the area of the photographs showed for each site was ensured. Tasks 2 and 3 were completed by all sites by the 25th May 2025. Task 4 was not completed by trainees, but further training on assessment of biofilm using image analysis was requested. No experiments or samples were lost, photographs were taken in sufficient quality. Thus, the international participatory research experiment was completed. Non-specialists can run a field test and take part in the assessment of samples if the NOFOUL teaching by demonstration is followed. The assessment of biofilm may need further training. For summer 2025 the trainees planned to continue field experiments with the aim to identify the biofouling problem and invasive species at their sites, antifouling coating evaluation, and facilitating collaborations and HE teaching.

3. IAMU Biofouling Network and Webinars

The aim of the Biofouling Network was to facilitate knowledge exchange on biofouling and antifouling, networking, training, and collaborations in projects, for experts and novices, interest groups, academics and mariners outside of the NOFOUL project. The Biofouling Network was limited to IAMU members. The network

was set as a tool to identify people within the IAMU who share the same interest, here biofouling and antifouling. Within the network the NOFOUL project can transfer their learning and knowledge while non-project participants can benefit and exchange knowledge depending on their level of knowledge. The network organised by NOFOUL has had the function to disseminate NOFOUL outcomes, introduced IAMU members to the issues of biofouling and antifouling, offered training, networking, and collaboration. Particularly, training was identified as a key aspect in International Maritime Organisation Resolution MEPC.378(80) requiring mariners be trained in the subject biofouling and antifouling. The training for mariners and HE lecturers could be an important role of the network. NOFOUL-trained non-specialists demonstrated their capability to transfer knowledge to the IAMU Biofouling Network via webinars and to students of one of the partner universities (CMU) increasing the pool of training opportunities for mariners and HE lecturers. Webinars are currently the key tools for connecting the interest group in the IAMU Biofouling Network. Members are globally distributed and dependent on virtual meetings. The IAMU Biofouling Network webinars are designed by NOFOUL to focus on specific biofouling or antifouling topics. The topics are presented by slide shows with at least two presenters. The discussions following were open to everyone; questions or contributions were presented by Chat or Speech with or without camera. During the webinar a number of polls were introduced, while after the webinar a survey was available to complete optionally. The IAMU Biofouling Network was initiated by NOFOUL during the IAMU AGA 25 in their progress report presentation and with flyers. The Network grew from the presentations of each webinar. The IAMU Biofouling Network counts currently 47 members, from Asia, Europe, Africa, the Americas, and from 16 IAMU member Universities. The webinar participation decreased from the first to the third webinar (71, 44, 20). This trend was expected; the first webinar demonstrated a new topic for IAMU to be offered by their association and more participants were attracted. In the following live webinars, fewer participants were attracted as webinars were recorded. The survey at closure of the webinars included 11 questions. Two questions were considered 1) “Would you like to be a part of IAMU Biofouling Network?” 2) “Would you like to see follow-up sessions on related topics?”. Most participants (90%, 86%, 83%; Figure 1) indicated they would like to participate in the network or already were. The number of participants already in the network increased from webinar to webinar (14%, 27%, 33%). Most participants would like to see further webinars on the topic (100%, 95%, 92%; Figure 2).

Overall, the IAMU Biofouling Network has a positive effect on IAMU members from webinar to webinar. During the webinars knowledge on biofouling is not only transferred to participants, but knowledge exchange was demonstrated in the question and answer sessions while developing into discussions. NOFOUL-trained non-specialists disseminated the NOFOUL research and demonstrated their new knowledge and skill. During the last webinar, participants requested training such as NOFOUL partners received, and this demonstrated the importance for IAMU members to understand biofouling.

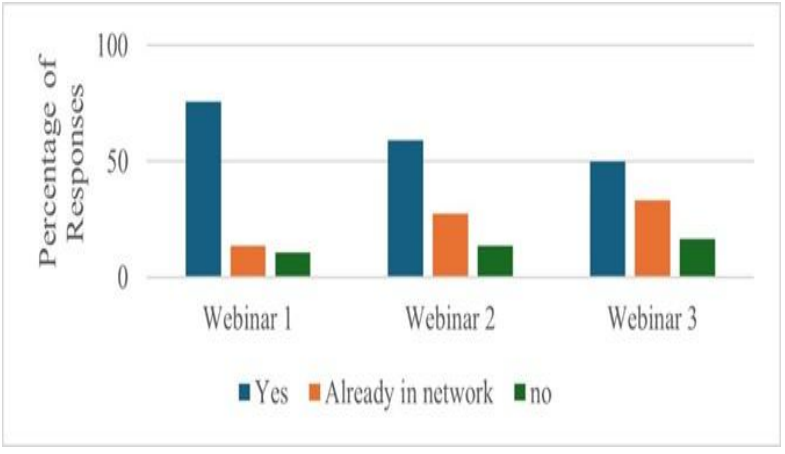


Figure 1. Percentage responses for each webinar (Question: Would you like to be a part of IAMU Biofouling Network?)

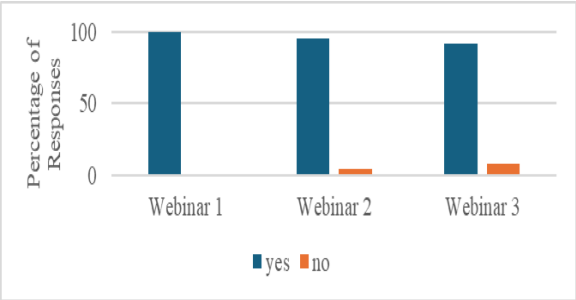


Figure 2. Percentage responses for each webinar (Question: Would you like to see follow-up sessions on related topics?)

4. HE maritime teaching on biofouling

The NOFOUL Project HE initiative on marine biofouling has demonstrated student interest and engagement. A class presentation on marine biofouling where NOFOUL results were shared with students in Electrical Engineering at Constanta Maritime University (CMU), Romania in May 2025. The analysis of the feedback (40 students, 1 lecturer) demonstrated strong overall interest in the topic. The majority were keen to learn more about specific aspects of marine biofouling.

The survey results demonstrated a positive welcome of the biofouling educational content. Among the 40 student respondents, 26 (65%; Figure 3) rated their interest level as either "High" or "Very high" after completing the class. Specifically, 22 students indicated "High" interest, 4 reported "Very high" interest, 13 expressed "Moderate" interest, and only a single student reported "Low" interest. This distribution demonstrated that the educational approach of the NOFOUL project engaged the vast majority of participating students, particularly remarkable considering these were primarily engineering students specializing in electrotechnics.The strong interest levels suggested that marine biofouling, despite being a specialized topic, resonated with students when presented effectively. The highly positive response indicated that the course content successfully bridged the gap between technical engineering concepts and environmental applications. Thus, this approach demonstrated that biofouling was accepted by the students as a part of their syllabus.Students were asked if they are interested to learn more about marine biofouling, students showed a balanced but positive outlook. The survey demonstrated that 18 students (45%; Figure 4)) wanted to learn more, 18 students (45%) were uncertain but not opposed (“Not sure”), and only 4 students (10%) had no interest in further learning. This demonstrated that 90% of students remain open to expanding their knowledge on the subject, suggesting the course successfully established the relevance of biofouling in the HE syllabus. When students were asked if they are interested in participation in projects similar to NOFOUL including research, fieldwork, or engineering solutions they were cautious but keen to get involved: 24 students (60%) selected “Maybe– I need more information”, 13 students (32.5%) selected “Yes” and only 3 students (7.5%) selected “No”. These responses indicated that while most students require additional information before committing to project work, there was support to practical engagement. The high percentage of “Maybe” responses suggested an opportunity for program enhancement by providing clearer pathways and information about project participation options.

Overall, the NOFOUL HE initiative on biofouling demonstrated success in engaging electrical engineering students with environmental marine science concepts. The strong interest levels reported by students, together with their openness to further learning and project participation, indicate effective educational content and delivery. The survey showed valuable findings about student preferences, highlighting engineering applications, pollution concerns, and environmental impacts as particularly engaging topics. To maximize student involvement in biofouling research, structural support (mentoring, resources, recognition) is necessary. The outcomes suggested that further investment in these areas could transform moderate engagement into high, sustained participation, and foster the next generation of researchers and innovators in marine environmental protection (Siqian et al. 2024).

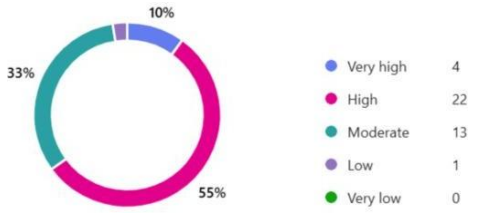


Figure 3. Student rate of interest in marine biofouling

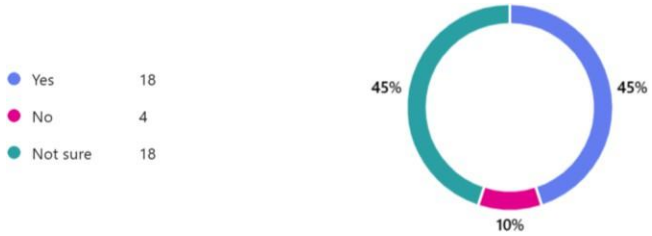


Figure 4. Interest of students in learning more about marine biofouling

5. The Future of Biofouling Understanding in Maritime

The NOFOUL project developed training and knowledge exchange approaches and trained non-specialists in biofouling concepts. Their training included a 2-day workshop and a participatory research field experiment, and resulted in knowledge transfer in a Biofouling Network with webinars and HE teaching. In the future, trained non-specialists from NOFOUL can transfer their knowledge to IAMU members and to colleagues and students even further.

The concept and approach of training non-specialists at LJMU may benefit other IAMU members in the future with further training workshops with NOFOUL partners. The transfer of knowledge may initiate and facilitate further field experiments promoting experiments, such as biofouling baselines for monitoring biofouling problem and non-native invasive species, as well as antifouling testing at the local site. These data may be collated in an IAMU data repository for applications such as modelling in commercial and environmental penalties, and Maritime HE. This may result in further participatory research.

6. Conclusion

The intersection of participatory research and antifouling innovation, driven by training, knowledge transfer and exchange, network development with webinars, and HE maritime teaching facilitated the viability of trained non-specialists within the biofouling and antifouling field. The participatory practices, and the co-creation of context-sensitive biofouling and antifouling engagement motivated the intercultural and interdisciplinary NOFOUL team and vice versa, thus, benefitting IAMU members.

Acknowledgement

The NOFOUL project was funded by IAMU and Nippon Foundation. The NOFOUL Team would like to express their deepest thanks to the numerous helpers and participants in the project. A very special thank you to the IAMU Biofouling Network members and for the support by Takeshi Nakazawa, Yusuke Moori and Shigemi Matsuzaki.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Harnessing Ocean Energy: Advancing Marine Renewable Technologies for Sustainable Coastal Development

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Abstract: Globally, the ocean contains a great deal of energy in many forms such as tidal, wave, salinity, and temperature changes between the deep sea and the surface. These vast amounts of energy have yet to be explored, thus there is a lot of potential for harnessing the aforementioned energies. The present investigation examines the methods and techniques of harnessing these energies by establishing Marine Renewable Technologies (MRTs) for long-term growth in coastal locations. Recent developments, including processes and issues in ocean energy technology, wave and tidal energy conversion mechanisms, and energy generation employing salinity gradients, are described. Meanwhile, economic feasibility and technical issues are addressed. Several important variables, including efficiency, reliability, financial considerations, and environmental factors, have been considered. Furthermore, the feasibility of blending these technologies with the current framework is assessed. The necessity of various rules and regulations for this task is also discussed in order to promote coastal growth, maintain marine life, and fulfill rising energy demand while lowering carbon footprint.

Keywords: Ocean Energy; Marine Renewable Technologies (MRTs); Sustainable Shore Development; Wave and Tidal Energy; Offshore Energy

1. Introduction

Electrical energy is always in high demand, both on land and on board. However, the use of fossil fuels contributes to increased carbon dioxide levels and, as a result, to climate change. The International Maritime Organization (IMO) has set a net-zero carbon objective for 2050, along with incremental checkpoints. This has instilled a sense of obligation to develop renewable energy. This is the ideal opportunity for a shift to alternate solutions for increased energy demands on board (White, J. K. 2024, Bello, U et al. 2021 & Hanspal, M. S.2024). Though improvements in solar and wind energy for power generation are very encouraging, the ocean has a large amount of untapped energy, particularly in coastal regions. Still, additional research is needed to capture such energy using MRTs in order to promote coastal growth (Wibisono, R. B 2024, Mehan, A. et al. 2023 & Koumentakos, A. G. 2019). In fact, the ocean serves as a reservoir of energy, containing wave energy, energy from varied tidal types, continuous current movement, temperature differences among ocean strata, and salinity differences between salt and freshwater. As a result, the ocean has an infinite supply of energy while being extremely clean and environmentally friendly. Therefore, if used properly, it might provide a sizable amount of energy for the maritime sector as well as for coastal development (Trenberth, K. E 2022). Unlike traditional high-carbon energy sources, ocean energy is almost always renewable and emits near-zero carbon. It may therefore fulfill the need for energy while also contributing to a clean environment. Such a change is critical for both environmental conservation and establishing a sustainable, promising future. Coastal regions are the largest space for the world population, making them particularly vulnerable to the detrimental consequences of climate change. This could result in excessive sea level rise, unpredictable weather events and other natural disasters that cause coastal erosion (Ruan, X et al. 2024). Such insights highlight the need for immediate strategic growth with an emphasis on environmental conservation. The above-mentioned issues can be addressed by creating energy from diverse ocean sources. These energies, particularly in coastal areas, have the potential to significantly boost economic growth while

also mitigating natural disasters (Mathew, J. T et al. 2025, Majumder, M. Z. H et al. 2024 & Chen, Q et al. 2025). This method of tapping energy can open the door for new enterprises to create such technologies while also creating job opportunities in coastal areas and increasing the prosperity of the coastal population (Boshell, F et al. 2020).

There are several chances to harness ocean-based energy, but equal impediments remain in the shape of advanced technology, capital and operational expenditures, and environmental protection until they are implemented (Jafarizadeh, H et al. 2024, Jamaleddin, N et al. 2024 & Simbolon, R et al. 2024). An efficient, consistent, and reasonably priced MRT is essential to producing the desired amount of ocean energy. This necessitates a thorough examination into enhancing performance, endurance, and mature technology to withstand the abrasive and corrosive marine environment. In addition, encouraging laws and regulations to ensure the commercial sustainability of such advancements are critical. As previously stated in the literature, this effort involves multiple ocean energies in the form of new MRTs and associated bottlenecks. The study also looks into the financial sustainability of ocean energy, considering capital and operating costs, as well as possible revenue streams. While examining commercial expenses such as starting and operating costs, this study also investigates potential sources of income. This study investigates numerous approaches for integrating the proposed MRTs into the present facilities, as well as the establishment of long-term coastal growth. This study also emphasizes the need for regulations that make it easier for such unique technologies to arise, as well as the necessity to raise public knowledge about the use of such energy sources. International help and cooperation are also required to hasten the process of implementing such MRTs.

The paper's structure is outlined below: Section 2 gives an overview of several maritime energy resources. While, Section 4 focuses on the many elements, including cost analysis and regulatory hurdles to capturing ocean energy. Section 5 discusses environmental issues and finally, the last section presents an overview assessment of the preceding topics and makes the required suggestions.

2. Maritime Energy Resources: A primer

The marine renewable power, also referred to as marine and hydrokinetic power, is a renewable electricity source that is generated from the inherent motion of water, such as wave action, tides, and river & ocean currents. A method named Ocean Thermal Energy Conversion (OTEC) is another way to utilize marine energy from variances in temperature in water. There is an abundance of opportunities to utilize marine energy. The entirety of the usable marine energy prospective in Asia is substantial; however, it differs significantly by country and region due to variations in coastline length, oceanic conditions, and advances in technology. The total projected marine energy potential in Asia (techno-economically achievable) between 2010 and 2022, according to studies by several Indian and international authoritative sources, is 300 to 400 GW. India's tidal energy potential is projected to be roughly 10 GW, with important spots in the Gulf of Khambhat, Gulf of Kutch, and regions of the Sundarbans. The most promising places for wave energy in India are across the western coast, mainly in Kerala, Karnataka, and sections of Tamil Nadu, with a capacity of 40 GW. Global ocean thermal energy conversion is expected to be up to 180 GW, with India accounting for only 2 GW, largely in the Andaman and Nicobar Islands.

2.1 Wave, Tidal, and OTEC: A Global Snapshot of Technological and Regional Readiness

Based on the statistics and site details, techno-economically possible and conceivable marine energy contributes around 54 GW in India in 2022, whereas it accounts for 57% of total power generation in the United States in 2019. Even if just a fraction of this technical resource potential is achieved, maritime energy technologies will have a significant impact on global energy consumption. However, the availability of resources alone is insufficient to take a technology to the commercial level. Table 1. provides a comparative overview of marine renewable technologies, including wave, tidal, and OTEC. Table 1. is developed based on reports from agencies such as the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), the United States Department of Energy, and the European Commission. Table 1 shows that Asia has enormous potential for wave and tidal energy, particularly around the coasts of India, Indonesia, and Japan, but OTEC remains mostly untapped due to a lack of proper warm water temperatures (excluding in Hawaii). It also demonstrates that Europe leads in market implementation, particularly in tidal energy in the United Kingdom and France. Wave energy is being developed, with many experimental projects in Portugal and Ireland. OTEC is currently in a developmental level. Furthermore, the United States has enormous prospects for wave energy throughout the Pacific coast (e.g., Oregon, California) and tidal energy in Alaska,

but OTEC remains restricted to exploratory initiatives in Hawaii.

Table 1. Regional Analysis of Wave, Tidal, and OTEC Technologies. TRL - Technology Readiness Level

Parameter	Asia	Europe	United States
Technological Maturity	Wave: Mid-stage (TRL 5–7) Tidal: Advanced (TRL 7–9) OTEC: Early-stage (TRL 3–5)	Wave: Mid-stage (TRL 5–7) Tidal: Advanced (TRL 7–9) OTEC: Early-stage (TRL 3–5)	Wave: Mid-stage (TRL 5–7) Tidal: Advanced (TRL 7–9) OTEC: Early-stage (TRL 3–5)
Status of deployment	Pilot & demo (India, Japan, Indonesia)	Pilot & demo (Portugal, UK, France)	Pilot plants (Oregon, Alaska)
	Limited Commercial Tidal	Commercial Tidal (France, UK)	Commercial Tidal (Alaska)
Accessibility of Resources	High		
	India, Indonesia, Philippines, Japan, South Korea	UK, Ireland, France, Portugal, Ireland	*Pacific Coast, Alaska*
Top Nations	India, Indonesia, Japan, South Korea, Philippines	UK, France, Portugal, Ireland	US (Oregon, Alaska, Hawaii); limited EU activity
Environmental Implications	Moderate (localized, with minimal emissions)		
Potential for Energy	Wave: 170–250 GW (Asia-wide) Tidal: 100–120 GW	Wave: 100 GW (EU-wide) Tidal: 20–25 GW	Wave: 64 GW (US-wide) Tidal: 12 GW
Required Infrastructure	Converters, offshore moorings, and grids	Barrages, tidal stream turbines, and grid connectivity	Deep sea pipes, tidal turbines, and buoys
Policy Assistance	Moderate to strong (India, Japan, South Korea, China); Limited for OTEC	Strong in EU (UK, France, Portugal)	Growing support (DOE, WA State, Hawaii)
Business viability	Improving but still not lucrative	Successful in specialized markets (France, UK)	R&D is still underway (especially in Hawaii
Opportunities for Development	High (particularly for wave and OTEC potential)	High (major EU investments, particularly Tidal)	Moderate (growth in wave, limited in OTEC)

Despite the abundance of resources, MRTs' practical applicability are severely limited by their low TRL. Asia and the United States are prime examples, demonstrating that the existence of resources alone will not result in widespread use of such energy until technology matures. This point is particularly prominent in Europe, where tidal power supplies are limited but commercially profitable due to high TRL. In contrast, tropical regions with strong temperature gradients were unable to successfully implement OETC. As a result, in addition to possessing adequate maritime resources, only technological improvements can help to maximize the utilization of available marine resources.

3. New Marine Renewable Energy Technologies

According to the preceding sections, contemporary MRTs primarily use electrical energy from waves, tides, and OETC. This section will provide a brief overview of the stated technologies. Figure 1 depicts a peek of energy generation using such resources

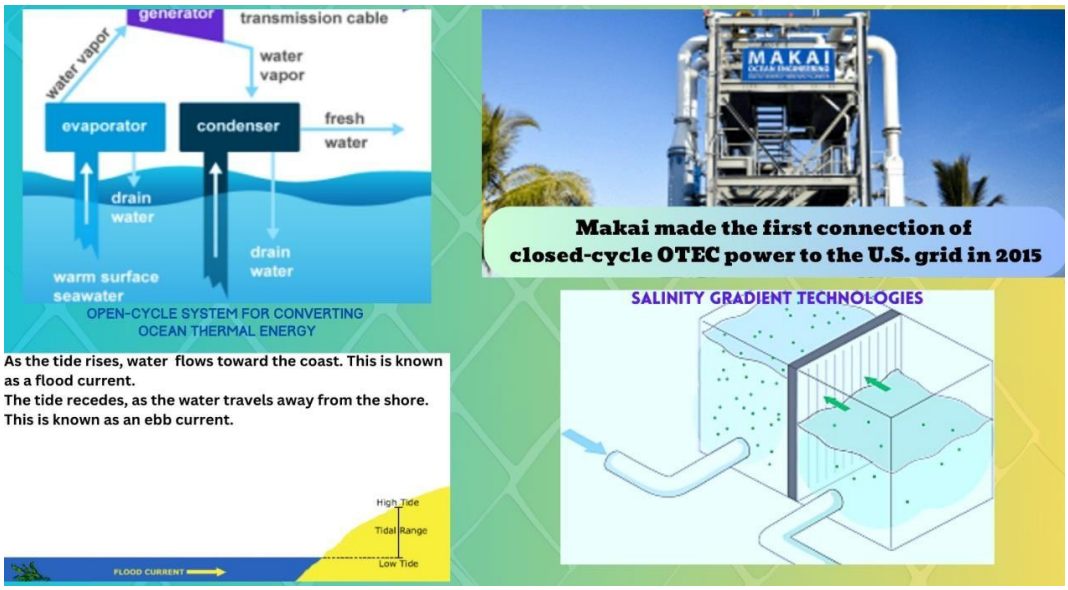


Figure 1. Various Ocean Energy Technologies (Bianchi, M. et al. 2024).

3.1. Wave Energy

Waves form when the wind interacts with the water's surface (due to temperature differences caused by the sun). The energy potential for waves is maximum between 30° and 60° latitude across both hemispheres on the west coast because of the worldwide orientation of the wind. As the waves progress, their dimensions increase. Wave Energy Converters (WECs) are used to extract energy from waves. There are seven common types of such converters: attenuators, point absorbers, pressure differentials, oscillating water columns, overtopping, and oscillating wave surge converters. The variety of these models is caused by differences in wave resources across locations and distances from the coast. Surface attenuators often feature many floating segments bonded to each other and aligned parallel to incoming waves. They employ the rise and fall of swells to generate a flexing action which can be turned into spinning or used to operate hydraulic pumps that produce power. Point absorbers take energy from the relative motion of a moving body responding to wave forcing and stationary or stagnant structures. The moving body can be situated on the surface or submerged, while the 'fixed' body could be the seabed or a different structure that is less impacted by wave movement. They are smaller in proportion to the length of the waves from which they obtain energy. This energy can be converted to electricity using a linear or rotational generator, or it can be utilized to pump the fluid directly. An oscillating column of water is used to harness the wave motion and create sufficient air pressure in the chamber using an air turbine. Air is drawn back through the turbine and into the chamber by the vacuum created as the water leaves the chamber. They can be found ashore or in deeper water offshore. Electricity can be generated by coupling the turbine to a rotary generator. Overtopping devices are lengthy structures which enable wave motion to raise a reservoir's water level above the surrounding ocean. Similar to traditional hydropower, energy is generated by forcing fluid through a low-head turbine connected to a generator due to the pressure differential between the reservoir's water and the surface water. The Oscillating Wave Surge Converter has two ends, one of which is hinged to the structure or seabed and the other of which is free to move. The horizontal motion of the wave surge causes relative motion of the body, resulting in energy being created and converted to electricity via a generator. Figure 2. depicts the described wave energy technologies.

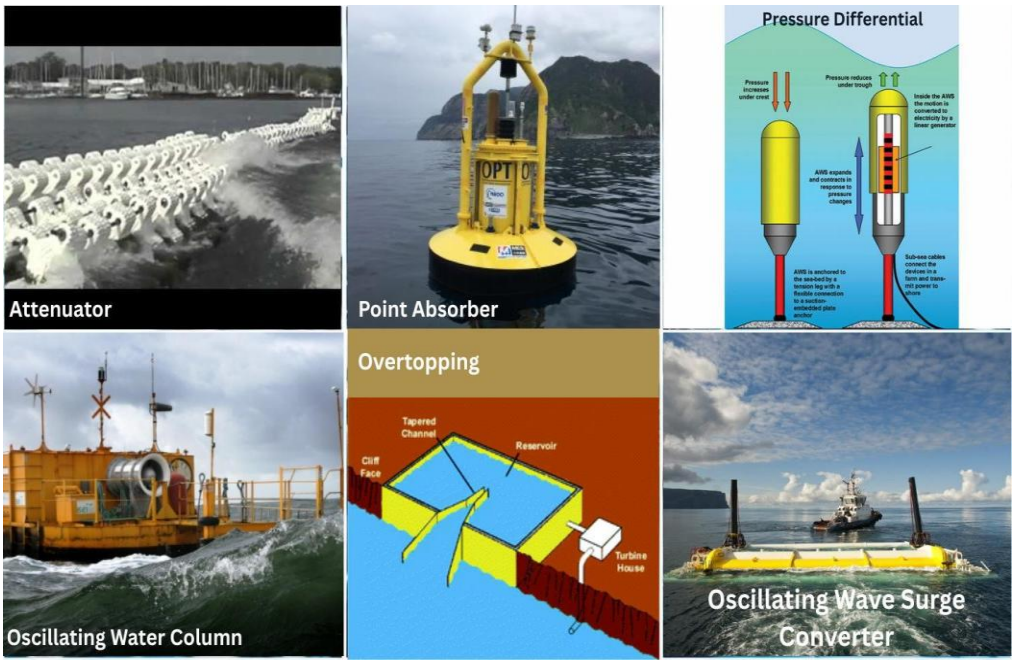


Figure 2. Classification of Wave Energy Conversion Systems.

3.2. Tidal Energy

Tidal energy has an extensive past, with cultures living along the shore using it for a variety of purposes decades ago. The first tidal power station was built in France (La Rance Tidal Power Station) in the middle of the twentieth century, and it is now the second largest station in operation, with a capacity of 240 MW. South Korea's Sihwa Lake Tidal Power Station is the world's largest tidal power station, with an installed capacity of 254 MW and ten turbines. Tidal and wave energy differ mostly in their source. The wind interacts with the ocean surface to generate wave energy, whereas gravitational forces provide tidal energy. Furthermore, the technology employed to harness each type of energy vary. Though waves and tides are sometimes used interchangeably, there is a distinct difference between the two. Tides are large waves that cause the sea to rise and fall near the shore. They exist as a result of the gravitational pull of the moon and sun. Their size varies with regard to the ocean as the planet revolves on its axis. In terms of tides, the moon has a greater influence than the sun because it is much closer to Earth.

The moon's gravitational pull causes four tides per day. However, local topography and ocean conditions can create minor differences. This typical pattern is known as the semi-diurnal tidal cycle, which has two high tides and two low tides every day, or a period of 12 hours and 25 minutes. This kind is common along Atlantic beaches. Parts of the Gulf of Mexico exhibit a diurnal rhythm with one high and one low tide every day. A mixed variety with two unequally high and low tides every day is also possible, as seen on the Pacific Coast of the United States. Tidal energy technology utilizes the potential or kinetic energy of moving water during tide flow using tidal barrages, tidal stream turbines, or innovative ways such as dynamic tidal power. This is commonly employed in coastal areas with a broad range of tides, such as France, the United Kingdom, and South Korea, because it is highly predictable. Despite the fact that environmental and geographical impacts must be addressed/regulated, the technology is established and thus reliable.

Tidal stream generating is similar to regular wind turbines in that it uses the fluid's kinetic energy to produce electricity. As the name suggests, a tidal stream generator involves placing a tidal turbine or other comparable technology inside the tidal flow, or stream of flowing water. The movement of volume of water works on the harvesting system, transferring energy. Tidal stream generating is similar to regular wind turbines in that it uses the fluid's kinetic energy to produce electricity. As the name suggests, a tidal stream generator involves placing a tidal turbine or other comparable technology inside the tidal flow, or stream of flowing water. The moving volume of water works on the harvesting system, transferring energy. Axial turbines, oscillating hydrofoils, crossflow turbines, and/or tidal kite systems are some of the standard models of tidal stream generators. Figure 3. illustrates a few of these technologies.

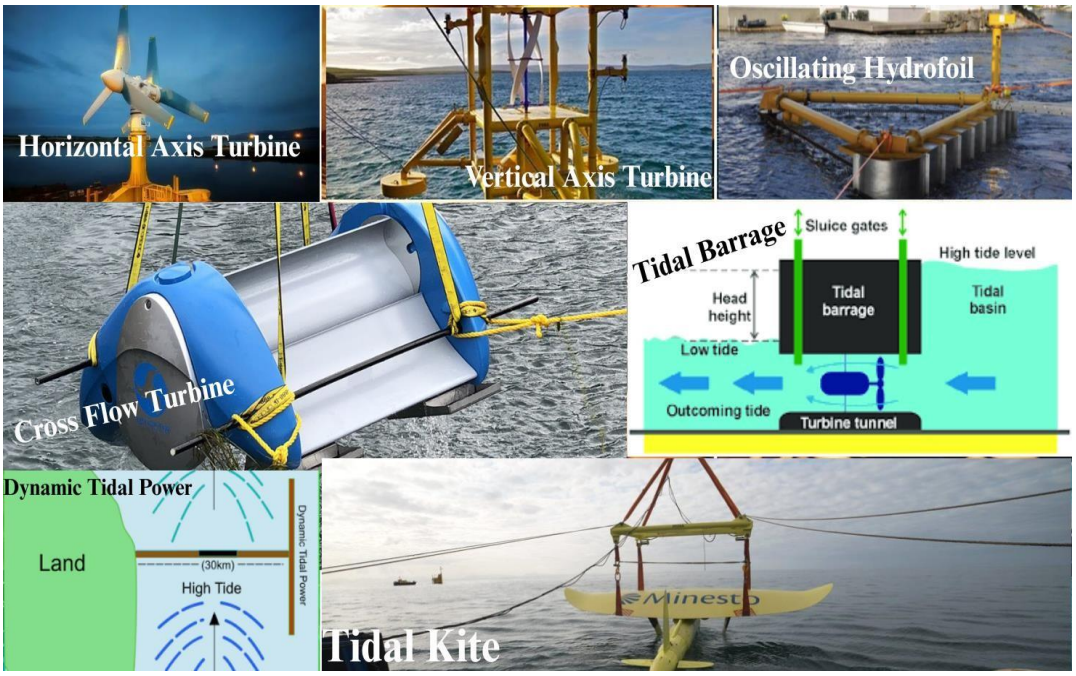


Figure 3. Illustrative Examples of Tidal Energy Conversion Technologies.

3.3. Ocean Thermal Energy Conversion (OTEC)

OTEC is one of the renewables that uses the temperature difference between surface water (hot) and deep water (cold) to generate electricity. A temperature differential of 20 degrees Celsius drives a turbine and develop usable energy. The world's first OTEC plant was erected in Matanzas Bay, Cuba, in 1930, with an open cycle model with a gross capacity of 22 kW that was not commercially feasible. Later, in 1979, an even more advanced closed-cycle OTEC plant known as Mini-OTEC was built off the coast of Hawaii, with a gross capacity of 50 kW and a closed-cycle system, becoming the first to generate net power at sea. To create energy, an OTEC facility must continuously use enormous amounts of hot and cold water. A 100 MW OTEC plant will use approximately 10-20 billion gallons of water each day.

OTEC systems are classified into several types, the most common of which are open-cycle and closed- cycle systems. A hybrid system is also available. Seawater serves various functions in the open cycle, including heat source, working fluid, coolant, and heat sink. Warm surface water gets to an evaporator, where it is quickly vaporized to steam in particle vacuum. A vacuum pump maintains low pressure in the evaporator. The low pressure helps in removing non-condensable gasses from the evaporator. The steam and water mixture from the evaporator then enter a turbine, which drives it and creates energy. The turbine exhaust is combined with cold water from the deep ocean in a direct contact condenser and released into the ocean. This cycle is then replicated. The cycle is described as 'open' since the condensate gets released into the ocean.

In a closed cycle, an operating fluid other than water is employed, such as ammonia, propane, or Freon. The warm surface water is transported to a boiler via pump. This hot water transfers its heat to the secondary working fluid, shedding energy, and gets released again at the ocean's surface. The vapors from the secondary working fluid produced in the boiler move a turbine, which generates power. The turbine effluent is cooled in a surface condenser using cold deep seawater and then fed back to the boiler via a pump. Warm, surface seawater enters a vacuum chamber in the hybrid cycle ocean thermal energy conversion process and is flash-evaporated into steam. The steam is utilized to evaporate a working fluid having a low boiling point, which subsequently powers a turbine to produce energy. The open-cycle is most suited for offshore installation, while the closed- cycle is best suited for onshore installation. However, both open-cycle and closed-cycle OTEC systems can be erected onshore. This technology is shown in Figure 4.

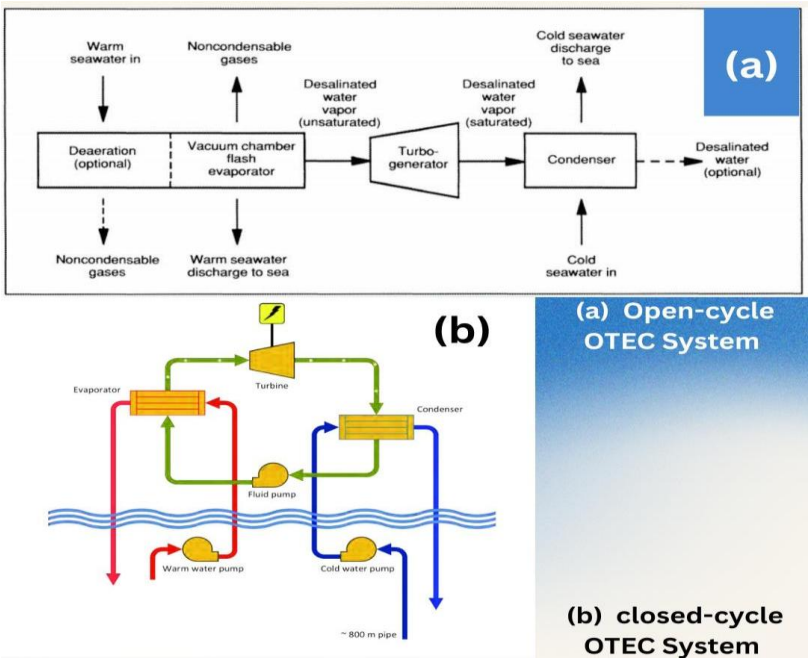


Figure 4. OTEC Technologies.

3.4. Salinity Gradient Energy

Another method for producing energy is through a salinity gradient. This employs salt concentration changes between saltwater (sea) and freshwater (river) to create a pressure difference.

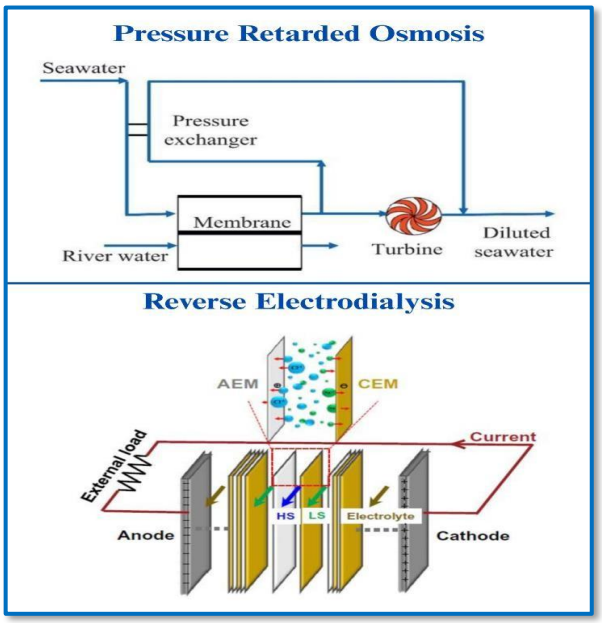


Figure 5. Key Technologies for Electricity Generation from Salinity Gradient Energy

This commonly occurs when a river flows into the sea. Saltwater will have a higher osmotic pressure than freshwater. The pressure differential is used to generate electricity. Many ways are being explored for such technology, with two of the most popular being reverse electro-dialysis (RED) and pressure retarded osmosis (PRO). The first approach entails building a salt battery in which ions are transported across membrane to generate energy, while the latter involves pumping freshwater through a semipermeable membrane into a seawater pressurized chamber. Increased pressure causes the turbine to revolve, resulting in the generation of electricity (Reyes-Mendoza. et al.2020).

RED produces energy through the regulated amalgamation of two water bodies with varying salinities (Sampedro, T. et al. 2024). This approach employs several anion and cation exchange members organized to create low and high salinity compartments (Guo, X et al. 2025). When freshwater and saltwater are injected into these membranes, opposite charges flow through the appropriate ions (cation, anion, etc.), resulting in electricity, just like an electric battery. PRO turns the osmotic pressure of the salt solution into hydraulic pressure, which drives the turbine and generates power (Pan, J. et al. 2024). As with RED, this technology takes advantage of the difference in saline concentration between fresh and salt water (Huang, Y. et al. 2025). Figure 5. Depicts prominent methods of creating electricity using salient gradient energy.

3.5. Technical and Functional Limitations

Even though various technologies are available for maritime renewables, there are still technical and functional limitations. Different structures are utilized in wave energy conversion technology; however, they are still in their early phases when compared to other renewable technologies such as wind and solar, and technological readiness must mature (Aderinto, T., & Li, H. 2018). The design, operation, and deployment of Wind Energy Converter (WEC) structures in the ocean environment presents a unique challenge relative to land-based systems. WEC's design requires it to interact with sea waves in order to extract energy from them. So, the problem is more severe. In addition to withstanding load changes during operation, the structure should be able to withstand major hurricanes, tsunamis, and other natural ocean catastrophes. Seawater is corrosive in nature, which may affect a few or several components of WEC. During the design phase, a detailed plan for operating and maintaining such a system must be developed. This is bound to raise the operational and maintenance costs. Another important factor to consider when planning a WEC system is location or accessibility, particularly if it is offshore. Construction issues are less common in coastal and nearshore WECs than in deep offshore WECs. This will improve accessibility as well. However, WEC constructions built near the shore have to cope with other regular coastal activities. Furthermore, the devices' accessibility for deployment and maintenance operations is critical in choosing the right technology, as performing maintenance at sea is both costly and unsafe (Tiron, R et al. 2015). The period for scheduling maintenance is difficult to determine because of incidents such as corrosion, wave stresses, and biofouling. Furthermore, deployment and maintenance activities necessitate sufficiently lengthy, consecutive time intervals in which the sea state is adequately calm. A balance between scheduling and doing maintenance should exist.

The majority of design and operational issues apply to tidal energy conversion systems as well. That is, the primary issues to be addressed are consistency, resilience, and installation (Segura, E et al. 2017). Furthermore, resource mapping for tidal energy currently lacks resolution and variety. Other peripheral and controlling components, such as power electronics, generators, gearboxes, and moorings, are to be enhanced alongside the core structure. New non-corrosive materials have to be employed to extend the plant's life.

The first and most significant problem in OTEC technology is the minimal temperature differential, which leads to reduced efficiency (Nakib, T.H et al. 2025). Even in tropical locations, the temperature differential between heat source and sink is typically 20 to 25 degrees Celsius, which is extremely low in comparison to other thermodynamic systems. Even under optimal conditions, the efficiency remains poor. However, using the appropriate working fluid and cycle can help to improve efficiency. Therefore, the design must prioritize these factors in accordance with capacity and application. The heat exchanger plays a critical role in the proper operation of the OTEC. In reality, the heat exchanger transmits heat from the hot surface to the working fluid. The rate at which this is accomplished has a significant impact on the overall efficiency of the system. So, parameters such as the number of heat exchanger plates/tubes, pressure drop, and heat flow rate/ heat transfer coefficient must be tuned to achieve promising outcomes.

The choice or mix of working fluids should be based on thermal efficiency, safety at work, and operational feasibility, as both the working fluid and the thermal cycle influence the system's total performance. In a few circumstances, alternate fluids/mix work effectively, but in others, they add complexity and handling dangers.

The evolution of the salinity gradient energy system began more than six decades ago, but it has struggled to gain traction due to poor real-time performance when compared to other renewable forms of energy (Essalhi, M et al. 2023). Hydrodynamic and mass transmission restrictions exist; however, these can be solved in the modern day with novel materials and careful design. While significant power density can be achieved in lab case tests with rigorously constant solution concentration, the practical energy conversion efficiency is not promising (Rastgar, M. et al.2023). Furthermore, this system has low stability and should be

addressed through alternate process design.

Biofouling is an acute issue in all ocean energy structures. It is described as the undesired formation of a microbial layer on the surfaces, which then leads to the infestation of submerged objects by fixing organisms. It grows over time into a glue-like biofilm that allows all bacterial species to attach to and proliferate. These biofilms are difficult to get rid of, reducing the overall performance of the system. This problem can be solved with appropriate ant biofouling techniques.

4. Ocean Energy: Costs and Constraints

While the technical and operational limits were addressed in the previous part, this section discusses the economic limitations. According to our earlier explanation, any enhanced design, technical novelty, maintenance, and parameter control during operation will all increase the system's cost.

At the design stage, planning for seamless operation of WEC requires an integrated operating and maintenance strategy, which incurs substantial lifecycle costs. The return on investment or payback period could be longer. The entire cost of a tidal energy system is determined by empirical data costs, significant changes in project cost approach, and location-specific costs. The different components of this are dynamic in nature, as is the overall cost. The technology is still in the development stage and has yet to be widely implemented. This may also be the cause for the high cost of tidal energy.

The majority of ocean energy structures require significant money and longer time to construct. Tidal energy technologies continue to pose significant risks in terms of cost and revenue, as well as to investors and insurers. Banks prefer to provide loans to low-risk short-term initiatives over high-risk long-term enterprises. To attain affordable prices in the near future, appealing incentives must be created to promote the development of the maritime energy sector.

For an OTEC system, the plant's size and location are critical to the entire budget. If the facility is built relatively close to the shore, the transmission costs could be significantly lowered. Furthermore, the cost of a certain heat exchanger, working fluid, or heat cycle may vary depending on the application, and each has a unique overall cost. If we want higher performance from this technology, we must make a trade-off between economy and output. The number of components in salinity gradients varies depending on the kind and the cost. The control of parameters and the necessity for greater maintenance raise the overall cost. Developing new regulations in support of ocean energy, creating incentives, and relaxing the procedures for selecting a site and simplifying the rules will assist not only improve marine energy but also significantly reduce overall costs.

5. Environmental Impacts of Ocean Energy

Potential environmental dangers of these developments include habitat damage, water flow patterns, electromagnetic radiation, and noise in aquatic settings. Ocean researchers must do rigorous testing prior to and following approval to ensure low dangers in those regions. The main challenge that arises in the sea environment is hydrodynamics. The severe wave pattern and repeatability of such occurrences must be analyzed using appropriate tools, such as CFD, to estimate the strong temporal variability, and the site may be chosen accordingly. Long-term wave climates at the locations that are relevant should also be addressed for analysis in order to lessen wave stress. Negative impacts of ocean energy structure include loss of ecosystems and degrading. The impacts vary depending on submerged surfaces, above-water platforms, and seabed changes. There is also a possibility that native or migratory marine species will become snagged or collide with the unit. Furthermore, it could affect the local flow and cause the relocation or diversion of larvae, spores, fish, and even marine animals, especially in large-scale installations. Some constructions release harmful fluids or paints into the surroundings. Perhaps the most serious environmental issues raised by OTEC systems is the chemical and thermal change of saltwater. The degassing activity may possess a negative effect on the quality of the local air, especially in locations near major OTEC facilities.

6. Conclusion

Marine renewable energy includes the extraction of electrical power through the motion of ocean waters, such as currents or waves, as well as temperature and salinity differential. This energy is the most unexplored kind of energy and remains in its infancy, but with great potential for producing energy in a more

environmentally friendly manner, minimizing carbon footprints. The advancements in wave energy conversion assessment approaches have been highly positive, since sophisticated computer software and apps are now accessible to foresee and model wave conditions at higher temporal and geographical resolutions. Tidal energy has significant potential to generate clean electricity in the medium and long future. Still, challenges such as cost-effectiveness, dependability, operational safety, site selection, environmental concerns, and longevity must be addressed through careful design and the use of novel materials in order to maximize the potential of tidal energy. The involvement of heat excangers, working fluid, heat cycle, and turbine is critical in OTEC, and the parameters must be tuned to achieve optimal performance. The scientific and commercial problems remain for salinity gradient energy technology, which has the highest cost and is still not working as predicted in real time. All of these technologies raise at least a few environmental concerns that must be addressed. Furthermore, legal issues such as site approval, loan lending, and strict laws restrict the system's growth. Rules and regulations must be standardized, and incentives for such efforts will make ocean energy extraction both promising and inexpensive. This paper provides an in-depth analysis of several MRTs, as well as technological, operational, economic, and environmental challenges. A few ideas are also provided to help MRTs grow.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Artificial Intelligence based Species Identification in Underwater Ecosystems: Advancing Marine Biodiversity Monitoring

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Abstract: This study promotes the exploration of marine resources and conservation in sustainable manner contributing towards Sustainable Development Goal 14. Marine ecosystem plays a crucial role in human well-being, social and economic development, and the global environmental balance that sustains life on Earth. These underwater resources will provide natural resources, including medicines, food, raw materials and energy resources. This article explores the deep neural network model for identification, classification, and monitoring of underwater species. By leveraging advanced AI techniques, the study seeks to enhance marine biodiversity detection and monitoring. The objective of this paper is to investigate the potential of vision-based object identification algorithms in underwater environments using diverse datasets. Underwater computer vision faces significant challenges, including distortion and attenuation caused by light propagation in water, as well as complex and dynamic operating conditions. Effective image segmentation and recognition models are used in the robust algorithmic design to ensure accurate and reliable species identification in underwater Arabian sea scenarios. The model attained 90% classification accuracy.

Keywords: Marine resources, Computer vision, Image segmentation, Underwater images.

1. Introduction

The Ocean, which covers most of the Earth's surface, regulates the climate and supports and influences all living organisms on it. The climate change caused by anthropogenic activities affects the Ocean environment the most, and it causes a disastrous impact on the living organisms. The extremely sensitive Marine habitat is threatened by land-based sources directly or indirectly causing ecological imbalance and affecting ecological sustainability. To deploy mitigation measures and conservation strategies, continuous monitoring is essential to ensure the marine ecological sustainability. Most of the traditional underwater habitat monitoring methods are destructive and time-consuming, which demands a non-destructive and sustainable way of tracking the sensitive marine ecosystem (Yang et al., 2024). Underwater imaging has emerged as an accessible and sustainable way for biodiversity monitoring, which is the basic step for marine research, using AUVs (Autonomous Underwater Vehicle), ROVs (Remotely Operated Underwater Vehicle), and UUVs (Unmanned Undersea Vehicle). The hundreds and thousands of images of marine organisms obtained were subjected to quantitative and qualitative analysis using different artificial intelligence and machine learning algorithms, which facilitate easy and accurate marine habitat assessment. The image-based taxonomical identification and detection of marine organism are mostly affected by color attenuation due to different luminosity due to reflection and diffraction effects of lights, turbidity, color deterioration, the movement of the organism and some biological characteristics like camouflage feature to escape from predators (Pachaiyappan et al., 2024).

For object detection and classification, deep learning algorithms are gaining popularity because of their accuracy and robustness. Deep learning has become one of the most significant breakthroughs in artificial intelligence and it has widespread application in computer vision, image analysis, language processing and

many more. Compared to traditional image processing and analysis techniques deep learning offers accuracy, precision and speed in target detection and analysis and this has made wide acceptance and adopted across various domains. Unlike shallow learning models, deep learning architecture utilizes multiple layers to process data, enabling the model to extract features from videos and images. Each layers contains processing units similar to artificial neuron that transform the input signals and these units adjust similar parameters through training based on experience (LeCun et al., 2015). Deep learning replaces manually engineered inputs with efficient, automated methods for feature learning and hierarchical feature extraction. Shape and color features are widely used for object detection and recognition for extracting species specific (Sun et al., 2014). The marine organisms vary in shape and it make shape-based feature extraction more precise. Image segmentation is a critical step in the target identification and classification and most of the time underwater automatic image segmentation become difficult because of poor illumination (García et al., 2010).

Leveraging the ResNet-50 Convolutional Neural Network (CNN) a robust artificial intelligence frame work was designed for species identification to reduce the challenges of manually identifying organisms (Habib et al., 2024). A comprehensive survey of deep learning was carried out for fish classification, emphasizing CNNs, RNNs, and hybrid approaches for improved species recognition under real-world underwater conditions (Saleh et al., 2022). For automated fish detection from underwater videos, haar cascade classifiers commonly used for face detection was developed and introduces a valuable dataset called ‘labeled fishes in the wild’(lfw-fish) (Cutter et al., 2015). This study is an initial effort to automate the monitoring of marine species in real world settings with constantly changing conditions, such as different lighting, clutter, and fish poses. This resulted in a growing fascination with computer vision and deep learning for automated fish identification. A two-stage deep learning system was designed to analyze temperate fish species, which have been largely overlooked in previous studies that primarily focused on tropical species (Muri et al., 2022).

This work focusses on the classification and object detection of multiple marine organisms from underwater images using a CNN based classifier and YOLOv8.

2. Methodology

2.1 Data collection

The underwater image data was gathered from Lakshadweep archipelago, the northernmost chain of atolls at the Laccadive-Chagos ridges, situated in the Arabian sea. The data collected through diver depended survey using underwater cameras. The data was collected at shallow water depth. The data includes coral reef associated marine organisms.

2.2 Data segmentation

The recorded videos were converted into frames per seconds using CNN. The targeted species was identified from the image and identified 14 organisms up to the species level using image-based taxonomic identification keys from different sources (Apte et al., 2011, Sastry et al., 2019, Dixit et al., 2017 & Cannon et al., 2003). The segmentation of identified organisms was performed manually by outlining the boundaries of the object of interest using bounding boxes and labelled using Image Annotator. The shape of the object was taken as an attribute to each annotated object to facilitate feature extraction, which allowed the model to learn the morphological features specific to each species (Figure 1. Annotation of marine organisms). This process creates pixel-level masks, and the annotations are exported in a compatible format for machine learning.

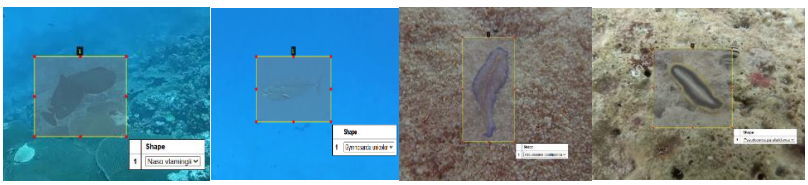


Figure 1. Annotation of marine organisms

2.3 Classification model architecture and training

The acquired images are preprocessed after segmentation followed by the model training (Figure 2. Model architecture). The proposed model adopts a CNN architecture personalized for multiple species

classification from underwater images. The network takes input images resized to 128×128×3 dimensions. It comprised three convolutional blocks (Figure 3. Frame work of the classification model).



Figure 2. Model architecture

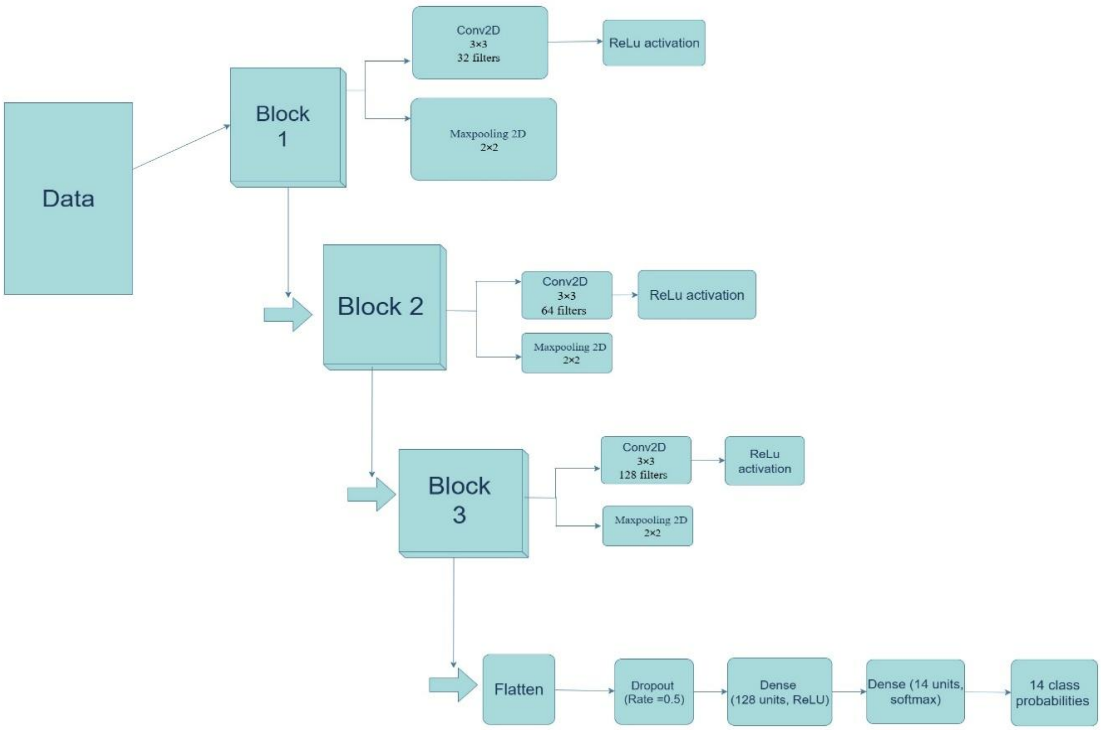


Figure 3. Framework of the classification model.

The underwater image data was divided into training (70%), testing (20%), and validation (10%) sets. The model training was performed using TensorFlow to classify the images. It loads the data from folders, preprocesses the images, builds a CNN architecture, compiles and trains the model with appropriate loss and optimizer settings, and then trains the model while monitoring its performance on a validation set. The test data was pre-processed for evaluation by rescaling, uploading the images from the specified folder into a generator with batch size 1 and categorical labels. It evaluates the trained CNN on this test set to compute loss and accuracy. To enable the classification of individual marine species from images following model training, a prediction pipeline was implemented.

2.5 Species identification model

The Convolutional Neural Network (CNN) was used for species identification. The training was conducted over 15 epochs with batch size of 32 and learning rate of 0.001. Data transformers, conversion to tensor format and normalization using a mean and standard deviation of 0.5, were implemented on both the training and validation datasets. The training and validation data was loaded in batches for training to improve generalization. During each training mode the data was passed through the model, loss computed, gradient backpropagated, and weights updated. Training accuracy was calculated using the ratio of correctly predicted labels to total sample. To monitor the performance, the model was evaluated on the validation dataset after each epoch. Sample prediction visualization was implemented to evaluate the model's accuracy and verify its object identification capabilities. From the validation dataset image per species is selected and the loaded image transformed to match the processing steps during the training. Each image is passed through the trained

CNN model without gradient computation and the output is processed to determine the predicted species index. This predicted label is compared with the ground truth species name extracted from the dataset.

3. Results and Discussion

The model was trained and tested with underwater image datasets obtained from Lakshadweep archipelago, which included fourteen species: *Acanthaster planci*, *Aluterus scriptus*, *Arothron meleagris*, *Chelonia mydas*, *Gymnosarda unicolor*, *Naso vlamingii*, *Pearsonothuria graeffei*, *Phyllidia varicosa*, *Plectorhichus vittatus*, *Pseudobiceros hancockanus*, *Pseudoceros duplicinctus*, *Pseudoceros galatheensis*, *Pseudoceros paralaticlavus* and *Spirobranchus giganteus*. The model's effectiveness was evaluated and attained a comprehensive test accuracy of 90%, demonstrating its ability to assess new data.

3.1 Classification Metrics

A detailed classification report was generated to describe the model's efficacy in terms of precision, recall, and F1-score of each species. The results of four marine species are presented in the table (Table 1) and it reflect the model's classification consistency across all categories, with good performance.

Table 1. Classification metrics

Identified species	Precision	Recall	F1-score
Acanthaster planci	0.96	0.96	0.96
Aluterus scriptus	0.93	0.56	0.70
Arothron meleagris	0.86	0.25	0.41
Chelonia mydas	0.78	0.85	0.82
Gymnosarda unicolor	0.97	0.97	0.97
Naso vlamingii	0.98	0.97	0.98
Pearsonothuria graeffei	0.98	0.90	0.88
Phyllidia varicosa	0.91	0.98	0.95
Plectorhichus vittatus	0.99	0.96	0.98
Pseudobiceros hancockanus	0.98	0.99	0.98
Pseudoceros duplicinctus	0.96	0.95	0.93
Pseudoceros galatheensis	0.63	0.83	0.77
Pseudoceros paralaticlavus	0.99	0.99	0.98
Spirobranchus giganteus	0.77	0.93	0.84

The model demonstrated strong performance across majority of the species. All species expect *Arothron meleagris, Chelonia mydas,Pseudoceros galatheensis,* and *Spirobranchus giganteus* showed a precision value higher than 0.90. Attained a recall value of higher than 0.90 for *Acanthaster planci, Gymnosarda unicolor, Naso vlamingii, Phyllidia varicosa,Plectorhichus vittatus,Pseudobiceros hancockanus, Pseudoceros duplicinctus, Pseudoceros paralaticlavus*, and *Spirobranchus giganteus.* F1-score was higher for eight out of fourteen species. The model recorded an overall accuracy of 90%, reflecting the model's robust performance.

3.2 Confusion Matrix Analysis

The confusion matrix was plotted to illustrate the model's analytical accuracy by comparing the predicted versus actual labels for each species (Figure 4). The diagonal elements of the matrix indicate correct predictions, while the values outside the diagonal represent misclassifications between the fourteen marine species. The model performed strongly on all species except *Chelonia mydas, Pseudoceros galatheensis,* and *Spirobranchus giganteus. Chelonia mydas* was confused with *Arothron meleagris* and *Pseudoceros galatheensis* with *Aluterus scriptus*. *Chelonia mydas* showed false negative for *Spirobranchus giganteus*. This suggests the need for further refinement, potentially through adding more training image samples of the species or feature augmentation techniques for better classification of species.

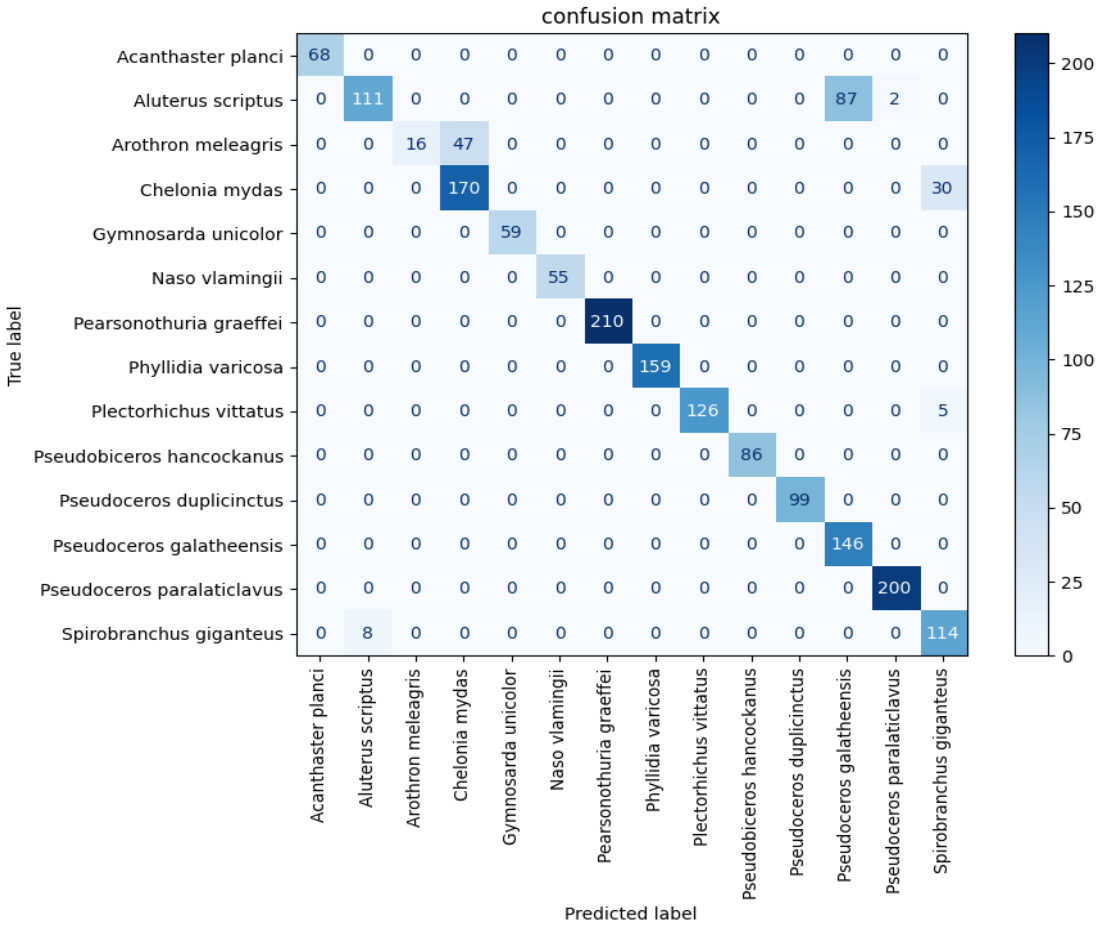


Figure 4: Confusion matrix for marine species classification

3.2 Species identification

The evaluation of the predicted model displays a marine species image along with predicted and actual species labels. Out of the 14 species 13 images were identified correctly and this demonstrate the model's accuracy and robustness (Figure 5). The misclassification occurred only in one species where predicted was *Chelonia mydas* and the true label was *Arothron meleagris*, this might have happened due to the species-specific features overlap.



Figure 5. Species prediction by the proposed model

4. Conclusion

This study developed and evaluated a deep-learning classification and identification model for marine species from underwater images collected from Lakshadweep. Fourteen coral reef-associated organisms were identified with different taxonomical keys. A Convolutional Neural Network (CNN) architecture was employed to train and validate the model on the annotated dataset comprising *Acanthaster planci*, *Aluterus scriptus*, *Arothron meleagris*, *Chelonia mydas*, *Gymnosarda unicolor*, *Naso vlamingii*, *Pearsonothuria graeffei*, *Phyllidia varicosa*, *Plectorhichus vittatus*, *Pseudobiceros hancockanus*, *Pseudoceros duplicinctus*, *Pseudoceros galatheensis*, *Pseudoceros paralaticlavus* and *Spirobranchus giganteus*. The performance evaluation demonstrated promising results, with a total test accuracy of 90%, supported by a confusion matrix indicating high precision above 0.90 for almost all the organisms. The F1-score was higher than 0.90 for all the organisms except *Aluterus scriptus*, *Arothron meleagris*, *Chelonia mydas*, *Pearsonothuria graeffei*, *Pseudoceros galatheensis*, and *Spirobranchus giganteus*. The findings highlight the potential of deep-learning techniques in enabling automated, precise identification of marine organisms, supporting applications in ecological surveillance, biodiversity evaluation and conservation efforts.

Acknowledgements

The first author, Dr. T. Sasilatha, Professor and Dean at AMET University sincerely acknowledges the financial assistance received in support of the Project titled, “Marine Exploration by Integrating Artificial Intelligence and Machine Learning towards Sustainable Ecosystem: A case study on Automated Species Identification and Characterization” funded by Ministry of Earth Sciences, Govt of India under the Deep Ocean Mission scheme.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

The future training needs for persons working in Remote Operation Center (ROC)

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Abstract: This article discusses the future requirements for the training and qualifications of people working in the Remote Operation Center (ROC) in autonomous shipping. Whether the training will be regulated by the STCW convention or whether such regulation will take place in a separate convention has not yet been specified. Based on previous research, it can be concluded that people need to understand navigation and regulations, and increasingly also have basic engineering skills and knowledge of fire protection systems and other emergency procedures. In some respects, the skills currently required of master mariners may also be abandoned and may be transferred to a land organization or shipping company. Nevertheless, they can be centralized, for example, to various commercial or legal experts in connection with the ROC. These include, for example, tasks related to cargo stowage planning and electronic transport documents, which have been the responsibility of the mates and masters on a vessel. With regard to training methods, the use of simulator training should be increased and intensified, as it provides practical training and can compensate for the lack of experience at sea. Simulator training can also increasingly be used to training relating to autonomous vessels in managing fault situations and accidents. According to the research results, two different points of view were presented: future individuals working in ROC´s should be either navigation specialists or IT engineers. Traditionally, the pedagogical models of maritime education in Finland have been based on PBL (Problem Based Learning), but the demands of increasing engineering competence also require the introduction of CBL (Challenge Based Learning) models in education.

Keywords: STCW convention; Remote Operation Center; Simulator training, Problem Based Learning, Challenge Based Learning

1. Introduction

This article is based on the research and development work that the author has participated in developing the Master of Maritime Management degree programs at the Finnish Novia University of Applied Sciences. (Sandell P, 2025). In the research and development work, the Master's degree programs were renewed to meet the needs of land-based maritime organizations with a view to the changes required by autonomous shipping in the work of shipowners' land-based organizations in the coming years. The renewal of the Master degree programs was carried out so that the sea captains and persons with a background in marine engineering, who are trained for management and expert positions in shipping companies, would be able to lead the future change as shipping companies transition to autonomous shipping, as the IMO MASS code enables the entry into force of the code for maritime traffic for autonomous ships. Marine Captain Education and Marine Engineer Education is a bachelor's level education that is currently regulated by the STCW Convention.

At the moment there are no defined rules and regulations regarding the competence levels of operators who will be working in Remote Operation Center (ROC). Current competence requirements for shore-sideersonnel are defined by the International Safety Management code. The ISM code states that the shore-side personnel need knowledge about traditional vessel operations like navigational practices, maintenance systems and procedures, machinery and equipment operation and manning requirements. These requirements are fulfilled in Finnish educational system by offering Master programs to persons who have already bachelor’s degree (sea captain or marine engineer) and working experience at sea (minimum two year after graduation from bachelor degree). It has been stated in previous research results that these existing requirements for

manned vessel shore-side personnel are highly relevant for ROCs too, since they operate the vessels at sea remotely (Ahvenjärvi, S. 2016.).

In this paper we concentrate on the findings from the point of view of the maritime education providers when training for the people working in the ROCs will be initiated by MET providers in future. The specific issues which will be under investigation are the following1) what kind of physical training facilities are needed,2) what kind of methodological approach should be used 3) how the curriculum structures should be developed etc.

2. Competence needed for ROC work

2.1 Introduction

When the work with adjusting the Master of maritime management degree programs to the needs of autonomous shipping was initiated a survey of previous existing research was made based on familiarization in existing literature and articles. It was possible to find some but not too many. The problem with the existing research was usually that there were no empirical knowledge or interviews conducted in existing ROCs. (Saha, R. 2023.) Therefore, we had to interview the users of the ROC which has been built for experimental autonomous shipping projects in Finland. This was helpful in a way that interview confirmed the findings which were gathered from the existing literature. The previous research highlights the importance of system understanding, communication and technical knowledge as well as maritime competence as key competences for remote operators. Some other competences were found also to be of importance, such as knowledge of regulations, navigational competence, and basic engineering knowledge. (Saha, R. 2023.) Knowledge of regulations together with navigational competence was especially relevant combination in connection to collision avoidance. This combination is also connected to the knowledge of the vessel's behavior mechanisms as an entity. This also relates to system understanding (Ahvenjärvi, S. 2016.). System understanding and technical knowledge is very important, without understanding the system and the technology behind it, it would be impossible for the remote operator to operate the vessel. This links to one of the other competences, which was engineering knowledge. With basic engineering knowledge it is more likely for the remote operator to understand the systems due to the high level of technology in autonomous shipping (Saha, R. 2023.).

As there are no defined rules and regulations regarding the competence levels of operators, it is still too early to plan curriculums. It is, however, clear that when analyzing the future education and how it is possible to provide the necessary skills for persons working in the ROCs, we should look at the future in two perspectives. First when set our sight to the near future we will face a situation in which there is a transformation of work from sea to land. This means that we will be able to use people in ROCs who have seafaring experience. They need new skills, but they only need additional skills which can be provided on basis of existing knowledge. Secondly, when look further to the future we will need another kind of education where the students have no previous knowledge of seafaring when they start their education to become ROC operators or fleet managers in ROC.

2.2 Terminology questions

The terminology and even job descriptions of the people working in ROCs is still undefined. Even the terms Remote Operation Center has been quite lately defined and confirmed by the International Working Group that develops the MASS Code (later the MASS IWG). Therefore, when the literature review was conducted, many different terms were used of the ROCs. What has been defined lately by the MASS IWG is the principle that also all autonomous vessels must have a master (on a vessel or elsewhere) who is responsible for the vessel and its operations. Therefore, when making the literature research, it was difficult to analyze the terminology as this principle had not yet been established when the previous research has been conducted. In this article we use the terms remote operator and the master. The remote operator will be a person who is in a remote operation center and physically maintains the connectivity to a vessel and operates it, but he/she is not necessarily the master. The master is a person who is also in ROC, but he can be responsible for several vessels at the same time, which all are under supervision/control by the remote operator.

Different terms have been used before of these persons, both in literature and in practice. When visiting and interviewing the persons in the experiment ROC, the term remote operator was used of the person who was operating the vessel from the ROC, but the person who was managing and under whose surveillance all the remote operations were, was called the fleet manager. He had his own room in ROC in which he had a view of all vessels under operation by the year remote operator. In terms of the draft MASS code, he could also called

the master (of all the vessels). In this article we use the terms of master and fleet manager as synonyms in relation to ROCs.

2.3 Educational background issues – Past and future MET

If we try to make a comparison of the work arrangement in the ROC just described, it resembles the division of work in vessels in a way that the mates in vessels are mainly responsible of navigation and master is kind of" a managing director" of the vessel who takes charge of navigation when entering/leaving port and in special circumstances at sea, but otherwise stays within his managerial duties. He has been promoted to be a master of a vessel after several years of work as a mate. This could be also the way the careers in RCOs would develop. After several years as a remote operator a person would be promoted to work as master and/or a manager of autonomous fleet. When we turn to analyzing this from the point of view of MET, it creates possibilities to reorganize the education of master's somewhat.

If we first think of a situation where most remote operators and masters are recruited to ROCs with conventional vessel working experience background, the education is supplementary education and as the persons have traditional STCW education and seagoing experience, they only need supplementary education that is needed to adjust their skills and experience to the new environment. System understanding and engineering skills are essential in this relation and problem-based learning in simulator environment is one possible way to take care of this. Secondly, we need to think about the situation in which we need to educate students, who have no seafaring background at all, directly to become remote operators. One would think that as the work at sea diminishes in amount, it will take a long time before we are lacking the workforce for those positions who do not have experience from sea. This is, however, not true.

In many countries we are already in a situation where seafarers are no longer available and so many are close to retirement that the workforce for ROCs has to be recruited from college students via maritime educational institutions. A good example is Japan, in which the political decisions have not made it possible to recruit workforce from foreign countries. If countries with similar policy start to develop autonomous shipping, they need to start educating young people to ROCs directly from schools without traditional seafaring experience. When we look to the future, it is far ahead in some countries in this respect in many countries, but in some it is terribly close.

When considering solutions for the future, we must not only stick to existing but also analyze the past. In Finland like in many countries before, maritime education was previously more clearly separated in several stages. A student first completed an education in three years which qualified to work as a mate. After a person had been at working life for year(s), he returned to MET institution for" a captain class". If we apply this same approach to work at the ROCs, it would mean that a person becomes a remote operator in three years and works in ROC under supervision of a master/fleet manager before completing his studies to become a master. This would help to recruit persons to ROCs faster, which is a relevant need in many countries where people are aging and amount of people in working life is diminishing. The solution described in the previous chapter has also other advantages. As the students need new skills in ROCs, we could also take out some issues from previous curriculums or they could be changed or left later to the last year's curriculum when/if the student returns to MET institution to become a master/fleet manager. What finally needs to be in the curriculum is also a question of how the work will be divided between shipowners' organization and the ROC. If only the operational issues are handled in the ROC and more is left to shipping company management, then we also need to analyze what skills are left to the master's degrees which qualify to the work in shipping companies' management which is separate from the ROCs. For example, most legal and economic issues could then be left to the master's degree level of education. As there are no defined rules and regulations regarding the competence levels of operators, we need to consider these issues more closely at a later stage.

3. Changes needed regarding physical training facilities

The maritime educational institutions are in a situation in which their premises have to be prepared for both traditional education and new form of education for persons working in remote operation centers. The training of seafarers for conventional vessels will not vanish. All types of vessels will never become autonomous vessels in a way that they would be unmanned. For example, cruise vessels will be manned vessels also in the future. Therefore, traditional education for conventional vessels will be needed as the remote operators are educated. This means that the MET institutions will need premises in addition to the previous ones which are suitable for this new education.

Simulator training will be an essential part of remote operators' education. It is very close to the remote operator's education and work at ROC. Most problems, if not all, that arise in the work can be simulated. When

an essential part of studies can be conducted in simulation environment, there will be need for several rooms for the purpose at the same time. This does not require large investments like investments were when simulator environments were created to MET institution for conventional seafaring education. These" conventional" simulators require a space which resembles and functions like Command Bridge of the vessel.

The simulators for ROCs are/can be something very different. In first place, they do not have a traditional command bridge with all its equipment. They have only screens and vessels can be navigated in ROC environment by use of a tablet, like in the actual ROC used for autonomous experiments in Novia University of applied Sciences in Turku, Finland. Fleet manager's space can require more screens depending on how large the operation area is, like in the ROC in Turku, in which case the operation area is in archipelago only. This means that the investments in technology for the MET institution can hardly be any issue at all compared to traditional simulator with the bridge environment.

We have limited information available about how this kind of education would be arranged but having visited the premises of a ROC test center in MET institution, a comparison with existing simulator environment can be made. One possible solution could be that the teachers work as fleet managers and remote operation students have several smaller simulation rooms with screens in each room as the teacher has an overview of the fleet operated by students all the time. In this kind of environment, the vessels (stage of autonomy II or III) can practice all kinds of situation also in a way that they simulate for example collision avoidance situation between themselves as instructed by the teacher, who then can take over or assist as fleet manager/Master.

4. Methodology needs for future training

4.1 Introduction

The technological complexity of ships due to automation requires the development of skills related to, for example, cyber security, ship equipment engineering, and software development. This results in a demand for strong problem-solving abilities, adaptability to technological changes, and continuous learning, which, in turn, requires maritime education and training to become more adaptive and responsive. This includes emphasizing lifelong learning, embracing an interdisciplinary approach, and promoting project-based and problem-solving learning methods.

In the Finnish education system, the Problem Based Learning (PBL) method has been used for a long time since 1990s. As a new method, the Challenge Based Learning (CBL) method has now been introduced, especially in engineering education, and its use is increasing especially with the teaching of autonomous shipping. (Sandell, P, Salokannel J et al, 2025.)

4.2 Problem Based Learning (PBL) method

Problem-oriented learning can be used as a methodological tool or as a strategy that covers the entire degree program. In Finland, this Problem Based Learning (PBL) method is used quite extensively in both universities and universities of applied sciences. (Nyyssönen, K. 2025.) In problem-based learning, instead of reading books excessively, students solve problems encountered in working life. It suits well in seafarers' education, both for sea captains and marine engineers.

Each course contains information learned and read in lectures, and in either classroom teaching, simulator or in the online part of the course, this knowledge can be applied in practice, which deepens learning and makes it more meaningful. In problem-based learning, students work in small groups on site or online, and the actual learning takes place by posing problems related to working life and the topic of the course. The teacher's role is to act as a person guiding the small group work, i.e. the tutorial, and not to provide ready-made answers. In addition to small groups, the teaching includes independent study and other teaching, such as lectures, seminar presentations, exercises and reading literature.

4.3 Challenge Based Learning (CBL) method

The concept of challenge-based learning was introduced in 2008 by the technology company Apple. Since then, the CBL method has been used internationally both in basic education and at the higher education level. The method is based on the concept of challenge-based learning, in which learning is based on active action and solving inspiring challenges in cooperation with peers, teachers and experts acting as partners. Challenge-based learning has been established as a successful method for delivering practical real-world learning experiences in engineering disciplines and it has been proposed as an evolution of the Conceive, Design,

Implement and Operate (CDIO) framework adopted widely in universities giving engineering education. (Morariu A. R, Tsvetkova A. et al., 2025.) The MASS code is goal-based legislation, and it allows for different methods to achieve the goals of the code. Therefore, CBL is method that can be fruitful way in achieving results when students are educated to ROCs. CBL aims to incorporate 21st-century skills, such as critical thinking, problem-solving, and technological competence, into PBL and integrate technology into the process. CBL's primary goal is for students to develop practical, real-world solutions to open-ended problems called challenges, not just to complete a critical thinking exercise. This renders CBL a natural extension of the previously existing methods like PBL. (Morariu A. R, Tsvetkova A. et al., 2025.)

4.4 Mixed method of PBL and CBL

Both methods are applicable and can be mixed in teaching. When analyzing their use in relation to person working in remote operation center, some generalization can be made. The work of a remote operator concentrates on solving problems which arise unexpectedly. Autonomous shipping should be autonomous in a way that operator is involved when autonomy fails. This creates a problem which must be solved. Therefore, PBL is a method clearly in place and its use in teaching is natural. Studying in simulator environment is a place where students are given problems, and their studies concentrate in solving the same problems which they face in real life situations. It is important to understand the systems on-board as well as be able to respond to alarms and then find the right response to the problem. Problems are created by the teacher and a solution can be found during the given tasks. There is usually a right answer to the problem and the scenario is built for the students to find it. Teacher can create endless number of scenarios for simulator. Connection to working life and unexpected problems that have arisen can be collected and simulated. It is therefore crucial the MET institutions co-operate with ROCs to collect information about real incidents that have arisen.

Challenge based learning in turn is more open ended. There is not necessarily an answer to the challenge, but it has to be created. Therefore, it has been used more in engineering studies than others. As the work in ROCs is considered to require more engineering skills/knowledge in future, also remote operators can benefit of its use. It is clear that when marine engineers work at shipping companies, they benefit even more of its use as they have to find new solutions on how challenges in technical processes of company's fleet are solved.

To summarize what has been stated, in the work of a remote operator, it is essential that a person is able to solve problems, and this has to be usually done in a limited timeframe in order to avoid accidents and further Problems. Challenges can be defined as something that should be solved to create systems that do not create problems when they are used. Both should be used when educating the remote operators.

5. Conclusion

The technological complexity of ships due to automation requires the development of skills related for example, cyber security, ship equipment engineering, and software development. This results in a demand for strong problem-solving abilities, adaptability to technological changes, and continuous learning, which, in turn, requires maritime education and training to become more adaptive and responsive. (Sandell P, 2025.) This includes emphasizing lifelong learning, embracing an interdisciplinary approach, and promoting project-based and problem-solving learning methods. (Sandell P, 2024.). Even though new competences are clearly needed, maritime competence and communication links to navigational competence which remain the core issue also in future training for persons working in ROCS. Since there are still a lot of manned ships, it is important for the remote operator to have good communication skills and understanding of maritime field, as he must communicate with persons working in both conventional vessels and remote operators of other vessels. The writer of this article has participated the work of MASS IWG preparing the MASS Code since 2022 as a part of delegation of Finland. In the last session of the MASS IWG held in June 2025 during the Maritime Safety Committee, many relevant issues were still left undefined and they will be transferred to the next MSC to be held in 2026. One of these is the delegation of Masters Duties under the MASS Code. After this session when the Mass Code has been finalized and approved, we will have a clearer picture of the training needs for future masters working in the ROC.

Cover Letter

Attached to this Cover Letter please find my manuscript entitled The future training needs for persons working in Remote Operation Center (ROC), submitted for publication in conference proceedings of the IAMU

AGA 2025.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Seafarers legal position when vessels are used for illegal activities against marine infrastructure

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Abstract: Between years 2023 and 2025, there has been a significant amount of damage in both the Baltic Sea and off Taiwan, in which either gas, electricity or telecommunications marine underwater cables have suffered either severe damage or been completely cut off. The anchors of the vessels have been identified as the sole cause of these damages. The authorities of the countries bordering the Baltic Sea have started seizing vessels and imposing a travel ban on vessels crews pending investigations and possible criminal proceedings. The most recent two cases are the Eagle S vessel (registered in Cook Islands) for Finland and the Vezhen vessel (registered in Malta) for Sweden. The both incidents have occurred during one moth only in December 2024-January 2025.This article focuses on these incidents off the coasts of Finland and Sweden and analyses the applicability and application of both international and national law when ships, their owners/operators and crews are suspected of sabotage, as well as aggravated interference with telecommunications. The ability of coastal states to intervene in the activities of vessels is based on both the UNCLOS Convention and national criminal law. In international waters, the provisions of international law concerning the state of necessity may also be applied, the conditions for the application of which are explained in the article. These enable the authorities to intervene in the operation of the vessel even when the vessel is outside territorial waters or economic zone. The criminal penalties for the ship's crew can be serious because of the suspicion of a serious crime. Prison sentences for such crimes are always unconditional, so the captain and crew members can face years in prison if found guilty. Shipping companies may also be sentenced to the criminal liability (liability of legal persons) for their actions, if it can be shown that the shipping company is aware of or has approved the activities. The compensation of damages is generally directed to ship-owner or operator, but also seafarers' liability for damages is an element which can be subject that arises in connection to criminal proceedings if they are found liable.

Keywords: Seafarers Criminal Liability; Sabotage; Underwater marine cables, Anchoring, UNCLOS

1. Introduction

Between years 2023 and 2025, there has been a significant amount of damage in the Baltic Sea, in which either gas, electricity or telecommunications marine underwater cables have suffered either severe damage or been completely cut off. The anchors of the vessels have been identified as the sole cause of these damages. The authorities of the countries bordering the Baltic Sea have started seizing vessels and imposing a travel ban on vessels crews pending investigations and possible criminal proceedings. The most recent two cases are the Eagle S vessel (registered in Cook Islands) for Finland and the Vezhen vessel (registered in Malta) for Sweden. The incidents occurred during one month only in December 2024-January 2025. After these incidents, several others incurred also in February-March after the abstract has been submitted.

2. Baltic Sea and underwater infrastructure

This article focuses on these incidents off the coasts of Finland and Sweden and analyses the applicability and application of both international and national law when ships, their owners/operators and crews are suspected of sabotage, as well as aggravated interference with telecommunications. **(**Bäckdén, P. 2023.). The Baltic Sea is used by the vessels which enter the Russian ports. On their way from the Danish straits to St. Petersburg, ships cross many cables laid on the seabed that cross the sea from one country to another.

For example, the vessel Eagle S was dragging its anchor on seabed for little less than one hundred kilometers close to the Finnish territorial waters and during that exercise, it broke altogether four telecommunication cables and 2 electricity transfer cables causing damage to cable owners which has, according to public sources, been estimated in tens of millions of US dollars or euros. Especially in the Gulf of Finland (between Finland and Estonia) the water dept. is so shallow that it is possible for the vessels anchor to reach the cables.

Underwater cable damages are not uncommon phenomena at sea. They happen accidentally when vessel have anchored and negligently do not check from the charts that they are in an area where the cables have been laid. Until the developments in past months the information where the cables have been laid has been public information. Due to the increasing number of incidents, however, the use of this information has been restricted, and all information is no longer publicly available.

Vessel owners are liable for the damage caused even when the anchor causes damage to cables incidentally. Liability is normally affected in a way that ship-owners liability insurance, the P & I club, pays compensation for the damage. If the owners of the damaged underwater infrastructure demand compensation and threatens to arrest the vessel, The P & I club normally gives a guarantee and the vessel can continue its journey. In these normal cases the vessel does not have to be arrested as the guarantee is in force if the investigation and possible legal procedures are over. In normal cases where the damage is unintentional, there is no procedure if the P & I Club accepts the amount of damage and the compensation for repairing the cable.

3. International legal background

3.1. United Nations Convention on the Law of the Sea, UNCLOS

The ability of coastal states to intervene in the activities of vessels is based on both the UNCLOS Convention and national criminal law. (Bäckdén, P. 2023.). According to Article 17 of UNCLOS, "ships of all states, whether coastal or land-locked, enjoy the right of innocent passage through the territorial sea." Innocent passage is defined as navigation that is not harmful to the security of the coastal state under Article 18 of UNCLOS. Article 19 of UNCLOS further elaborates on what constitutes innocent passage, stating that passage is considered innocent if it is not: 1) Prejudicial to the peace: Activities that could disturb the tranquility of the coastal state. 2) Threatening the good order: Actions that could disrupt the legal and social order of the coastal state. 3) Harmful to security: Any conduct that poses a threat to the state's safety, including military activities or espionage.

If we look closer to the facts of the case Eagle S, we can consider that if the vessel would have crossed the Finnish or Estonian territorial waters, it would have violated the UNCLOS as according to what has been stated above, its journey could not have been considered as" innocent passage".

For a long time, the width of Finland's territorial sea was 4 nautical miles, but it has since been changed to 12 nautical miles. However, in the Gulf of Finland, it has been agreed with Estonia that the territorial wall of the two countries will be left with a free passage route. Thus, in a large part of the Gulf of Finland, Finland's territorial sea does not reach the full 12 nautical miles and follows a fault line that runs at least 3 nautical miles from the central line of the Gulf of Finland. Correspondingly, the external border of the Estonian territorial sea is at least 3 nautical miles from the midline of the Gulf of Finland. On the basis of the demarcation, the route division used for international shipping in the area will be excluded from the territorial water control of the coastal states, and an unrestricted route will be secured for international maritime and air traffic to St. Petersburg and Kronstadt. (Hakapää K, 2010.)

In international waters, the provisions of international law concerning the state of necessity may also be applied, the conditions for the application of which are explained below. These enable the authorities to intervene in the operation of the vessel even when the vessel is outside territorial waters or economic zone.

3.2 The possibility of invoking an act of necessity

When a vessel registered in another state criminally destroys submarine cables on the high seas, the owner of the cables has several options under international law. The owner can report the incident to the authorities of the flag state of the vessel that caused the damage. The flag state has the responsibility to investigate and taking appropriate action against the vessel and its crew. Under the International Convention for the Protection of Submarine Telegraph Cables (Paris Convention), it is a punishable offense to willfully or negligently damage submarine cables. There the owner can seek compensation for the damages caused. The

owner can also pursue legal action against the offending vessel and its owners in the courts of the flag state or through international arbitration. **(**Thjoernelund M, 2009.)

These actions would not have been helpful if in the case Eagle S as the Finnish authorities would have had to act to prevent even further damage. In case like this regarding the possibility of invoking an act of necessity, international law recognizes the doctrine of necessity as a defense in certain circumstances. According to Article 25 of the International Law Commission's Draft Articles on State Responsibility, a state can invoke necessity to preclude the wrongfulness of an act if it is the only way to safeguard an essential interest against a grave and imminent peril.

In this case however the Finnish authorities were not forced to base their acts on act of necessity as the master of Eagle S voluntarily moved the vessel to Finnish territorial sea when asked to do that by the authorities. The authorities boarded the vessel only after the vessel had voluntarily entered the territorial's sea area where the authorities have jurisdiction to act and the vessel can be seized for investigation.

4. Seizure and arrest of vessels and the position of the crew

4.1 Seizure for investigation

The vessel may be detained for the duration of the investigation by decision of the authorities. The movement of crew on board the ship may be restricted to secure the investigation. The crew's right to communicate by telephone or online may be restricted and, if the investigation is prolonged, the crew may be banned from travelling or arrested. In the case of the Eagle S, the vessel was detained by the authorities for more than two months for investigation due to the investigation of the vessel, its anchor and crew interrogations. The criminal investigation lasted a total of five months, during which time three crew members were banned from traveling. The first two months the crewmembers were on board and the remaining three were ashore in Finland, waiting for the investigation to be completed and charges to be brought. Other crew members were allowed to leave with the vessel or when the replacement crew arrived before the departure of the vessel.

4.2 Seizure for collateral damage in relation to criminal procedure

n addition to the investigation, the authorities can apply for the seizure of the vessel. A prerequisite for the imposition of a confiscation of security is that the property belongs to a person who is suspected of a crime or who can be sentenced to compensate for the damage or to pay compensation or to forfeit a sum of money to the State, and there is a risk that the said person will try to avoid payment of a fine, compensation for damages, compensation or a sum of money by hiding or destroying his or her property, fleeing or in some other comparable way. Before the prosecution is brought, an application for the seizure of property may be made by an officer with the power of arrest. Once charges have been brought, the prosecutor may make a claim. If a vessel is ordered to be confiscated, the crew will have to spend all the time on board for the duration of any criminal proceedings, as the maintenance and servicing of the vessel is necessary to maintain its value. If the entire crew is not subject to a travel ban, the owner of the vessel may change the crew or the part of the crew that is not subject to a travel ban. The trial and its various court instances can take up to years, and the security confiscation can be kept in force until the vessel can be sold by the authorities to cover the damages suffered by the owners of the underwater infrastructure.

4.3 Arrest of vessel

Arrest plays a key role in securing maritime claims in general. The arrest of a vessel secures the right of the court to examine the claim and the enforcement of a future judgment or arbitral award. The Maritime Codes regulations in Nordic countries are based on Arrest Convention 1952. In addition to the provisions of the Maritime Code, the provisions of the Code of Judicial Procedure and the Enforcement Act on precautionary measures and their enforcement are also applied to the seizure of a vessel. (Wetter stein, P. 2024.) It is often the owners of the underwater infrastructure who must initiate the arrest first as a precautionary measure when there is still no knowledge of the essential evidence for criminal procedure and seizure for collateral damages. Even in cases where the vessel is arrested the crew must stay in the vessel during the arrest as the vessel must be maintained. Crewmembers can also be prohibited to travel when the vessel is arrested if the investigation is ongoing. In this way Seizure for collateral damage in relation to criminal procedure and arrest are both ways to

prevent the vessel from leaving and they are both initiated for securing the compensation of damages. The first one is initiated by the administration and the second one by owners of the underwater infrastructure. Both can cause that the vessel to stay in a foreign country for months or even years.

5. Crew Penalties and Liability

Cutting submarine cables with an anchor can be punished as aggravated destruction and aggravated interference with telecommunications. Both crimes are punishable only if they are intentional. A conviction for aggravated destruction always leads to a prison sentence, the length of which can vary from two years to ten years. Aggravated interference with telecommunications is punishable by imprisonment for a minimum of four months and a maximum of five years.

The criminal penalties for the ship's crew can be serious because of the suspicion of a serious crime. Prison sentences for such crimes are always unconditional, so the captain and crew members can face even up to 15 years in prison if found guilty. This kind of penalties can be compared in length with trafficking large amounts of drugs with a vessel in Nordic countries jurisdiction.

The compensation of damages is generally directed to ship-owner or operator, but also seafarers' liability for damages is an element which can be subject that arises in connection to criminal proceedings if they are found liable. Shipping companies may also be sentenced to criminal liability (liability of legal persons) for their actions, if it can be shown that the shipping company is aware of or has approved of the activities.

5. Conclusion

The Eagle S case can become important precedent. It has achieved a lot of publicity worldwide. By the time this article is published, it is probable that at least the first instance criminal court proceedings have ended, and we are aware of the faith of the persons involved. It is important that seafarers will be informed of the outcome. Even the time spent in foreign country under investigation is a fact which should be considered even when any similar intentional acts cross a seafarer's mind in future.

Cover Letter

Attached to this Cover Letter please find my manuscript entitled Seafarers legal position when vessels are used for illegal activities against marine infrastructure, submitted for publication in conference proceedings of the IAMU AGA 2025

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Life Skills, Technological Awareness, and Attitude of Maritime Students toward Emerging Technologies: Bases for a Proposed Academic Intervention Plan

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Abstract: This paper compares and investigates the association between three constructs, namely, life skills, technological awareness, and attitude toward new technologies, among maritime students. A descriptive approach was employed to analyze data collected from a survey administered to 3,552 students from maritime schools. Statistical analyses were done using Mean, Standard Deviation, One-way Analysis of Variance, Scheffe test, t-test for Independent Samples, and Pearson's r, which revealed high levels of life skills and awareness of emerging technologies, and a highly positive attitude toward them. Significant differences were noted when students were clustered according to academic institutions, degree programs, and academic year level. It was also found that life skills, technological awareness, and attitude towards technology are moderately correlated. Enlightened by the findings, the researchers developed an Academic Intervention Plan to prepare students for the growing demands of the industry in this digital era.

Keywords: life skills; technological awareness; emerging technologies; maritime students; academic intervention plan

1. Introduction

In this digital era where everything changes fast, being technologically literate is an advantage for seafarers. Seafarers must not only be able to communicate effectively, but also adapt to and manage technology as the industry transitions toward digitalization and automation. Alongside this, seafarers must possess adequate coping skills to survive (Chen et al., 2018). They must also be physically, mentally, and technologically ready to adapt to these technological evolutions in keeping with the enormous challenges that could affect their career and work performance. Rethinking education and training must align with technological innovations (Wagner & Włochowicz, 2021). Technology must be emphasized in designing effective educational curricula that heavily rely on critical thinking skills and problem-solving techniques (Hendawi & Nosair, 2020). As a Global Maritime Professional, a person working in the maritime sector must possess all the technical skills necessary for their specific operational job and must display high levels of leadership, professionalism, and ethics, interpersonal skills, emotional intelligence, and sensitivity to the needs of people from different cultural backgrounds. They must be adept at contemporary maritime industry issues (International Association of Maritime Universities (IAMU). With these priorities, honing the seafarers' life skills and technological preparedness is crucial and must be seriously addressed by maritime institutions.

2. Theoretical Framework

The Social Cognitive Theory, as proposed by Albert Bandura (1963, cited in Colledge, 2002; Bozack, 2011), and Technological Determinism (Oliver, 2011; Hallstrom, 2022) discuss the interconnectedness between life skills and technological awareness. Individuals learn and acquire skills through observation, imitation, and modeling of others; hence, individuals who interact with others with strong technological awareness are more likely to develop

similar skills. Technological Determinism Theory, on the other hand, suggests that technology can shape society and influence human behavior.

2.1 Objectives

This investigation specifically aimed to: (1) Determine the level of life skills of maritime students as a whole and grouped according to MHEI, program, and academic year level; (2) Determine their level of technological awareness and prevailing attitude toward emerging technologies when taken as a whole and grouped according to the same variables; (3) Find out if their life skills, technological awareness, and attitude toward emerging technologies significantly differ when the same variables are considered, and (4) Determine if there is a significant relationship between maritime students' life skills, technological awareness, and attitude toward emerging technologies. This study proposes an Academic Intervention Plan to optimize strengths and bridge gaps.

3. Methods

Descriptive comparative and correlational designs were employed in this study. The respondents were 3,552 maritime students taking up Bachelor of Science in Marine Transportation and Bachelor of Science in Marine Engineering from seven Maritime Higher Education Institutions in the Philippines, selected through stratified proportional random sampling. Data were gathered through a researcher-made survey questionnaire composed of the following parts: Part 1-Respondent's Profile, Part 2- Life Skills Inventory, Part 3 - Survey on Technological Awareness, and Part 4 - Survey on Attitudes toward Emerging Technologies. Validity and reliability were established through factor analysis**,** Lawshe's Content Validity Ratio (CVR), and Cronbach's alpha. Data were analyzed using mean and standard deviation, One-way ANOVA, Scheffe test for post hoc test, t-test for independent samples, and Pearson's *r*. inferential statistics were set at .05 alpha.

4. Results and Discussions

4.1 Life Skills

Table 1 reveals a *high* level of life skills on all dimensions, with an overall mean of 3.87 and the highest means obtained for Self-Management Skills (3.97), Resilience Skills (3.94), and Interpersonal Communication Skills (3.88), and the lowest for Problem-Solving Skills (3.76), implying that maritime students have a satisfactory ability to regulate their behavior, thoughts, and emotions, manage their time, accomplish their tasks, deal with stress, adapt to change, work under pressure, and upgrade themselves to grow in knowledge. Today's generation of future officers needs to develop optimum skills to easily adapt to the realities of seafaring (Estimo et al., 2020; Ghosh & Emad, 2024). Moreover, equally important as the acquisition of cognitive skills is the development of social and emotional coping skills, also known as life skills, which help promote the development of well-being and competence in young people as they face the challenges and realities of life (Yadav & Iqbal, 2009).

Table 1. Level of Life Skills of Maritime Students of MHEIs in the Six Dimensions When Taken as a Whole.

Dimensions	SD	Mean	Interpretation
Self-Management Skills	0.69	3.97	High
Resilience Skills	0.82	3.94	High
Interpersonal Communication Skills	0.82	3.88	High
Leadership Skills	0.82	3.84	High
Decision-Making Skills	0.78	3.83	High
Problem-Solving Skills	0.76	3.76	High
Total	**0.69**	**3.87**	**High**

4.2 Technological Awareness

Maritime students have a *high* level of technological awareness, implying that they satisfactorily understand the knowledge and skills relevant to the role of technology in the context of school and seafaring and of some

technologies that have emerged in the maritime industry. However, formal education about purpose and the competencies necessary to operate autonomous ships is important (Ghosh & Emad, 2024; Sharma & Kim, 2022). The Social Cognitive Theory by Albert Bandura (1963, cited in Colledge, 2002; Bozack, 2011) suggests that individuals who observe and interact with others with strong technological awareness are more likely to develop similar skills.

Moreover, the Technological Determinism Theory cited in Oliver (2011) and Hallstrom (2022) suggests that technology can shape society and influence human behavior. Both theories suggest that individuals with strong technological awareness are better equipped to adapt, succeed, and thrive in a technologically advanced society.

4.3 Attitude toward Emerging Technologies

The data from the attitudinal survey revealed a *positive* attitude (M = 3.96, SD = .70) toward the role of emerging technologies in the shipping industry. This implies that they hold no resistance to the idea of adopting smart technologies in their work as future seafarers. Receptiveness to change requires a stronger infrastructure, specialized knowledge, training, a long-term vision, cost-benefit analyses, and sufficient utilization to sustain the change (Moerschell, 2009).

4.4 Differences in Maritime Students' Life Skills, Technological Awareness, and Attitude toward Emerging Technology

4.4.1 Life Skills

Overall, significant differences in all components of the students' level of life skills were found when grouped according to MHEI (*F*-value = 17.69; *p*-value = 0.000).

Table 2. One-way ANOVA on Life Skills When Classified according to MHEIs.

Variables	Sig.
Life Skills	.000
Interpersonal Communication Skills	.000
Problem-Solving Skills	.000
Decision-Making Skills	.000
Leadership Skills	.000
Resilience Skills	.000
Self-Management Skills	.000

Table 3 reveals that the life skills of BSMT and BSMarE students are significantly different in all dimensions, implying that BSMT students have better life skills than BSMarE students.

Table 3. T-test on Life Skills When Classified according to Program.

Variables	Sig.
Life Skills	.000
Interpersonal Communication Skills	.000
Problem-Solving Skills	.004
Decision-Making Skills	.000
Leadership Skills	.004
Resilience Skills	.000
Self-Management Skills	.000

The life skills that first-year, second-year, and third-year maritime students have acquired are also significantly at different levels, as revealed in Table 4.

Table 4. One-way ANOVA on Life Skills When Classified according to Year Level.

Variables	Sig.
Life Skills	.000
Interpersonal Communication Skills	.001
Problem-Solving Skills	.000
Decision-Making Skills	.000
Leadership Skills	.000
Resilience Skills	.000
Self-Management Skills	.000

4.4.2 Technological Awareness

Significant differences were found in the maritime students' level of Technological Awareness when grouped according to MHEI (F-value = 12.18; *p*-value = 0.000). The results also revealed that BSMT students are more technologically aware than BSMarE students. No significant differences were noted in the technological awareness of maritime students when grouped according to academic year level. Technology at the university level has become a key component in creating educational courses (Hendawi & Nosair, 2020). Investigations must be done to examine where it stands in the context of the students' awareness and attitude, as adopting any new technology is influenced by these factors. Hence, when an institution implements technology, it must consider students' level, knowledge, and attitude (Nasur & Bogusławski, 2020). Technological awareness influences people's attitudes toward technology (Lee et al., 2005). Resistance to technology is mitigated if its target users are properly educated and trained about its functions and benefits.

4.4.3 Attitude toward Emerging Technologies

When grouped according to MHEI, the attitudes of maritime students toward emerging technologies differ significantly (F-value = 13.61; p-value = 0.000). Moreover, significant differences were also noted when maritime students were grouped according to degree program (p- value = 0.000) and academic year level (F-value = 8.47; p-value = 0.000).

Table 5. One-way ANOVA on Attitude towards Emerging Technologies When Classified according to MHEIs.

Variable	Sources of Variation	Squares	df	Sum of Mean Square	F	Sig.
Attitude toward	Between Groups	39.15	6	6.53	13.61	.000
Emerging	Within Groups	1699.79	3545	.48		
Technologies	Total	1738.94	3551			

Table 6. t-test on Attitude towards Emerging Technologies when classified according to Program.

Programs	n	Mean	SD	t	df	Sig.
BSMarE	1280	3.89	.715	4.444	3550	.000
BSMT	2272	3.99	.688			

Table 7. t-test on Attitude towards Emerging Technologies When Classified according to Year Level.

Variable	Sources of Variation	Sum of Squares	df	Mean Square	F	Sig.
Attitude toward	Between Groups	8.26	2	4.13	8.47	.000
Emerging	Within Groups	1730.68	3549	.49		
Technologies	Total	1738.94	3551			

Seafarers equipped with essential life skills, such as interpersonal communication skills, problem-solving skills, decision-making skills, leadership, resilience, and self-management skills, are better prepared to handle the challenges and demands of their profession, particularly with the continued advent of new technologies. Furthermore, cooperation, creativity, invention, and other applicable skills must be directly taught to prepare students for success in whichever jobs, trades, occupations, or professions they will join after graduation (Kivunja, 2015).

Technological awareness at the university level has become a key component in creating educational courses (Hendawi & Nosair, 2020). Investigations must be done to examine where it stands in the context of the students' awareness and attitude, as adopting any new technology is influenced by these factors. An institution that implements technology must consider students' awareness level, knowledge, and attitude (Belkhir, 2025). Technological awareness influences people's attitudes toward technology (Lee et al., 2005). Resistance to technology is reduced if its target users are properly educated and trained about its functions and benefits. The researchers of this investigation argue that the attitude of maritime students toward emerging technologies can be more positive if their technological awareness is improved.

4.4.4 Relationship between Life Skills and Attitude toward Emerging Technologies

Table 8 reveals that there is a moderately significant positive relationship between maritime students' life skills and attitude toward emerging technologies (p-value = 0.000). This implies that strengthening their life skills can have a moderate influence on their development of a positive attitude toward emerging technologies.

Table 8. Relationship between Maritime Students' Life Skills and Attitude toward Emerging Technologies.

Variables	r	Strength of Relationship	p
Life Skills	0.636	Moderate	0.000*
Attitude toward Emerging Technologies			

**p<0.05, Significant*

4.4.5 Relationship between Maritime Students' Tech Awareness and Attitude toward Emerging Technologies

Table 9. Relationship between Maritime Students' Tech Awareness and Attitude toward Emerging Technologies.

Variables	r	Strength of Relationship	p
Technological Awareness	0.661	Moderate	0.000*
Attitude toward Emerging Technologies			

One's attitude towards a new technology is formed based on his knowledge of it (Harborth & Kreuz, 2020; Lee et al., 2005). If students are educationally well-equipped, they are more likely to embrace technology than resist it. Lee et al.'s (2005) research supports the Theory of Reasoned Action (TRA), which suggests that users' knowledge is an important predictor of their decision to adopt new technologies. If you inform people of the advantages of technology, they are likely to take a positive stance towards it. This underscores the need for including broad knowledge and training programs covering the operations, advantages, and potential utilization of newly developed technologies in the shipping industry in the maritime education curriculum to create a positive and receptive mentality towards new technologies among the students in maritime education. Maritime schools can also incorporate courses related to the new technology in their curriculum to cultivate the interest of students in the new technology in the maritime industry.

5. Conclusion

Today's maritime students are equipped to survive in this modern world. The life skills that they acquire improve as their education levels up. Their high awareness of emerging technologies and their positive attitude toward them are shaped by the relevant education and training they receive while in academe. However, a more tailored approach is needed to enhance their familiarization with technologies specific to their course programs. This calls for an integrated approach that focuses on nurturing life skills and technological awareness to have a significant impact on students' attitudes toward emerging technologies,

which the Academic Intervention Plan aims to address.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Finding Importance of factors by statistical analysis of big data – maritime accidents happened in Indian waters

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Abstract: Maritime industry accidents that always raised awareness among researchers and policymakers. This paper aims to search for the operational factors by bibliometric analysis. Secondly, check their potential in the real-time occurrences of maritime accidents and incidents that happened in the Indian Ocean between 2014 to 2023. In total, 5865 related papers obtained from a bibliometric search were examined for four types of accidents. VOS viewer software is used to find the factor terms and, document-term matrix. Statistical analysis resulted in nine groups and their influence on four kinds of accidents, like collision, capsize-sink, fire-explosion, and grounding, are found in the documents by using the statistical method of neural network. Then these factors are applied to real-time incidents and accidents. Each case of marine accidents is found with 36 factors of operation and 49 variables that are related to the vessel and incidents. Factor analysis of these factors resulted in six new variables that possess close resemblance to the above nine groups of bibliometric analysis. Logit regression of these factors over 860 real-time accidents concluded that 24 factors are highly vulnerable to the occurrence of accidents and must be eliminated, whereas the other 12 can be reduced to a safer extent by taking necessary steps.

Keywords: capsize and sink, fire and explosion, collision, grounding, bibliometric analysis,

1. Introduction

Two main causes are postulated for ship losses (Faulkner, D. 2003(: (1) the operational causes contribute around 60% of cases, including fire, collision, and machinery damage, (2) design and maintenance-related causes contribute 40% of cases, involving cases like water ingress, hull breaking in two, and capsizing. Accidents are often multifaceted, as many different factors impact the cause of one accident (Koliousis, T. 2012) or one factor may be responsible for many different causes of different sorts of accidents (Sampson *et.al.* 2002). Different documents identify various factors causing these accidents to varying degrees. This paper presents a bibliometric statistical analysis of the available documents of maritime accidents, aimed at identifying the influencing factors associated with these events. Later, these factors are applied over a data set of real-time accidents to examine the vulnerability potential for their occurrence.

2. Methodology of Bibliometric analysis

2.1 Review design

Factor analysis of maritime accident data is a part of big data analysis that can be regarded as a disruptive technology used to extract valuable insights. This data analysis was done on two different sets of maritime data related to accidents and incidents. Initially, the bibliometric analysis was carried out, and significant, prevalent factor variables were found that are directly or indirectly responsible for the occurrence of accidents. The bibliometric review was introduced by Pritchard (1969) with an argument that it has the potential to provide insights into research in a specific field by using quantitative analysis of data. Thereafter, the influence of these variables over the real-time accidents has been analysed.

2.2 Collection of documents and indexing strategy, and screening

The Scopus database is preferred as it is comprehensive and wide [Hosseini MR *et.al.*] [Hong Y *et.al.*], also a rapidly growing database in providing prominent academic literature in any specific scientific domain [Chadegani DAA *et.al.*] [Olawumi TO *et.al.*]. "Co-occurring keywords analysis" was carried out with an online search of documents using specific keywords "maritime accident", "ship accident", and "incident". The documents include journal articles and conference proceedings, as these are reliable, dependable sources and provide more exhaustive material than other sources [Zheng X *et.al.*]. The data was then imported into VOS viewer for study. This resulted in 5865 documents, subjected to the second phase of analysis for specific keywords such as collision, capsize & sink, fire & explosion, and grounding for analysis.

Table.1: Outline for research design

SCOPUS database Initial output = 18258 documents subjected to screening Filtered Output = 5865 VOSviewer for text mining Bibliometrics Co-occurence of keywords analysis	Duplication removal has eliminated 4888 duplicates from 18258 documents. Later relevancy and other screening criteria resulted in 5865 documents. All 5865 document abstracts were subjected to keyword analysis by using VOSviewer software [Cobo MJ *et.al.*], [Van Eck NJ *et.al.*], resulting in 72540 terms as keywords. Out of which 1572 keywords were selected that have a 12 times repetition. Scrutinizing each one qualitatively narrowed down to 104 terms.

2.2 Categorizing documents with Co-occurring keywords analysis and finding the category of factors

The documents obtained spreads over six themes: 1) Different categories of incidents or accidents. 2) Different methods used for accident analysis. 3) The influence of a factor or a group of factors on the causation.) Suggest regulatory requirements. 5) Descriptive analysis of certain types of incidents or accidents. 6) Comparative study with the other sectors. As per these themes, nine groups of influencing factors were obtained by using cluster analysis.

For this, a data matrix was prepared consisting of literature versus the group of factors for each type of accident. This matrix was transported to SPSS for factor analysis and neural network formation. These nine groups are as Group 1 is ship-related factors (denominated as G1, shipRF) are the ship characteristics related to ship construction, ship design, installed equipment, damage and deterioration of the structure/equipment/system, like age, length, draught, hull, damage conditions, superstructure, freeboard, etc. These ship-related factors include the ship's original parameters, which lead to the strengths and weaknesses of the ship. Group 2 is the cargo-related factors or cargo-carrier-related factors (G2, cargoRF) are in the domain of the type of cargo, different types of ships for these cargo transports, and cargo transport activities. It includes all types of cargoes and types of ships used for this cargo transport, like bulk carriers, fishing vessels, etc., and different types of cargoes like oils, chemicals, timber, ore, containers, grain, vehicles, and passengers in ferry transport. There are dangers associated with each type of cargo, a variety of types of vessels used for this cargo transport, stowage of cargo, degree of diligence maintained for stowage; and all of these affect the seaworthiness of the vessels. *Group 3* is the technical conditions related factors (G3, TechRF), which include the technicality of operation, running defects, shortcomings, and technical support culture in the organisation. Examples like steering failure, hull failure, engine failure, absorbed energy, released energy, accident report details, actual design, AIS data, aluminium structure, bottom plate damage, bottom strength, brittle crack, brittle fracture, collision avoidance processes, collision damages, compartment structure, composite material used, composite material types, bow effects, etc. *Group 4* is the vessel operability related factors (G4, OpbltyRF) that reflects the operational condition and nature of the ship at the time of accident, and includes factors like dynamic stability, emergency standby, fire/explosion potential, factor of safety, various failure potentials, elapsed fatigue life, flooding ability, grounding ability, hazard situations, instability standard, intact stability condition, metacentric height, performance of related machinery, any prediction done before, prevention standards, protection probability, quality standards, reliability standards, technical requirements, hull resistance, material safety standards, ship capsizing prevention criteria, existing threats, unsinkability conditions, etc. *Group 5* factors related to nature or environment(G5, NatenvRF) contain factors in the domain of weather and climate conditions, sea conditions, environment etc. are like air pressure, humidity, temperature,

beam sea condition, buoyancy factor, calm water condition, date, weather forecast, predicted and announced environment, existing environmental condition, heavy sea, heel tendency, incident time, marine environment, nature, observation made, ocean condition, oil pollution potential, oil spill area, period of the incident, sea condition, sea state, shallow water, wind speed, speed of the ship, water surface effects, time domain, time-domain simulation, water level, wave encountered, wave condition, predicted weather, weather report, wind, seasons etc. *Group 6* is the navigational condition-related factors (G6, NavRF) related to navigation activities like rudder angle, course, moment, motion, movement, navigation watch, roll, roll damping, roll motion, roll response, swell, slip, transportation, treatment, trim, etc. *Group 7* represents human factors (G7, HumanRF) are due to human resources involving seafarers and related organisations like shipping offices, cargo handlers, owners, ports, etc. The factors remain in the domain of qualification and competence, readiness to incident, work culture, job specification, communication, language, organizational culture, behavioural approach, ability, act, behaviour, attitude, master, casualty response, concept understanding, human concern, contacts, country, crew, crew leader and member, decision, education, emphasis, experience, fatality response, free enterprise, group behaviour, human error, human factor, human life, knowledge, life, member, passenger, patient, person, position, regulator, relation, relationship, survival, survivor, training, etc. *Group 8* is the route or passage related factors (G8, RouteRF) are related to the passage, are like traffic level, area of disaster, routing effect, range of operation, place, port, sea, seaway, space, world, approach, region, area channel, circumstance, coast, depth, distance, distribution, field, location, regular path, route, stage, strait, voyage, etc. Finally, *Group 9* is the organisation related factors (G9, OrgznRF) are like obligation towards and control of flag state, port state, regulatory authorities, IMO, international law, national law and the keywords are classification society, company control, agreement, government, guideline, rule implementation, code implementation, policy regulation, AIS data, industry, information, major loss, management, impact, pollution possibility, principal, organisational program, procedure, property, recommendation, report, response, rule, finding, investigation etc.

3. Analysis for bibliometric

3.1 Statistical analysis for analyzing the importance of a group

These factor groups and the importance of these factors were found for four fundamental categories of accidents, such as capsize and sink as 1, collision as 2, fire and explosion as 3, and grounding as 4, in Table 1. These accidents are dependent variables, and factor groups are independent variables used for statistical analysis. The total number of documents searched is 5865. For each, a document–term matrix was prepared under these nine groups. Then the matrix was transported to SPSS 20. Taking the nine groups as independent variables, explorative principal component factor analysis was applied with Varimax rotation. The Kaiser–Meyer-Olkin and Bartlett's test revealed that the data is appropriate for analysis, according to the KMO measure of sampling adequacy value of 0.8 or more, and significance value less than 0.05. Refer to Table 1. Factors of the groups were extracted based on the following three analytical criteria: (i) Pairwise deletion, (ii) Eigenvalue more than 1.0, and (iii) factor loading more than 0.50. Some groups that failed to attain a minimum loading of 0.5 were less effective or less important for the category of an accident. If the theoretical significance of any item was considered important, then they were considered. The data is subjected to a Multilayer Perceptron Network of Neural Network analysis, with the dependent variable being the type of accidents, and the nine groups of factors are regarded as the independent variable. Partition for training kept 70% and for testing 30%. Rescaling the covariate kept the standardised form. In each case, the model summary revealed that relative errors are almost the same for training and testing. Again R-squared value for the residual versus predicted value plot is very low. Independent variable importance visualised from this analysis. The correlation matrix in each case reveals that there exists a good correlation (value greater than 0.5) 1) between technical factors and vessel operability standard factors, 2) between organizational, rule, and regulatory control-related factors with vessel operability standard factors.

3. Results discussion for bibliometric analysis

Table 2 specifies the steps and numerical values for each activity. After checking the KMO values data is processed for neural network analysis in a multilayer perceptron, keeping 70% cases for training and the rest 30% for testing. The importance of the nine groups of factors towards all four types of accidents analyzed from the documents is shown in Figure 1

Table 2: Statistical activities

Activity	1	2	3	4
Number of documents obtained after bibliometric keyword search	5865	5865	5865	5865
The number of literature documents remained after filtration	641	1902	768	673
Number of factor-terms found by using VOSviewer	14233	21303	15356	14928
The final number of factor terms after filtering	480	626	269	1406
'KMO and Bartlett's test' - KMO measure of sampling adequacy	0.883	0.799	0.906	0.781
Significance value	0.000	0.000	0.000	0.000
Communality table infers the weightage of the factors, and the extraction method applied is Principal Component Analysis	G4>G8> G3>G9	G3>G4 >G1>G8	G3>G4 >G9>G5	G3>G1 >G4>G2
In a multilayer perceptron in neural networks training percent and the testing percent	67.7% 32.3%	69.8% 30.2%	70.2% 29.8%	67.2% 32.8%

3.1 Factors for capsize and sink, collision, fire and explosion, and grounding

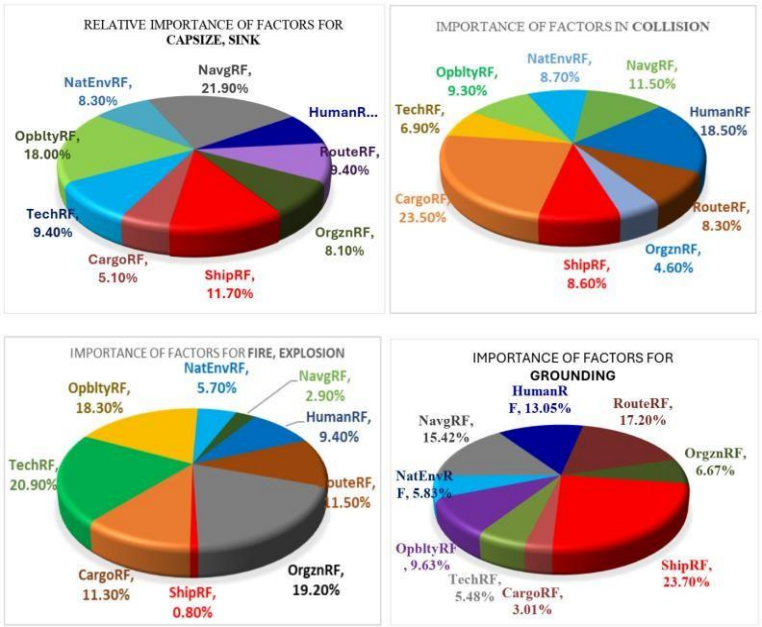


Figure 1. Factors for capsize and sink, collision, fire and explosion, and grounding.

4. Application over real-time incidents

4.1 Real-time incident data, factors, and their correlation and factor analysis by using SPSS 20

Real-time accident data collected from the accidents that occurred in the Indian Ocean limits (geographical limitation) from 2011 to 2023. A total of 1497 accidents were reduced to 860 cases after data refining. Each case is characterized by 49 variables and 36 reason factors. Here, only factors are considered, and those responsible for the occurrence of these accidents were traced from each case and collected and collated together. These factors are either direct or latent concealed types possessing effect over the occurrence of accidents, and hundreds in number that compiled to 36 reasoning factors. Bivariate correlation among the factors resulted in 97.2% of correlations being below 20% weightage. Out of (36X36 = 1296) relations, a total of 37 relations are more than 0.2 or less than – 0.2; this means 2.8% correlations are above 20%; Only 6 correlations are more than 0.3 or less than – 0.3.

These 36 factors in the form of a questionnaire valuation were subjected to dimension reduction factor analysis by using SPSS 20 and resulting in 13 components with eigenvalues greater than 1. Descriptive method chosen, KMO and Bartlett's test, and Anti-image test are opted for; For Extraction, Principal components method used. The Varimax rotation method is used and suppresses small coefficients below 0.4; This resulted KMO value is 0.708, sufficiently good (values more than 0.5 are considered good). Bartlett's Test of Sphericity showed the value of R=0, significance value less than 0.05 (obtained value = 0.000). This indicates that the total dataset is fit for factor analysis. Communality of each factor (initial value) for all is more than 0.3 (if this value is less

than 0.3, it can be regarded as a factor directly, which can create a critical situation). Also, extraction is more than 0.3. These 13 components, which are obtained by the quantitative method, cannot evaluate the matters subjectively. So, subjected to a qualitative clustering to overcome the limitation of statistical analysis. Hence, closely associated factors (subjectively) were put into a single group and resulted, 6 groups of factors. Thus, 36 factors are grouped into six variables. Table 2 describes how these factors are grouped.

4.2 Close resemblance with factors of bibliometric analysis – grouping these factors

Owing to these two facts, the factors were evaluated subjectively, and this reduced the 13 components to 6 close groups. These six groups were found to have a close resemblance to the factors obtained from bibliometric analysis. Each one is considered a factor that substantially hampers healthy and desirable sustainable maritime practices.

Table 2 - Resemblance between factors of real-time data and the factors of bibliometric data.

Variable	Factors from real-time data – answers to Questionnaires	Factors from Bibliometric data	Remarks
Management and watch-keeping standards 1st variable –	Observation, watchkeeping found improper; 2. Wrong order/information – passed on or perceived and wrongly followed. 3. The procedures followed are neither right nor approved for cargo, machinery, and other operations. 4. Working in improper conditions, negligence of human values, and not following a safe and secure culture. Poor judgment leading to wrong action Sleepy and sleep debt Stress Fatigue Watch routine found defective 9. Equipment in ER, cargo, and others is uncertified or improperly used, or substandard 10. Defective bridge performance & defect in using navigational equipment Poor communication	Group 6 is the navigational condition-related factors (denominated as G6 or NavRF) Group 5 is the factors related to nature or environmental factors (denominated as G5 or NatenvRF)	Management and watch keeping values on board; contains items regarding management on board, watch-keeping of all departments; navigation-related problems are a result of this. Stress and fatigue are generated due to mismanagement. And procedures with non-conformities, or a careless attitude from the person on board, or from the organization, support, and culture.
Competent & trained response to vessel operability standard-2nd variable	Negligence of maintenance or PMS bluffed 13. Maintenance hull, m/c without a proper schedule or PMS, not there or missing Incompetent crew; poor training, 15. Alarms defective or not understood, or incompetent to detect and act on alarms	Group 4 is the vessel operability-related factors (denominated as G4 or OpbltyRF),	It is management on board, watch-keeping of all departments, Irresponsible behaviour, and policy paralysis, resulting in running with equipment having non-conformities
Technical and machine response 3rd variable	16. Incompetent traffic management or preparation Steering gear defective Propulsion m/c defective 19. Operation errors of the pilot or during maneuvering Sudden power failure of rudder gear or ME, or any major equipment	Group 3 is the technical conditions related factors (G3 or TechRF) Group 8 is route or passage-related factors (G8 or RouteRF)	Contains items regarding items required for vessel motion, also Readiness for the traffic congestion, Machinery response during traffic movement or maneuvering, also mismanaging the traffic.
Human element 4th variable.	Labour condition – MLC related Inadequate capacity/ manpower Lack of motivation	Group 7 is the human factors (denominated as G7 or HumanRF)	Contains items regarding motivated and sufficient manpower, MLC 2006 related, compatibility, and control;

Ship systems, design, and handling 5th variable	FFA equipment is defective The pollution equipment is defective 26. Load line, water/weather-tight integrity defective LSA equipment is defective Radio/ communication equipment defective Cargo operation equipment is defective Emergency preparedness	Group 1 is the ship-related factors (G1 and shipRF Group 2 is the cargo-related factors or carrier-related factors (G2or cargoRF)	Contains defects and non-conformities regarding statutory requirements like LSA, FFA, Communication, Load line, emergency preparedness, pollution-related equipment, and safe cargo handling equipment
Vessel responsiveness 6th variable	31. Certified and verified construction and repair, or handling, not followed AIS status 33. Collision avoidance rules are noncompliant (both local and international) Overcrowding/overloading Certification, documents incomplete ISM non-conformities found live, incomplete	Group 9 is the organisation-related factors (denominated as G9 or OrgznRF)	Contain items for deficiencies towards ISM, AIS operation, Collision regulation, policy defects for overloading and overcrowding, certification, and document.

4. Analysis of application and discussion of results

The impact of these factors is analyzed, which hampers the sustainability and leads to the occurrence of accidents. Logit regression helps to find the Beta value = Logit = Log of (P/Q) = Log of (Probability of major loss/probability of minor loss), and this has predicted change in log odds – for a single unit change in the predictor, and there is Exp(B) change in the probability of outcome. Thus, the probability of a Major loss is found in percentages when a variable increases by one unit. This is a kind of predictive analysis.

Table 3. For Logit regression to find the probability of a major loss for the real-time accident data

Variable	B=Logit = Log (P/Q)	Odds ratio = Exp(B) = P/Q	Probability of the major loss = Odds/(1+Odds)	The probability of Major loss in percentage when the variable increases by one unit
Factor 1	5.911	369.249	0.997299	99.73%
Factor 2	14.727	2487558.801	1	100.00%
Factor 3	-8.442	.000	0.000216	0.02%
Factor 4	4.244	69.667	0.985849	98.58%
Factor 5	-4.219	.015	0.014501	1.45%
Factor 6	8.172	3540.935	0.999718	99.97%

5. Conclusion

Factors 1, 2, 4, and 6 show that unless these factors are accounted for and taken care of, they are going to produce definite disturbances and losses. Thus, from the 36 factors that have been quoted, only 12 factors can be reduced by using alternate arrangements, and the remaining 24 factors need to be neutralized.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Exploring Factors Influencing Workplace Wellbeing and Mental Health among Indian Seafarers

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Abstract: Seafarers play a pivotal role in retaining international trade. However, their psychological wellness remains overlooked due to the maritime industry's high-pressure and physically demanding nature. Seafarers working on long-voyage vessels stay in an isolated environment for months. Prolonged exposure to stressors such as social isolation, extended work time, and restricted access to the external environment can severely impact their overall wellness. Revitalising this gap, this study explores how psychological factors such as stress, anxiety, and depression influence seafarers' occupational wellness. It was based on a structured survey that included 380 seafarers from various vessel types and employment responsibilities. The results show that seafarer wellness is exorbitantly impacted by all three psychological elements, with depression having the huge impact, followed by stress and anxiety. This highlights the compelling need for maritime policymakers to prioritise psychological well-being alongside physical safety. Interventions such as onboard mental health support, access to counselling services, and better work-rest balance can elevate individual wellness and organisational sustainability. By aligning with the objectives of Sustainable Development Goal 3 – Good Health and Well-being, the present study evokes the pressing need for integrating mental health strategies within the maritime sector's broader health and safety framework.

Keywords: Seafarers, Mental health, Occupational wellness, stress, anxiety, depression,

1. Introduction

Mental health is inevitable for overall health (Çelik Maşalacı, 2024). The World Health Organisation (WHO) defines health as "a full condition of physical, mental, and social well-being, not only the absence of sickness or disability". Workers' psychological wellness is highly affected by physical and psychological environmental conditions (Belloni et al., 2022). In the seafarers' context, maritime labour can be more laborious and tiresome due to the nature of the profession. The work-life environments of the seafarers are closely associated. They are intertwined with isolation, intense workload, trouble sleeping, noise, vibration, long working hours, and a lack of socializing opportunities (Price, 1997). The significant prevalence of stress, anxiety, and depression among maritime labourers has been identified as a critical factor contributing to poor mental health and diminished life satisfaction within this industry (Baygi et al., 2022). The transactional model of stress and coping by (Lazarus & Folkman, 1984) lays a robust theoretical foundation for this study. It explains how the collective impact of stress, anxiety, and depression on seafarers' well-being affects their physiological as well as psychological outcomes at work.

There have been tremendous studies paying heed to mitigating the effects of shipping activities in the sea. Though seafarers' role in global trade is indispensable, their mental well- being and safety conditions often face significant challenges (Krämer, 2024). Despite accelerating interests, psychological aspects of well-being have received poor attention in maritime health research, which has largely concentrated on physical health hazards (Jonglertmontree et al., 2022). Prolonged working hours at sea, social isolation, and effort- reward imbalances are some of the characteristics that have been identified in thorough assessments on mental health difficulties as major contributors to the decline of mental wellness (Song et al., 2021). Due to heightened understanding of mental wellness at work, concerns regarding the psychological hazards faced by seafarers have started attracting attention very recently (Pauksztat et al., 2022). However, there is little, inconsistent, and fragmented empirical evidence on the frequency of depression, anxiety, and stress issues in this regard,

particularly when compared to other demographics (Mellbye & Carter, 2017). Therefore, ensuring the mental well-being of seafarers is a crucial aspect of safeguarding their overall health and professional productivity (Herrman et al., 2004; Nittari et al., 2024). This research gap reinforces the demand for statistical evidence that contextualizes psychological distress as a critical predictor of overall maritime occupational wellness.

In this given backdrop, the current study aims to explore how stress, anxiety, and depression affect seafarers' overall well-being, which is operationalized through the constructs of mental health, physical and mental harmony, and physical health (Russell, 1973; Tsui, 2021). The present study intends to provide statistical evidence on the psychological health burden within this occupational group and its consequences for personal and organisational well-being using a convenience sample of 380 seafarers employed on ships. The maritime industry has recognised the significance of addressing these issues concerning Sustainable Development Goals (SDG 3 – Good health and Well-being), where the focus is on ensuring healthy lives and promoting well-being for all at all ages, and promoting sustained, inclusive and sustainable economic growth (Carrera-Arce et al., 2022; Noufal et al., 2023). This adds to the literature by shifting the emphasis from discrete stressors to a comprehensive understanding of how mental health variables jointly shape wellness at sea.

2. Literature review and development of hypothesis

2.1 Occupational challenges and wellness of seafarers

Seafaring is a unique and demanding profession where the workers are in the workplace during both working and non-working hours (Brooks & Greenberg, 2022). Apart from being isolated in a setting that is not ideal for their mental health, maritime workers frequently endure prolonged exposures to acute physiological situations such as loud noises, vibrations, scorching weather, and fluctuating moisture conditions in the sea (Ana Slilkovic & Penezic, 2015). As per organisational stress theories, such as the Job Demands-Resources (JD-R model) (Demerouti et al., 2001), demanding aspects of work can deplete employees' energy and resources, thereby accelerating the risk of physiological and psychological health issues (Bakker & Demerouti, 2007). A gap between the effort and reward received at work is highly disheartening, as it violates the expectations about the same (Siegrist, 1996). Newer studies highlight the significance of promoting initiatives for resilience-building, mental health literacy and organisational support as new approaches to reducing occupational stress and assuring well-being among high-risk workers, including seafarers (Dohrmann et al., 2019; Tsui, 2021; Wadsworth et al., 2008)

As a multidimensional concept, the wellness of employees is overarchingly construed as a vital deciding factor of organisational sustainability, entailing physical, emotional, and mental health dimensions (Nielsen et al., 2013; Pauksztat et al., 2022). In Maslow's need hierarchy theory, optimal employee performance is attainable only when elementary physiological and safety requirements, such as mental well-being and physical stability are satisfied (Gartner et al., 2016; Locke & Robert Baum, 2014). Digital mental health solutions such as mindfulness applications and Cognitive Behavioural Therapy (CBT) have proven successful in lowering stress, anxiety, and depression symptoms, therefore enhancing the psychological well-being of seafarers (Brooks & Greenberg, 2022). Furthermore, improvements in cardiometabolic health indicators have been demonstrated by workplace wellness initiatives that emphasize healthy eating exercise (Peñalvo et al., 2021).

2.2 Depression

Depression is a psychological disorder that has a very complex etiology associated with a range of symptoms like anger, guilt or shame (Vignola & Tucci, 2014). It has an adverse impact on psychological and occupational well-being regardless of a worker's field of employment. It causes emotional and cognitive problems, lowers productivity, increases absenteeism, and has a huge impact on business and society (de Oliveira et al., 2023). Depression is shown to have detrimental consequences on occupational wellness regardless of business or occupation. Studies show that the severity of depression symptoms is directly linked to increased job impairment (de Oliveira et al., 2023; Sarkar et al., 2024; Tsui, 2021). Workers in various industries may be further impacted by factors that can exacerbate depression symptoms, such as expectations, inadequate control, job insecurity and unequal pay (Sarkar et al., 2024). Hence, we hypothesize that;

H1: Depression impacts the wellness of seafarers

2.3 Anxiety

According to (Graeff, 2007), "anxiety is a vague and unpleasant feeling of fear or apprehension that may be characterized by a tension or discomfort derived from the anticipation of danger" (Vignola & Tucci, 2014). It is linked to the perception of environmental settings like people, places, or activities that are contrasted with past experiences that trigger brain systems that have adaptive functions (Gray, 1987). Accordingly, anxiety can be viewed as an emotion associated with a behaviour risk evaluation (Graeff, 2007). Workers experiencing anxiety may exhibit withdrawal syndrome, sleep deprivation, loss of interest in work or any other activities, which could further impact their overall mental health (Maddock, 2024). Improvement in working atmosphere such as skills and discretion, work intensity, and work time and quality improves mental health outcomes such as anxiety, loss of confidence, loss of social dysfunction and risk of clinical depression (Belloni et al., 2022; Wilhelm et al., 2004) (Wilhelm et al., 2004). High pressure workplaces, job uncertainty, poor working relationships, and tight deadlines are all prevalent causes of workplace anxiety, regardless of the industry (Hwang & Jo, 2021).Hence we hypothesize that,

H2: Anxiety influences the wellness of seafarers.

2.4 Stress

Stress has been traditionally defined as, "an emotional experience accompanied by persistent tension, irritability, and a low threshold for frustration or disruption" (Vignola & Tucci, 2014). It leads to negative affect, emotional distress, and physiological changes in the mental state of an individual (Mello et al., 2007). According to (Lovibond & Lovibond, 1995), stress is "an emotional state that varies according to an individual evaluation of situations, experienced as a threat, harm or challenge". It leads to difficulty in relaxing and nervous arousal and ultimately leaves a person easily disturbed, irritated or hyper-reactive (Lovibond & Lovibond, 1995; Vignola & Tucci, 2014). Sustained exposure to challenging job conditions might overwhelm the neural system, causing decreased concentration, irritation, and low energy levels (Tsui, 2021). This accumulated tension may eventually result in somatic complaints such as headaches, burnout, muscle pain, and cardiovascular problems (Mello et al., 2007; Peñalvo et al., 2021). People who are under long-term stress have increased rates of disengagement and burnout, especially in solitary or high-risk work contexts (de Oliveira et al., 2023). Hence, we hypothesize that;

H3: Stress influences the wellness of the seafarer

3. Methodology

3.1 Data

The present study focuses on seafarers presently employed abroad in a wide variety of categories, such as container ships, bulk carriers, and tankers. To ensure coverage across the entire range of nautical roles, respondents came from various hierarchical grades, ranging from ratings to masters. The practical challenges of reaching this highly transient population led to the use of a convenience sampling method. However, participants were purposefully selected from various ship types operating under a range of shipping companies to increase the findings' diversity and generalizability. This method assisted in capturing a variety of shipboard settings and working conditions that could affect seafarers' mental and physical health. A total of 380 valid responses were collected.

3.2 Measure

The DASS-21 scale, created by (Lovibond & Lovibond, 1995), was used to measure anxiety, depression, and stress. It offers a valid and dependable framework for capturing the structure of negative emotional states. The tool is suitable for various respondent demographics because it has been culturally modified and psychometrically verified in several contexts, including the version by (Vignola & Tucci, 2014). There are 21 items on the scale, with seven items representing stress, anxiety, and depression, respectively. A five-point Likert scale, with 1 denoting "strongly disagree" and 5 denoting "strongly agree," was used to record responses. Three dimensions were used to quantify wellness: bodily health, mental and physical harmony, and mental health. This multifaceted approach to wellness is influenced by recent empirical research on measuring well-being in high-stress work environments (Tsui, 2021) and foundational work on social and psychological well-being (Russell, 1973). Standardized data analysis and interpretation were made possible by the instrument design's use of the same 5- point Likert scale to guarantee consistency across all constructs.

4. Statistical analysis

4.1 Analysis of Normality and Common Method Bias

Tests for normality and common method bias were conducted to guarantee the accuracy of the data and the suitability of applying parametric statistical techniques. With specific values of - 1.182, -1.913, 0.152, -0.504, -0.212, and -0.540, respectively, the normality assessment showed that all constructs, Depression, Anxiety, Stress, Mental Health, Physical and Mental Harmony, and Physical Health had skewness values within the acceptable range of -2 to +2, as advised by (George & Mallery, 2010). These findings confirm the data's eligibility for parametric analysis. Harman's single-factor test, which addressed any common method variance, revealed that a single factor only explained 32.48% of the overall variation, far less than the 50% criterion recommended by (Cooper et al., 2020). This result ensures that the observed variance is not elementarily attributable to the measurement technique employed, suggesting that common method bias is not a critical concern in the investigation.

4.2. Exploratory Factor Analysis

The suitability of the data for factor analysis was verified by conducting the Kaiser-Meyer- Olkin (KMO) test and Bartlett's Test of Sphericity. The KMO value (0.892) results showing an excellent sampling adequacy (Nkansah, 2018), and Bartlett's test of sphericity is also statistically significant ($\chi^2 = 6084.084$, df = 325, $p < 0.001$), confirms that correlations between items are sufficient for factor extraction. Exploratory factor analysis (EFA) was performed on 35 items, and four components were extracted with Eigenvalues above 0.5, adhering to the Kaiser criterion (Nkansah, 2018). Several items from the DASS-21 scale were eliminated due to factor loadings lower than the permissible limit of 0.50. Removing items with weak factor loadings is a standard and acceptable practice in scale validation to ensure construct clarity and improve model fit (Hair et al., 2010). The commonalities ranged from 0.702 to 0.869, suggesting that the extracted factors explained a subsequent portion of the variance in the observed variables. A Varimax rotation was applied to enhance interpretability. The Rotated Component Matrix grouped items under four distinct factors: Depression (DPR1–DPR5), Anxiety (ANX1–ANX4), Stress (STR1–STR3), and Wellness, represented by Mental Health (MEN1–MEN6), Physical and Mental Harmony (PMH1–PMH4), and Physical Health (PHY1–PHY4). All retained items exceeded the minimum threshold of 0.50 for factor loadings, indicating strong associations between them and their respective constructs (Hair et al., 2010).

4.3 Reliability

All six constructs depicted strong internal consistency for the reliability scores, significantly higher than the generally recognised cutoff of 0.70 (Nunnally & Bernstein, 1994). In particular, the Cronbach's Alpha values for depression, anxiety, stress, and mental health were 0.847, 0.778, 0.853, 0.940, 0.832, and 0.886, respectively.

4.4 Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) was used to validate the structure of the factor found by exploratory factor analysis and evaluate the measurement model's construct validity. Several indications in the first-order CFA met suggested levels, indicating a satisfactory model fit. According to (Kenny et al., 2015), the relative chi-square (CMIN/DF) was 1.914, within the permissible range of 1 to 3. The Root Mean Square Error of Approximation (RMSEA = 0.049) with a Close of 0.585, the Comparative Fit Index (CFI = 0.956), and the Normed Fit Index (NFI = 0.913), further proved the strong model fit (Byrne, 2001; Hooper et al., 2008; Hu & Bentler, 1999). The robustness of the measurement model was seconded by the SRMR value of 0.045, which stayed below the limit of 0.08.

In addition to the first-order construct, a second-order CFA was also conducted to confirm the higher-order construct, which encompasses mental health, physical health, and harmony. The second-order CFA also showed a reasonable model fit, indicating that the wellness construct is accurately represented as a higher-order latent variable. All these findings support the model's measurement integrity and structural validity.

4.5 Discriminant Validity and Convergent Validity

Strong convergent validity is indicated by Average Variance Extracted (AVE) values for all constructs exceeding the suggested cutoff of values of 0.50, for all variables depression, anxiety, stress, mental health, physical and mental harmony, and physical health is 0.536, 0.513, 0.662, 0.726, 0.588, and 0.664 respectively (Hair et al., 2010). This validates a significant amount of variance shared by the indicators for each concept. Discriminant validity is confirmed by comparing the AVE of each component with the Maximum Shared Variance (MSV). The fact that the AVE values for every construct are higher than the corresponding MSV

values shows that each construct in the model is unique (Fornell & Larcker, 2016). Also, discriminant validity is further supported by the fact that the square roots of the AVE values (seen diagonally in the correlation matrix) are greater than their inter-construct correlations (Fornell & Larcker, 2016). All constructions have Composite Reliability (CR) ratings between 0.804 and 0.941, higher than the suggested cutoff of 0.70. This demonstrates the high internal consistency and dependability of the items used to measure each component.

5. Testing of hypotheses

Using AMOS, a Covariance-Based Structural Equation Modelling (CB-SEM) technique was used to investigate the structural relationships between the research variables. This made it possible to investigate, within a theoretical framework, the direct impacts of stress, anxiety, and depression on seafarers' well-being. Below is the model fit, path estimates, and their importance and ramifications. All three proposed routes were statistically significant in predicting sailors' well-being, and the structural model showed a satisfactory fit, as shown in Figure 1. Wellness was most affected by depression (β =.632, p <.05), stress (β =.186, p <.05), and anxiety (β =.105, p <.05). When taken as a whole, these three psychological categories have significant predictive value, accounting for 58% of the variance in wellness (R2 = 0.58). The Depression, Anxiety, and Stress Scale (DASS-21), created by (Lovibond & Lovibond, 1995) which accurately measures negative emotional states, and the wellness scale, which was modified from (Russell, 1973) and (Tsui, 2021) and defines wellness in terms of mental and physical harmony, physical health, and mental health, both support these findings.

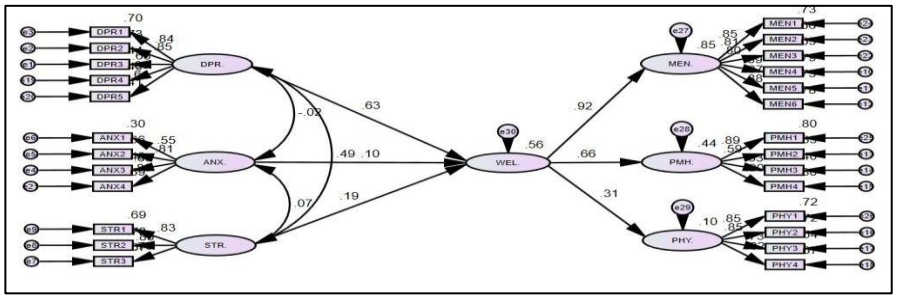


Figure 1. CB SEM Model

Table 1. Conclusion of hypotheses test

Hypothesis	Paths	Standardized estimate (β)	p-value	Result
H1	Depression influences the wellness of seafarers	.632	< 0.05	Supported
H2	Anxiety influences the wellness of seafarers	.105	< 0.05	Supported
H3	Stress influences the wellness of the seafarers	.186	< 0.05	Supported

Source: Compiled by the researcher

The observed relationships are theoretically supported by the Job Demands–Resources (JD-R) model (Demerouti et al., 2001), which emphasizes how a lack of coping resources in high- demand occupations like maritime work can result in psychological strain and decreased well- being, and the Transactional Model of Stress and Coping (Lazarus & Folkman, 1984) which describes how people cognitively assess and react to stressors. The idea that depression presents a higher danger to occupational well-being than anxiety or stress alone was confirmed when it was found to be the most significant factor. The CB-SEM model structurally validates these theoretical linkages, and the model's explanatory capacity is visually confirmed by the standardised regression weights shown in Figure 1. These findings highlight the significance of prioritizing the initiatives that promote psychological wellness in the seafaring profession to protect the workers' well-being.

5. Discussion

The goal of the current study was to determine how stress, anxiety, and depression affect seafarers' well-being. The results are in line with the transactional model of stress and coping (Lazarus & Folkman, 1984),

which signifies how psychological pressure affects mental and physical health. The substantial impact of depression on well-being confirms earlier findings that depression is linked to decreased productivity, reduced occupational functioning, and absenteeism (de Oliveira et al., 2023; Sarkar et al., 2024). This implies that seafarers who experience depressed symptoms may have worse physical and emotional health and perform worse at work.

Anxiety and wellness have a favorable association, which is in line with research showing that anxiety is a major mental health problem among employees, frequently outperforming stress and depression (Maddock, 2024). Despite being weaker, the link is still statistically significant and illustrates the underlying difficulties of mental strain and job instability in the maritime industry (Hwang & Jo, 2021). Stress also had a substantial impact on wellness, consistent with research showing that long-term exposure to work-related stress can result in burnout, exhaustion, and psychosomatic symptoms (Peñalvo et al., 2021; Tsui, 2021). Additionally, this supports earlier findings that the high-stress and isolating work environment of mariners contributes to psychological distress (Song et al., 2021). All the results point to the need for comprehensive interventions because mental health issues are ingrained in the sailing experience.

6. Conclusion

The impact of stress, anxiety, and depression on sailors' well-being is empirically supported by this study. These three psychological elements account for 58% of the variance in wellness, highlighting the significance of putting mental health first in marine work situations. According to (Jonglertmontree et al., 2022), this study broadens the focus to include psychological factors. It confirms their importance in guaranteeing worker well-being, unlike traditional maritime health research that mostly concentrates on physical circumstances.

The cross-sectional design of the study and the dependence on self-reported metrics restrict its applicability, besides providing the relevant information. Future studies have been recommended to adopt a longitudinal design to examine how the psychological and occupational wellness of maritime workers is altered as time passes. Future studies shall incorporate contextual variations such as countries, industries, cultural backgrounds or places. Moreover, paying heed to the possible moderating effects of factors such as digital mental health resources, approaches for boosting resilience, and organisational support is necessary. Adopting qualitative techniques, such as focus group discussions and interviews, may assist in improving our understanding of how mariners encounter and manage psychological difficulties.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

A Study on the Linguistic Features of IMO Legal Proposals

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Abstract: To assist China in enhancing the quality of its IMO proposals and its voice in global maritime governance, this paper employs data collection and analysis tools such as Python, LancsBox, and AntConc to conduct a comparative analysis of the linguistic features among three corpora: proposals submitted by China to IMO (PRCN), proposals from five selected countries (PRCAUKA) and the reference corpus from the American National Corpus (RCANC). It is found that PRCN has higher lexical diversity than PRCAUKA but lower one than RCANC; both proposal corpora have over 60% content words, with nouns being the dominant; PRCN's average word length is slightly shorter than PRCAUKA's and much shorter than RCANC's; syntactically, PRCN has the shortest average sentence length, and both proposal corpora mainly use declarative and non-simple sentences; all three corpora have low readability scores, with the two proposal corpora less readable despite shorter sentences than RCANC; IMO proposals follow standard formats, with cohesion mainly via reference and conjunctions. Suggestions are put forward based on the above findings.

Keywords: IMO Legal Proposals; Corpus; Linguistic Features; Chinese Discourse; Maritime English

1. Introduction

The International Maritime Organization (IMO) is a specialized agency of the United Nations responsible for the safety of maritime navigation and the prevention of marine pollution from ships. To achieve this objective, IMO has developed a comprehensive regulatory framework for shipping in the areas of maritime safety, environmental concerns, legal affairs, technical cooperation, and efficiency of navigation. A plethora of proposals for regulatory work have been submitted by Member States, the Secretariat, or other stakeholders to the relevant IMO institutions.

As a Category A Council Member of IMO, China is deepening its influence on the international shipping arena and, at the same time, striving for greater representation within IMO. However, existing researches in China (Han, 2012; Fang, 2015; Yu, 2021; Zhou, 2024) have only scratched the surface in terms of their linguistic characteristics, failing to provide a detailed and systematic stylistic analysis. Other researches (Sun, 2010; 2012) have reviewed the quantity and content of the proposals submitted by various countries to IMO, finding that the number of proposals submitted by China was small and there had been no contribution on some topics. Compared with traditional Western developed countries such as the United States, Norway, and the U. K., as well as the neighboring country Japan, there is still a gap in terms of participation in various topics. There is still room for improvement in China's overall influence. (Yu, 2021)

To help China improve its proposal-writing ability and visibility in global maritime governance, this paper utilizes Python, LancsBox, AntConc and other data-collection and analysis software to study the linguistic features of proposals from various countries at lexical, syntactic, and textual levels.

2. Research Data Collection

Downloaded from Docs.imo.org, a specialized website providing various documents related to IMO, 81 proposals submitted to the Legal Committee of IMO during 2013-2024 were chosen as samples. Among them, 10 are from China, and 71 from five randomly selected countries (Canada, United Arab Emirates, Ukraine, South Korea and the United States of America). They were built into two separate corpora (PRCN & PRCAUKA). Then the American National Corpus (ANC) was downloaded and randomly-sampled (government, policy and law) as a reference corpus to compare with the self-constructed corpora. These three

corpora are described in Table 1 and appear in our main text as: PRCN, PRCAUKA, and RCANC, respectively.

Table 1. Description of the Corporate

Corpus	Submitter	Pieces of Proposals	Total words
PRCN	China	10	25,946
PRCAUKA	Canada	24	198,176
	United Arab Emirates	15	
	Ukraine	13	
	Republic of Korea	11	
	United States of America	8	
RCANC			20,940

3. Results and Discussion

3.1 Linguistic Features at the Lexical level

According to Hu (2016), lexical features of translated language involve overall features of lexical use and features in the use of specific words and phrases in translated texts. The overall features can be identified through investigating the type/ token ratio, the lexical density, and the average word length.

3.1.1 Lexical Diversity: TTR

Lexical diversity refers to the range of variation in the use of words in a text, which can be measured in a variety of ways, such as the Type Token Ratio (TTR) in Table 2.

Table 2. TTR

Corpus	Types	Tokens	TTR
PRCN	2795	25946	0.107723735
PRCAUKA	6866	198176	0.03464597
RCANC	5114	20940	0.24422158

The TTR of China's proposals is higher than that of the other five countries, and also higher than that in Han (2012) (0.0574), whose corpus consists of 67 pieces of IMO proposals from Norway, the US, Denmark, the UK, etc. This means that the texts of the proposals submitted by China have become richer in terms of vocabulary in recent years, and although the overall number of China's submissions is smaller, more different vocabularies have been used in the submitted proposals, and the expressions have become more accurate and diversified, almost as diversified as those in the BNC corpus in Han (2012), whose TTR is 0.116.

However, comparing RCANC, PRCN and BNC, the TTR of RCANC is nearly twice as much as that of PRCN, and significantly higher than that of the BNC corpus in Han (2012). This may be accounted for by the text type in the selected sub-corpus of ANC (government, policy, and law). In general, the more diverse the text is, the more difficult it is for people to understand it. However, we found the proposals more difficult compared to General English. The readability of a text may not be proportionate to the diversity of vocabulary

3.1.2 Lexical Density

According to Baker (1995, p.191), lexical density is the percentage of lexical as opposed to grammatical items in a given text or corpus of texts. It is calculated by dividing the number of lexical items by the total number of words in a text or corpus and multiplying the result by 100 to arrive at a percentage. As a concept in Computational Linguistics, it can reflect the information capacity and diversity of a text. The higher the lexical density, the more information and diversity a text has, and the lower the lexical density, the easier the text is to understand for readers. As cited in Huang (2009, p.108), the lexical density of most written texts exceeds 40%, whereas the lexical density of spoken texts varies greatly. There are also differences between written texts, usually related to the type of genre. Literary texts tend to have a lower lexical density compared to non-literary texts such as academic papers, with a trend indicating that the information load gradually increases.

Table 3. Lexical Density

	PRCN	PRCAUKA	RCANC
Noun	9284/25946（35.78%）	4456/198176（35.23%）	8789/25940（41.97%）
Verb	3977/25946（15.33%）	29674/198176（14.97%）	3357/25940（16.03%）
Adjective	1885/25946（7.27%）	15237/198176（7.69%）	1948/25940（9.3%）
Adverb	844/25946（3.25%）	5812/198176（2.93%）	659/25940（3.15%）
Total	61.63%	60.82%	70.45%

As is obvious from Table 3, the proportions of content words in the two proposal corpora do not differ much, accounting for 60% of the total. This figure is consistent with the findings (61.47%) of Han (2012), whose corpus consists of 67 pieces of IMO proposals from Norway, the US, Denmark, the UK, etc. Among these content words, nouns account for the highest proportion, reaching 35%. They are followed by verbs and adjectives, while adverbs account for the smallest proportion. As a formal or written motion, proposals are put forward to persuade IMO member states to approve and finance the proposed project. To some extent, IMO legal proposals are a type of political text, and one of the most important means of demonstrating a country's national strength and international influence. Submitting excellent texts to all levels of IMO meetings means exporting a country's national working experience and governance concepts, effectively implementing them within the country and promoting them globally. This is conducive to enhancing a country's discourse power and influence within IMO. Therefore, it is not hard to understand why IMO proposals have a high lexical density. Additionally, the nominalization of verbs and adjectives is more common in formal texts, which can make the text seem more objective and detailed. This feature also aligns with the requirements of the national narratives

Compared with PRCN and PRCAUKA, the lexical density of RCANC is much higher. Among them, the difference in noun density is more significant. This is because the use of some shipping terms in IMO proposals covers a relatively narrower range of nouns in their lexicons, and these specific nouns reflect some specific information about IMO or its work; whereas ANC belongs to general English, and accordingly, the range of its words is more diverse. Moreover, the main topics comprised in the sub-corpus of ANC (government, policy, and law) are wider than those of PRCN and PRCAUKA (legal proposal), suggesting a higher information load.

3.1.3 Average Word Length (AWL)

The average word length (AWL) is the ratio of the total number of letters of all words in a text to the total number of words. As an important factor reflecting the stylistic characteristics of a text, it is used as a metric to gauge the readability and complexity level of a text. Taking three different types of texts in the Brown Corpus as examples, the AWL of newspaper and periodical texts (Categories A, B, C) is 4.73, that of academic texts (Category J) is 4.93, and that of various novels (Categories K, L, M, N, P, R) is 4.31. (Chen & Cui, 2010, p.40

.

Table 4. Average Word Length

Corpus	Average Word Length	Standard Word Length
PRCN	5.145456	3.067614
PRCAUKA	5.2290034	3.1744995
RCANC	6.8012896	4.8391404

By comparison, the AWL of PRCN is slightly lower than that of PRCAUKA as shown in Table 4. This indicates that the wording in the proposals of the five countries is relatively more complex, and the texts in PRCAUKA are more difficult to understand than those of the Chinese proposals. However, the AWL of RCANC is 6.8, which implies that, on average, each word in RCANC contains 6-7 letters. As a result, the texts in RCANC are more complex than those in both PRCN and PRCAUKA. The complexity of the words within a text is often determined by its content (such as topics related to government, policy, law, etc. as in RCANC).

3.2 Linguistic Features at the Syntactic level

According to Hu (2016, p.107), overall syntactic features involve average sentence length, average length of sentence segments, load capacity of constructions, and frequencies of simple and complex sentences, and so on. In this section, we will discuss the sentence type, average sentence length, and sentence readability.

3.2.1 Sentence Type

Sentences may be classified along the intersecting dimension of structure and function. The traditional approach presents a binary division in terms of structure: simple sentence and non-simple sentence (complex sentence & compound sentence). (Hu, 2017, p. 81) The functional approach divides sentences into declarative, interrogative, imperative and exclamatory ones. The most common sentence type in PRCN and PRCAUKA is declarative, with relatively fewer interrogative ones, which are mainly used to raise questions and prompt thinking. There are almost no imperative or exclamatory sentences in both proposal corpora. In terms of sentence structure, there are far more non-simple sentences than simple ones in the corpora PRCN and PRCAUKA. Taking PRCN as an example, the total number of sentences calculated by Python is 1024, with 823 non-simple ones, accounting for 80.37% of the total. This high ratio is characteristic of academic, technical, or professional writing styles, suggesting that the texts in the PRCN corpus convey very complex and interrelated ideas. The intended audience should have a certain level of expertise or at least the ability to process complex language. This explains the relatively low readability of the IMO proposals to general or lay readers.

3.2.2 Average Sentence Length (ASL)

Average sentence length (ASL) refers to the average length of sentences in translated texts, which are generally identified by periods, question marks, and exclamation marks. By using WordSmith, one can easily obtain statistics regarding ASL. Based on the ASL one can get an idea of the complexity of the sentence and the difficulty of the text as well as its readability. The longer the sentence, the more complex and difficult it is for people to understand it, and the lower its readability. (Hu, 2021, p.27)

Table 5. Average Sentence Length & Readability

	Average Sentence Length	Sentence Readability
PRCN	30.488836	47.35
PRCAUKA	35.966606	44.54
RCANC	40.26923	55.1

In Table 5, the ASL of PRCN is 30.49, meaning that each sentence in it contains approximately 30 words. In contrast, the ASL of PRCAUKA is about 36, and that of the proposals in Han (2012) is 33.03. Noticeably, the ASL of RCANC is 40.27, a value much higher than that of PRCN, with an average of about 10 more words per sentence. The reason is that when writing a proposal, one must follow the more strict norms of IMO, requiring sentences to be concise and clear. In contrast, the texts in RCANC has fewer restrictions, covering a wider range of content (such as topics related to government, policy, law, etc.), carrying more information, and being more diverse. By comparison, Laviosa (1998) found that the ASL in the translated English texts he observed was 24.087, 54% higher than that of the non-translated texts (15.626). (Hu, 2016) Referring to 3.1.3, it can be concluded that the complexity of the words and sentences of a text is often determined by its content.

3.2.3 Sentence Readability

Obviously, all the readability scores in Table 5 (PRCN at 47.35, PRCAUKA at 44.54, and the assumed RCANC at 55.1) are relatively low on a scale where higher numbers indicate greater readability. This suggests that the texts in these corpora are of a relatively high difficulty level. For example, a Flesch Reading Ease score of 47.35 for PRCN indicates that the text is somewhat difficult to read. It may contain complex sentence structures and long syllables that make it challenging for the average reader, as is discussed in 3.1.3 and 3.2.1. The low scores may also imply that the proposals are likely filled with specialized terminology, especially considering the nature of the maritime industry. In contrast, the readability score of RCANC is higher (55.1), which suggests that the texts in it may be easier to comprehend. This is a very interesting fact, considering that the main topics in RCANC (government, policy and law) are broader than those in PRCN and PRCAUKA (both related to legal proposals), and the average word length and the average sentence length in RCANC (6.8012896 and 40.26923 respectively) are higher than those in PRCN (5.145456 and 30.488836 respectively) and PRCAUKA (5.2290034 and 35.966606 respectively). Again, this confirms that the readability of a text may not be proportionate to the lexical diversity, the average word length, and the average sentence length.

To explain this, we may have to resort to the different readership and the technical terms in them. Governmental, political, and legal texts in RCANC are often written to be more accessible to a wider audience, whereas these proposals are likely intended for a specialized audience, such as maritime law experts, shipping

industry professionals, or international policymakers. Such individuals are more likely to be familiar with the technical terms and complex concepts in the proposals in PRCN and PRCAUKA, and can better understand the content despite the high reading difficulty.

3.3 Linguistic Features at the Textual level

IMO proposals are essentially a type of international official documents. As documents within the United Nations system, they possess the authority and solemnity common to international documents. (Zhou, 2024) The discussion of linguistic features at the textual level can be conducted through the analysis of proposal types, proposal structure, and cohesion and coherence.

3.3.1 Types of Proposals

According to Yu (2021), proposals are generally classified into four types: reports, motions, comments, and information, as can been seen through their titles. Among the 81 proposals in the two corpora PRCN and

PRCAUKA, 7 start with "Report", 6 with "Comments", and 1 with "Information" in their titles. Proposals starting with "Summary of results of" should also be categorized into "reports". Others start with "Proposed measures" and "Proposed framework, methodology & work plan", showing their practical nature by giving suggestions and advice for practical problems in the international maritime field.

3.3.2 Structure of Proposals

Due to the continuity of organizational documents, and to improve administrative efficiency and reduce the workload of text processing, IMO has issued word template and "IMO Style guide" (IMO, 2018) to standardize the form and style of the proposals submitted by various countries and organizations. A typical proposal usually contains the following parts: Title, Summary, Introduction, Background, Analysis, Output, and Action requested of the Committee. (Sun, 2018)

3.3.3 Cohesion and Coherence

In view of the authority and solemnity of IMO proposals, it is especially important to pay attention to their cohesion and coherence. According to Halliday and Hasan (1976), cohesion is expressed partly through the grammar and partly through the vocabulary in the lexico-grammatical system. Grammatical cohesive devices are generally function words without lexical meaning, including reference, substitution, ellipsis, and conjunction, whereas lexical cohesive devices are mostly content words, including reiteration and collocation. Fang (2015) examines the grammatical cohesion in IMO proposals and finds that the most frequently used grammatical cohesive device is reference, followed by conjunction, ellipsis, and substitution, with ellipsis and substitution only accounting for about 2 percent of total frequency of grammatical cohesion. Among different types of reference items, demonstratives are used most while personals least. With regards to conjunctions, additive and causal relations occur most frequently, whereas temporal relations are rarely used. These findings are a bit different from those of the present corpora, as can be seen in Table 6.

Table 6. Referential & Conjunctional Cohesive Devices

Category	PRCN		PRCAUKA		RCANC	
	Frequency	Ratio	Frequency	Ratio	Frequency	Ratio
Personal Ref.	298	1.15%	2475	1.25%	413	1.97%
Demonstrative Ref.	2765	10.66%	20604	10.4%	1626	7.77%
Comparative Ref.	224	0.86%	1923	0.97%	180	0.86%
Total Ref.	3287	12.67%	25002	12.62%	2219	10.6%
Additive Conj.	1089	4.2%	8370	4.22%	960	4.58%
Adversative Conj.	62	0.24%	531	0.27%	61	0.29%
Causal Conj.	69	0.27%	394	0.2%	37	0.18%
Temporal Conj.	31	0.12%	226	0.11%	26	0.12%
Continuative Conj.	2	0.008%	17	0.009%	6	0.029%
Exemplification Conj.	4	0.02%	138	0.07%	18	0.09%
Total Conj.	1257	4.84%	9676	4.88%	1108	5.29%

Similarly, the most frequently used grammatical cohesive device is reference, followed by conjunction. And the most widely used reference items and conjunctions are demonstratives and additives respectively. Since IMO proposal is essentially a type of formal documents, personal references are rarely used due to its requirement for objectivity. (Fang, 2015) However, demonstratives, especially "the", "that", and "this", are frequently employed to avoid repetition, achieve a more logical organization, and help bridge the gap with the audience, thereby making the proposals more persuasive. Since most proposals, especially the annexes after a proposal, follow a problem-solution structure, there are relatively higher ratio of causal conjunctions in the proposals. In addition, the proposal contents, like problems, difficulties and provisions, are often organized sequentially or hierarchically. That is why additive conjunctions are most frequently used in IMO proposals.

4 Conclusions and Suggestions

By comparing Chinese proposals (PRCN), proposals from five other countries (PRCAUKA), and a reference corpus (RCANC), this study has identified distinct linguistic features of IMO legal proposals at the lexical, syntactic, and textual levels. These findings have important implications for improving the writing quality of proposals. Based on the proposal structure, the following suggestions are put forward to enhance China's voice in IMO:

4.1 For China's Proposal-Writing Improvement

For China's proposal to be accepted by IMO Secretariat, proposal drafters should always use the word template issued by IMO, follow the "IMO Style Guide", and strive to improve the proposal from lexical, syntactic, and textual aspects. At the lexical level, although China's proposals show relatively high lexical diversity, further efforts can be made to balance the use of specialized and common vocabulary. Always pay attention to the latest conceptual expressions in IMO and the updates of its glossary (Zhou, 2024, p.69), and use common and widely-recognized maritime terms. When introducing new or complex concepts, provide clear definitions or explanations. At the syntactic level, given the relatively low readability scores, consider simplifying sentence structures where possible without sacrificing the precision of legal and technical content. Use more straightforward, short, and medium-length sentences to break up complex ideas, especially when presenting key points. At the textual level, strengthen the use of cohesive devices to enhance the logical flow of proposals. When using causal or additive conjunctions, ensure that the relationships between sentences and paragraphs are clear. Also, pay more attention to proposal structure, making sure each part is well-developed and connected. This will enable IMO member states to quickly understand and accept China's viewpoints and suggestions.

Meanwhile, tailor proposals to address global maritime issues that are imminent and of common concern while highlighting China's unique experience and solutions. Carefully study IMO documents and working methods (IMO, 2023), especially the biennial priorities and the High-Level Action Plan.(Zhang, 2017, p.33) Strengthen the research on the development trends of the formulation and revision of IMO conventions and rules, and focus on major hot topics of IMO, such as the reduction of greenhouse gas emissions from shipping, the review mechanism for IMO member states, goal-based new ship construction standards, and the operating rules for ships navigating in Arctic waters. Plan moderately in advance, break down tasks into details, clarify specific research directions, conduct in-depth special studies, offer practical solutions to specific problems, and put forward proposals in a timely manner. That is, make the proposal "SMART": specific, measurable, achievable, realistic, and time-bound. (IMO, 2023, Annex p.7)

4.2 For Enhancing China's Influence in IMO

To enhance China's influence in IMO, proposal drafters should display China's position and viewpoint, and highlight China's unique experience and solutions. Excellent proposals are the output of a country's work experience and management concepts. (Zhang, 2017, p.33) Appropriately share China's successful experience and innovative practices in maritime management, ship technology, port construction, etc. In addition, emphasize international cooperation. Emphasize China's readiness to work with other countries to address maritime challenges, share experience, and promote the improvement of the global maritime governance system.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

The directions of changes in motivators for choosing a career at sea

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Abstract: The share of seafarers from the European Union, including Poland, in the global seafarer workforce is steadily declining. Actions taken at the EU level or the national level in Poland are not yielding the expected results. The article presents the results of a study aimed at identifying and ranking the motivators for choosing a career at sea amongst today's youth and the previous generation. A triangulation of research methods was used to achieve the research objective. Qualitative research, conducted amongst former seafarers and the older generation of seafarers, was based on structured and unstructured interviews. Future seafarers—students—were the subjects of quantitative research, conducted using a survey questionnaire. The respondent study was preceded by a thorough literature review.

The research results revealed significant differences in the perception of a maritime career as a professional development path. The older generation primarily pointed to economic and political factors, the younger generation emphasized financial aspects and the uniqueness of the profession, while identifying separation from loved ones and monotony as the most significant drawbacks. The study's findings and conclusions enabled the conclusion of recommendations for institutions within the maritime sector, particularly higher education institutions, regarding the promotion of careers at sea.

Keywords: Polish seafarers; maritime studies; seafarer profession trends

1. Introduction

Maritime transport is a major component of the European Union's economy (in the EU's external trade, 75%, and in the internal trade, approx. 33% of the volume of cargo is transported by sea) (Draghi 2024a). Nowadays, the role of maritime transport is not limited only to transporting cargo between specific loading and unloading points. In a report prepared for the European Commission, Mario Draghi pointed out the need for the EU to better respond and adapt to conditions of lower geopolitical stability. This requires, amongst other things, self-reliance in security matters to a greater extent than before, which means having its own transport potential in external contacts. In this way, maritime transport, including the fleet, is becoming an important element in ensuring the EU's security in the economic and military dimension (Draghi 2024b). Meanwhile, the share of ships under European flags in the global fleet is constantly decreasing. While at the beginning of the 21st century, the EU-flagged fleet, expressed in DWT, accounted for approximately. 22% of the world fleet, in 2024, this share was slightly over 12% (UNCTAD 2021). A similar downward trend applies to EU seafarers working on EU-flagged ships, especially officers. In 2014, around 65% of officers on EU ships were EU citizens; in 2022, the percentage has fallen by almost 40 percentage points, to only approx. 26% (EMSA 2025). A downward trend was also noted in the case of regular crews (EMSA 2025). Taking it all into consideration, the conclusions are clear – the EU fleet is increasingly operating outside the jurisdiction of the European Union, and ships under EU flags are being increasingly crewed by seafarers from outside the EU."

2. Literature review

2.1 Shortages of seafarers

The risk of a global shortage of maritime personnel has been reported for years by organizations associated with the shipping sector, although estimates of the depth of the deficit vary, sometimes dramatically. The reasons behind such a state of affairs are primarily the lack of reliable sources (electronic seafarer registers) and the high mobility of seafarers. David Glen presented the problems of estimating labor

supply resources in detail in the article What do we know about the labor market for seafarers? A view from the UK (Glen 2008). Table 1 displays estimates of officer shortages provided in the main publications on the size and structure of the maritime labor market: Seafarer Workforce Report and Manning. Annual Review & Forecast (BIMCO, ICS 2021; Drewry Maritime Research 2024).

Table 1. Shortages of seafarers estimated by BIMCO&ICS and Drewry Maritime Research

	Source	BIMCO&ICS	Drewry Maritime Research
Year	Level of competence	operational and management (officers)	
	2005	-10 000	No data available
	2010	-13 000	-29 800
	2015	-16 500	-22 000
	2021	-26 240	-20 450
	2024	No data available	-39 754

Regarding officer cadres, the figures of both institutions indicate a continuous and deepening deficit. Significant differences between the columns result from different data collection methodologies. Nevertheless, regardless of the methodology, the data ranging from -10,000 (BIMCO, ICS 2021) to -39,754 (Drewry Maritime Research 2024) indicate a deepening personnel crisis requiring immediate actions that would reverse the current trend. Personnel shortages on a global and European scale are reported by, amongst others; (Sambracos and Tsiaparikou 2001; Alderton and Winchester 2002; Leggate 2004; Caesar et al. 2015; Mitroussi and Notteboom 2015; Bagoulla and Guillotreau 2016; Ting 2017; Tsai and Liou 2017; Exarchopoulos et al. 2018). The solutions to the problem indicated by researchers are primarily actions promoting work at sea (Leggate 2004; Glen et al. 2007; Widell and Ljung 2014; Bagoulla and Guillotreau 2016; Tai 2016*)*, improving the quality of education, e.g. through dual education (introduction of double qualifications - deck and engine) (Leggate 2004), unification of education programs in various countries (Bagoulla and Guillotreau 2016), promotion of higher education extended to transport and logistics issues (Ting 2017), promotion of continuous and lifelong learning and ongoing adaptation of programs to the rapidly changing technological environment (Widell and Ljung 2014; Tai 2016; Kagola 2017). Researchers also point to the need for improvement of living and working conditions at sea (Caesar et al. 2015; Tsai and Liou 2017; Exarchopoulos et al. 2018) and social campaigns aimed at improving the image of a career at sea (Leggate 2004; Widell and Ljung 2014). The European Parliament even "calls for actions to be taken to raise the prestige of maritime professions and to increase their attractiveness in the eyes of all young people, and in particular in the eyes of European youth" (OJ 2005/C 157/06 2005). Some of the solutions proposed in the literature are implemented by the actions taken by the IMO, starting in 2008, when the "Go to Sea!" campaign was launched. The IMO directs its actions along two tracks.

It undertakes initiatives aimed at popularizing knowledge about work at sea and being a kind of tribute to people doing this work: 2010 was declared the Year of the Seafarer, the Day of the Seafarer was established (June 25), International Day for Women in Maritime was established (May 18). IMO also conducts activities supporting those already working or planning to work at sea: Seafarer Crisis Action Team (SCAT) - a team to solve individual problems of seafarers and their legal protection, Maritime SheEO Leadership Accelerator Programme (LEAP) - a program in partnership with WISTA supporting the development of women's careers in the maritime sector, the Next Wave Seafarers project in partnership with Saudi Arabia enables seagoing internships on board ships for cadets from the least developed countries and small, developing island states (Least Developed Countries LCDs, Small Island Developing States SIDS).

So far, the recommendations of researchers, the actions of the IMO, and other organizations associated entities operating in the shipping sector have not brought the expected results. This is indicated by increasingly worrying statistics, especially disadvantageous for Europe. For young Europeans, work at sea is no longer attractive - they prefer jobs on land, which are less mentally and socially demanding.

2.2 Incentives for pursuing a maritime career

In the literature concerning various aspects of work at sea, much attention is paid to reports from studies aimed at identifying factors encouraging people to take up such a job. The issue of identifying these factors is crucial for understanding the mechanisms leading to imbalances on the maritime labor market (shortages of officers, surpluses of enlisted crews) and the decreasing resources of seafarers (both officers and

enlisted crews) from Traditional Maritime Nations and, more broadly, from the most developed countries. Among the many factors encouraging people to take up work on ships, listed as first is attractive salary (Sambracos and Tsiaparikou 2001; Wu and Winchester 2005; Fernandez Gonzalez et al. 2014; Mitroussi and Notteboom 2015; Mehrara and Rezvanian 2016; Albert et al. 2016; Tai 2016; Tsai and Liou 2017).

Another factor is job security, considered as the relative assurance of getting hired, as the seafarers have the access to the global labor market (Wu and Winchester 2005; Fernandez Gonzalez et al. 2014; Mitroussi and Notteboom 2015; Bagoulla and Guillotreau 2016; Tai 2016). Following determinant is clear career advancement path, transparent procedures and communication in the workplace, as well as a certain degree of professional flexibility that allows for the development of both a maritime and shore-based career (Mitroussi and Notteboom 2015; Bagoulla and Guillotreau 2016; Mehrara and Rezvanian 2016; Tsai and Liou 2017). The next most frequently mentioned contributors include the prestige of maritime professions (Sambracos and Tsiaparikou 2001; OJ 2005/C 157/06 2005; Mitroussi and Notteboom 2015; Tai 2016) and work-life balance (Thomas et al. 2003; Mehrara and Rezvanian 2016; Albert et al. 2016).

Amongst other, less emphasized by the respondents factors there were: professional development through continuous learning, the country's maritime traditions as well as family traditions, the opportunity for adventure, relatively long vacations compared to land-based workers, as well as a sense of freedom and the dynamic nature of the working environment (Widell and Ljung 2014; Mitroussi and Notteboom 2015; Albert et al. 2016; Kagola 2017).

3. Methodology of research

The aim of the conducted research was to identify and hierarchise the factors determining career choice among two groups of respondents. The larger group consisted of students from the Navigation Faculty and the Mechanical Engineering Faculty of the Gdynia Maritime University. The second group included graduates of this university who started their studies before or at the very beginning of Poland's systemic and economic transformation. Different research methods were chosen for each group, tailored to their specific characteristics and size.

3.1. Student Survey

Students at Gdynia Maritime University were subjected to a questionnaire survey. A total of 172 individuals participated: 92 students from the Navigation Faculty and 80 students from the Mechanical Faculty. All respondents were first-year students enrolled in programs conducted following the STCW Convention requirements. The survey was carried out in April and May 2024, using a questionnaire as the diagnostic tool. The questionnaire contained 13 questions: closed, semi-open, and open-ended. The sampling was purposive, and the research objective determined the choice of research method – statistical analysis was limited to descriptive analysis and response structure analysis. These analyses were conducted using STATISTICA 13.0 software (TIBCO Software Inc.). To explore what influenced students' choice of maritime careers, questions were asked regarding their motivation to pursue studies at Gdynia Maritime University, their knowledge of working conditions at sea, positive and negative aspects of maritime work, and finally, their level of independence in making decisions about their choice of studies and future career paths (see Table 2).

Table 2. Responses to selected questions from the survey questionnaire

Frequency of indication	Choice of studies at GMU	Positive aspects of working at sea	Negative aspects of working at sea	Familiarity with the realities of working at sea	Independence in making decisions about choosing studies at GMU
	(a)	(b)	(c)	(d)	(e)
1.	High earnings (64,53%)	High earnings (51,16%)	Being away from family (43,60%)	Yes (a family member works at sea) (30,23%)	Independently (48,78%)
2.	Job security (63,37%)	Opportunity to travel the world (12,79%)	Loneliness (8,14%)	No (belief: interesting work, opportunity to travel the world) (24,42%)	Influenced by family (34,15%)
3.	Opportunity to travel the world (47, 67%)	Interesting work (9,88%)	Isolation (2,91%)	No (belief: hard work, good earnings) (20,93%)	Influenced by friends (10,98%)

In the summary of the results, one of the most surprising conclusions is the low level of independence

regarding the choice of career path (e). Less than half of the young people (47.78%) declared independence in choosing their studies and career route. Nearly the same proportion (45.13%) indicated that their decision was influenced by family members or acquaintances. This suggests that their decisions are not solely based on their internal beliefs, and as a result, they may be more likely to give up their studies or career path at the first difficulties or failures. This is especially true when their perceptions of working at sea conflict with their vision of such work. Among the respondents, about one-third indicated familiarity with the realities (d), while nearly half have only a general idea of this type of work: almost a quarter of respondents see working at sea as interesting and an opportunity to travel (a positive, romantic view), while 20% have a more realistic perception viewing it as hard work but one that offers high wages. Regarding the question about the reasons for choosing studies at GMU (a), students cited up to three responses, assigning them a rank. In the case of positive (b) and negative (c) aspects of working at sea, students themselves formulated their opinions. Answers. Based on the obtained results, one can outline the profile of a GMU student as a person guided by pragmatism (high earnings, stable job) as well as the attractiveness of the future profession (opportunity to travel the world). This is confirmed by the positive qualities of "maritime" professions expressed by students, where high salary is preceded by "traveling the world" and "interesting work." If we look at the frequency of positive and negative aspects indicated by students, it suggests that they are more convinced of the positive (c) aspects of working at sea than the negative (d) ones (greater dispersion of responses). This raises the question: Are students aware of the hardships of working at sea? Will encountering the negative aspects, which they perhaps do not yet fully realize, cause them to seek high-paying, secure jobs on land?

3.2. Study of the Older Generation of Seafarers

The second part of the study was conducted among a different group of respondents. This group consisted of individuals who chose a career at sea during a time when Poland, as a socialist state, was part of the so-called Eastern Bloc of "People's Democracy." Polish citizens had limited civil liberties; among other things, they were not allowed to leave the country without government permission (possessing a passport was not common, and passport holders could not keep it at home but only at designated government offices). The irrational centralized economy led to Poland being a country with market shortages, where from the mid-1970s onwards, rationing was introduced for basic foodstuffs and later extended to other essential goods. Maritime shipping services were one of the sources of foreign currency earnings for the state, which made the expansion of the fleet a national priority. In the early 1980s, over 300 merchant ships were registered under the Polish flag, with a tonnage placing Poland among the largest owners of the world's maritime fleet (UNCTAD 1983). Managing such a large fleet required substantial human resources, exclusively Polish nationals. At that time, Poland had two higher education institutions training officers for the merchant navy: in Tczew (since 1920), later moved to Gdynia (since 1930), as well as in Szczecin (since 1947). Recruits underwent multi-stage entrance examinations in scientific subjects and underwent highly restrictive medical tests, which only allowed those meeting the strict criteria to begin maritime studies. Under these circumstances, only some of the aspiring students and future sailors could realise their plans.

The aim of the conducted research was to gather information about the motivations of the time, understanding of the specifics of working at sea, and the degree of independence in choosing future career paths, followed by a comparison with the responses of current Gdynia Maritime University (GMU) students.

For the research, a method combining qualitative and quantitative approaches was selected – a mixed interview. Closed-ended questions were also included alongside open-ended questions, so that the responses provided during the interview could be compared with the answers obtained from the student survey questionnaire. The selection of respondents was purposeful – respondents were chosen to meet two conditions simultaneously: they currently are or were employed at sea, and their maritime work was a consequence of studies at GMU started before the systemic and economic transformation of Poland, i.e., no later than 1989. The group consisted of 30 individuals—graduates of GMU who began their studies before 1990. Most respondents (56%) decided to pursue a maritime career independently, while half as many respondents (28%) declared that their family participated in the decision to choose their field of study. The main factors influencing the decision to study maritime-related fields were: job security (72%), high salary (62%), the opportunity to leave the country and travel around the world (60%), and perceiving maritime work as something exceptional, prestigious, and distinctive compared to other “ordinary” professions (56%). Regarding the positive and negative aspects of working at sea and their knowledge of its specifics, respondents' answers were nearly unanimous. When asked about the positive sides of a maritime career, they pointed to the same factors that motivated them to study at maritime faculties. Concerning the negative aspects, almost all responses focused

on one main issue – being separated from family. About 47% of respondents were familiar with the specifics of maritime work. The individuals surveyed are still professionally active, with 35% working on ships (all at management levels), and 65% working ashore in companies directly related to maritime transport (also in top positions). The most common reasons for ending a career at sea were: family reasons, increasingly burdensome bureaucracy, the rising number of inspections, and professional burnout. These are aspects that young people are already aware of at the stage of preparing for their future profession.

4. Results and recommendations

The reason for conducting research on the factors determining the choice of a maritime career is the increasingly widening deficit of merchant navy officers, according to statistical data. The problem of the officer shortage, despite efforts undertaken for several years by IMO and collaborating organizations, has not decreased; on the contrary, it is deepening. The literature offers numerous solutions, although they mostly focus on the effectiveness of education and its relevance to rapidly changing conditions.

To determine what might motivate young people to decide on a maritime career, two respondent groups were examined: former students of GMU and current students, who differ in age by approximately one generation. Former students had the opportunity to study after demonstrating knowledge in STEM subjects and excellent health, having competed against several to a dozen other candidates. Current students are required to meet a formal criterion of having completed secondary education.

The difference in the attractiveness of maritime studies for young people stems from their needs and the possibilities for their realisation. The older generation points to motivators that could only be fulfilled at sea or that offered the highest likelihood of fulfilment through maritime work. The younger generation identifies motivators whose achievement is in no way dependent on working at sea (see Table 3).

Table 3. Responses to selected questions from the survey questionnaire

Students of Gdynia Maritime University starting their studies			
before 1989		in 2024	
Determinants of choosing a maritime career	Possibilities of achieving the goal outside the maritime path	Determinants of choosing a maritime career	Possibilities of achieving the goal outside the maritime path
Job security	No	High earnings	Yes
High earnings	No	Job security	Yes
Opportunity to leave the country and travel the world	No	Opportunity to explore the world	Yes

Under these conditions, the solution seems to be creating an image of maritime work as employment in a modern technological environment, full of challenges related to continuous learning. It is also worth highlighting aspects of working at sea that current sailors often point out in numerous studies: a clear career advancement path with well-defined criteria for progressing to higher levels, the opportunity to achieve work-life balance through strict separation of work time from free time, as well as flexible employment options, such as the possibility of transitioning from shipboard positions to land-based jobs and vice versa.

Limitations

The authors are aware that the obtained results do not characterise the population of former, current, or future Polish sailors. The uneven and relatively small sample sizes of respondents do not allow for universal conclusions to be drawn. They serve as a contribution to further research on a larger scale.

Acknowledgements

The research presented was financed by the Polish Ministry of Science within the framework of the program "Regional Excellence Initiative" (RID), under the project "PROGRESS". It was also supported by Gdynia Maritime University's internal grant no. WZNJ/2025/PZ/09.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

A Framework for Continuous Improvement of Safety at Sea

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Abstract: Safety is neither a static state nor an absolute phenomenon. It changes as technology, organizational procedures, and human behavior do. The challenges of maritime safety are examined in this paper, with particular attention paid to learning from accidents, training standards, risk analysis, fitness for purpose versus compliance, and the function of audits and inspections. Using insights from the application of the International Safety Management (ISM) Code and creative training approaches, this paper suggests a framework for ongoing safety practice improvement. A range of research and data collection methods have been employed with specific use of Pareto analysis and accident reviews. The results include analysis of some 1000 accidents at sea together with the outcomes of audit reports, and ship inspection in ports. This paper makes special references to a proposed taxonomy model and an overall framework identifying the key factors contributing to accidents and incidents at sea.

*Keywords***:** Maritime Safety, Risk Assessment, Quality Assurance, Accidents, Audits and Port Inspection.

1. Introduction

A cornerstone of global trade, shipping is still faced with emerging and persistent safety-related crises. Seaborne incidents reflect glaring failures in the implementation of stringent regulatory regimes, such as the ISM Code and the Standards of Training, Certification, and Watchkeeping (STCW). Whereas such legislation lays down the bare requirement of compliance, such regimes are not always adequate to prepare ships for the operational conditions of the dynamic maritime world. Too often, compliance is reduced to box-ticking exercise where the need to comply takes priority over the equally compelling need to be fit for purpose. Whilst, rightly there is a great deal of efforts in learning from accidents and sharing data (Zachau, 2023) in this connection, nevertheless, the outcomes of ISM Code audits and port inspections are often not seen as important means to reduce accidents and incidents at sea (Ziarati et al., 2024; De Melo Rodriguez et al., 2024). Furthermore, whilst human factors are still the major contributory cause of maritime incidents, and this is compounded by such factors as substandard training, fatigue, commercial pressure, as well as bad leadership, there are often no distinction between non-quality assurance and quality assurance issues and neither a clear distinction is made between crew-related and company related errors/mistakes. The issue of human element calls for additional focus on competence to operational needs, thorough improvement, and safety-oriented culture with high focus.

Interestingly inspection and audit procedures are another problem as the data is not used systematically to reduce accidents at sea and in ports. In in study by Zachau (2023) issues regarding analysis of accident investigation reports highlighted several areas for improvements. The study was complemented by Ziarati et al. (2024) and De Melo Rodriguez et al. (2024). A new taxonomy of the contributing factors and underlying causes of maritime and port accidents was produced by the latter two studies which looked at how well safety management systems worked and found significant gaps in risk perception, training efficacy, and safety measure implementation. The study found that many safety protocols were not adequately applied in real-world operational settings, with crew members struggling to retain and apply training under high-pressure conditions.

This paper was written in support of the C4FF led EU funded OPTIMISM project. The key aim of OPTIMISM project is to develop a unique training program for the ISM Code implementation, going beyond the conventional course design methodologies by introducing several novel quality and risk reduction concepts with a view to revolutionize safety training in the shipping industry.

2. The Quality Coin: Fitness for Purpose vs. Compliance

A key contribution of this paper is the development of the Quality Coin Model (Figure 1), which offers a framework to distinguish between compliance and fitness for purpose in maritime safety.

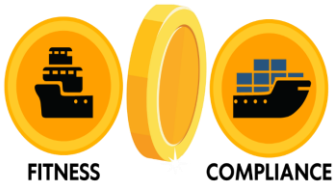


Figure 1. Coin of Fitness for Purpose vs. Compliance

Compliance, in this context, refers to adherence to established procedures, as outlined by a company's Safety Management System (SMS) under the ISM Code. Fitness for purpose, on the other hand, assesses whether the implemented safety measures are effective and practical in real-world conditions. Furthermore, apart from the company's procedures (manual) there are other safety rules such as collision regulations, cyber security and so forth that needs to be seriously taken into consideration. Even, when these are considered earnestly there are issues of misinterpretation of the rules for instance with Rule 19 of collision Regulations (Velikov et al., 2018).

The ISM-Code provides companies with the freedom to develop their own SMS, allowing them to tailor policies and procedures to their specific needs. Consequently, external auditors assess compliance based on the companies' internal safety systems rather than universal standards. This flexibility, while good for customization, has meant that very few instances occur when Document of Compliance (DOC) or Safety Management Certificate (SMC) is suspended or withdrawn when there are serious deficiencies. For ensuring quality and operation safety, the fitness-for-purpose concept is to be more than mere superficial compliance and involves deep analysis of human and system failures. The variability of PSC inspection regimes across regions, for instance, under the Paris Memorandum of Understanding, further complicates the implementation of uniform standards. The methods used during the inspection, as well as the nature of the questions posed, are not standardized and could affect the validity of the results.

3. Known and Unknown Risks

The Risk-Assessment Coin, which was developed in the context of this research (see Figure 2), provides a double-sided approach to managing risk.



Figure 2. Known vs Unknowns

In contrast, human experience emphasizes the importance of risk management that may be measured using present-day understanding and experience. It operates under the concept that "if it can go wrong, it will." As such, this calls for the establishment of thorough plans and procedures to integrate human factors considerations, with the aim of reducing errors and mitigating anticipated risks. The second mode, identified as Unknown, involves risks not identified because of a lack of adequate information base. Such uncertainties represent the kind of situation where thorough preparation and formulated procedure do not prevent accidents. Conventional risk assessment approaches are invalidated in such situations, and external learning, as well as

dedication to continuous education, comes into the picture, focusing on the enterprising correction of errors. 'Error' under this mode is defined as a lack of correspondence between outcomes and intended safety controls.

Alongside the Risk-Assessment Coin, this research introduces the Fitness (for purpose) Triangle (see Figure 3). The intended approach assures constant coherence between these three key elements: **Jobs:** Clearly defined roles and responsibilities tailored to operational needs; **People:** Continuous development of skills and competencies and **Plans and Procedures:** Adaptive safety measures that evolve alongside industry advancements.

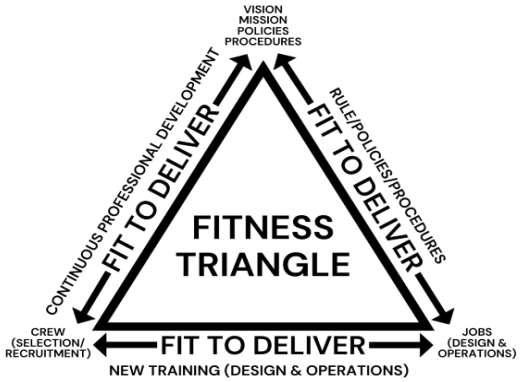


Figure 3. Fitness Triangle

The Triangle emphasizes the need for constant improvement and adjustments, which ensures safety protocols are in place and responsive to identified as well as unknown threats. The process of improvement in this cycle aligns with the recognition of "we know what we do know" and "we do not know what we do not know," thus establishing the need for systems that can forecast and adapt to emerging challenges (Ziarati, 1995).

4. Fitness Triangle: Integrating Policies, jobs, and People

The idea of the Fitness Triangle underscores the importance of aligning three basic components - Crew, Jobs/Responsibilities, and Policies/Procedures - to ensure the safety of the vessel as well as the crew. Fitting these components into place requires continuous professional education and training of crew personnel about their respective jobs and the protocols that need to be observed. It also requires constant evaluation and updating of policies and duties to ensure that the guidelines are feasible and relevant in operational applications. The shipping industry faces significant challenges in meeting this alignment. There are several accidents and incidents traceable to human errors which occur in the preparation, execution, or compliance stages of safety policies, procedures, and plans. These were largely caused by job design deficiencies, lack of proper correlation of duties assigned with the skills of the crew, and recruitment and selection inefficiency. Results drawn from over 100 accident reports and feedback received through questionnaires reveal recurrent human factors concern in the application of the ISM Code (Ziarati et al., 2024).

5. Education: Challenges and Solutions

The effectiveness of the ISM Code finally hinges on the availability of adequate training and readiness on the part of maritime workforce personnel which is dealt incidentally by the STCW Convention. However, current training and education procedures are faced with several challenges. Majority of training programs place greater focus on theoretical orientation and standardized examination formats, making effective weaknesses in the areas of practical skill and aptitudes to counter different challenges. For example, students/cadets generally need to score 40% to 60% in order to pass a maritime education course, and no actual tests are even carried out in some courses, hence rendering vast regions of ability unexamined. Such tests are conducted on discrete areas of learning and, in some cases, discrete skills, rather than assessing whether a crew member can execute successfully his or her duty under simulated practice, across the entire spectrum of the skill base required.

Conventional shipboard training, required as part of the ISM Code (Element 6), in all its great worth, possesses inherent limitations, for instance, how a new crew member is trained to be familiar with the ship layout

and equipment. How is this done is often found to be informal and not fully documented in majority of the cases observed as part of this project. The implementation of simulator-based training within maritime education can significantly enhance crew readiness (Valikov, et al., 2018). Such programs allow one to gain needed skills while simultaneously developing important decision-making skills in a controlled environment.

The procedural quality system described under the ISM Code, as presented in Figures 4 and as proposed in the OPTIMISM training program plays an important function in maintaining safety while operating in the maritime industry and maintaining environmental integrity. The elements of quality assurance (QA) such as safety and environmental policies, procedures, and plans are intended to ensure operational preparedness. In parallel, quality control (QC) involves external checks such as audits and inspections, which could and should be used to verify compliance with QA requirements.

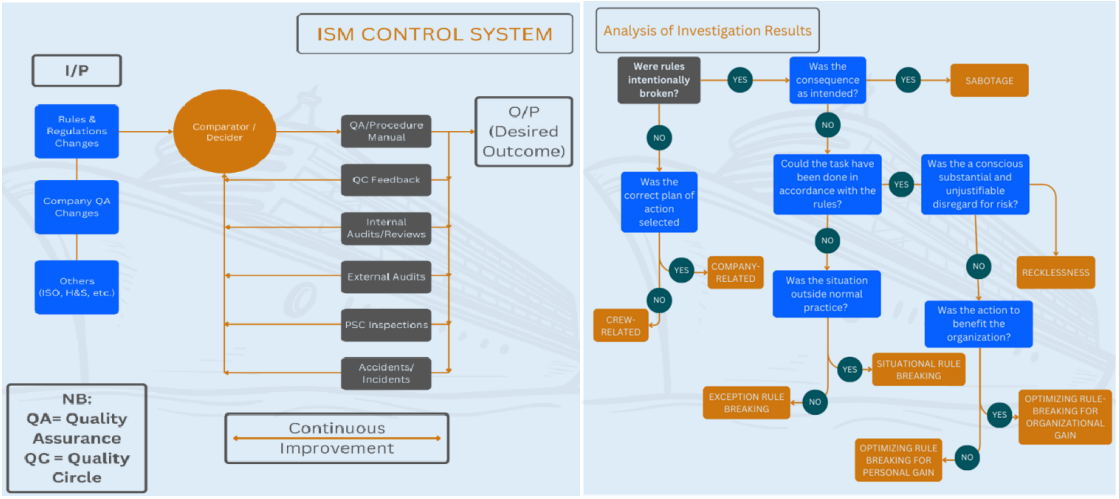


Figure 4. OPTIMISM ISM-Code Control System Model and Figure 5: Analysis of Investigation Results - Crew mistakes vs Company errors

6. Accident Analysis: A Holistic Approach

The analysis of maritime accidents requires a systematic and comprehensive approach that considers multiple dimensions. Accidents often reveal gaps in these systems. A non-conformity, identified through ISM audits or a deficiency arose from the port inspections, may result in incidents that question the fitness of QA documentation or QC mechanisms. Figure 5 is adapted from Baines (2008) have been used in this project primarily to identify if an accident is company-related or crew-related. There are two categories: Errors in QA (e.g., inadequate policies or procedures) or Mistakes in connection with non-QA issues (e.g., implementation issues or lack of competence). A thorough accident investigation (Ziarati et al., 2024) examined these categories alongside contributing factors like human vulnerabilities, communication gaps, and decision-making or leadership or supervision errors/mistakes. Weather and sea conditions, though often predictable, also influence accident causation. However, commercial pressures should never override safety considerations in adverse conditions. Beyond environmental factors, human elements such as psychological, physiological, and behavioral issues significantly impact maritime safety. These factors, coupled with evolving technology, organizational dynamics, and job roles, necessitate continuous refinement of policies and procedures.

7. Organizational, Personal, and Behavioral Factors

Maritime safety is profoundly affected by organizational, personal, and behavioral factors, which often serve as root causes of accidents and non-conformities in the case of audits and deficiencies in the case of port inspections. The details of these factors were outlined in sufficient depth in a paper presented in IAMU'24 (De Melo Rodrigeuz et al., 2024). A review of some 200 accidents led to identifying the root causes of and contributing factors to accident at sea. These causes and factors were taxonomized as a result of the review. Figure 6 provides a visual representation of the taxonomy. There are over 25 kinds of contributing elements and underlying causes for maritime mishaps and accidents.

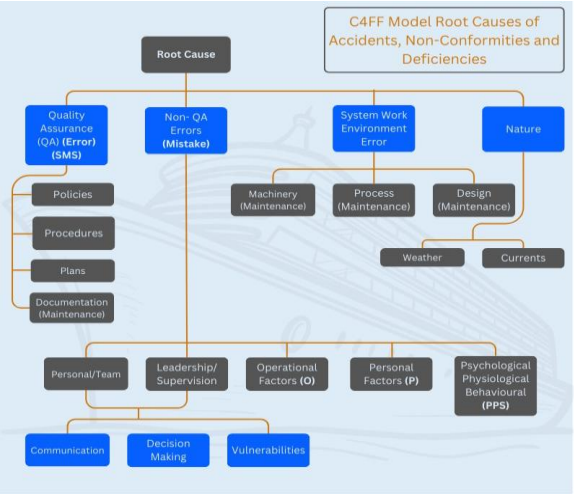


Figure 6. Root Causes of Accidents, Audit non-conformities and port inspection deficiencies (Source: Ziarati et al., 2024 – www.mairfuture.org).

8. Learning Accidents

After examining the results of external audits, port inspections, and over 200 accidents, C4FF has identified the top 25 root causes of accidents, non-conformities, and deficiencies. The sample results from these accidents reported in Ziarati et al. (2024) and De Melo Rodriguez et al. (2024) are shown in Table 1, where each group category has its top root causes. The important root causes and contributing factors are also recognized within each category group. The Leadership factor, specifically "insufficient risk evaluation, poor team composition, manning issues, excessive pressure to complete a task, and assigning tasks without the necessary qualifications, experience, or equipment," was identified as the primary cause of accidents.

Table 1. The top 25 categories of the root cause of, or contributing factor to, accidents and incidents at sea (Ziarati et al., 2024 and De Melo Rodriguez et al., 2024) – A sample of 10 accidents are shown below to demonstrate methodology)

Legend: • = Applies

NO	Vessel	Accident type	Working Environment				Personal										Leadership				Organisation						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		Loss of Stability								•	•	•	•		•		•	•	•	•		•	•	•	•		•
2		Human Factor			•	•									•		•	•	•				•			•	
3		Collision			•						•						•	•	•		•	•	•	•	•	•	•
4		Operational Accident		•	•					•			•				•	•	•		•	•	•		•	•	
5		Operational Accident		•	•									•				•	•		•	•	•			•	
6		Collision		•			•											•			•	•	•				•
7		Grounding		•									•				•	•			•	•	•	•		•	•
8		Collision		•						•			•		•			•			•	•	•			•	
9		Grounding								•			•	•				•	•		•	•		•			
10		Capsize		•			•	•	•	•	•		•	•	•		•	•	•	•	•	•		•			•

8.1 Learning from Audits

Table 2 shows the data obtained from IACS which in the main supports the data presented by Lloyd's Register (LR) namely that ship maintenance, ship board operations and compliance with rules/regulations are the top three highest frequency non- conformities respectively. As can be seen there were some forty-five thousand non-conformities noted during 2018-2022. The LR data, representing 15% of the overall total, showcases certain distinctions when compared to the IACS data, as it highlights non-conformities at the sub-element level. LR data points out that non-compliance with rules and regulations is the most frequently observed non-conformity. Thus, breaking the ISM Code elements into sub-elements has some important value (Ziarati et al., 2024 and De Melo Rodriguez et al., 2024).

Table 2. ISM Non-Conformities Observed 2017-23 - (Source: International Association of Classification Societies (IACS)

Non Conformities Observed/Noted								
Row Labels	1 Jan - 31 Dec 2018	2 Jan - 31 Dec 2019	3 Jan - 31 Dec 2020	4 Jan - 31 Dec 2021	5 Jan - 31 Dec 2022	Grand Total	Average	
1. General	1401	1203	1207	1824	1765	7400	1480	1.2.2.1 - Safe Working Practices, 1.2.2.2 - Safeguards against identified risks, 1.2.2.3 - Safety Management skills & preparing for emergencies, 1.2.3.1 - Compliance with rules & regulations; 1.2.3.2 - Taking into account of codes, guidelines & standards; 1.4 - Functional Requirements
2. SAFETY AND ENVIROMENTAL PROTECTION POLICY	112	72	90	112	135	521	104.2	2.1 - Establishing a safety & environmental policy; 2.2 - Implementing the SMS Policy
3. COMPANY RESPONSIBILITY AND AUTHORITY	230	184	183	205	186	988	197.6	3.1 - Ship owner assigning ISM responsibility; 3.2 - Defining & documenting responsibilities and 3.3 - Adequate resources for the DPA
4. DESIGNATED PERSON(S)	95	76	83	79	107	440	88	4 - Role of the DPA
5. MASTER'S RESPONSIBILITY AND AUTHORITY	322	328	286	309	380	1625	325	5.1.1 - Master implementing the SMS Policy; 5.1.2 - Master motivating the crew; 5.1.4 - Master verifying SMS related activities; 5.1.5 - Master periodically reviewing the SMS and 5.2 - Use and knowledge of the overriding authority
6. RESOURCES AND PERSONNEL	1642	1625	1425	1732	1877	8301	1660.2	6.1.1 - Master properly qualified for command; 6.1.2 - Master fully conversant with SMS; 6.1.3 - Master given necessary support; 6.2.1 - Ship manned with qualified and medically fit personnel; 6.2.2 - Ship appropriately manned to safely cover all operations; 6.3 - Crews familiarisation on board; 6.4 - Adequate knowledge of rules and regulations; 6.5 - Identification of training needs; 6.6 - Working language used and 6.7 - Effective communication used.
7. SHIPBOARD OPERATIONS	2038	1897	1848	2027	2424	10234	2046.8	7 - Shipboard Operations
8. EMERGENCY PREPARDNESS	1201	1195	1033	1202	1470	6101	1220.2	8.1 - Identification of contingency plans; 8.2 - Drills & exercise planning for emergencies and 8.3 - Companys ability to respond to emergencies.
9. REPORTS AND ANALYSIS OF NON-CONFORMITIES, ACCIDENTS NAD HAZARDOUS OCCURRENCES	1127	1088	1028	967	1107	5317	1063.4	9.1 - Reporting, investigating, analysing accidents, NCs, etc. and 9.2 - Implementation of corrective actions.
10. MAINTENANCE OF THE SHIP AND EQUIPMENT	3968	3689	3296	3778	4419	19150	3830	10.1 - Establish procedures to maintain the ship; 10.2.1 - Inspections held at the proper interval; 10.2.2 - Deficiencies reported; 10.2.3 - Appropriate action on deficiencies taken; 10.2.4 - records of activities maintained; 10.3 - Identification & Measures for critical equipment and 10.4 - Inspection routines & follow up incorporated in the maintenance routines.
11. DOCUMENTATION	1152	965	912	968	1086	5083	1016.6	11.1 - Establishing document & data control; 11.2.1 - Valid documents available on relevant locations; 11.2.2 - Review & approval of (changes to) documentation; 11.2.3 - Obsolete documents promptly removed and 11.3 - Suitable & effective SMS maintained.
12. COMPANY VERIFICATION, RECIEW AND EVALUATION	692	713	679	719	728	3531	706.2	12.1 - Internal audits at 12 month intervals12.2 - Personnel undertaking tasks in conformity with Companys responsibilities; 12.3 - Management review; 12.4 - Audits and corrective actions in accordance with procedures; 12.5 - Independence of internal auditors; 12.6 - Reporting results of internal audits and reviews and 12.7 - Timely corrective action on findings noted.
Grand Total	13980	13035	12070	13922	15684			

8.2 Learning from Port Inspections

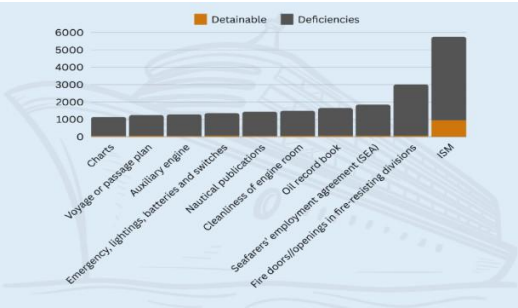
The number of ISM defects found in various PSC MoUs is shown in Table 3 below, with a significant percentage of them being detainable. Comparable figures for the Paris MoU are shown in Table 4. PSC Paris MoU documented over 100,000 defects between 2019 and 2021, including 5,000 ISM non-conformities (Paris MoU Annual Report, 2022).

Table 3a. Port State Control (PSC) MoU Observed deficiencies

PSC MoU	US Coast Guard MoU	Mediterranean MoU	Black Sea MoU	Tokyo MoU	Riyadh MoU	Indian Ocean MoU Secretariat
PSC Inspections with ISM deficiencies	929	944	1743	5630	891	1666
ISM and ISM-related deficiencies	1152	5657	11756	6187	994	1751
Detainable ISM and ISM related deficiencies	313	1213	1799	1230	42	332

Table 4. PSC Paris MoU Observed deficiencies – 2019 – 2021 and Figure 8. The ten most frequent deficiencies detected - Paris MoU 2019-21 [9]

Year	2019	2020	2021
Number of inspections	17,916	13,168	15,387
Number of individual ships inspected	15,447	12,092	13,797
Number of deficiencies	39,821	28,372	36,113
Number of detainable deficiencies	3,015	2,182	3,274
Detentions in % of the total number of inspections	2.98	2.92	3.43
Number of refusals of access to ports	25	8	11



As can be seen from the figure in Table 4, according to Biocic et al. (2023) the ISM deficiencies show by far to be the highest category of deficiencies, responsible for some 25% of the deficiencies in the top 10 categories.

9. Conclusions

The analysis of maritime accidents, audit results and port inspection using the taxonomy developed by C4FF for the OPTIMISM highlights the importance of not focusing on accidents only but to take the outcomes of the ISM audits and port inspection more seriously and systematically. Each non-conformities identified in audits and deficiencies observed in inspections can be a root cause or a contribution factor in future accidents. Application of Pareto analysis to find the highest frequency non-conformities, or deficiencies or in accidents' root causes as outlined in C4FF/OPTIMISM taxonomy could help in finding which factor if addressed would have the greatest impact in improving safety.

The root causes of accident reported here are very similar to those reported in a Strathclyde paper (Stoeve et al., 2023) and is in line with results reported in Ziarati's early papers Ziarati et al. (2017). The data from IACS demonstrates the shipboard operations and ship maintenance consistently identified as the most frequent areas of concern whereas if the audit outcomes are considered at sub-element level, as in the case of LR data, failure to comply with rules and regulation was found to be the number 1 offender. Additionally, according to the Paris MoU, ISM-related deficiencies represent the highest category of detainable deficiencies, with at least 500 detentions attributed to ISM failures.

The key findings of the research so far are that the risk assessment methodologies have to change to ensure learning from ship audits and port inspections are incorporated within a robust safety quality assurance and control system coupled with continuous learning from practice of establishing quality circles in shipping companies involving all staff members/employees.

To enhance the ISM Code, it might be worth incorporating certain elements of the PSC inspection process, such as unannounced inspections and the taking into account of external evidence alongside company-developed policies.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Women in Maritime: Gender Equality, its Challenges and Opportunities

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Abstract: The global maritime industry, traditionally a male-dominated field, face significant challenges in achieving gender equality. The reports reveal that women make up less than 2% of the global seafaring workforce. This reflects barriers to recruitment, retention, and career advancement for women. A recent study undertaken by two of this paper's authors—shows that technological advancement on board ships might hold the possibility of reducing some of these barriers and establishing incentive for women to take up seafaring. Building on this research and with the aim to gain a deeper understanding of women's work experiences amid a backdrop of rapid digitalization and automation, we did a study that explored the multifaceted problems faced by the women in the maritime industry. Based on a comprehensive methodology, including qualitative and quantitative data collection, the results highlighted several challenges facing women including a masculinized culture, harassment and safety issues, work-family balance, wage disparities, absence of mentorship, physical and mental well-being concerns. Many of these were identified as among the major hindrances that deter women from taking up maritime career. However, it was also suggested that emerging technologies can mitigate some of these barriers and foster a more diverse maritime workforce by reducing physical demands and facilitating remote operations. The key recommendations of the study include significant policy interventions, promoting cultural change, harassment combat, reinforcing mentorship programs, and offering equitable career progression opportunities. This study by reinforcing its commitment to gender equality aligns with the IMO's Women in Maritime Programme and the United Nations Sustainable Development Goal 5. By foregrounding actionable trajectories towards a better gender-equitable maritime future, this research findings can serve as a valuable resource for maritime industry stakeholders, educational institutions, and policymakers. We call for continued research into the intersection of gender and technology, emphasizing the requirement for empirical data in guiding effective policies and practices that will transform the maritime industry for generations to come.

Keywords: *Gender Equality, Maritime Industry, Women Seafarers, Digitalization, Workforce Diversity, Maritime Education and Training, Human Factor, Human Element*

1. Background and Literature Review

The maritime industry, a crucial sector of the world economy, has been traditionally a male-dominated industry, with women facing significant barriers to enter and advance. This section examines the historical evolution of women's workforce participation, the drivers and complexities influencing their involvement, as well as their modern-day status in various industries, particularly in the seafaring profession in the merchant fleet. It also outlines how digitalization and automation influence women's participation in the industry, both in terms of opportunities and challenges.

1.1 Historical Evolution of Women's Workforce Participation

The participation of women in economic activities has varied significantly over time. Women took part in farming, trade, and home production in premodern agricultural economies (Estlund, 1995; Milkman, 2013). During the medieval period, women were often involved in family trades and guilds, but their

involvement in commercial and administrative roles was limited (Horrell & Humphries, 1995; Prasad, 2001). The Industrial Revolution marked a watershed, as women shifted from rural labor to factory- based work in textiles and apparel production, though under harsh conditions and low wages (Horrell & Humphries, 1995). Pressure for workers' rights in the 19th and 20th centuries led to improved working conditions and gender protections.

The World Wars accelerated women's participation in different sectors, including manufacturing and engineering, as they filled jobs vacated by men (Falconi, 2020). Social forces following the wars pushed women back into the home, but feminist movements in the second part of the 20th century, coupled with legislative interventions like the Equal Pay Act, fostered gender equality in the workplace (Falconi, 2020; Prasad, 2001). Women nowadays work in many fields like technology and finance, yet problems like wage gaps and underrepresentation in leadership still plague them globally (Forum, 2023).

1.2 Drivers and Complexities of Women's Workforce Participation

Several factors drive women's workforce participation. One of the primary enablers is education, as increased access to education opens up career opportunities (Horne, 2017). However, work and education correlate differently across regions and life stages, more commonly following a U-shape where both illiterate women and those who are highly educated work more (Singh, 2024). Socio-economic circumstances, social norms, and urban-rural location also influence participation rates (Parnell, 2022). Paid parental leave and anti-discrimination laws are government policies that create enabling environments, and economic need and shifting cultural attitudes towards dual-income families enable women's employment (Kelly et al., 2022; Lari, 2022).

Women's employment has economic dividends, including GDP growth and business performance enhancement (Christiansen, 2016). Socially, it enables gender role change, financial independence, and improved family outcomes. Yet complications, particularly in work-life balance, follow, for women typically bear primary caregiving responsibilities, which generate stress and career stagnation (Izzaty Shahirah Nor Sham, 2021). Occupational segregation and workplace discrimination also complicate advancement (Hossain, 2018; Semyonov, 1980). Technological change, such as remote working and the gig economy, has created opportunities, with women able to balance careers and family work (Prabha, 2023).

1.3 Women's Participation Across Industries and the Blue Economy

Women have also increased their numbers in traditionally male-dominated fields like STEM, where they now comprise 28% of the global workforce but remain excluded from leadership roles (UNESCO, 2021). On the other hand, women dominate the fields of healthcare (70%) and education but face wage disparities and fewer chances of promotion (Ayaz, 2021; Evetts, 2017). The Blue Economy, encompassing sectors like fisheries, coastal tourism, and maritime transport, offers opportunities for women but remains dominated by men. Women in fisheries and aquaculture represent almost 50% of the labor force, mostly in post-harvest operations, although gendered divisions confine their involvement in principal production (FAO, cited in World Economic Forum, 2024). In coastal tourism, women play a role by engaging in ecotourism and handicrafts, although they tend to hold low-income jobs (Quang, 2024). In offshore renewable energy, women occupy only 21% of positions, with barriers ranging from socio-cultural norms to lack of gender-sensitive policies (WWF, 2023; Bagdi et al., 2023).

1.4 Women in the Maritime Industry: Focus on Seafaring

The maritime industry, and seafaring in particular, reflects deep-seated gender disparities. Women comprise just 1.28% of the global seafaring community, predominantly in catering roles onboard cruise ships (Baltic and International Maritime Council (BIMCO), 2021; Emad & Oxford, 2008; Srinivasan, 2021). At officer ranks within the merchant fleet, their representation is even lower, with less than 5% occupying commanding roles (Narayanan, 2023). Barriers include restricted access to training, a lack of female role models, and societal perceptions of seafaring as a man's job (Kitada, 2021). Long periods spent at sea conflict with domestic responsibilities, particularly for mothers, and sexual harassment coupled with the absence of support structures onboard exacerbate challenges (Dragomir, 2018; Lyu, 2023). Pay disparities in some companies are stark, with women receiving 50-60 pence for every pound that men receive (Emad, 2018; Kelly, 2021).

Programmes like the IMO's Women in Maritime Initiative and the Pacific Women in Maritime Organization aim to promote gender equity, but progress is slow (Pratiwi, 2024). Regional differences persist, with countries

like Sweden having higher female representation (13-19%) compared to China (Lyu, 2023; Nastalli, 2022). The industry's "hegemonic masculinity" culture and gendered language also exclude women (Connell, 2005).

1.5 Impact of Digitalization and Automation

The advent of Maritime 4.0, including remote operations and automation, presents an opportunity to amend gender inequalities. Maritime Autonomous Surface Ships (MASS) and Remote Operating Centers (ROCs) reduce physical demands and risks like harassment, making jobs more accessible to women (Cai, 2025; Emad, 2022; Emad, 2020; Emad & Shahbakhsh, 2022; Nasaruddin & Emad, 2019). Remote operation enhances work-life balance, enabling women with domestic responsibilities to participate (Kim, 2019). Nevertheless, challenges remain, as the shift to IT-intensive jobs can leave behind women who are not specially trained, because of the male-dominated nature of IT (Carey, 2017). Cybersecurity threats and the need for gender-sensitive design of technology complicate the transition (Wróbel, 2017). Without deliberate inclusivity, automation can entrench existing gender disparities.

To sum up, women's participation in the workforce has progressed significantly, but the maritime industry lags behind in achieving gender equality, particularly in seafarer roles. Cultural obstacles, harassment, and unequal pay are some of the challenges that persist, whilst digitalization and automation present some opportunities for inclusivity. The remedy is in thorough policy-making, specialized training, and cultural adaptations to allow for equal participation of women, aligned with global targets such as SDG 5 and organizational performance enhancement.

2. Method

This study employed a mixed-methods research design to be able to investigate the determinants of women's uptake of the seafaring profession in the face of ongoing digitalization and automation of the maritime industry. This allowed for the integration of quantitative and qualitative data, facilitating a comprehensive understanding of both measurable barriers and the complex experiences of women at sea. The inquiry was exploratory and descriptive, aiming to document individual perceptions, organizational practices, and overall industry trends, given the complex socio-cultural context of the shipping sector (Emad & Kataria, 2022; Makri, 2021).

The inquiry followed a multi-phase design. Phase one involved a comprehensive literature review, reviewing existing research on women's work in seafaring, maritime human resources, and shipping 4.0 technology consequences. This phase was important for establishing a foundation of knowledge regarding women seafarers and the technological environment in shipping. The second phase was primary data collection from three target groups: active seafarers, ship-based maritime professionals, and other maritime stakeholders including academics, technology providers, and policy advocates.

A purposive sampling strategy was pursued to attain a heterogeneous respondent group of 108. This was augmented with snowball sampling for reaching expert respondents. The data was gathered using a structured Qualtrics-based survey questionnaire of 25 questions. The qualitative data collected through closed-ended and open-ended formats questions to provide quantifiable inputs. The survey questionnaire was administered online over two months using targeted email invitations and professional networks to attain wide geographic and professional coverage.

Quantitative data were submitted to descriptive statistics, and qualitative data from open-ended questions were thematically analyzed to guide more in-depth insights and validate findings. Ethical clearance was given, participant anonymity was preserved throughout the study, and arrangements were in place for respecting requests for sensitivity around sensitive matters.

3. Analysis and Results

3.1 Introduction

This chapter presents the findings of a mixed-methods study examining women's work within the maritime industry, and in particular how technology is shaping a digitalized maritime future. Data were collected from 108 women actively employed across various segments of the maritime industry using quantitative surveys and qualitative data. The findings are organized into four principal categories: (a) demographic profile of the respondents, (b) factors shaping women's participation in seafaring, (c) impact of technology on women's participation, and (d) path towards gender equality in the maritime industry. The findings present key trends, statistical findings, and in-depth insights of the female maritime labor force, constituting a concrete foundation for understanding challenges and opportunities.

3.2 Demographic Profile of the Respondents

3.2.1 Roles in the Maritime Industry

Based on the descriptions of their current roles and career histories the participants belonged to three categories: (a) active seafarers, (b) shore-based maritime professionals, and (c) other maritime stakeholders. The categories were reasonably well distributed, with active seafarers constituting the largest group (37%), followed by shore-based maritime professionals (33%), and other maritime stakeholders (30%). The second group included policymakers, technology providers, academicians, and other professionals working in the maritime sector. The relative number of respondents from each category gives the combination of various perspectives, as may be evidenced from Figure 1, that enhances the study's ability to collect different experiences from the sector.

3.2.2 Years of Experience

The participants' base of professional experience ranged from less than 1 year to over 20 years. This range adds depth to the data by incorporating both early-career and veteran professional input. New entrants could provide fresh input on emerging issues, while veterans could provide historical context and longitudinal observations, collectively expanding the view of women's participation at every phase of their careers.

3.3 Factors Affecting Women's Participation in Seafaring

This study aimed to identify significant barriers to the participation of women in seafaring in a maritime industry undergoing digitalization. Through quantitative questionnaires and qualitative open-ended questions, several significant factors were elicited, as discussed below.

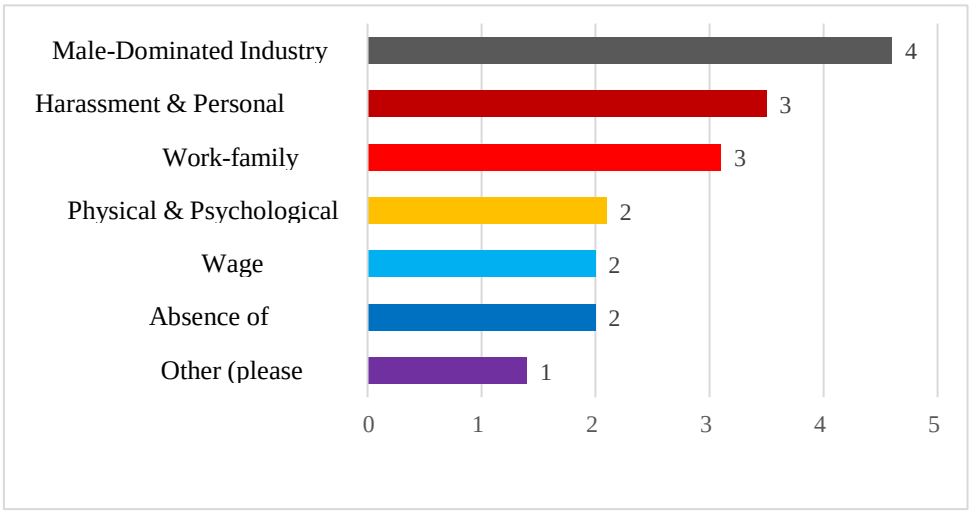


Figure 1. Factors affecting women's participation

3.3.1 Male-Dominated Industry Culture

- Quantitative answers, as graphed in Figure 1, identified a male-dominated culture as the biggest barrier to women's participation in seafaring, having been cited by 46 respondents. To explore this facet in greater depth, three probing questions were posed.
- Gender-Specific Challenges: Approximately 80% of respondents reported having experienced gender- specific challenges in their careers. Frequency varied, with "Sometimes" being the most common response (42%), followed by "Never" (22%), "Often" (16%), and "Very Frequently" (9%). Qualitative responses offered an explanation of the challenges, such as being met with skepticism by colleagues, needing to prove capability, feeling outnumbered, and continuing stereotypes about female capabilities and visibility. One of them noted, "Being in a male-dominated profession, I also share common challenges…," and another one confirmed, "Yes, occasionally, doubt from others, pressure to prove myself, and the feeling of being outnumbered. Classic stereotypes on females and work recognition."
- Effectiveness of Gender Equality Initiatives: When asked about the effectiveness of existing gender equality initiatives, 72% of the sample found them "Moderately effective," 21% "Highly effective," and 8% "Not effective at all." Qualitative answers described the initiatives as a "step in the right direction" but commented that "there is still a long way to go" for skills to outweigh gender. Positive directions, such as more women in management, were identified, though some participants felt the focus had to be on developing "the perception and courage of female individuals" to enter the field rather than depending on systemic change alone.
- Changes Required to Enhance: Respondents proposed numerous changes to challenge the male-

dominated culture, including equal pay (n=40), increased access to education and training, flexible working, cultural norm changes, mentoring programs, strict anti-discrimination policies, and conducive national and international policies. Qualitative suggestions emphasized the need for "equal opportunity, more representation, and a cultural shift in which respect and competence weigh more than gender," along with leadership training and good working conditions.

3.3.2 Harassment and Safety Risks

Harassment and safety hazards were a significant obstacle, with 35 respondents mentioning it in the quantitative data (Figure 2). Roughly 40% of respondents reported that they had experienced or observed harassment or discrimination at sea, and 60% reported no such incident. How they were handled was rated on a scale of 1 (Not at all) to 7 (Extremely well handled), which provided a mean score of 5, with responses varying between 4 and 6, indicating a neutral to moderately positive attitude.

Qualitative responses provided additional context. One participant shared, "Fortunately, I haven't had it happen to me personally, but I've seen instances where women weren't taken as seriously, some do say something, some don't. It just depends on what leadership does; good officers squash it, but there is still a long way to go." Another highlighted agency by stating, "Yes.". Harassment/discrimination will stop if the victim will stand up for themselves." Reporting mechanisms were highlighted as central, with one participant advising, "First inform your supervisor or manager of what you see and what you hear, as you are that person's voice and eyes to report the truth." Moreover, a broader context was exposed: "Yes, for us as a citizenship development requirement, we encounter such actions on board by my fellow workers (both male & female), but we take the initiative to help those elderly women and report to the human resources."

These risks coincide with physical and mental health concerns, cited by 21 respondents. Harassment incidents contribute to stress, anxiety, depression, and trauma, compromising well-being and retention. Unsafe environments cause vulnerability, particularly on long voyages, sustaining a cycle that deters women from seafaring.

3.3.3 Work-Family Conflict

Work-family conflict was the third most significant obstacle, cited by 31 respondents. Follow-up questions explored this issue:

- Impact on Career Progression: Over half the sample reported a "Moderate impact" of family care on career progression, while over one-third reported a "Significant impact," and 12.5% reported an "Extreme impact." The average impact was 5 on a scale of 7. Open-ended responses echoed the challenge of balancing long sea travel with family care demands, compounded by social roles of women as primary caregivers. As one put it, "Long time at sea makes it hard to combine family and career, especially for women," and another, "Society's attitude and expectation, especially for women who are expected to take care of the family and children."
- Work-Personal Life Balance Challenge: Over 70% of respondents assessed work-personal life balance as being moderately to extremely challenging, with 5% marking it as "Extremely challenging." The mean challenge level was 5 on a scale of 7. Open-ended comments noted time management, with respondents remarking on the need for "an effective time management schedule that allows for self- care and flexibility."
- Balance Strategies: Time management was stressed as most critical, along with self-care like getting "enough sleep and eat good foods" and enjoying work while taking care of personal needs.

3.3.4 Absence of Role Models and Mentorship

The majority (well over two-thirds) of the respondents reported few or very few female role models in the industry, with only one respondent seeing representation as high. A minority noted seeing women leaders gradually increase, a sign of gradual change. Few visible role models disillusion potential women, making mentorship critical.

3.3.5 Organizational Support and Equal Opportunities

Organizational support was seen as vital, with nearly two-thirds saying it aids retention a great deal. But 16% saw its role as little or nothing. Qualitative remarks praised female-only workshops and mixed recruitment but also noted tokenistic behavior. Follow-up questions revealed:

- Training and Development: The most common programs were leadership training, technical skill development, and upskilling, with only 12 participants reporting mentorship programs. As one participant noted, "We all have training, not only for women. They give us training especially for developing oneself and improving." Anti-harassment training was received by 20 participants.
- Wage Gap: While 20 first cited wage gap as an obstacle, many perceived wages to be equal, with

comments like "Seafarer salary is based on the position, not on gender, so there is no bias." Others advocated transparency by suggesting, "Implementation of gender equal pay policy and reporting system can bring a big difference."



Figure 2. Challenges and Pathways to Gender Equity in the Maritime Industry

3.4 The Impact of Technology on Women's Participation

Participants were optimistic about the role of technology, with only 4% doubting its utility. Qualitative responses highlighted the issue of automation and digital tools reducing physical demands, as one respondent stated, "Technology levels the playing field, especially automation, digital tools and smarter ships make skill matter more than strength", "Opening more doors for women." Technology also enabled communication, networks, and online learning, with proposals like "More online courses & tutorials, develop apps and show (share) in social media that can easily access info." Remote work was also considered a benefit, though one respondent cautioned, "It may help but cannot fix the deeply ingrained cultural or structural barriers on its own."

3.5 Pathways to Gender Equity in the Maritime Industry

Suggestions from respondents were actionable across five areas:

- Measures to Improve Gender Equality: Equal pay (65%), improved education (58%), flexible arrangements (56%), cultural change (56%), and anti-discrimination policies (52%) highly ranked.
- Changes Wanted: Answers mirrored measures, with an emphasis on policy, culture, and support.
- International Organizations' Role: Overall, 56% thought the IMO's role was "Significant" (41%) or "Very significant" (15%), with comments like "I think the IMO has a huge impact on the way that companies operate and have an ability to change the maritime industry for the better."

- Attracting Women: Responses included visibility, training, and role models.
- Advice to Young Women: Top advice was "Be mentally and emotionally strong" (67%), "Be confident" (65%), and "Seek mentorship" (61%), with one respondent exhorting, "Maritime is not only for men; we, women, can do it too. Believe in yourself."

Overall, these results reveal a male-dominated culture, harassment risk, work-family conflict, and absence of mentorship as prime challenges, with technology and policy initiatives offering promising directions to equity

4. Discussion and Conclusion

This study presents a detailed examination of the facilitators and barriers to women's participation in seafaring amid an increasingly digitalized maritime industry. Drawing upon the responses of 108 women—seafarers, shore-based personnel, and other maritime stakeholders—the research identifies a masculinized culture, harassment and safety issues, work-family balance, wage disparities, absence of mentorship, and physical and mental well-being concerns to be major hindrances. The male culture was the greatest obstacle, with qualitative findings pointing to ongoing stereotypes, bias, and pressure to demonstrate ability. Harassment and safety issues impact 40% of those surveyed, with uneven handling pointing to the necessity for strong, transparent processes. Work-family conflict, a concern for over a third of the respondents, is exacerbated by long sea trips and societal pressures on women as primary caregivers, necessitating better time management and support.

Despite these challenges, there is confidence in the progressive potential of technology. An overwhelming majority of participants view digitalization, automation, and smart systems as tools to level the playing field by reducing physical demands, enhancing connectivity for crew communication with loved ones, improving safety, and enabling accessible training and shore-based jobs. However, technology alone cannot eradicate deep-seated cultural or structural issues, which implies that complementary policy measures are necessary.

The findings point to the necessity of targeted policies to advance gender equality. To combat the male- dominated culture, compulsory gender sensitivity training, inclusive communication policies, and leadership diversity metrics are needed. To minimize harassment, zero-tolerance policies, confidential reporting and victim support systems need to be in place, with the assistance of technology through secure apps and tele-counselling. To minimize work-family conflict, flexible contracts, longer maternity leave, and reliable onboard internet are necessary, supported by crew scheduling software. The absence of role models and mentors for women necessitates structured programs, online communities, and visibility programs to inspire and advise women. Equal opportunity means gender-blind recruitment, transparent salary ranges, and equitable access to training, enabled by digital platforms and audits.

This research provides a seminal contribution to the maritime literature, integrating quantitative trends and qualitative richness to render women's experiences visible. It emphasizes the potential of technology in dismantling barriers and creating inclusive possibilities, while charting a course for policy interventions by shipping companies, the IMO, governments, and training institutes. The proposed framework connects barriers to concrete actions, with technology as a significant enabler, paving the way for a gender-equal maritime workforce.

Looking to the future, longitudinal studies need to assess policy impacts on retention and well-being, and cross-cultural investigations can establish best practices globally. Further exploration of specific technologies, mental health counseling, male champions, and mentoring programs will inform. Quantification of economic returns on gender equality can also force investment. Collectively, these efforts have the potential for a more inclusive, resilient, and sustainable maritime industry, in which women can thrive without systemic barriers.

Acknowledgment

"The materials and data in this publication have been obtained through the support of the International Association of Maritime Universities (IAMU) and The Nippon Foundation in Japan."

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Integrating System Dynamics into Maritime Education for Green Shipping Corridors and Decarbonization Strategies

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Abstract: The shipping industry plays a central role in global trade. Large container ships operate on the long-haul corridors between Asia and Europe, transporting enormous amounts of cargo (UNCTAD 2023) while contributing significantly to greenhouse gas emissions. In response to climate change and increasing pressure from regulators, efforts to reduce the carbon footprint of shipping have gained momentum and led to the development of green shipping corridors — designated routes that use alternative fuels, energy efficiency measures, and advanced digital tools to significantly reduce emissions (ONCS & AIPL 2023). These initiatives are a decisive step towards sustainable shipping. However, their successful implementation requires employees with expertise in alternative fuels, voyage optimization, emissions monitoring, and operational adjustments to new regulatory frameworks. This study examines how these new environmental and technological challenges can be effectively integrated into shipping education and training programs. A particular focus is placed on simplified System Dynamics modelling as a pedagogical tool to improve students' understanding of the complex interrelationships involved in shipping decarbonization. Using a case study of container ship transportation from Asia to Europe, the study demonstrates how simplified models can simulate fuel consumption, emissions, regulatory compliance, and economic trade-offs along these critical trade routes. By incorporating real-world scenarios, students can analyze the impact of operational decisions on overall emissions and assess the feasibility of low- carbon strategies such as slow steaming, the adoption of alternative fuels, and digital voyage optimization. The challenge is translating these highly technical and policy aspects into engaging and practical learning experiences for maritime students to ensure they are prepared for the rapidly evolving regulatory and operational landscape. Educators can use system dynamics modelling to introduce a structured yet intuitive approach to understanding the non-linear relationships (Duggan 2016) that influence sustainable shipping practices. The study proposes a framework for incorporating interactive simulation tools into maritime education to bridge the gap between theoretical knowledge and real-world applications. The results show the importance of integrating environmental awareness, digitalization, and decision-making skills into educational programs to ensure that future maritime professionals can actively contribute to the decarbonization of the shipping industry.

Keywords: Decarbonization, System Dynamics, Maritime Education, Container Shipping, Alternative Fuels, Slow Steaming, Regulatory Compliance, Emission Reduction

1. Introduction

Green shipping corridors could be the key to reducing greenhouse gas emissions on a global scale. These are defined shipping routes between two or more ports that aim to introduce zero- and low-emission fuels and technologies by harmonizing regulations on these routes (Jugović et al. 2025), for example, container shipping between East Asia and Europe. One such corridor could be for container ships between the port of Shanghai and the Port of Koper. Figure 1 presents the key stakeholders involved in the green corridor, along with their respective constraints and inputs (ABS 2023). As not all inputs are relevant for every case study, appropriate assumptions are applied where necessary. For the purpose of model development, the following framework focuses solely on port-level analysis, with the Port of Koper selected as the reference case. The Port of Koper is an important trading partner for Central European countries such as Hungary and Austria and

therefore has a strategic logistical position. Ships in transit are the main emitters of greenhouse gases in maritime transport, but ports also play a role in emitting greenhouse gases (especially if they accommodate many ships). For this reason, the implementation of measures such as onshore power supply (OPS) and alternative fuels (such as methanol, ammonia, and hydrogen) is needed to reduce port emissions (Alamoush et al. 2020). At sea, slow steaming is the main method of reducing emissions from older ships. Organizing all these potential variables in a dynamic model requires realistic planning and a common regulatory framework. This is a difficult task not only for policymakers but also for academic educators who will have to teach the new generations of seafarers in this area.

This paper explores the possibilities of System Dynamics (SD) modelling in education by making such a scenario possible. SD, as the name suggests, provides an excellent dynamic, simulation-based framework for students and teachers to engage with different decarbonization environments, rather than just static calculations of emissions or the costs of those emissions. In our model, we have created an SD model for the GHG emissions of the container terminal in the port of Koper, including different variables from the electrification of port equipment to OPS, as this port is the last node in the potential green corridor between Shanghai and Koper. By implementing this SD model in maritime educational institutions, new opportunities could arise as this model could not only be improved, but also new models could be developed by supporting students in developing new feedback loops and scenarios. By presenting this model and its possible extension, learning can also include demonstrations of how new technologies, regulatory changes, and operational measures can change emission levels in each area. This study is an educational link between theory and practice in relation to reducing greenhouse gas emissions by providing students with a clearer picture of dynamic processes. Therefore, this study aims to answer the following research question: Can System Dynamics serve as an effective educational tool to improve students' understanding of greenhouse gas emissions in maritime contexts?

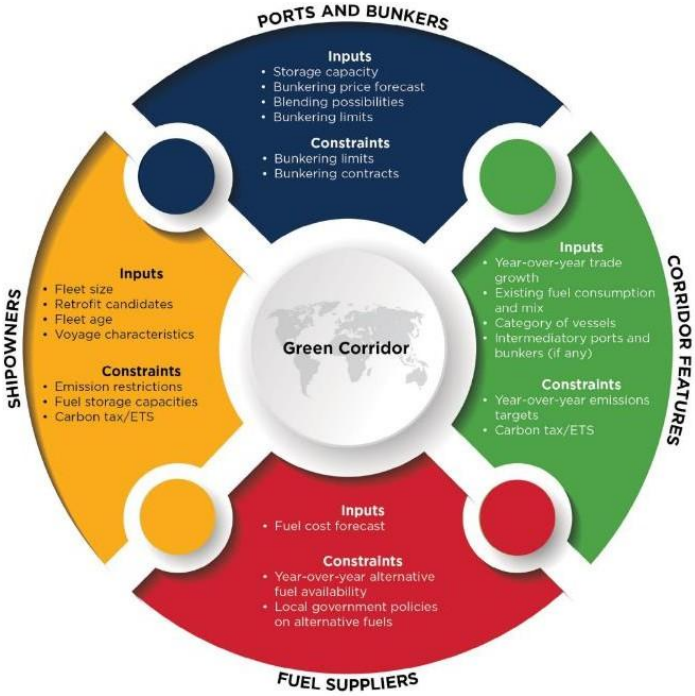


Figure 1. Various stakeholders, i.e., sub-models of the green corridor

2. Materials and Methods

This study aims to develop an SD model that could decarbonize the container terminal of the Port of Koper as the last link of the green shipping corridor between Shanghai and Koper even faster than proposed by the IMO. Voyages on the open oceans are the main source of greenhouse gas emissions in this corridor, but ports also play a role. Both ports and ships need to be decarbonized if the green corridor is to work. Therefore, reducing emissions from the Port of Koper is essential. The main objective is to teach seafarers the benefits of modelling with SD and how different port variables are linked and can reduce emissions. For this reason, the

chapter is divided into four parts:

- Model Design and System Boundaries.
- Data Inputs and Major Assumptions.
- Simulation and Coding Environment.
- Pedagogical Framing and Educational Application.

2.1 Model Design and System Boundaries

The presented model focuses on feedback loops, stocks, and flows in a time horizon from 2023 to 2050.

The IMO has set the following timeframe for emission reductions in the maritime sector (IMO, 2023):

- 20 % (preferably 30 %) reduction compared to 2008 by 2030.
- 70 % (preferably 80 %) reduction compared to 2008 by 2040.
- Achieve net zero by 2050.

The total emissions of a container terminal at a given time are the main stock of our model, with inflows from energy consumers (port equipment and ships) and outflows from emission reductions due to countermeasures. Feedback loops capture the introduction of new technologies and the gradual increase in the carbon price. As mentioned above, this model is very aggressive and assumes full electrification of port equipment by 2040, a high uptake of OPS, and a complete infrastructure for bunkering ships with green fuels. The basic flowchart is as follows:

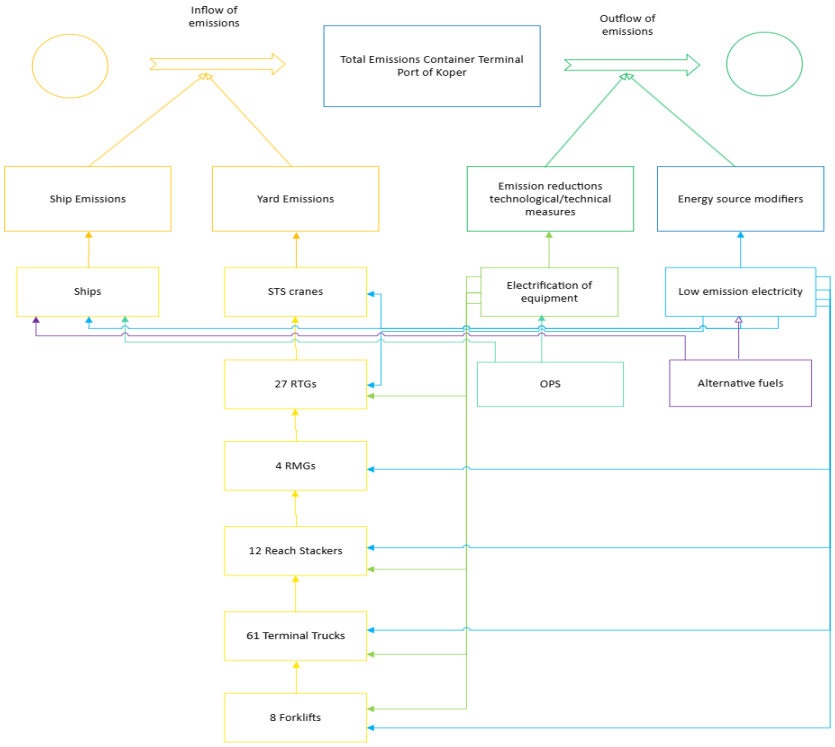


Figure 2. Flowchart of the System Dynamics model of the container terminal in the Port of Koper

The developed model aims to reduce emissions by using annual time steps to strike a balance between granularity and educational simplicity. Considering the system boundaries, there are emissions associated with:

- Port equipment such as STS cranes, RTG cranes, RMG cranes, reach stackers, terminal trucks, and forklift trucks.
- Reefers (although these emissions are all indirect, as all reefers are electrically powered).
- Ships and their auxiliary engines during berth.
- Emission savings from electrification (although the energy source must be low emission), OPS, and alternative fuel bunkering infrastructure.

The basic flowchart (Figure 2) of our SD model revolves around the main stock, in our case the total emissions of the terminal. The inflow of emissions or the increase of emissions in the main stock is generated by ships and port equipment. The outflow of emissions or reduction in inventory is caused by emission reduction measures such as OPS, the introduction of alternative fuels and the electrification of port equipment (STS cranes, RMGs, RTGs, reach stackers, terminal trucks and forklifts). Electrically powered equipment must also be powered by low-emission sources, otherwise they have no impact on overall emissions. OPS only affects ship emissions for obvious reasons. Alternative fuels are only used for the auxiliary engines of ships in our model.

2.2 Data Inputs and Key Assumptions

To design a model that is useful for educational purposes, data from various sources was used:

- Data on the number of individual port equipment and container vessels calling at the port of Koper in 2023.
- Emission factors for port equipment are based on industry reports for similar equipment. (Port of Los Angeles 2017; Port of Los Angeles Harbor Department 2024; Champkin 2020; Pashkevich et al. 2019; Dongqi Crane n.d.; GP Storage Containers 2023).
- The working hours of equipment were also determined on the basis of industry reports (Saanen and Soto Pascual 2020; International Transport Forum 2021; Razeghi et al. 2023).
- Research sources on future prices of nuclear energy from the future Krško 2 nuclear power plant (NEK2), as wind and solar energy are not profitable in Slovenia due to the lack of these two sources (Spasić 2024).
- Financial databases for investments and cost estimates (FreightWaves Staff 2019; McBride et al. 2020; Sisson 2017; Ruedig 2024; Thunder Said Energy 2024; Nolan 2024; MHE Bazar 2024; Terminalift LLC n.d.; Andersson and Márquez Salazar 2015; Alfa Laval et al. 2020; Semchukova et al. 2024; Ewing 2023).

Table 1. Working hours and Emission Factors of port equipment

	Emission factor (CO2EQ/hour)	Working hours (hours)
RTGs	160	5000
STSs	7.5	3876
Terminal Trucks	50.5	1832
Reach Stackers	26.9	3876
Forklifts	18.76	1832
RMGs	18	5000
Reefers	1.04	8760

Key assumptions of the model are:

- Most of the port equipment is electrified by 2050 (80 to 90%).
- OPS is possible at 4 out of 5 berths, significantly reducing ship emissions, provided the electricity is low-carbon.
- For methanol and ammonia bunkering, infrastructure is built and commissioned by 2040, with investment in hydrogen minimized due to high CAPEX (Semchukova et al. 2024).
- The carbon intensity of the Slovenian electricity grid is set at 80 g CO_2/kWh (Electricity maps 2025) and is expected to be reduced over time by NEK2.
- Carbon price set at EUR 73 per ton CO_2EQ in 2023 (Twidale 2025) and increasing linearly to EUR 269 per ton CO_2EQ in 2050. This affected the cost calculations.

Each appliance was assigned a specific emission factor (kg CO2/hour) and working hours per year. In our model, future electricity consumption is also included in the model to calculate future electricity costs.

2.3 Simulation and Coding Environment

We used the Python programming language3.5 to develop our system dynamics model, primarily

because it is ideal for educational purposes as open-source software. The code has a clear and modular structure, making it easy to adapt to different scenarios. Within the model, we used NumPy for numerical calculations and time series processing, while Matplotlib was used to visualize emission trends and feedback dynamics. System dynamics concepts such as stock-and-flow mechanisms, policy response lags, and ignition effects were implemented through user-defined loops and formulas. Important parameters, including the adoption rates of mitigation measures and emission reduction targets, can be easily adjusted. The model calculates total emissions over time and shows the impact of different decarbonization strategies, such as onshore power supply (OPS), fuel switching, and electrification. This structure makes the model ideal for use in the classroom, where students can strengthen both their Python programming skills and their systems thinking skills.

2.4. Pedagogical Framing and Educational Use

The main objective of this article is not only to demonstrate the applicability of System Dynamics (SD) in supporting the decarbonization of ports, but also to highlight its value as a pedagogical tool in maritime and port-related education. System Dynamics provides an effective framework for engaging students in port logistics and maritime engineering courses by allowing them to explore key sustainability challenges through simulation and critical thinking. Through this approach, students can better understand the contribution of port activities to overall maritime emissions, analyze the trade-offs between different decarbonization measures and associated costs, and develop systems thinking skills that can be transferred to other areas of maritime studies. In addition, they gain practical experience in developing and experimenting with different SD scenarios, which improves analytical thinking and decision-making. The case study of the Port of Koper, chosen for its regional importance to Central and Eastern European economies and its strategic relevance in the context of the potential Shanghai–Koper Green Corridor, serves as an illustrative example of how local dynamics intersect with global changes in maritime transportation. By exploring these interlinked levels, students gain a holistic understanding of sustainable maritime logistics. The model presented lends itself well to a variety of educational applications, including group-based projects in which students compare outcomes under different assumptions, exercises that require setting specific environmental or operational goals and then developing appropriate intervention strategies, and adapting the model framework to other ports and case studies.

3. Results and Discussion

The results we obtained from our aggressive simulation show one of the possible ways in which the container terminal Port of Koper can be decarbonized by 2050. They can also be used as an educational case study for maritime students. In this way, the results of this study have both technical and educational value. This dual purpose sets this model apart from other standard analyses and establishes a link between curriculum development and systems.

3.1 Emissions Trajectory and Reduction Levers

The presented model starts in 2023 with a baseline of a total of 24,500 tons of CO2EQ emissions generated at the container terminal in the Port of Koper in that year. These emissions were generated by ships (their auxiliary engines during berth) and port equipment such as RTGs, STSs, and terminal trucks. Emissions are being continuously reduced at a rate that will exceed the IMO's targets by 2050, when the model will reach near-zero emissions.

The strategy consists mainly of the following measures:

- Complete electrification (100 %) of port equipment such as RTGs, reach stackers, terminal vehicles, and forklift trucks.
- Introduction of OPS at 4 out of 5 berths.
- Development of an infrastructure for ammonia and methanol by 2040 so that ships can be refueled with low-emission fuels.
- Low-emission power supply (nuclear energy), probably from the NEK2.

Of the individual measures, RTG electrification contributes the most to the decarbonization of the container terminal (more than 35% reduction in emissions), which is due to the high energy consumption, long working hours, and the high emission factor of diesel. Closely followed by OPS with more than 30% of the total reduction, as it reduces ship emissions, which in another scenario or model could be the largest emitters in

ports. The electrification of other port equipment, such as reach stackers, terminal trucks, and forklift trucks, only contributes a few percentage points. OPS and fuel switching on ships overlap. For this reason, we attach less importance to fuel switching in terms of overall emissions reduction, but there are still costs involved as the infrastructure for bunkering environmentally friendly fuel needs to be built. The graphical model shows a continuous reduction in total emissions:

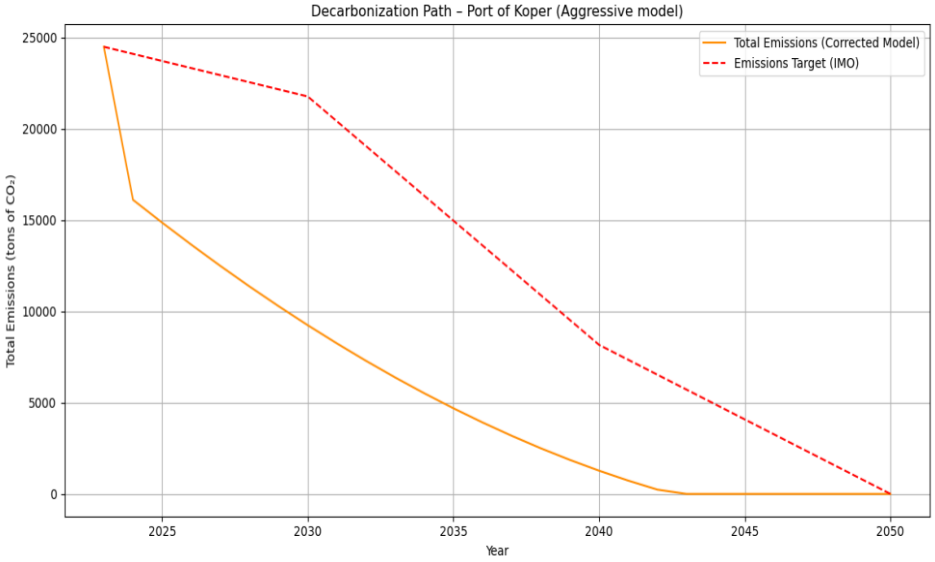


Figure 3. Modelling total level of emissions of aggressive model.

3.2 Economic Interpretation: Costs, Benefits, and Carbon Pricing

Ambitious decarbonization requires large CAPEX. These can be partially amortized by the elimination of the carbon tax and by operational efficiency due to improved technologies. Our model includes a linear increase in the carbon price from EUR 73 in 2023 to EUR 269 in 2050 per ton. This reduces the overall cost of the transition, i.e., for investments in electrification, alternative fuel infrastructure, and OPS. We have drawn some conclusions from our model from an economic perspective:

- RTG electrification offers the highest return on investment through a combination of high emissions reduction and low unit costs.
- OPS is capital-intensive but offers long-term savings when carbon costs are factored in, especially as electricity becomes decarbonized and potentially cheaper.
- Electrification of trucks and forklifts has moderate payback periods, although the comparatively low emissions contribution guarantees that their net economic benefit is lower.
- Alternative fuel infrastructure has the highest initial cost and lowest short-term return on investment from a port's perspective, as most of the costs are borne by port operators, while the benefits (i.e., cleaner shipping) primarily accrue to shipowners.

By changing adoption rates, students can also calculate new costs by making the model either more aggressive or less aggressive, which is more in line with IMO goals. In this way, more strategic planning is possible by using adoption rates in the model that are easier for ports to bear economically.

3.3 Systems Behavior and Feedback Loops

SD is so good precisely because it shows systemic dependencies between variables that are not visible in linear models. Our model contains a positive feedback loop between the gradual increase in carbon prices and the adoption rate of policies, as a higher price forces the port to accelerate the decarbonization process. The feedback loops that emerge in SD are not only analytical tools but also learning tools for students. In this way, they begin to learn and understand the non-linear dynamic transitions of SD. This knowledge is necessary for any future research on greenhouse gas emissions modelling and policy planning.

3.4 Pedagogical Applications and Learning Outcomes

The model presented offers significant pedagogical value by encouraging active student engagement and the development of critical analytical skills. It allows learners to explore the relative effectiveness of different decarbonization measures, e.g., identifying which measures deliver the greatest emissions reductions. Learners are encouraged to change the implementation rates of electrification and onshore power supply (OPS) to simulate alternative policy scenarios, as well as introduce additional constraints, such as increased electricity or carbon prices, to assess the model's response to external variables. Through these activities, the model supports the acquisition of essential soft skills, including critical thinking, scenario analysis, and evidence-based decision making. It not only enables a deeper understanding of the green transition in the maritime sector but also provides a practical environment in which students can experiment with different pathways and evaluate the outcomes of their decisions. The Port of Koper serves as an instructive example due to its strategic role in Central European logistics; however, the structure of the model is flexible enough to be adapted to other ports of interest. This adaptability inherent in the system dynamics approach makes the model an ideal teaching tool, which can be continuously expanded and refined, providing an open learning platform that evolves with the students' questions and the complexity of the topic.

4. Conclusion

Decarbonizing the maritime sector requires both innovative thinking and technological progress. Cost analysis is also required to maximize performance. All of this can be achieved through exercises, adaptive judgment, and a clear vision to connect the dots of a dynamic system. This report provides an SD model of the container terminal at the Port of Koper, which is both a technical and a learning platform. The Port of Koper is the last link in the potential Shanghai-Koper green shipping corridor. As such, it could prove valuable in the context of grassroots actions for global decarbonization. This study proves that measures such as the electrification of port equipment and OPS (provided they are enabled with low-emission sources), alongside a green fuel infrastructure, can lead to the container terminal port of Koper being almost emission-free in 2050. Our model even exceeds the IMO's gradual decarbonization targets.

The advantage of the model also lies in its possible integration into lessons. By building different scenarios and feedback loops, students gain knowledge about the economic, operational, and environmental dimensions of port decarbonization. The model thus provides a basis for linking theory and practice, allowing teachers to teach students systems thinking and emissions planning in a pragmatic and data-driven way. As green shipping corridors are increasingly seen as one of the possible solutions for decarbonizing maritime transport, courses need to keep pace. By equipping students with new knowledge in simulations, they can not only learn new things about reducing greenhouse gas emissions but also gain knowledge to find new solutions. Our case is an empirical and globally transferable model of how to achieve this. The model can be extended by either transferring it to other ports, using continuous real-time data, or extending the model to hinterland terminals. By introducing simulation-based techniques into maritime education, SD provides an excellent working basis for students to acquire new skills in the field of green transition.

Acknowledgements

The authors acknowledge the financial support of the Slovenian Research and Innovation Agency (Grant No. L7-60164).

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Regulatory challenges and future directions in cyber security for Maritime Autonomous Surface Ship (MASS)

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Abstract: The adoption of Maritime Autonomous Surface Ships (MASS) is transforming the global shipping industry, delivering operational, environmental, and safety advantages. However, this technological leap brings with it a host of cybersecurity vulnerabilities. This paper analyzes the evolving international regulatory framework for MASS cybersecurity, identifies current obstacles, and suggests policy measures for more effective governance. The discussion highlights the urgency of establishing enforceable international standards, updating legal conventions to reflect digital threats, and strengthening both risk management and insurance practices to safeguard autonomous vessels.

Keywords: MASS, Cybersecurity, IMO, Cyber-seaworthiness, Cyber Risk Management

1. Introduction

The maritime industry is undergoing a profound transformation driven by advances in automation, artificial intelligence, and digital connectivity. One of the most disruptive developments is the emergence of Maritime Autonomous Surface Ships (MASS), which are expected to deliver substantial improvements in operational efficiency, sustainability, and navigational safety. According to the International Maritime Organization (IMO), MASS range in autonomy from conventional ships with automated systems to fully autonomous vessels without any onboard crew. However, the digital foundation of these vessels introduces significant cybersecurity risks, especially given their reliance on complex software systems, satellite communication, and remote-control architecture. The maritime industry has witnessed significant cyber incidents, such as the Maersk ransomware event, attacks on COSCO and HMM, and the 2022 breach at the Port of Lisbon, all of which emphasize the critical operational, financial, and reputational risks associated with maritime cyber threats. These challenges are magnified in the context of MASS, where remote management and the absence of onboard personnel limit immediate response capabilities. As MASS shift the operational paradigm of shipping, they simultaneously demand a reimagining of the legal and regulatory infrastructure that governs maritime safety. This paper critically evaluates the global cybersecurity regulatory landscape as it relates to MASS, highlights its deficiencies, and proposes a set of strategic reforms. Central to this analysis is the argument that cyber seaworthiness must be recognized as a core principle of maritime safety, embedded in international law and industry standards such as the ISM Code and conventions governing contracts of carriage.

.2. Current Regulatory Regimes and Challenges

2.1 International Regulatory Regimes

Several initiatives have emerged to address cybersecurity in maritime operations, yet most remain at the level of soft law or voluntary compliance. At the international level, the IMO has issued Resolution MSC.428(98), which recommends integrating cyber risk management into the International Safety Management (ISM) Code. This resolution urges flag states and operators to implement cyber safeguards within existing safety management systems. However, the non-mandatory nature of the guidance has resulted in uneven application across jurisdictions, and in many cases, inadequate enforcement mechanisms are in place. In the European context, Directive (EU) 2016/1148—commonly referred to as the Network and Information Security (NIS) Directive—aims to enhance the cybersecurity of operators of essential services, including port

authorities and shipping companies. The European Union Agency for Cybersecurity (ENISA) has further provided technical guidelines and operational support to enhance cybersecurity resilience. Additionally, private maritime organizations such as BIMCO have issued cyber risk clauses for shipping contracts and have developed industry-wide best practices.

Despite these efforts, one of the most persistent challenges is the insurance sector's limited capacity to address cyber risks. Standard marine insurance policies often invoke the Institute Cyber Attack Exclusion Clause (CL380), which excludes coverage for losses arising from cyber incidents. As a result, shipowners face uncertainty regarding compensation in the event of cyberattacks, potentially leaving them exposed to substantial financial liabilities. The lack of tailored insurance solutions for cyber risks undermines the industry's ability to effectively manage and transfer these emerging threats.

2.2 Structural Weaknesses and Legal Ambiguities

A critical gap in the current legal framework is the absence of binding international regulations specifically designed to govern cybersecurity in the context of MASS. The regulatory patchwork in place today does not impose consistent standards or provide enforceable obligations that apply globally. This regulatory vacuum is particularly problematic given the transnational nature of shipping and the potential for cyberattacks to originate across borders and impact multiple jurisdictions simultaneously. Furthermore, foundational maritime conventions such as the United Nations Convention on the Law of the Sea (UNCLOS) and the Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation (SUA Convention) were developed in a pre-digital era and are not fully equipped to address issues related to autonomous technologies. Questions remain unresolved regarding the legal status of remote operators, jurisdiction over cybercrime occurring at sea, the attribution of liability in the event of a cyber breach, and the classification of cyber intrusions under existing definitions of piracy or unlawful acts. Operationally, the deployment of MASS increases the attack surface available to malicious actors. Cyber risks affecting navigation systems, communication links, sensor data, or algorithmic decision-making processes can have cascading effects—ranging from delayed cargo delivery to environmental disasters and even collisions at sea. These threats are compounded by the difficulty of real-time human intervention, especially in fully autonomous operations.

3. Recommendations for Cyber Risk Prevention Regulations

To build a secure foundation for autonomous maritime operations, a multidimensional approach to regulatory reform is essential. First, the IMO should prioritize the creation of a binding, goal-based regulatory code for MASS, which would be embedded into the SOLAS Convention. This code must establish enforceable minimum standards for cybersecurity while preserving operational flexibility. Requirements should include regular cyber risk assessments, active monitoring systems, and comprehensive incident response protocols.

In parallel, the SUA Convention must be updated to classify cyberattacks—including data manipulation, ransomware, and remote interference—as maritime crimes. This revision would help resolve jurisdictional challenges, enable legal prosecution of transnational cyber offenders, and provide a strong deterrent against emerging forms of digital piracy.

Furthermore, the concept of cyber seaworthiness must be fully integrated into safety compliance regimes. Traditionally, seaworthiness has been a fundamental legal obligation under contracts of carriage. As articulated in Kopitoff v Wilson (1876), a seaworthy vessel is "good and… in a condition to perform the voyage then about to be undertaken." Later jurisprudence, including McFadden v Blue Star Line [1905], emphasized that a vessel must have "that degree of fitness which an ordinary careful and prudent owner would require… having regard to all the probable circumstances of it." Under the Hague and Hague-Visby Rules, this obligation has evolved into a duty to exercise due diligence in making the vessel seaworthy. In the context of MASS, seaworthiness must now extend to cybersecurity readiness, given that digital failures can be as catastrophic as mechanical ones. The ISM Code, as the globally recognized framework for safety management, should be amended to include explicit standards for cyber risk governance. Non-compliance with such standards could render a vessel unseaworthy under both legal and commercial terms. This expanded interpretation of seaworthiness includes requirements for independent cybersecurity audits, certification of critical systems, access control, and continuous monitoring of onboard a shore-based systems. Port State Control inspections must also integrate cybersecurity checks to ensure compliance across global ports.

Lastly, the insurance sector must adapt by creating cyber risk coverage models tailored for MASS.

Standard exclusion clauses are insufficient in the face of increasing cyber-related losses. Instead, insurers should provide modular coverage options, including silent cyber endorsements, buy-back clauses, and tiered risk pools. For these mechanisms to function effectively, regulators and insurers must collaborate to develop standardized policy language and data-sharing protocols.

4. Conclusion

The integration of Maritime Autonomous Surface Ships into global commerce introduces both transformative potential and unprecedented cybersecurity vulnerabilities. Existing legal and regulatory frameworks—rooted in an analog era—are inadequate to safeguard these digital vessels. As MASS operations become more common, the notion of cyber seaworthiness must be formally recognized and institutionalized within maritime law and safety management systems. Comprehensive reform is required at multiple levels: the development of a binding MASS Code, revision of the SUA Convention, expansion of seaworthiness to encompass cyber resilience, and restructuring of maritime insurance products. These reforms must be guided by a unified international strategy that anticipates technological change and mitigates systemic risk.

Ultimately, ensuring cybersecurity in MASS is not merely a technical issue—it is a matter of global legal coherence, commercial reliability, and operational safety. By proactively addressing these challenges, the international maritime community can create a sustainable and resilient future for autonomous shipping.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Navigating beyond borders: cultivating affective competencies in future global maritime professionals through study away programs

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Abstract: Preparing future global maritime professionals requires programs that develop competencies across cognitive, affective, and psychomotor domains, as outlined in the Global Maritime Professional Body of Knowledge (2019). While cognitive learning has traditionally dominated maritime education and training (MET), affective and psychomotor learning are gaining recognition. This study explores affective development through a short-duration experiential learning program in which U.S. maritime academy students visited a Japanese MET institution (Sholdt & Rooks, 2024). Activities included lectures, site visits, cultural exchanges, and cross-cultural engagement. U.S. students aimed to build cultural awareness, maritime insight, and leadership skills, while Japanese students focused on improving English and intercultural competence. Affective learning among U.S. students was assessed using pre- and post-testing of cultural intelligence (CQ), focusing on drive, knowledge, strategy, and action (Ang et al., 2015). Results showed significant gains in most of the dimensions of CQ. Reflection papers and participant feedback also indicated strong affective growth for both groups. The study underscores the transformative impact of "study away" experiences (Namaste & Sturgill, 2020) and offers recommendations for MET programs aiming to foster affective competencies in preparing globally competent maritime professionals.

Keywords: Maritime Education and Training (MET), Learning Outcomes Assessment, Affective Domain, Cultural and Diversity Awareness, International Study

1. Introduction

As the maritime industry continues to evolve, the demand for professionals equipped with not only technical expertise but also cultural competence and other affective knowledge and skills has never been greater. The Global Maritime Professional Body of Knowledge (IAMU, 2019) emphasizes the importance of cultivating competencies across all learning domains (e.g., cognitive, affective, and psychomotor). Yet, maritime education and training (MET) has traditionally emphasized cognitive learning, often at the expense of the affective and psychomotor dimension learning. This imbalance presents a critical challenge: how can MET programs more effectively foster the holistic development of future global maritime professionals?

Affective learning is the development of human reactions and responses to contextual environments (Krathwohl et al., 1964). Affective learning outcomes are commonly expressed as attitudes, beliefs, biases, interests, motivations, and values. Affective learning is essential for navigating the complexities of international maritime work environments (both at-sea and ashore), particularly as we see increased digitalization, decarbonization, and diversification. In fact, educators have established that learners are less effective at applying their cognitive knowledge and skills when they lack the necessary affective competencies (Boud & Falchikov, 2006). Drawing on the framework of Cultural Intelligence (CQ), learning is operationalized through four dimensions (i.e., drive, knowledge, strategy, and action). In particular, CQ drive reflects an individual's interest, confidence, openness, and persistence in cross-cultural interactions (Ang, Van Dyne, & Rockstuhl, 2015). CQ drive is essentially an affective learning outcome and competency.

Prior research has established the efficacy of short-duration study abroad in enhancing CQ (e.g., Dou, et al., 2024, 2023). However, their assessment of CQ was primarily qualitative. Cheung, et al. (2022) call for quantitative approaches to identify the significant development in the affective learning domain. Further, few studies have focused specifically on the affective gains associated with short-duration programs in maritime contexts.

This study addresses that gap by examining affective learning outcomes from a three-week study away program involving U.S. maritime students visiting a Japanese MET institution. Similar to the conceptual research model of Dou et al. (2024), this study focused how the educational and travel components of the program impacted personal development, specifically development of CQ and related affective competencies. The program integrated maritime academic lectures, maritime industrial site visits, cultural excursions, and structured intercultural engagement with host students (Sholdt & Rooks, 2024). Using a mixed-methods approach, we assessed changes in students' CQ through pre- and post-program testing, alongside qualitative analysis of reflection papers and reaction surveys. Results revealed significant learning gains in three of the four CQ dimensions suggesting that short-duration immersive experiences can meaningfully enhance students' readiness for global professional environments. By foregrounding affective learning, this paper contributes to a growing recognition of the need for more balanced and integrative approaches to learning in MET. It also highlights the transformative potential of "study away" programs, or educational experiences that take place outside students' usual learning environments (Namaste & Sturgill, 2020), in cultivating the full spectrum of competencies required for global maritime leadership.

2. Methodology

2.1 Participants

This study's participants are comprised of two groups of university students. The primary focus of the study is a cohort of 16 undergraduate students from the Massachusetts Maritime Academy, who participated in a short-term international field study program in Japan. The American were selected based on their academic performance and interest in international maritime studies. At Massachusetts Maritime Academy, all students enrolled in the International Maritime Business program are required to complete a 6-credit academic experiential learning program in their second year (including programs in Belgium, Germany, the Netherlands, Norway, Singapore, South Africa, Thailand, United Arab Emirates, and United Kingdom) (see Paul, et al. (2023) for a regression analysis and comparison among these locations). Additionally, 138 Japanese undergraduate students from the Graduate School of Maritime Sciences at Kobe University make up the second group of participants. These students were members of four different required English courses that were visited by the American students as a part of the study program. Involvement in the activities with the American students was a required part of their courses.

2.2 Study Design

The study employed a mixed-methods approach to quantitatively investigate changes in student cultural competence of the American students using the Cultural Intelligence (CQ) assessment in a pretest and posttest format. Additionally, two forms of qualitative analysis were performed: 1.) Level 1 reaction survey data were collected to gauge students' perceptions of the program's impact on their learning, 2.) content analysis of weekly and summary reflections was used to confirm students' perceptions of program learning, particularly in the affective learning domain. Reaction surveys were used to assess the Japanese students' perceived value and benefits of incorporating the interaction activities with the American students into their English courses.

2.3 Data Collection

The American students completed the CQ (T1) pretest in January 2024 and the CQ (T2) posttest assessment in September 2024. The CQ instrument comprises four dimensions: *drive* (affective openness), *knowledge* (cognitive understanding), *strategy* (meta-cognitive preparation), and *action* (behavioral adaptation), each dimension includes three to four items. The short-duration international experiential program was conducted in May 2024. On the final day of the program, participants completed a reaction survey, which included 10 scaled questions assessing the contribution of various program elements to their

learning, as well as open-ended questions about personal growth, favorite program aspects, potential program improvements, advice to future participants, and general reactions. They also provided their recommendation of the program using standard net promoter score methodology. In addition to completing weekly reflective writing assignments about their experiences during the program, participants also completed a summary reflection in September. At the end of the class periods that involved interaction activities with the American students, the Japanese students completed online reaction surveys that covered two dimensions: perceived value (4 items) and benefits (4 items) that were assessed on a 6-point Likert scale. One additional open-ended item provided opportunities for the Japanese students to share memorable experiences from the interactions.

2.4 Procedure

Prior to the short-duration international experiential program, the American students attended briefing sessions and completed the initial CQ assessment. The Japanese students were informed about the pending visits and some of their regular classroom activities were focused on tasks that prepared them for these visits. During the program, the American students engaged in daily activities designed to foster cultural immersion and joined English classes for direct interaction with Japanese students (Sholdt & Rooks, 2024). After the program, the American students completed the final CQ assessment and submitted reflection papers, which were analyzed for thematic content.

2.5 Data Analysis

For the American students, quantitative data from the CQ assessments were analyzed by pairing students' CQ T1 results with their CQ T2 results and plotting learning gains (T2 scores – T1 scores) as a function of pretest T1 scores for each of the four CQ dimensions. Cohort averages and variances were computed for learning gains across all dimensions and were analyzed using a paired t-test. Reaction data were summarized by creating distributions, identifying median responses, and ranking program elements based on mean scores. Open-ended responses in the reaction survey, weekly and summary reflections were analyzed using conventional content analysis to identify themes, with the top three themes provided for each item. Additionally, a net promoter score was calculated for the program. For the Japanese students, quantitative data from the reaction survey were summarized by identifying median and mode responses, and the open-ended responses were analyzed for common themes for which high-frequency specific points were identified.

2.6 Ethical Considerations

Informed consent was obtained from all participants, and their data were kept confidential. For the American students, the study was approved exceptionally by the institutional review board (IRB) at the US institution per CFR 45 part 46.104.d(1). For the Japanese students, appropriate institutional protocol was followed.

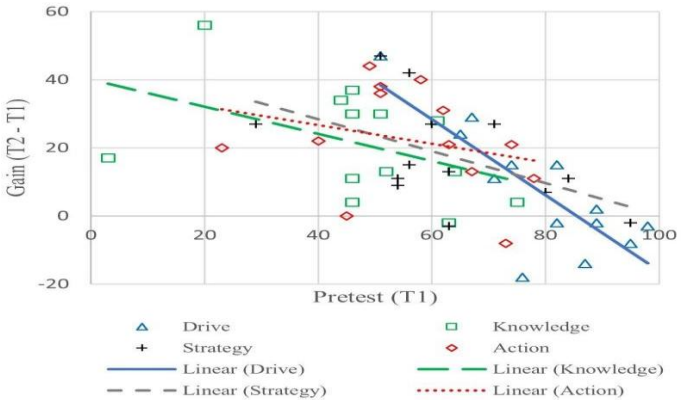


Figure 1. Summary of CQ Scores (n=12 students) here the pretest score (CQ T1) is plotted on the abscissa and the learning gain (CQ T2 – CQ T1) is plotted on the ordinate

3. Results

This study included quantitative analysis of CQ using a pretest and posttest format, as well as qualitative analysis of program reaction survey responses and reflective writing assignments.

3.1. Cultural Intelligence (CQ) Dimensions and Affective Learning of American Students

Two forms of analysis were performed on the data. As a first pass, the learning gains (i.e., CQ T2 – CQ T1) for each of the CQ dimensions (drive, knowledge, strategy, and action) were plotted as a function of the CQ T1 pretest measures of cultural intelligence. This format of presentation is mainly graphical. It provides a deeper understanding of the nature of the CQ learning that resulted from the program.

In Figure 1, it can be seen that the dimensions of CQ knowledge (cognitive), strategy (meta-cognitive), and action (behavioral) were relatively uniform (as evidenced by the least squares regression line) in that there were positive learning gains across the board. As expected and observed, lower pretest scores have a greater capacity for upside learning gains, while relatively higher pretest scores have less upside learning gain potential. Of particular interest was the CQ drive (affective) dimension results. Here, while the slope was greater (perhaps indicating increased gains), it was mainly due to the fact that almost half of the students experienced learning losses from pretest to posttest.

To further understand the significance of these learning gains (and losses), a paired sample t-test was performed. Table 1 shows the results of the t-test analysis.

Table 1. Summary of Paired t-Test Results for Cultural Intelligence (CQ) of American Students

CQ dimension	T1: Pre-Program		T2: Post-Program		t (11)	p	Cohen's d
	M	SD	M	SD			
Drive	78.9	13.2	86.3	11.2	-1.44	0.17498	-0.60
Knowledge	47.5	18.8	68.6	18.4	-4.66	0.00055*	-1.14
Strategy	62.8	16.8	80.5	15.9	-4.17	0.00130*	-1.09
Action	56.5	15.5	78.7	18.8	-5.13	0.00025*	-1.29

In this analysis, it was demonstrated that there were significant learning gains in CQ for action (behavioral) knowledge (cognitive), and strategy (meta-cognitive) (at the 5% significance level) – listed from greater to lesser learning gains. However, there was not a significance difference in the learning gain for drive (affective) (at the 5% significance level).

3.2. Reaction Survey and Student Perceptions of Learning for American Students

The end-of-program reaction survey indicated that, the modal (and median) rating of how each educational component contributed to learning was the top rating on a 5-point scale. Table 2 provides a list of those educational elements in descending order (based on proportion of students indicating 5 on 5-point scale).

Table 2. Effectiveness of Educational Components Beneficial to Learning for American Students

Educational Component	Proportion Top Rated
Open Exploration	100.0%
Maritime Excursions	93.8%
Cultural Excursions	87.5%
Interacting with Japanese Students	75.0%
Planned Weekend Activities	68.8%
Culture and Language Lectures	68.8%
Maritime Project	68.8%
Faculty Lectures	62.5%

The content of responses to several open questions were also analyzed. Each question was provided three themes based upon highest frequency of the theme across student responses. Table 3 summarizes the

main themes that resulted from the content analysis.

Table 3. Emergent Themes from American Student Reactions to Program

Reaction Object	First Theme	Second Theme	Third Theme
Personal Growth	Cultural awareness	Personal growth and adaptability	Broadening horizons and increased motivation
Favorite Program Elements	Excursions and sightseeing	Cultural immersion and interactions	Free exploration and personal time
Opportunities for Improvement	Logistics and practical suggestions	More enhanced interaction with Japanese students	Additional excursions
Advice to Future Participants	Be open to new experiences	Practical tips and advice	Keep a journal or vlog
Final Thoughts	Gratitude and appreciation	Positive experience and enjoyment	Keep it going and future intentions

Fifteen of 16 students stated the experience was very effective (highest rating) in helping them learn about culture and cultural competence. Fifteen of 16 students stated this experience was either effective or very effective in helping them learn about the maritime industry. The net promoter score (NPS) for the program was 85%, indicating a highly-positive experience, with scores above 70% considered among the best in higher education programs (which has an average of 32% according to Hanover, 2022).

3.3 Summary American Student Reflections on Program

Several months after the international experience, students are required to complete a summary reflection. The following are the top five themes that emerged because of a content analysis:

- Personal Growth / Self-Discovery
- Cultural Appreciation
- Independence / Adaptability
- Interest in Global / Maritime Careers
- Academic and Professional Development

3.4 Japanese Students' Post-Program Reaction Survey

For the reaction survey results related to the perceived value of the interaction activities, student responses to items (had meaningful discussions, would enjoy more opportunities to communicate, group work was more interesting, good use of class time) had a median score of 5 out of 6 and a mode of 6 for all items except for one item (group work was more interesting) which had a mode of 5. For the perceived benefits items (build confidence to communicate in English, build confidence to work with others from different cultures, more class visits would be helpful, learned about life in different culture), the items all had a medium of 5, and two items had a mode of 6 (build confidence to communicate, more visits would be helpful, while one item (learned about life in America) had a mode of 4 and one item (build confidence to with others from different cultures) had a median of 5.

The top themes mentioned in the open-ended question were:

- Specific Topics: what they learned, what they discussed, what they taught.
- Communication: successes, difficulties, both successes and difficulties.
- Overall Experience: cultural differences/similarities, enjoyable, helpful.

4. Discussion

In conclusion, this study away program was effective for learning of both the American and Japanese students, in different ways. For the American students, while the qualitative results indicated the program was highly rated and provided strong development in general. However, even though most dimensions of CQ

were significantly developed (knowledge, strategy, and action), there was insufficient evidence from the quantitative analysis to indicate there were affective learning gains as observed in the results for the drive dimension. Clearly, "measuring and modelling learners' emotional and affective states remains a difficult task," particularly in an experiential context (Bamidis, 2017). While this study provides an advancement in the quantitative assessment of affective learning, more work needs to be performed in the area of directing affective learning, itself. It is insufficient to merely design a program and expect affective development. More attention must be focused on the learning design. Specifically, the taxonomy of affective development is hierarchical and scaffolded in nature and learners should be progressed through the stages (from receiving to characterizing) intentionally with specifically designed learning activities. The overall positive responses by the Japanese students provide evidence to support the success of these plans. In both dimensions, perceived value and perceived benefits, the Japanese students responded positively, and when given an opportunity to share any kind of insight about their experiences, most chose to report positive interactions related to learning, teaching, successes, and benefits. Relative to the experience of the American students who are experiencing the full study tour in a foreign country, the Japanese students have much more limited involvement. However, their side of the experience appears to be perceived as unique, positive, and beneficial.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

What Competencies will be Required of Global Maritime Professionals in the Next Five Years?

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Abstract: The purpose of this study was to identify the most important competencies of global maritime professionals for the next five years. A survey was developed based upon the literature. The online survey was administered via email to approximately 700 potential respondents (including stakeholders at MET institutions and IMO registered NGOs) in February to April 2024. 239 surveys were returned and 190 were considered useable. This represents an approximate response rate of 46.4% from IAMU members and 7.5% from IMO NGOs. Using a variety of methods, the competencies were ranked. The basic competencies for global maritime professionals have remained relatively stable, at least from when originally identified in 2018 until now. Competencies vary slightly depending upon which "mega- trend" context was considered (digitalization, decarbonization, or diversity). Additionally, emphasis should be roughly equally devoted to developing outcomes in the affective, cognitive, and psychomotor domains. The results of this survey will be used to inform the revision of the focus areas in the second edition of the Global Maritime Professional Body of Knowledge. Additionally, MET universities and other training providers may find the results useful as they adjust their programs to prepare global maritime professionals for the future.

Keywords: Global Maritime Professional, Competencies, Digitalization, Decarbonization, Diversity

1. Introduction and Overview

The maritime industry is undergoing a profound transformation driven by global mega-trends such as digitalization, decarbonization, and increasing diversity. These shifts demand a reevaluation of the competencies required of Global Maritime Professionals (GMPs) to ensure they remain effective and adaptable in a rapidly evolving operational environment. While the original Global Maritime Professional Body of Knowledge (GMP BoK) published in 2019 (IAMU) provided a foundational framework, the pace of change necessitates and a regularly recurring understanding grounded in current industry realities and educational imperatives.

This study addresses a critical gap by systematically identifying the most essential competencies for GMPs over the next five years. Drawing on a revised survey instrument informed by recent literature and comparable educational frameworks, the research captures expert perspectives from across the maritime education and training (MET) community and affiliated stakeholders. The findings not only reaffirm the enduring relevance of core competencies such as decision-making and critical thinking but also highlight emerging priorities like adaptability and resilience.

There is a growing literature debating on the future of work of seafaring, especially considering some mega trends, such as digitalization, decarbonization and diversity, that are not maritime-specific, but affecting maritime operations and business on a rapid scale. For this version of this paper, we present a summary of the most pressing issues identified in the literature materials reviewed. The Transport 2040 reports by the World Maritime University (Ölçer et al., 2023; Schröder-Hinrichs et al., 2019) underscore how maritime careers are being redefined by technological disruptions such as automation, AI, and green

propulsion systems. These reports employ multimethod research to assess occupational safety, mental health, and the skill profiles of future seafarers. They warn that while seafarers will remain essential, many roles will shift onshore or become increasingly automated. There is a strong call for lifelong learning strategies and support systems to facilitate these transitions. Similarly, the World Economic Forum (2023) highlights that 44% of workers' skills will be disrupted by 2027. The report notes a critical gap between the skills businesses need and their current upskilling strategies—issues echoed in the maritime context by the BIMCO/ICS Seafarer Workforce Report (2021) and DNV (2022). DNV presents detailed scenarios showing the training infrastructure required for alternative fuel operations, spotlighting the urgency of regulatory agility and investment in trainers, simulators, and modern curricula. Reports by the Maritime Just Transition Task Force (2022) and SkillSea (2022) focus on the urgent need to integrate green skills into maritime training programs. These initiatives map out the competencies needed to support decarbonization and energy transitions in shipping. Several sources bring attention to the mental and emotional toll of maritime professions, particularly during disruptive events like the COVID-19 pandemic. The Seafarer Happiness Index (Mission to Seafarer, 2023) and the study by Pauksztat, Grech, and Kitada (2022) document fatigue, isolation, and dissatisfaction exacerbated by poor leadership and limited mental health support. The World Bank (2022) and McKinsey (2023) emphasize the role of digital competencies, not just technical knowledge, in shaping resilient and future-ready professionals. In summary, the literature consistently reveals five interconnected themes: (1) the skills mismatch between education and labor markets; (2) urgent demands for decarbonization-aligned training; (3) the mental health and well-being of seafarers; (4) digital transformation of training methods; and (5) the need for cross-functional and hybrid skill sets. Revising the GMP-BoK necessitates incorporating these dimensions into a dynamic, modular framework that is responsive to global labor trends and maritime sector-specific challenges. It must be inclusive of new career profiles, lifelong learning paths, and policy recommendations for training systems, both onboard and onshore.

The results of this study are intended to inform the second edition of the GMP BoK and provide actionable insights for MET institutions, regulatory bodies, and policymakers. By aligning educational outcomes with anticipated industry needs, the maritime sector can better prepare its workforce for the challenges and opportunities of the coming decade.

2. Methods

This study examined the competencies needed of seafarers in the next five years. To elicit expert perception of those competencies, we created a survey that was to be administered online.

2.1 Survey Design

This study used a survey instrument that was based upon the preliminary survey used in 2018 for the creation of the original GMP BoK published by the International Association of Maritime Universities in 2019 (see Appendix III for details about the preliminary survey). Specifically, almost all of the 28 competencies identified as most important in that 2018 survey were also included in this survey instrument. In order to ensure each competency was mutually exclusive, roughly eight of those competencies were combined into four (e.g., mentorship was considered an aspect of leadership, and so they were not listed separately).

In addition, since the Civil Engineering Body of Knowledge *(CEBoK)* was used as an inspiration for the GMP BoK, and has subsequently undergone revision, the new revised CEBoK was used to inform this survey instrument as well. This survey instrument captured all of the relevant, non-discipline specific competencies from that body of knowledge. As a result, that body of knowledge was mainly used to adjust terminology. Simplified terms were adopted from that body of knowledge (e.g., the term progressive mindset was dropped from the competency for lifelong learning).

Lastly, a third source of competencies was used to expand the list of competencies that were used in this survey instrument. The *World Economic Forum's Education 4.0 Taxonomy* published in 2023 was also used because it was focused on "broadly developing future-ready skills" across many domains of learning (including affective, cognitive, psychomotor, and interpersonal). The preliminary survey from 2018 captured most of the competencies in that taxonomy. However, the following competencies were added: community/civic responsibility, creativity, curiosity, emotional intelligence, empathy & kindness, grit & perseverance, initiative, negotiation, and systems analysis). These competencies were included as a basis to

identify emergent competencies (rather than under the hypothesis that they would be required in the future).The review of relevant literature was used primarily to validate the list of competencies and provide context to this study. The review included reports, scholarly articles, and books that were published after the 2018 preliminary survey through the end of 2023 (a roughly five-year period). About 88 sources were found to be relevant and underwent two rounds of review. Roughly 54.8% of the 31 competencies were explicitly identified in the literature and 71.0% of the competencies were either identified explicitly or implicitly in the literature. In addition, three mega-trends that are underway and will be relevant for at least the next five years were identified in the literature: decarbonization, digitalization, and diversity. These mega-trends were used in a second grouping of questions that were context specific.

The survey instrument contained the following four sections: demography, general competencies, scenario-specific competencies, and comparison of learning domains. The demographic questions included questions about age, gender, nationality, seafaring experience, and industry sector. The general competency questions asked participants to rate the importance of each competency on a 5-point scale (from not important to important) and provided a blank to fill in other competencies. The optional scenario-specific competency questions asked participants to identify the top 10 competencies need for each of the mega-trend scenarios: decarbonization, digitalization, and diversity. The optional learning domain questions asked participants to compare the relatively importance between each pair of learning domains (affective, cognitive, and psychomotor) using the format recommended in the Analytic Hierarchy Process. In addition, there were two open questions to allow participants to expand upon their responses.

2.2 Procedure and Participants

A stratified sampling strategy was used. Two primary groups were targeted: 1.) educators and stakeholders at maritime education and training institutions, and 2.) other key constituents in the maritime community. On 16 February 2024, the survey was deployed to get input into which competencies are most important to develop in global maritime professionals (and therefore include in the GMP BoK 2/e). It was primarily administered via email (roughly 200 to IAMU representatives, 300 to IAMU recent authors, and nearly 200 to 88 the NGOs with consultative status at IMO). We also posted the survey on the IAMU website and it was shared via the Secretariat's social media accounts. We also asked participants to share the survey with those in their professional networks. By 1 April 2024, we received 190 completed responses (there were 239 total, of which 16 were duplicates and 33 were incomplete). It is not possible to determine who completed these responses. However, it seems likely that the majority were due to the email solicitations. In that case, this represents approximate response rates of 46.4% from IAMU members (considering overlap between the two lists) and 7.5% from the NGOs. It should be noted that there may be some bias in the results because the survey was predominantly distributed via email (with a limited response to social media) and a small response rate was achieved from the other (non-MET) key constituents in the maritime community. Figure 1 provides a breakdown of some of the key demographics of the respondents.

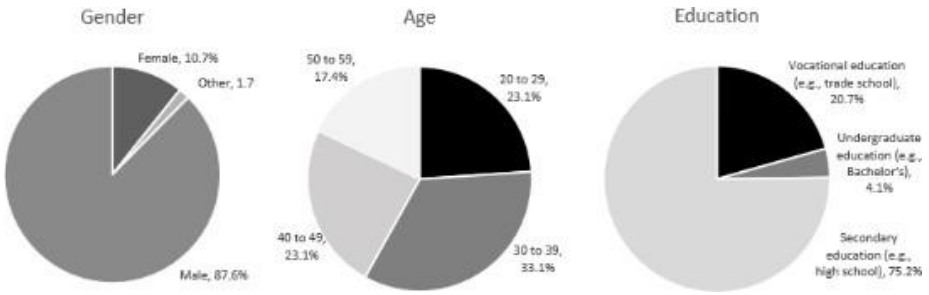


Figure 1: Demographic breakdown of survey participants (by gender, age, and education)

More than two-thirds of the respondents were from the MET community, and the remainder were roughly equally distributed among the other six industry sectors (shipping & operations, maritime law & finance, maritime technology, NGO, port & logistics services, government & administration, or education & training). Slightly more than one-third of the respondents were not licensed, roughly one-third were licensed

with more than 10 years of experience, and the remainder were licensed with less than 10 years of experience.

3. Results

Response distributions were created and summary statistics were calculated for the 31 competencies the respondents were asked to rate on a 5-point importance scale. The responses were analyzed cross-sectionally according to the demographics. Top-10 lists of competencies were created for the three scenario questions (i.e., digitalization, decarbonization, and diversity). Relative weights for the three learning domains (i.e., affective, cognitive, and psychomotor) were computed. There were insufficient responses to the open-ended questions to warrant a detailed analysis.

3.1 Competency Ratings

The competencies were ranked using four different methods:

1. Absolutely Important: The total respondents who indicated a competency was "absolutely important" (score of "5"), was computed and the percentage of respondents indicating such was calculated. The competencies were then ranked based upon the percentage of respondents who indicated that a particular competency was "absolutely important" (from highest percentage to lowest percentage). This is shown in column 2 of Table 1.

2. Important: The total respondents who indicated a competency was either "important" or "absolutely important" (score of either "4" or "5"), was computed and the percentage of respondents indicating such was calculated. The competencies were then ranked based upon the percentage of respondents who indicated that a particular competency was either "important" or "absolutely important" (from highest percentage to lowest percentage). This is shown in column 3 of Table 1.

3. Above Mode: For each competency, it was determined if it was rated above the respondents modal rating for all competencies. The total respondents who rated a competency above their modal rating was computed and the percentage of respondents indicating such was calculated. The competencies were then ranked based upon the percentage of respondents who indicated that a particular competency was above the respondents' modal rating (from highest percentage to lowest percentage). This is shown in column 4 of Table 1.

4. Mean Rating: While not strictly theoretically valid for ordinal data, it is quite a common practice to assign each point on the scale with a number (e.g., 1 for "not important" through 5 for "absolutely important") and calculate the mean "score." This was done for each competency and then the competencies were ranked according to their relative mean importance scores. This is shown in column 5 of Table 1.

It should be noted that the rankings resulting from these four methods are highly correlated ($\rho>0.95$ for each pair). As a result, the competency rankings remained relatively stable independent of the ranking method employed.

The rankings of the four methods were averaged and a final ranking was created using this averaging method (see column 6 of Table 1). In this case, a mean rating was calculated for each competency from the response distributions. It should be noted that this grouping of competencies remains relatively stable independent of ranking method. Additionally, and average ranking was created (from the other four methods) and the results are provided in Table 1.

Table 1. Ranking of Competencies for Global Maritime Professionals

	5	4+5	>Mode	Mean	Average
Decision Making (Time-Sensitive)	1	3	1	1	1
Critical Thinking & Problem Solving	2	1	2	2	2
Capacity for Lifelong Learning	3	6	3	3	3
Adaptability & Resilience	5	2	4	4	4
Collaboration & Teamwork	4	4	5	5	5
Professional & Ethnical Responsibility	9	5	8	6	6
Digital Literacy	7	8	7	7	7

Situational Awareness	6	7	9	8	8
Maritime English	8	10	6	10	9
Risk & Uncertainty Management	11	9	10	9	10
Leadership	10	11	11	11	11
Interpersonal Communications	12	12	13	12	12
Environmental Stewardship	14	13	14	13	13
STCW Technical Competence	13	15	12	16	14
Physical & Mental Fitness	15	16	15	14	15
Initiative	18	14	17	15	16
Emotional Intelligence	16	17	18	17	17
Maritime Business Knowledge	20	18	16	18	18
Cultural Awareness	19	23	19	19	19
Global Perspective	17	21	23	20	20
Growth Mindset	22	19	25	21	21
Grit & Perseverance	24	22	20	22	22
Community & Civic Responsibility	21	25	22	23	23
Digital Skills & Programming	25	20	24	24	24
Systems Analysis	26	24	28	25	25
Empathy & Kindness	23	28	26	26	26
Creativity	27	27	21	28	27
Dexterity & Coordination	28	26	30	27	28
Curiosity	29	30	27	30	29
Legal Literacy	30	29	29	29	30
Negotiation	31	31	31	31	31

Source: Authors' own elaboration

No significant differences due to gender (ρ=0.879), education (ρ=0.806), industry sector (ρ=0.884) were identified.

3.2 Scenario-Specific Competency Ratings:

The academic and industry-specific literature indicates that there are three mega-trends that will shape the workforce future in the maritime industry over the next decade. These mega-trends may be described as digitalization, decarbonization and diversity as follows:

- *Decarbonization* (e.g., shift to alternative fuels). The International Maritime Organization has set goals to reduce greenhouse gas emissions by 20-30% by 2030, to 70-80% in 2040, and to reach net-zero by about 2050.

- *Digitalization* (e.g., autonomy). This mega-trend is resulting from technical progress, increasing development of internet and processing speed, abundance of big data and sensors, globalization, and new technologies such as artificial intelligence, internet of things, and augmented reality.

- *Diversity* (of the maritime community). According to several sources, there has been a growing supply deficit in the number of seafarers over the past five years. For example, women are significantly underrepresented in the maritime community and the International Maritime Organization is committed to helping its members achieve gender equality.

Respondents were then asked to indicate the top ten competencies needed in each of the three mega-trend scenarios (decarbonization, digitalization, and diversity). The percentage of respondents who indicated

each competency in the top ten was then computed. The top ten competencies for each mega-trend were then computed based upon the percentage of respondents who indicated the competency was necessary for the particular mega-trend (see Table 2 for top ten competency list from highest to lowest).

Table 2. Top Ten Competencies for Three Different Mega-Trend Scenarios

Decarbonization		Digitalization		Diversity	
Environmental stewardship	40.0%	Digital programming skills	43.5%	Emotional intelligence	41.1%
Global perspective	31.6%	Digital literacy	44.7%	Empathy & kindness	40.5%
Professional & ethical responsibility	22.6%	Capacity for lifelong learning	36.3%	Collaboration & teamwork	40.0%
Community & civic responsibility	21.6%	Systems analysis	36.3%	Cultural awareness	40.0%
Risk & uncertainty management	21.6%	Critical thinking & problem solving	34.2%	Interpersonal communications	36.3%
Adaptability & resilience	21.1%	Adaptability & resilience	25.3%	Leadership	34.2%
Critical thinking & problem solving	20.5%	Creativity	25.3%	Professional & ethical responsibility	31.1%
STCW technical competence	19.5%	Maritime business knowledge	23.7%	Community & civic responsibility	30.0%
Legal literacy	18.9%	Decision making	23.2%	Adaptability & resilience	28.9%
Capacity for lifelong learning	18.4%	Maritime English	21.1%	Physical & mental fitness	26.3%

Source: Authors' own elaboration

3.3 Relative Weighting of Learning Domains:

Using the Analytic Hierarchy Process, relative weights among each of the three domains were calculated based upon each respondent's judgments. A consistency ratio was also calculated to compare the respondents' judgments to random. In general, the relative emphasis on each domain was as follows:

- Affective = 20% to 30%
- Cognitive = 25% to 35%
- Psychomotor = 35% to 50%

If we assume the respondents understood the question (which may not be true in all cases), this gives some preliminary evidence for the continued use of default equal weights (roughly one-third to) across the three learning domains.

4. Conclusions

The findings of this study offer a timely and comprehensive update to the competency framework for Global Maritime Professionals, reflecting both continuity and change in the skills landscape. The survey results underscore the enduring importance of foundational competencies such as time-sensitive decision-making, critical thinking, and lifelong learning skills that remain central to effective maritime operations across all contexts. Notably, adaptability and resilience emerged as a newly emphasized competency, signaling a growing recognition of the need for psychological and operational flexibility in an increasingly complex and uncertain maritime environment.

These findings suggest that while the core competencies of GMPs have remained relatively stable since 2018, the contextual application of these skills is becoming increasingly nuanced. The results also affirm the relevance of a balanced approach to learning across the affective, cognitive, and psychomotor domains, with survey respondents supporting an approximately equal weighting among these areas.

The alignment between the survey results and current industry trends is particularly evident when competencies are examined within the context of the three identified mega-trends: decarbonization,

digitalization, and diversity. While seven of the nine competencies added from the WEF taxonomy did not rise above the bottom third in the first part of the survey (general seafarer competency), they were much more strongly represented in the context of the mega-trends. Therefore, as these trends increasing impact the maritime industries, we should expect the competencies required of seafarers, and GMPs more generally, to shift much more dramatically.

From a policy and training perspective, the implications are clear. MET institutions should prioritize curriculum updates that integrate both enduring and emergent competencies, with particular attention to scenario-based training that reflects real-world challenges. Regulatory bodies, including the International Maritime Organization, may also consider these findings in the ongoing development of competency standards and certification frameworks.

Finally, this study highlights the value of continuous stakeholder engagement in shaping educational priorities. Future research should explore longitudinal trends in competency development, assess the effectiveness of revised training programs, and further investigate the impact of mega-trends on workforce readiness. By maintaining a dynamic and evidence-based approach to competency development, the maritime sector can ensure that its professionals are equipped to navigate the evolving demands of the global maritime landscape.

Acknowledgements

This study was conducted as a work package for the review and revision of the Global Maritime Professional Body of Knowledge sponsored by the International Association of Maritime Universities and the Nippon Foundation. We are grateful to the guidance and support provided by IAMU Executive Director Takeshi Nakazawa and our advisor for the committee, Professor Michael Manuel of the World Maritime University.

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Proceedings of the
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Understanding the concept of safe distance in maritime navigation: insights from simulator-based training

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Abstract: Safe distance is a fundamental concept in maritime navigation, directly impacting the safety of vessel operations. This study aims to investigate how novice navigation students, trained in the International Regulations for Preventing Collisions at Sea (COLREG) but lacking practical experience, interpret and apply the concept of safe distance. Conducted at two European Maritime Universities - Gdynia Maritime University (Poland) and the University of Split (Croatia), the research employs bridge simulator exercises to evaluate performance in crossing and head-on scenarios. The participants taking part in the study were divided into two groups. The first group had to interpret the concept of safe distance for the exercise scenarios. The second group was guided by limitations in the form of recommendations from navigation procedures. The results showed significant differences in the decisions made, which allowed for the identification of the impact of the procedures on these decisions. The participation of students from two different universities, and consequently cultural differences and differences in the way classes were conducted on the decisions made, also proved to be significant. The study is valuable for lecturers and instructors from MET centers. It may also prove crucial for the authorities responsible for creating recommendations in internal navigation procedures. The results present practical insight into students' perception regarding the requirements (or lack thereof) of navigation procedures, as well as the perception of safe distance. This emphasizes the importance of balancing the theoretical knowledge provided and its practical application at the training stage.

Keywords: COLREG, Safe distance, MET, Human factors, Ship's bridge simulator

1. Introduction

Preventing collisions at sea starts with safe navigation, and the concept of a *"safe distance"* between ships plays a critical role in ensuring effective collision avoidance (Huang *et al.*, 2020). The International Regulations for Preventing Collisions at Sea (COLREG) do not define "safe distance" between vessels, which varies depending on the situation. Instead, COLREG provides a structured framework for navigational decision- making, but its practical application is subject to various human influences. Especially the practical interpretation of these rules (Žagar et al., 2020) and environmental factors (Pietrzykowski and Uriasz, 2009; Tam and Bucknall, 2010). A significant body of research has focused on modeling ship domains as an area around the vessel, and is recognized by other ships as a zone they should not enter, and furthermore, keep clear of (Goodwin, 1975). Ship domains are used for a variety of purposes, adopting various approaches (Wang, 2010; L. Gucma, 2012; Hansen et al., 2013). However, their original goal was to estimate the capacity of a waterway (Fujii and Tanaka, 1971). The domain is recognized as geometric and kinematic aspects of safe passing distances, also determined by practical exercises on bridge ship handling simulators (Pietrzykowski, 2008; Pietrzykowski and Uriasz, 2009). These studies aim to define quantitative thresholds for safe encounters at sea, often through advanced simulations or statistical analyses of traffic data (Zarzycki et al., 2025).

However, less attention has been paid to the human interpretation of safe distance, particularly among novice navigators who possess theoretical knowledge of COLREG but have minimal practical experience in applying these rules. The current study addresses this gap by investigating how young maritime students perceive and apply the concept of safe distance in typical open-sea scenarios under good visibility. Unlike prior research focused on calculating optimal passing distances (Lazarowska, 2017) or the distance of evasive maneuver initiation (Zarzycki et al., 2025), this study seeks to understand the subjective interpretation of safe distance among novice navigators and to explore how their decision-making is influenced by procedural constraints such as minimum distance requirements, and whether these effects vary across cultural and institutional contexts.

The study further explores whether the introduction of a procedural rule, such as a minimum safe passing distance, affects the behavior and decision-making of novice navigators. This dimension of the research is significant, as procedural frameworks are frequently implemented within the maritime domain to promote standardized practices in operations and minimize potential risks (Rajapakse et al., 2022). However, the extent to which such constraints shape decision-making, particularly in the context of limited experience, remains underexplored. In summary, this study aims to answer the following research questions:

1. How do novice navigators interpret the safe distance?
2. Does the introduction of limiting procedures influence the interpretation of safe distance?
3. What impact does the introduction of limiting procedures have on the safe distance maintained during navigation?
4. Do cultural differences affect the interpretation and application of safe distance?

By focusing on these questions, the study contributes to the broader understanding of human factors in maritime safety, offering insights for maritime educators, regulators, and training program designers on how best to prepare future navigators for real-world decision-making at sea. The research utilizes bridge simulator exercises carried out at two European maritime institutions: Gdynia Maritime University (GMU) in Poland and the Faculty of Maritime Studies at the University of Split (PFST) in Croatia. Students were assigned to groups either operating with or without procedural limitations and were engaged in crossing and head-on navigation scenarios, during which their decision-making and navigational behavior were systematically recorded for analysis.

2. Methodology

This study utilized an experimental approach based on the Wartsila NTPRO 5000 navigation simulator to explore how novice navigators interpret and apply the concept of safe passing distance in maritime contexts. Participants, all of whom had theoretical knowledge of the COLREG but limited practical experience, completed structured simulator exercises designed to emulate crossing and head-on situations in open sea conditions.

2.1 Study Design

The research was organized into three phases: Introduction, Exercise simulation, and Summary, as illustrated in Figure 1.

Phase 1: Introduction - the first phase prepared participants for the simulation exercises through: Familiarization: participants were introduced to the simulator environment, controls, and procedures. Each was assigned a unique 'Exercise Participant Number' for data tracking purposes. Data collection: demographic information. Pré-exercise questionnaire (referred to by the acronym ‘PRE Q’): participants completed an online questionnaire (hosted via Microsoft Forms) to assess their baseline understanding of what constitutes a safe passing distance between vessels under good visibility conditions: Question: ” Based on your current knowledge and experience, what do you consider to be a safe passing distance between two vessels on the open sea under good visibility conditions? Please provide a safe distance in Nautical Miles [Nm]”

Phase 2: Exercise simulation - involved two simulation exercises, based on COLREG rules:

- Exercise 1 (R-15) – Crossing Situation Rule 15:

After a structured briefing, participants navigated a crossing scenario where the target vessel maintained a steady course and speed. Participants were divided into two groups:

Group A: Tasked with determining the safe distance based on personal judgment and best knowledge.
Group B: Instructed to maintain a minimum distance of at least 1 NM, reflecting standard operational procedures.

- Exercise 2 (R-14) – Head-on Situation Rule 14:

Following a similar briefing, participants engaged in a head-on encounter scenario under identical conditions. During both exercises, the simulation software automatically recorded ship maneuvering parameters, capturing data prepared before the exercise: latitude, longitude, heading, speed over ground (SOG), rudder angle, distance, and bearing to the target vessel. The primary behavioral metrics assessed were: when the participants initiated a maneuver, the minimum distance maintained during the encounter, and when they resumed their original course.

Phase 3: Summary - following the exercises, participants completed a post-exercise questionnaire referred to by the acronym 'POST Q', identical to the pre-exercise one. A debriefing session was held, during which simulation data and participant behaviors were reviewed and discussed. This phase encouraged critical reflection on decision-making processes and adherence to safe distance protocols.

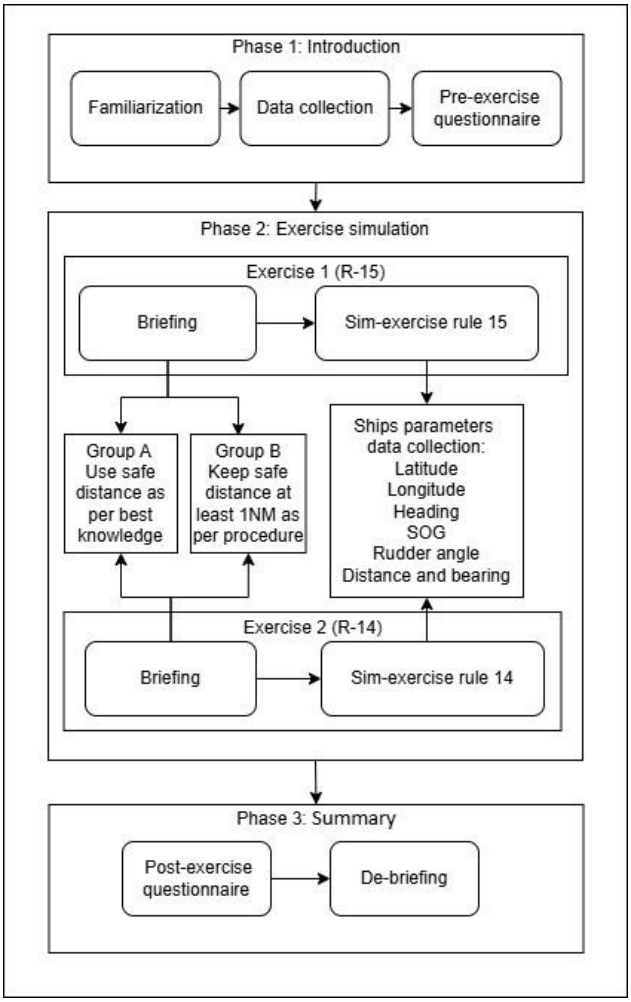


Figure 1. Overview of the study phases and exercise structure.

2.2. Simulation exercise scenarios

Two bridge simulator exercises were conducted as part of the experimental design, representing typical collision-risk scenarios under the COLREG between two vessels at open sea with good visibility. The ship's particulars have been presented in Table 1.

Table 1. Target and own ship's particulars.

Ship particulars	Own ship IAMU Split	Target vessel IAMU Gdynia
Vessel type	LNG	Container
Displacement	142272.0 t	132540.0 t
Length	315 m	347 m
Breadth	50.0 m	42.8 m

Draft	12.0 m	14.0 m
Max. speed Type of engine	19.5 knt	22.8 knt
Type of propeller		
	Diesel 2 x 14560 kW	Diesel 1 x 60950 kW
	FPP	FPP

2.2.1 Exercise R-15 – Crossing Situation (COLREG Rule 15)

In R-15, the own ship *IAMU Split* is proceeding on a northerly course with a speed of 19.5 knt, while the target vessel *IAMU Gdynia* is approaching from the starboard side (BRG: 046°, DIST: 11.0 NM, CPA: 0.026NM, TCPA: 23:30min), and crossing the own ship's course on a steady heading of 270° and speed of 20 knt.

2.2.2 Exercise R-14– Head-on Situation (COLREG Rule 14)

R-14 represented the own ship proceeding on a northerly course with a speed of 19.5 knt and the target vessel on a reciprocal course, converging directly toward each other (CPA: 0.0 NM and TCPA: 17:30min). This situation required a clear and timely decision in line with Rule 14, which stipulates that both vessels should alter their course to starboard; nevertheless, in this scenario, the target vessel maintained a constant course 180° and speed of 20 knt. Visualization of both exercise scenarios is presented in Fig.2.

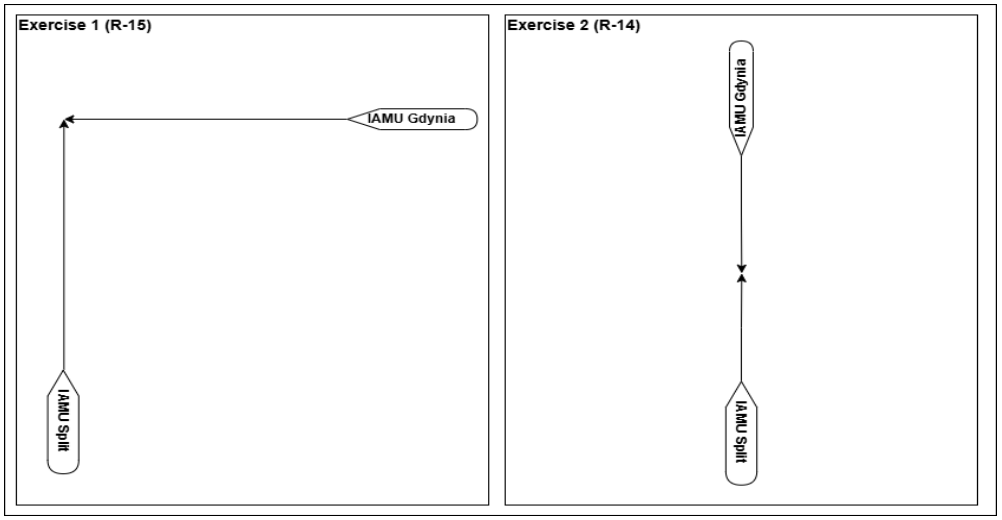


Figure 2. Visualization of exercise scenarios.

3. Results and Analysis

This section presents the study's findings, which examined how maritime students interpret the concept of safe passing distance between vessels and how procedural constraints influence their perceptions and navigational behavior. The analysis is organized into four parts: participant statistics, survey results, simulator exercise outcomes, and a comparison between students declared safe distances and their actual maneuvering behavior.

By comparing responses and actions of students from two maritime universities, the study also investigates the role of institutional and cultural differences in shaping navigational judgment. The combined analysis of questionnaire responses (before and after simulation) and detailed maneuvering data provides a comprehensive view of how theoretical understanding, procedural guidance, and simulated practice converge to influence safety-related decision-making in collision-avoidance scenarios.

3.1 Participants' statistics

A total of 122 maritime students participated in this study. The participants were recruited from two European maritime universities: GMU, 60 students, and PFST, 62 students. In order to evaluate comparability, students were divided into two predefined groups (A or B), as presented in Table 2.

Table 2. Participants' statistics

	Gdynia Maritime University		University of Split	
Scenario	Group A	Group B	Group A	Group B
Number of Students	30	30	26	36

By ensuring this distribution, we were able to examine the performance of students from different educational backgrounds under equivalent conditions. Figure 3 presents the percentage of students in each scenario.

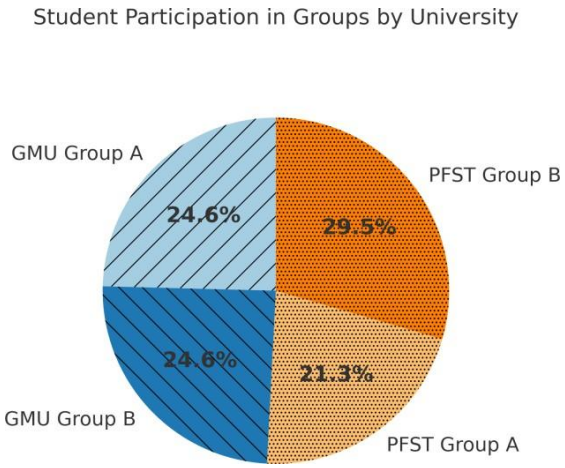


Figure 3. Participant's statistics.

3.2 Results from questionnaires

The surveys aimed to assess the students' understanding of the meaning of "safe passing distance" between vessels, in accordance with COLREG guidelines, at open sea and with good visibility conditions.

At the beginning of the exercise, the participants from both groups were asked the same question to estimate what they considered a safe passing distance, based on their best, current knowledge. The same question was repeated once the simulation exercises had been completed. That approach allows for a comparative analysis of how their responses changed as a result of the practical training and implementations of procedural requirements. The average results from PRE Q and POST Q for both institutions and Groups are presented in Figure 4.

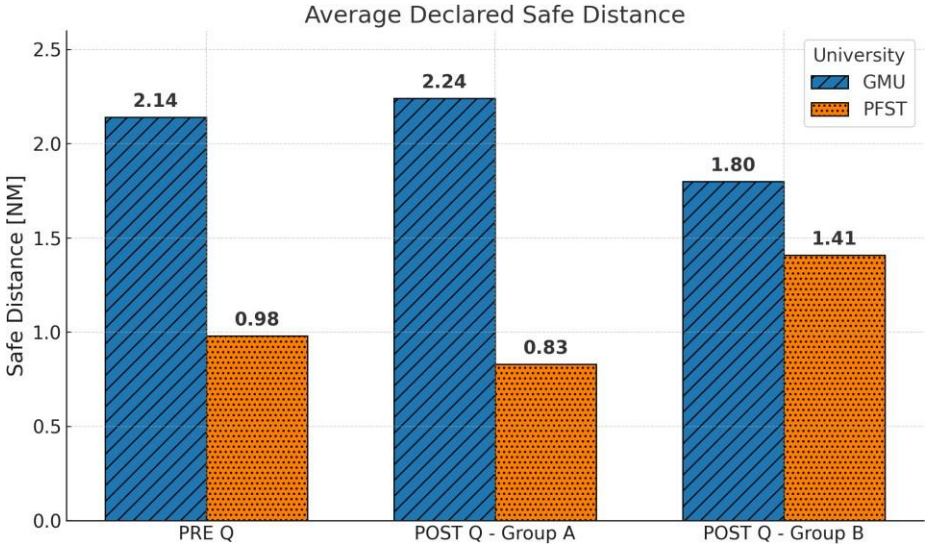


Figure 4. Results of questionnaires.

In the PRE Q, significant differences were observed between students from both institutions regarding their initial judgment of an appropriate safe passing distance between two ships. GMU students generally estimated a larger distance compared to students from PFST. This may reflect variations in institutional emphasis on safety margins or cultural perceptions of navigational risk.

Nevertheless, a change in perception after completing the simulator exercises was observed in either GMU or PFST students. Moreover, the post-exercise responses indicated that practical experience significantly influenced the novice navigators' interpretation of safe passing distance, encouraging a more critical assessment of appropriate passing margins. This suggests that the exercises in simulator environments can effectively shape safety-related judgment in novice navigators.

An analysis of the responses across the groups revealed apparent differences. In Group A, which conducted operations without any procedural limitations, only minimal changes were observed in their safe distance estimations. There was a slight increase of 0.1 NM for GMU students and a reduction of 0.15 NM for PFST students. In contrast, Group B - where a minimum distance of 1 NM was enforced - showed greater changes: GMU students reduced their estimates by 0.34 NM, while PFST students increased theirs by 0.43 NM. This demonstrates that procedural limitations significantly influenced students' perception of safe distance, particularly when paired with simulator-based learning.

3.3 Results from the exercises (R-15 and R-14)

The chart presented in Figure 5 illustrates the minimum, maximum, average, and median passing distances recorded during R-15 (Crossing Situation). The results are categorized by experimental group (A and B) as well as by university (GMU and PFST), allowing for a comparative analysis of how institutional background and procedural constraints influenced participants' maneuvering behavior in crossing scenarios.

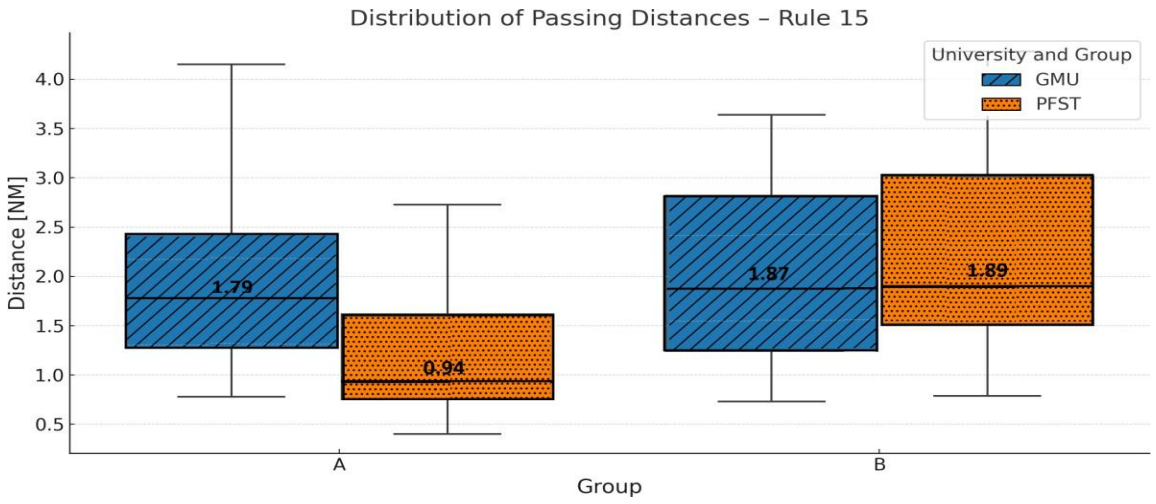


Figure 5. Passing distances recorded during Exercise R15

In Group A, where students navigated without a predefined minimum distance, GMU participants maintained an average passing distance of 1.79 NM, while PFST students averaged a significantly lower distance of 0.94 NM. However, in Group B - where a procedural requirement of at least 1 NM was introduced- the average passing distances for both universities became closely aligned: 1.87 NM for GMU and 1.89 NM for PFST. This convergence suggests that procedural constraints contributed to standardizing safety behavior across different training backgrounds.

Figure 6 presents the minimum, maximum, average, and median passing distances recorded during R-14 (Head-on Situation). As with the previous chart, the data are disaggregated by group and by university, providing insight into how participants from different institutions responded to the head-on encounter scenario under varying procedural conditions.

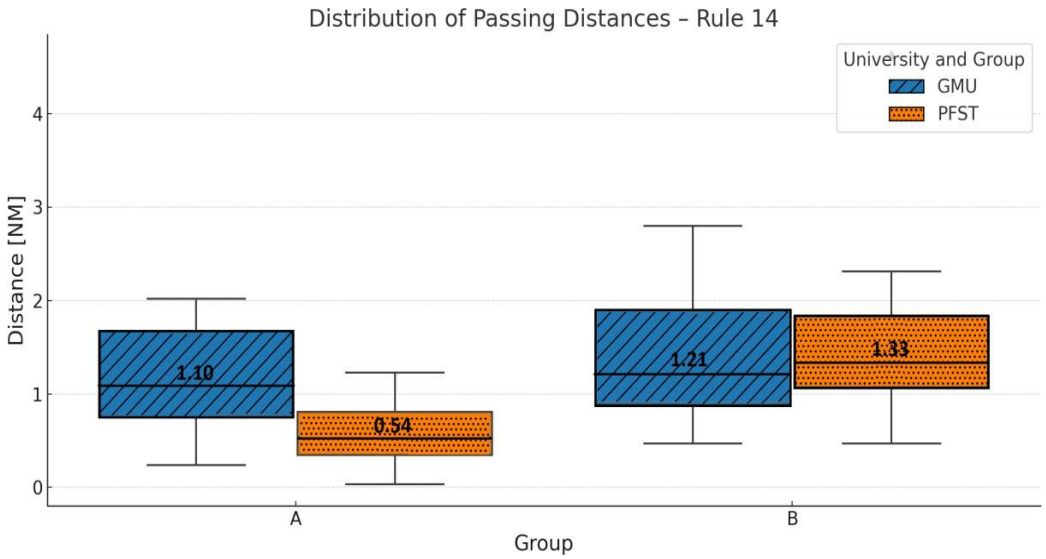


Figure 6. Passing distances recorded during Exercise R14

Similar patterns were observed during R-14. In Group A, where no procedural guidance was provided, GMU students maintained an average passing distance of 1.10 NM, while PFST students passed significantly closer, averaging just 0.54 NM. In Group B, after the introduction of a procedural requirement, the passing distances for both institutions became nearly identical - 1.21 NM for GMU and 1.33 NM for PFST. The results from R-14 support those reported in exercise R-15, indicating that the implementation of procedures (Group B) promoted similar behavioral patterns across both student cohorts. Importantly, the effect of the procedure was more evident among PFST students, who initially exhibited significantly smaller passing distance estimates without structured guidance.

3.4 Comparison of results from simulator exercises and questionnaire responses

To gain more insight into the relationship between students' subjective approach to safe passing distance and their actual behavior in simulated navigation scenarios, responses from the PRE Q were compared to the minimum distances recorded during both exercises.

The first observation indicates that students from Group A often approached another vessel closer than the safe passing distances previously stated in the PRE Q. This tendency was evident in students from both institutions. GMU participants reported an average safe distance of 2.14 NM, yet their actual passing distances decreased to 1.79 NM (R-15) and 1.10 NM (R-14), respectively. Among PFST students, the discrepancy was even more substantial: although their reported threshold averaged about 0.98 NM (R-15), their reported passing distances decreased to 0.94 NM and 0.54 NM (R-14), respectively. These results suggest a significant discrepancy between theoretical knowledge and applied behavior. The lack of explicit operational guidance leads novice navigators to deprioritize established (their own) safety margins, potentially due to underestimating the risk of collision or overestimating their ability to control the vessel in the simulated environment.

When the minimum safe distance was procedurally required (Group B), the results from simulator exercises showed another insight. The procedural rule had a notably corrective effect on PFST students, where their pre-exercise estimates had suggested lower safe distances. Their actual passing distances during the exercise increased substantially, to 1.89 NM (R-15) and 1.33 NM (R-14), respectively. In contrast, the procedural rule had a less significant impact on GMU students. Their actual passing distances during the exercise decreased to 1.87 NM (R-15) and 1.21 NM (R-14), respectively. The core finding is that even with the formal (procedural) requirements in place, the average GMU students' passing distances continued to fall below the estimates provided in the PRE Q.

3. Discussion

The main aim of this study was to address the research questions concerning novice navigators' understanding the concept of safe passing distance. The simulator-based exercises and accompanying

questionnaire analysis provided a comprehensive basis for responding to each of the proposed questions.

The survey data and exercises conducted among students from Gdynia Maritime University (GMU) and the University of Split (PFST) enabled a comparative analysis of how future officers, at a similar stage of education, define the concept of safe passing distance in specific navigational scenarios (RQ1). As detailed in the results section, substantial differences were observed in the initial interpretations provided by students from both institutions, highlighting the influence of educational background and training emphasis on safety-related perceptions.

The experimental division into two groups (A and B) allowed the researchers to evaluate whether the introduction of procedural constraints - specifically, a mandatory minimum safe passing distance - influenced participants' perceptions (RQ2). The differences observed between the POST Q responses of Group A and Group B were pronounced and consistent across both universities. This pattern was also reflected in the results of the simulator exercises. The analysis indicates that the imposition of procedural guidance significantly affected the participants' perception and interpretation of safe distance during encounters at sea. Addressing RQ3 - what kind of impact these constraints had - again requires reference to the detailed results. For GMU students, the declared average safe distance decreased from 2.14 NM (PRE Q) to 1.8 NM (POST Q), suggesting that procedural engagement prompted a reassessment of previously overestimated margins. Conversely, PFST students initially reported a much lower average of 0.98 NM, which increased to 1.41 NM after introducing procedural guidance. Although the change direction differed between the groups, the procedure had a unifying effect: it standardized safe distance perception across both universities. This alignment was particularly evident in the simulator results for Group B, where passing distances became nearly identical between GMU and PFST participants.

Beyond questionnaire results, the exercises themselves revealed significant variation between the two institutions in how students interpreted and applied the concept of safe distance in practice. These differences are attributable to the theoretical instruction provided by faculty, as the participants had no practical sea- going experience. The study's design, therefore, allowed for the examination of RQ4 - whether institutional or cultural factors affect perception. The PRE Q results alone confirm this: GMU students indicated an average safe distance of 2.14 NM, while PFST students reported only 0.98 NM. Such discrepancies highlight how theoretical education, shaped by institutional norms and expectations, can significantly influence students' judgment in the absence of real-world experience.

Overall, the findings emphasize the crucial role of practical training and procedural guidance in shaping consistent safety behavior among novice navigators. The observed variations further support the need for harmonized training standards to ensure a common understanding of fundamental navigational concepts such as safe distance, especially in multicultural and multi-institutional maritime environments.

4.1 Limitations

This study was conducted at only two European maritime universities, which limits the generalizability of the findings to a broader population of novice navigators. The results reflect the perceptions and behaviors of students from these specific institutions and may not represent the full diversity of maritime training environments.

Additionally, the study was carried out using ship bridge simulators, which, while highly effective for training and research, do not fully replicate real-world navigational conditions. In particular, the perception of safe distance, mainly when relying on visual assessment, may differ in actual sea conditions due to factors such as weather, motion, and stress levels.

Although both universities used simulators from the same manufacturer (Wartsila NTPRO 5000), configured with identical scenario files and environmental settings, potential differences in the ergonomics of the simulator setups, such as equipment layout and display arrangement, may have influenced how participants accessed and interpreted navigational data. These subtle variations could have affected their decision-making processes and safe distance estimations.

4.2 Future research

The simulator-based design of this study, which enabled the recording of multiple navigational parameters during exercises, offers valuable opportunities for extended analysis. Future research could delve deeper into maneuvering behavior by examining correlations between specific decision points, timing of actions, and situational variables.

Expanding the study to include a larger number of maritime education and training institutions would improve the generalizability of findings and allow for a more comprehensive comparison across diverse training cultures and environments. Another promising direction would be to conduct similar exercises with professional officers representing varying levels of seagoing experience and with various ranks. This would answer the question of how the experience influences the perception of safe passing distance.
Moreover, as the present study was designed in good visibility conditions, the further studies might investigate if restricted visibility scenarios could affect distance perception and decision making, including meteorological conditions like fog and heavy rain, or part of the day, dusk, or night. That might be investigated both with and without procedural constraints.

5. Conclusion

The study investigated how novice navigators with a lack of practical experience interpret the concept of safe distance for scenarios: on the open sea and with good visibility conditions. The results showed that apart from the common theoretical knowledge provided, the cultural and institutional factors of a given MET center are relevant.

The main aim of the study was to determine the impact of introducing elements of navigation procedures (in the form of limitations on the minimum distance of passing another vessel), resulting in a change in the perception of safe distance. It turned out to be significant and was confirmed not only in surveys before (PRE-Q) and after the exercise (POST-Q), but also by comparing the results of the exercises carried out in both groups of students (with and without procedural limitations). One of the findings indicates that during simulation, participants mainly approached another vessel closer than the safe passing distances previously reported in the PRE-Q. That was observed primarily in the group without procedural limitations. Moreover, this tendency was evident in students from both institutions.

Nevertheless, the primary outcomes of the study showed that introducing a standardized restriction for students from different universities resulted in achieving similar distances while passing another vessel. This effect suggests that such a solution can be an effective tool for improving safety at sea, especially for seafarers with less practical experience, by gaining theoretical knowledge in different MET centers. Identification and interpretation of such factors seem to be an important addition to the theoretical knowledge provided during the education of future officers.

Acknowledgements

The authors are grateful to the students of Gdynia Maritime University and the University of Split who participated in the study as volunteers. The study was supported via Gdynia Maritime University internal grant #WN/2025/PZ/01 and #WN/2025/PZ/12.

CRediT

P.K.: Methodology; Conceptualization; Investigation; Resources; Formal analysis; Visualization; Writing – original draft; Writing – review and editing
K.F.: Conceptualization; Methodology; Investigation; Resources; Formal analysis; Visualization; Writing – original draft; Writing – review and editing
F.B.: Investigation; Writing – review and editing M.M.: Investigation; Writing – review and editing
L.V: Conceptualization; Writing – review and editing; Validation; Supervision

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Enhancing standardized VTS communication skills through digital educational tools

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Abstract: The safety of maritime navigation is heavily influenced by human factors, with effective communication playing a critical role. In recognition of this, the maritime industry has long sought to standardize communication protocols to promote consistency and clarity across the global maritime domain. Nevertheless, routine interactions between shore-based service operators and ship crews often diverge from these standardized protocols, revealing persistent challenges in their practical implementation. In response to these challenges, an international collaborative initiative titled Digital Education for Maritime Communication (DigiMar) was launched, bringing together Maritime English instructors and maritime safety agencies. One of the key outcomes of this project has been the development of 20 open-access instructional videos tailored specifically for Vessel Traffic Service (VTS) operators. These videos are intentionally concise, emphasizing language economy in external VHF communications between VTS personnel and ship crews. Each video incorporates phonetic, lexical, pragmatic, and cognitive components to ensure both linguistic accuracy and pedagogical effectiveness for learners from diverse geographical and linguistic backgrounds. Additionally, the project underscored the need to reassess and harmonize maritime communication standards—many of which were established decades ago—considering evolving operational demands and technological advancements in the sector.

Keywords: communication, instructional videos, VTS, DigiMar

1. Introduction

Maritime communication plays a vital role in ensuring the efficient functioning of all onboard operations, as well as the broader management and coordination of vessel activities within the maritime industry and its complex, multifaceted systems. Routine maritime communication refers specifically to ship-to-shore and shore- to-ship exchanges that, while not related to emergency scenarios, are nonetheless critical for maintaining safe navigation, particularly in coastal waters. To mitigate potential misunderstandings arising from cultural differences, linguistic variability, and ambiguous phrasing, maritime communication has been subject to extensive regulation and standardization, aimed at fostering clarity, precision, and consistency.

Nevertheless, empirical studies have indicated that actual communication practices in professional maritime contexts often diverge, sometimes significantly, from established standards (Dževerdanović-Pejović 2013, Jurkovič 2022). Another observation emerging from previous research is that corpus-based investigations into authentic routine ship-to-shore maritime communication and the associated training practices tend to rely predominantly on Standard Marine Communication Phrases (SMCP) published be the International Maritime Organization in 2001 as the prescriptive standard (Jurkovič 2022), overlooking the subordinate documents such as International Telecommunication Union (ITU) Manual for Use by the Maritime Mobile and Maritime Mobile-Satellite Services (2020a).

In an effort to address the gaps identified in previous research, as well as those revealed through the analysis of authentic routine maritime communication, a comprehensive study has been undertaken, starting with four foundational regulatory documents:

- Manual for Use by the Maritime Mobile and Maritime Mobile-Satellite Services (ITU 2020a,

2020b)

- IALA VTS Manual (IALA VTS Manual 2008 and an amended 2022 version)
- IALA Guideline G1132: VTS VHF Voice Communication (IALA Guideline 2017, and updated versions from 2017 and 2022 included here)
- Standard Marine Communication Phrases (IMO SMCP 2001).

In addition, the study incorporated an extensive review of numerous documents, academic papers, and reports pertaining to standardized maritime communication and its associated training methodologies. The overarching aim was to develop a robust, evidence-based suite of open-access digital educational tools designed to support the professional development of shore-based service operators, maritime students, navigators, and other relevant stakeholders. Central to this initiative was the design, implementation, and evaluation of instructional video materials specifically targeting routine maritime communication practices.

2. The DigiMar Project

Digital Education for Maritime Communication (DigiMar) is an international collaborative ERASMUS+ project that has gathered Maritime English instructors and maritime safety agencies from various geographical regions (Slovenia, Croatia, Montenegro, Finland, Sweden, and Norway). The project idea stems from previous research on standards pertaining to maritime communication, and their practical application in real-life professional environment (Bocanegra-Valle 2011, Bostrom 2021, Dževerdanović Pejović 2013, Jurkovič 2022). The project was launched in October 2023 and is to be finalized by October 2026.

The primary objective of the project is to enhance navigational safety by examining and addressing the role of maritime communication in mitigating risks. Specifically, the project's final goal—realized through three interconnected technical work packages—is the development of open-access digital tools designed to support continuous, self-directed learning, foster interaction between research and educational (particularly lifelong learning) spheres, and reinforce the linkages among education, research, innovation, and practical maritime operations. To ensure a rigorous foundation, the project involved a comprehensive analysis of internationally recognized rules, procedures, and standards governing maritime communication, as well as a critical review of relevant scholarly literature focused on standardized communication protocols and training methodologies. In parallel, a systematic inventory was compiled to identify instances of non-compliance with standard communication protocols that have had direct or indirect implications for navigational safety. This included the examination of documented marine accident cases - sourced from relevant databases - in which inadequate communication was identified as a contributing factor.

Furthermore, the project team collected and analyzed authentic samples of routine maritime communication across the various geographical regions involved, aligning each sample with the prescribed standard communication protocols. These samples provided key variables for the targeted development of instructional video materials aimed at promoting the correct application of standardized communication in shore-to-ship exchanges. All activities and progress reports produced by the participating higher education institutions (HEIs) were systematically reviewed, evaluated, and formally approved by the respective maritime safety agencies (MSAs). Looking ahead, the remaining project activities include the development of a chatbot tool for practicing Vessel Traffic Services (VTS) communication, along with a post-instructional spoken database comprising authentic routine maritime communication exchanges for each region. These samples will again be aligned with the standard communication protocol to evaluate the potential impact of the implemented training interventions.

The digital tools developed through this project will be made freely accessible to students, professionals, and the broader maritime community. In addition, research-based recommendations for revisions to the current standard protocols of maritime communication will be submitted to the relevant international regulatory bodies responsible for maritime communication oversight, such as IMO, ITU, IALA, and EMSA.

3. Instructional Videos – the Methodology

The development of the instructional videos was grounded in the findings of prior research and analytical work conducted within the scope of the project. The selection of topics and communicative scenarios for these instructional materials was informed not only by the recommendations outlined in

standard maritime communication protocols, but also by the analysis of authentic corpora and their degree of alignment with these standards across the various geographical regions included in the study.

The design and production of the instructional videos adhered to a set of pedagogical and technical guidelines that were collaboratively established by the project partners, including both higher education institutions (HEIs) and maritime safety agencies (MSAs). In total, 30 scenarios and corresponding video modules were developed and categorized into two proficiency levels: basic (Table 1) and advanced (Table 2).

Table 1. Routine maritime communication – Basic level.

Introduction
1. Introducing DigiMar videos
B – Establishing the context
What is VTS?
Defining routine maritime communication
C – VTS phraseology
Structuring routine maritime communication
Understanding and applying standard VTS phraseology
D – Clarity of speech
Phonetic alphabet and figures
Understanding tenses
Using action verbs
Message markers – question, answer, request
Message markers – information, advice, warning
Speed messages
Closing the communication loop
Negative confirmation
Speaking formally and clearly
Simple statements and questions
Wordiness
B – Ambiguity
Avoiding ambiguity
Avoiding ambiguity caused by modal verbs
Using prowords
Prowords for avoiding ambiguity

Table 2. Routine maritime communication – Advanced level.

Introduction
Introducing DigiMar case study videos
Routine maritime communication case studies based on accident investigation reports
Collision in a congested waterway
Near-miss between incoming and outgoing vessels
Vessel grounding caused by communication breakdown
Grounding on a underwater reef on a calm night
Collision in foggy conditions
Routine maritime communication case studies based on authentic situations and contexts
Traffic coordination in complex meeting maneuvers
Refusing permission to drift
Traffic coordination in complex overtaking maneuvers
Tugging operation

4. Pedagogical and Technical Considerations in Creating Instructional Videos

The instructional videos categorized under the basic level are primarily designed for maritime students and trainees, offering foundational knowledge and practice in standardized routine maritime communication.

In contrast, the advanced video modules incorporate a range of case studies that illustrate the critical role of effective communication in promoting safe and efficient maritime operations. Relying on the concept that genres serve specific communicative purposes, along with the generic structures of genres as outlined by Swales (1990), we find that all video presentations follow a specific structure that enables users to easily follow and understand them. The video presentations and instructions have been structured according to four

defined moves:

- Move 1: Addressing the audience, introducing background
- Move 2: Introduce the communicative purpose of the video, stating whether the video is of learning type of interactive
- Move 3: Content: instructional, multiple choice, gap filling, repetition of the segment
- Move 4: Thanking the user and referring to useful links, documents

All visual content was consistently generated using artificial intelligence to clearly delineate the communicative turns between Vessel Traffic Services (VTS) operators and ship personnel (Figure 1).



Figure 1. Cover page of an instructional video – basic level.

Additionally, all identifying information, including names and specific references, was anonymized and generalized to ensure data protection and maintain a neutral, context-independent instructional environment. (Figure 2).

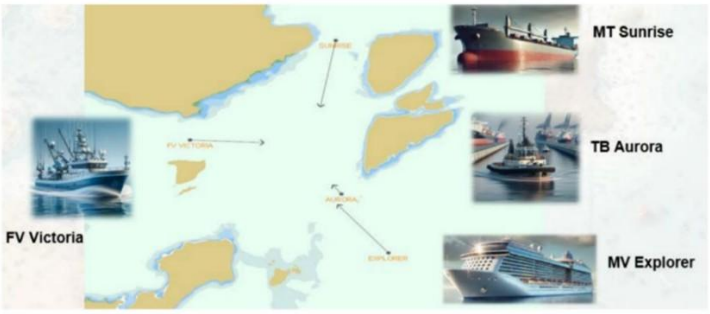


Figure 2. Anonymized names of vessels.

It is worth mentioning that the creators of the videos faced a challenging undertaking. On the one hand, the aim was to generate an open-access database of videos that would be available to users worldwide. This pedagogical endeavor was made even more difficult considering the project partners' differences in culture, collective mindset, competencies of VTS operators, number of VTS stations, etc. However, the outcomes of the instructional videos revealed that the communicative issues are generally similar, with most of them revolving around the following points. These are: establishing communication, exchanging information, and ending conversations (Bocanegra Valle 2011). Next, the external VHF communications led between VTS operators and ships greatly missed closed loop communication, by which the recipient of the message acknowledges the receipt of the message by repeating the relevant part of the sender's message (IMO SMCP, 2001, 14). This was accompanied by a lack of linguistic signals indicating that communication was closed. The third general trait identified in the collective analysis of the partners' scenario corpora pertains to the absence of language tools used to provoke, enhance, and lead the conversation to encourage communication and verify the information being conveyed. This feature is referred to as variables and includes various linguistic elements, such asprowords (repeat, say again, over, understood, this is, over, out, information, warning, request). Finally, the project team's decision to differentiate between "positive" and "negative" keywords, which will significantly contribute to the effective production of chatbots, was based on the observation that the collected materials of authentic maritime routine communications contained excessive words that could lead to ambiguity, while at the same time omitting those that might improve

understanding of the message. Examples of positive keywords include must, say again, over, and out, whereas negative keywords should be avoided, as they may result in ambiguity, misunderstanding, or a lack of assertiveness, or could be culturally inappropriate (e.g., negative, can't, please, might, Sir, Madam, sorry).Following a comparative evaluation of several available tools for video production, ElevenLabs - in conjunction with PowerPoint presentations - was selected for its demonstrated advantages in producing high- quality, natural-sounding speech, accurate pronunciation, and adaptability to a range of English accents. The video production process adhered to established pedagogical principles, which included a structured design framework comprising an introduction, demonstration, and conclusion. Additional instructional design considerations included maintaining a concise video length (not exceeding six minutes), the use of clear and accessible language, and the incorporation of elements aimed at promoting learner engagement and interactivity. The two sets of videos, basic and instructional are interactive in nature and discursively structured to maintain the audience's attention. One of the rhetorical features of both sets of videos is based on a question- and-answer pattern (e.g. "Why is it important to use action verbs? Well, these verbs make statements more concise and clearer to the listener. Thus, your statements are more direct and easier to understand"). This approach enhances the contextual or communicative context (Bhatia, 2013) by clarifying the participants, Communicative goals, audience, and their relationships.

5. Deployment, Evaluation and Further Steps

The instructional video materials underwent multiple levels of evaluation to ensure their pedagogical effectiveness and technical accuracy. Maritime Safety Agencies (MSAs) played a pivotal role in this process by verifying the correctness of communication procedures and identifying potential gaps or areas requiring enhancement. This validation phase directly supports the project's qualitative objective of achieving a minimum user satisfaction rate of 80%, with feedback from pilot testing informing refinements prior to final dissemination. Based on insights gathered during the testing phase, revisions to the instructional videos were made to address identified shortcomings. This iterative development process enhances the overall quality of the materials by integrating authentic feedback from both maritime professionals and learners. Modifications may include improvements in linguistic clarity, audiovisual components, or content alignment with users' needs and training objectives. Such refinements ensure that the instructional resources adhere to the highest educational and technical standards, thereby advancing the project's overarching aim of promoting maritime safety through improved communication practices. The final phase involves the publication of these instructional videos in an open-access format, thereby ensuring broad accessibility and maximizing the project's impact. By offering unrestricted public access, the project extends its benefits beyond the immediate consortium, enabling continued evaluation, broader adoption, and long-term sustainability. This open-access strategy promotes knowledge- sharing within the global maritime education and training community, supporting ongoing professional development and the dissemination of best practices in standardized maritime communication. Once developed by higher education institutions (HEIs) in collaboration with - and approved by - MSAs, the instructional materials will serve as the foundation for the development of interactive chatbots. These tools are designed to support the acquisition of routine maritime communication skills and competencies among VTS operators and their instructors, maritime students and educators, and other interested stakeholders. The digital tools will be formally presented and promoted among relevant stakeholders in the partner countries, with the goal of collecting further feedback from maritime professionals, operators, and instructors. All online educational materials will be accompanied by evaluation forms to solicit input from a broad audience, including the general public. Subsequent revisions and refinements, based on this feedback, will be collaboratively discussed and implemented by project partners to ensure continuous improvement.

6. Conclusion

The primary objective of the research conducted under the DigiMar project is the development of instructional videos designed to enhance routine maritime communication competencies among students and shore-based professionals, ultimately contributing to the improvement of navigational safety. A total of 30 instructional videos, each accompanied by a written script, have been made publicly available for open access and evaluation on the official project website https://digimar.si/. The next phase of the project involves the development of interactive chatbots, which will be accessible not only to students and professionals but also to a broader public audience for further use and assessment. The study has identified several challenges and inconsistencies in the practical application of standardized maritime communication

protocols. In addition, it has underscored the lack of harmonization and the need for updates to existing regulatory frameworks. Although the instructional videos are developed in alignment with the guidelines set forth by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), the International Telecommunication Union (ITU), and the Standard Marine Communication Phrases (SMCP), these standards - formulated decades ago - warrant critical reconsideration in light of contemporary operational practices and technological advancements in maritime communication.

Acknowledgements

This research is co-funded by the ERASMUS+ Program of the European Union.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Fostering gender equality in maritime innovation: Economic growth and sustainable development

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Abstract: Maritime industry has a prominent place in the global commerce but the industry poses some challenges when it comes to sustainability, technology, gender equity. While the clean technologies and environmental sustainability demand grows, women are still underserved in the sector when it comes to leadership positions and R&D. This study aims to trigger innovation and economic growth through sustainable model for gender equality in maritime field. Through analysis over global frameworks, the study shows that more women's involvement not only promotes workforce diversity, but increases the rate in development of green technologies, and promotes inclusive leadership. The paper gives an emphasis to the fact that gender equality in maritime education, R&D and leadership positions is essential towards achieving the environmental and economic challenges of the industry in line with the United Nations' Sustainable Development Goals (SDGs).

Keywords: Gender Equity, Economic Growth, Maritime Innovation, Women Empowerment, Sustainable Development

1. Introduction

Maritime industry is the most important pieces of global trade as it carries almost 80% of global goods. The shipping industry, as one of the key players in the global trade, supports job creation, economic growth, as well as supply chain management globally. However, this critical industry is plagued with serious issues that undermine its viability in the long-term run; environmental issues, technological advancements, and the requirement to adjust to climate change are a few among them. Whereas the maritime industry is primary importance, the major issue that has not been greatly addressed thus far is the gender imbalance in the maritime industry. Even many initiatives taken towards sustainability and technology innovation, the under-representation of women in leadership, research and development (R&D), innovation and many other areas of innovation, remain a major obstacle to the potential growth and adaptation of the sector to contemporary challenges (Barrios et al., 2020). The gender gap in the maritime industry is most apparent in the reduced female participation in decision-making roles and lack of their participation in the development of innovative technologies that can assist the industry to manage the environmental impact (Kumadeka, C. M. A. 2022). Women comprise a limited portion of the maritime workforce and their percentage of representation in leadership positions and more specifically R&D is virtually non-existent. Such lack of gender diversity in the workforce is not only a failure to capitalize upon social equity, but a strategic disadvantage to the industry. Studies have been conclusive in demonstrating that diverse teams; among them gender balanced teams, are more likely to be innovative and deliver solutions that are more extensive for complex problems. This implies the insufficiency of female participation is a hindrance to the capacity of the maritime industry to produce innovative solution for sustainability, resource efficiency, as well as for environmental protection (Boström et al., 2025).

Considering the current world's challenges in conservation of the environment, depletion of resources, and the need for carbon emission reduction, the maritime industry is under pressure to adopt clean technologies and improve on the environmental footprint. This entails the construction of fuel-efficient vessels, alternative sources of energy as well as green shipping technology. While the industry has not fully exploited the potentials of gender equality being used to fuel these innovations (Akhavan, M. (2024).

Gender-neutral policies that

Promote women's involvement in maritime education, research, and leadership can bring the innovation much-needed support for sustainable maritime technologies creation. Advocating for gender equity is a question of social justice (Di et al., 2023). It also forms a strategic lever for the maritime industry to bind with the United Nations' Sustainable Development Goals (SDGs) and deliver to the soaring calls for sustainable practices (Butt, J. S., & Kousar, F. 2024). In this way, as the sector moves towards embracing green technologies, women's leadership, and entrepreneurship could serve to ensure that the innovations are not only innovations but also environmentally friendly (Wang et al., 2020). This paper seeks to explain that gender-inclusive maritime sector policies not only have an essential role to play towards gender equity, but also in stimulating technological changes and economic growth, and towards the adoption of sustainable practices. From the global frameworks that advance women's leadership and gender equality, this study will explain how it is possible to increase women's participation in the maritime industry to make the sector more inclusive, diverse, and resilient (Angelidaki, S.K. 2023). Gender equality's roles in achieving the eco-friendly technologies and the green maritime practices will also be discussed in the paper, with a view to shaping the future where maritime sector equally helps to greatly contribute to the global economic growth and environmental sustainability.

2. Objective of the Study

To understand the way gender inclusive policies in maritime sector, promote innovation, economic growth, and sustainability and to look at the role of women leadership on technology advancements, green technologies, and job creation, as well as recommendation towards the improvement of policy framework that supports global sustainability goals.

3. Literature Review

The maritime sector is essential to the global trade and economic development as it contributes to the transportation of almost 80% of goods to the world's population by means of sea shipments (UNCTAD, 2020). Yet, in spite of the key significance for the global economy, the sector continues to experience regular issues, namely connected with gender inequality, sustainability, and technological innovations (Elston et al., 2024). Limited representation of women in the maritime sector with specific focus on leadership roles positions and in research and development (R&D) is yet a major block in efforts of the industry to innovate and play a critical role in solving vital issues such as environmental sustainability (Froholdt et al., 2015). This literature review looks at the role of gender equality in enhancing maritime innovation, economic growth, and sustainable development. Gender disparity in the maritime industry has been recognized as an important aspect. The maritime sector has, traditionally been male dominated and the women represented a very small percentage in the workforce. Statistics indicated that women only account for approximately 2-3% of the total global maritime workforce and their numbers in leadership and decision-making positions are scant. (UN Women 2019) Apart from being a social miscarriage of justice, the underrepresentation is also a business miss opportunity for innovation and economic development (Mollaoglu et al., 2024). Although there is increased worldwide focus on matters such as gender equity and sustainability, women are grossly underrepresented especially in the areas of research, R&D and green technologies (Karadencheva, A. 2025). There is an actual implication of gender imbalance in the innovativeness of organisations. Studies have always indicated that diverse teams are better in solving problems and innovation. For example, McKinsey & Company (2020) study shows that the organisations with a larger percentage of women at the top are more likely to be innovative and successful financially. In the area of the maritime business this could be directly linked to the ability of the business to embrace new eco-friendly technologies, and reduce emissions of carbons and principle of sustainability on whole.

The influence of gender diversity on innovation is widely understood elsewhere, but in maritime, it has not been analysed yet. Works suggests that teams with diversity in gender present different opinions that are key for generating new ideas. Lack of women holding top roles and positions in R&D has slowed the growth and use of sustainable maritime technologies such as energy-saving ships, alternative fuels and green technologies. Often, when it comes to saving the environment, women are placed more often at the front of efforts connected to sustainability and green solutions. The study reported above, shows that supporting both genders encourages the industry to develop innovative ways to address the sustainability issue. For instance, female leaders often choose to promote environmental practises that play a big role in the growth of maritime innovation. As a result, more women taking part in such activities can accelerate the use of green technologies

and bring these activities in line with international environmental aims. Many are realizing that gender equity is both an issue of social justice and an important reason for economic progress. In 2020, the World Bank claimed that a greater participation of women in the workforce can drive economic growth and raise productivity. By making the maritime industry gender-inclusive, more employment, better leadership and new technological advancements can be made towards wider economic development. Being inclusive of both genders helps organisations gain better performance reported that teams with equal numbers of men and women record higher engagement from staff and better overall performances. Thanks in part to gender diversity, organisations are more likely to fully grasp their customers' needs and have more potential for business growth.

Diversity in gender among leaders at seas can directly shape the course of technology. The unique ideas of women about sustainability, clean energy and resources inspire better and more inclusive approaches to meeting global development objectives. Women's growing roles in maritime leadership serve both to advance gender equality and to encourage economic growth by using new technologies and more sustainable techniques. Achieving gender equality is essential for sustainable development to happen (Kitada, M. 2021). The Sustainable Development Goals mentioned by the UN, SDG 5 on gender equality and SDG 13 on environmental sustainability reveal that these are in fact two connexions of the same issue. Women need to take on leadership and participate in maritime transportation to support sustainable practises and new ideas. Findings show that gender inclusion in groups helps them create solutions to problems related to economics and the environment (UN Women, 2019). Because the industry is feeling pressure to shift into eco-friendly technologies and follow new standards, female leaders might start to lead the adoption of sustainable approaches in shipping. Improvements in gender equality can give a lift to the creation of energy-saving vessels and alternative energy sources needed to improve sustainability in the maritime field (Ojwala, R. A. 2023). While there is plenty of research on gender equality in other fields, not much has been written about diversity in maritime technology. We need to investigate if having gender diversity in leadership changes the sustainability impact and economic growth of the maritime field. The study of women's active involvement in R&D and green technology in the marine industry might give us useful clues about the relationship between gender fairness and caring for the environment. It is also possible through such study to see which organisations and regions are leading the way in building gender diversity in education, training and leadership of the maritime sector. No women in top or research jobs in the maritime industry will hold back the industry from facing the challenges of sustainability and economic developments (Onwenume, U. P., & Udaba, F. N. 2025). Having equal rights between genders on ships and in maritime jobs is essential for justice, as well as for promoting new maritime inventions and sustainable business practises. Supporting women in the fields of maritime education, scientific work and leadership could help increase maritime diversity and speed up the development of environmentally friendly technologies on which the United Nations SDGs are built. To achieve a more welcoming, creative and permanent maritime sector, we should ensure women are encouraged and supported to join in its future development.

4. Methodology

This research aims to analyse the effect of gender-inclusive policies on maritime innovation and the economy, as well as sustainable development in the maritime segment. The research uses quantitative approach whereby hypothesis testing through T-tests and ANOVA is used to examine the relationship between gender equality in the leadership and R&D functions and the consequent effects on innovation, economic growth, and sustainability. Having 180 participants from various sections in the maritime industry such as leadership positions, research and development departments and policy formulating areas is what the study aims at. Survey on participants' green technology development, economic performance and sustainability practice is conducted. The sample is split into two different groups of male and female participants. To ensure representation, stratified random sampling is used, maritime professionals from different geographical areas, firms of different sizes, and maritime specialties, are chosen. The independent variables are gender diversity in terms of leadership and R&D positions and dependent variables are innovation, economic growth, and sustainability. Innovation is determined by the number of new technological systems, especially the green systems and alternative fuel systems. Assessment of the economic growth is based on participants' perceptions about profitability, market share, and expansion of business (Baker, M., & Alkoyak-Yildiz, M. 2022). The sustainability is measured by adopting eco-friendly practises, reduction of the carbon as well as alignment to the UN Sustainable Development Goals (SDGs).

The hypothesis tested is as follows:

Null Hypothesis (H0): There is no significant difference in the level of innovation, economic growth, and sustainability practices between male and female participants in the maritime sector.

Alternative Hypothesis (H1): Gender equality in leadership and R&D roles leads to greater innovation, economic growth, and sustainable practices in the maritime sector.

The T-tests also compare the means of male and female participants to determine their influence on technological developments, economic achievements, and the implementation of sustainability practises in their essential aspects. The differences between companies with different gender inclusivity levels and green technologies and sustainable practises adoption are analysed using ANOVA. The results' statistics will be significantly found when the p-value is < 0.05, assuring that gender equality will improve innovation and sustainability in the maritime industry. One can get a thorough look at how inclusive gender policies positively impact economic and environmental success in shipping. Hypothesis testing is aimed at finding evidence to show that improving women's roles in leadership and R&D leads to fresh ideas and lasting solutions in maritime sectors.

5. Results and Discussion

T-tests and ANOVA analysis in this study have given us important insights into how gender-inclusive policies benefit maritime innovation, economic growth and sustainability. In the sections that follow, the research findings are explained as they relate to the hypotheses and the results from statistical tests.

5.1 T-test Results

T-test outcomes show that women and men differ a great deal in all the three metrics involved. The outcomes of the T-test are summarized in Table 1.

Table 1. Result of T-test by Gender

Metric	Male Mean	Female Mean	T-statistic	P-value
Innovation	74.29	81.78	-4.39	0.00002
Economic Growth	70.70	80.18	-4.88	0.000002
Sustainability	73.16	78.82	-3.34	0.001008

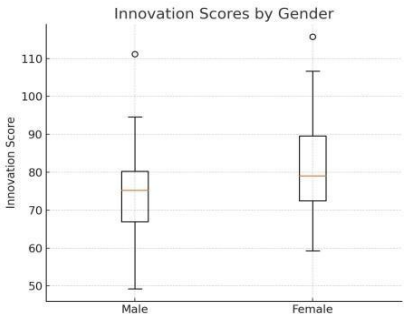
Source: Primary data

5.2 Innovation: On average, female participants scored higher in innovation than male participants and the difference was very significant (T-statistic = -4.39 and P-value = 0.00002). It shows that combining different genders leads to improved progress in introducing environment-friendly technology and safe shipping practises in the maritime sector.

5.3 Economic Growth: When it came to believing they were improving economic growth in the maritime industry, females outscored males, with a mean of 80.18 to 70.70, a T-statistic of -4.88 and a P-value of 0.000002. It points to the fact that having gender-inclusive leadership helps a company does better, enter new markets and increase profits.

5.4 Sustainability: Women performed better (mean = 78.82) in sustainability than men did (mean = 73.16), with a T-statistic of -3.34 and a P-value of 0.001008. This result indicates that promoting gender diversity in these leadership roles encourages attention to sustainable technologies, lowering carbon emissions and following the UN's SDGs.

The next plots illustrate the distribution of scores for Innovation, Economic Growth and Sustainability for males and females. They also draw attention to how much the scores for the two groups vary statistically.



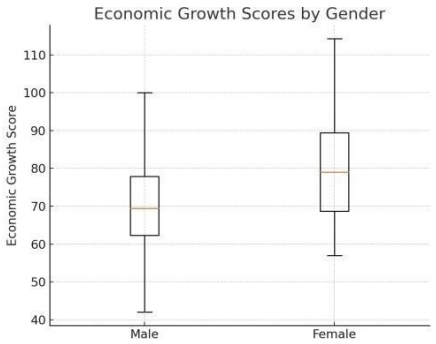


Figure 5.1. Innovation Scores by Gender

The results from the box plot prove that female employees receive a higher median grade and show a larger range of Innovation scores, confirming the T-test findings on inclusive teams' innovation.

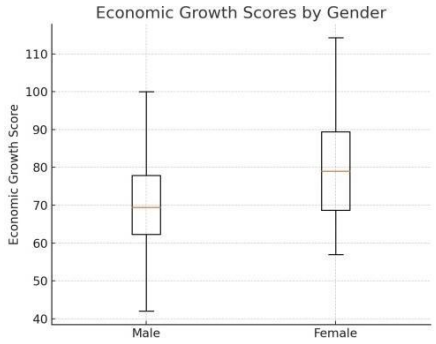


Figure 5.2. Economic Growth Scores by Gender

The box plot on Economic Growth finds that women report much better results, with less fluctuation, suggesting they contribute much to growth in the maritime field.

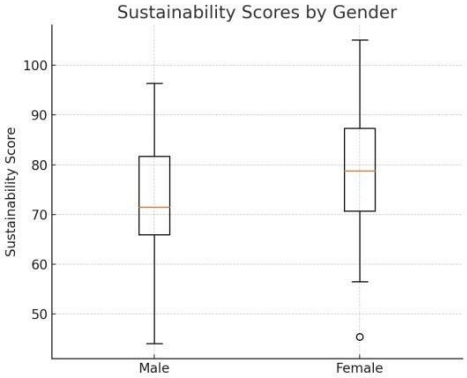


Figure 5.3. Sustainability Scores by Gender

The box plot for Sustainability also supports this idea as female participants again have the highest median and narrow spread of scores.

5.5 ANOVA Results

The rationale behind conducting an ANOVA was to investigate if companies with higher gender diversity than others have much more effective approaches to sustainability practices, new product ideas, and revenue growth. The test looks at three different groups:

High gender diversity**:** Organizations with a female leadership team and research & development team that is more than 40% female.

Medium gender diversity**:** Companies that have 20-40% women working in leadership and R&D.

Low gender diversity: Companies whose leadership and R&D departments have fewer than 20% women. The findings from the ANOVA analysis are summarized in Table 5.2 below:

Table 5.2. Results of ANOVA

Metric	High Gender Diversity (Mean)	Medium Gender Diversity (Mean)	Low Gender Diversity (Mean)	F-statistic	P-value
Innovation	82.14	78.25	74.09	5.67	0.004
Economic Growth	81.53	77.45	71.89	6.42	0.001
Sustainability	80.42	76.31	72.04	4.98	0.008

*5.6 Innovation***:** Higher gender diversity within organizations (mean=82.14) resulted in greater levels of innovation than were found in firms with medium (mean=78.25) and lower gender diversity (mean=74.09). The strong positive relationship between gender diversity and new technology is clear from the F-statistic of 5.67 and P-value of 0.004.

Economic Growth**:** Researchers found that companies with greater gender diversity achieved higher economic growth on average (mean = 81.53), compared to companies with medium (mean = 77.45) and low diversity (mean = 71.89). The result shows that business success is strongly influenced by how diverse the gender composition of the workforce is.

Sustainability**:** Firms with high gender diversity had better sustainability practices (mean = 80.42) than those with medium (mean = 76.31) and low gender diversity (mean = 72.04), as shown by an F-statistic of 4.98 and a P-value of 0.008.

The findings make it clear that making maritime activities gender-equal is key to promoting innovation, the economy and sustainable development. The paper highlights how inclusive teams are more likely to produce new technology that addresses the pollution challenges faced by the maritime industry. In addition, having women lead and take part in research and development increases the country's economic growth which promotes following sustainable practices set by the global community. The evidence backs up the idea that safe and equal workplaces in the maritime sector also boost the economy's performance and help it thrive. Leading women in the sector focus on sustainability to benefit creative problem solving that directly addresses concerns relating to the industry's effect on nature (Rizky et al., 2025). Encouraging women in leadership and offering equal rights in research will allow the maritime industry to appreciate diverse thoughts and design solutions needed for both the economy and the environment. For this reason, planning for gender-inclusive policies should focus on resilience, progress, and sustainability, besides being an issue of equity.

6. Recommendations

Given that the study stresses the importance of gender diversity for maritime progress, a set of recommendations is offered to help increase gender equality and lead to more growth and sustainability in this industry:

1. Promote Gender-Inclusive Policies in Leadership and R&D Roles: Maritime organisations should include women in job recruitment and promote them to higher and more advanced positions. As a result, these activities form the basis for dedicating resources to green engineering and lesser-polluting shipping.

2. Enhance Women's Participation in Maritime Education and Training: Invest more in programmes that prepare women for maritime engineering, handling shipments, and other green issues.

3. Develop Mentorship and Leadership Development Programs: These skills programmes ought to support women's efforts to advance become leaders and explore innovations, motivating them to move up the career ladder in the industry.

4. Encourage Collaboration between Gender-Diverse Teams: Maritime organisations ought to help create team settings where people of all genders cooperate well. By setting up projects that include members from many parts of an organization, people can collaborate and support sustainability and innovation.

5. Implement Gender Diversity Metrics and Accountability: Sector players should introduce both gender diversity measures and strict accountability systems to remain on track with the progress of efforts towards gender equality in shipping. Fonts must be closely watched and are essential for the company's annual performance review.

6. Foster Gender-Sensitive Workplaces: Help set up workplaces that respect genders, provide various types of work flexibility, and provide support to families. Thanks to these measures, women can handle work-

life situations better, so they stay active in the maritime industry.

7. Encourage Public and Private Sector Partnerships: Working together with private sector firms, governments and industry organisations should promote strategies and guidelines that support more women in leadership and R&D positions in the maritime industry.

8. Promote Research on Gender and Innovation in Maritime: Back studies on the effects of gender diversity on maritime innovation and efforts toward a sustainable future. Research from both academics and industry provides proof of strategies to increase gender inclusion and new ideas.

9. Strengthen Gender Equality Frameworks Globally: The International Maritime Organization (IMO) and similar worldwide organizations must boost and advance gender equality programs that motivate women to be involved in each field of the shipping industry, whether that is research, innovations or leadership.

7. Conclusion

The role of gender equality in driving innovation within the maritime industry, expansion of economic prosperity and as a factor contributing in sustainability of the maritime industry has been brought into light in this study. As much as the industry is lulled with a lot of challenges when it comes to environmental sustainability and technical development, the phenomenon of women inclusion especially in the leadership and R&D aspect represents a unique opportunity of developing innovative solutions and boosting the implementation of green technologies. The outputs of T-test and ANOVA findings indicate that gender-diverse teams lead to an increased score of innovation, better performance economically, and improved sustainability practises. To the point where enterprises are more likely to make decisions centred on sustainable practises if they have a larger representation of females in positions of leadership and decision making, it would lead to a significant positive effect on both the environment and the economy. This highlights the relevance of creating an inclusive environment in which gender diversity will make the necessary changes in the practises and tactics in this sector. In addition to this fact, the current research underlines the fact that gender equality in the maritime sector is not only a social justice but a strategic advantage. Increasing women's involvement into maritime education, research, and leadership stimulates a new vision in the sector, improves problem-solving skills, and triggers technological developments in line with the global sustainability agenda. Evidently, the development of gender-inclusive policies within maritime industry can play an important role in the development of green technologies, making the sector more economically sound, and moving it closer to the United Nations' Sustainable Development Goals (SDGs). The maritime sector must proactively be gender equal to capitalise on the full potential of the workforce as well as technologies necessary for the challenges of the future. Through developing inclusive policies and empowering women, the industry can clear the way for a more innovative, sustainable, and fair maritime industry.

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The 25th IAMUC
Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Implementation of Advanced Learning Methods in Maritime Education Through the UniTrain System for Enhancing the Teaching Practices of Process Measurement Variables

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Abstract: Onboard ships, many process measurement variables (PMV) are continuously performed and supervised, and they are essential for the control and monitoring of different ship's systems. Monitoring parameters which are involved in these measurements are temperature, flow, level, pressure, speed, mass, density, etc. Each PMV requires the application of appropriate process sensors (PS) and measuring equipment to ensure accurate and reliable monitoring of fundamental ship processes. A proper understanding of the functionality and operating principles of these PS, as well as the technologies used for their integration and data processing, is crucial for the education of future Electro-Technical Officers (ETO) and Marine Engineers (ME). The modern maritime industry requires the integration of advanced learning methods into educational processes to enable students to acquire essential practical knowledge alongside theoretical foundations. In this context, the use of sophisticated laboratory and simulation tools, such as the Lucas Nülle UniTrain System (UTS) for Temperature/Pressure/Force (TPF) measuring processes, represents a significant step forward in modernizing the teaching practice of process measurements. On this way, students have opportunity to work with experimental modules that include the calibration of an instrumental amplifier, analysis of errors in temperature measurements, operation with various temperature sensors (NTC, Pt100, KTY, thermocouple), as well as the use of strain gauges and the Wheatstone bridge (WB) for force and torque measurements and analysis.The paper provides a detailed presentation of the laboratory exercises conducted on the UTS, including measurement methods and results analysis, which contribute to a better understanding of the calibration process, implementation and the characterization of various PS. Additionally, the paper presents an overview of the Basic Process Measurements (BPM) that are monitored onboard for the purpose of managing fundamental ship processes, establishing a direct connection between theoretical foundations, laboratory experiments, and real-world applications in the maritime industry.

Keywords: process measurements, education, learning methods, Electro-Technical Officers

1. Introduction

Shipboard metrology represents a key segment in the supervision and control of onboard processes, encompassing a wide range of measurements related to fundamental technological systems on a vessel. Specifically, accurate measurement of PMV, such as temperature, pressure, flow, level, etc., is essential for ship systems' optimal functioning and maritime operations' safety.

The PS used in shipboard systems are often of a complex nature, as their functionality is based on sophisticated principles of energy conversion. For instance, the operation principle of a resistance thermometer for temperature measurement relies on converting a physical quantity (temperature) into the electrical resistance of a wire-based sensor.

The exact temperature value can be determined based on the measured electrical resistance level. In addition to sensors, measurement systems often include a measuring transducer (transmitter), which may

contain a series of conversion chains aimed at forming a standardized output signal. These transmitters are characterized by specific input and output features, which define their accuracy and reliability under real working conditions. The input characteristics of measuring transducers include the measured variable, measurement range, and span, while the output characteristics encompass the type of measuring signal, signal range, output impedance, and noise level. It is also important to emphasize that proper calibration of these measuring devices directly affects the accuracy of measurements and data reliability, which are crucial for managing shipboard systems.

However, the education process of future ME and ETO officers cannot be based only on gaining theoretical knowledge. Implementation of laboratory exercises is very important for knowledge and skills improvement, especially for understanding of complex measurements processes onboard. During practical exercises, students are having the opportunity to get familiarized with the application of PS and different measuring instruments and become able to interpret different sensors output values independently. Also, for Maritime Electrical Engineering and Marine Engineering Students, hands-on work in the laboratory is very important for developing their analytical thinking and practical competencies. Laboratory exercises are the students' first work experience with PMV measurements and opportunity to learn how and which kind of instrumentation and procedures to use for different types of process measurements. On this way, students have their first interaction with measuring equipment, such as sensors, transducers, processor units, etc., what helps them to understand all principles of measuring systems. By gaining this experience in laboratories, students are getting prepared to implement the knowledge and experience in real shipboard conditions, where measurement accuracy is crucial for the safety and efficiency of different ships' systems (Furmankiewicz et al., 2023).

For teaching the measurements processes Virtual Instrumentation (VI) became very important, as it is giving opportunity to create simulations and visualization of complex measuring processes by using general purpose PCs together with assigned data acquisition hardware and specialized software, such as LabVIEW. LabVIEW is allowing us to create a virtual measuring instrumentation environment which is behaving as a replica of the traditional instrumentation but with higher flexibility and adaptability to the different teaching needs.

Recently, Remote Laboratories (RL) have become increasingly popular and implemented in the teaching processes. This allows students at different educational institutions to use hardware and do experiments with the same real equipment, which is remotely available to all of them, does not matter where they are located (Albu et al., 2004). Examples of implementation of remote experiments and prototypes through the internet deployed for testing the characteristics of distance relays are presented in "Blackburn & Domin, 2006" as sample of implementation of RL in contemporary education models.

This paper aims to present the application of the Lucas Nülle UTS in the education of students in shipboard measurements. The focus is placed on the analysis of laboratory exercises that include the use of various temperature sensors and relevant measuring instruments. The scientific contribution of this paper lies in demonstrating the effectiveness of the UTS as a modern tool for enhancing the teaching process through the integration of theoretical knowledge with practical skills. Additionally, the paper provides an analysis of experimental results that enable a deeper understanding of sensor characteristics, thereby establishing a connection between laboratory experiments and real-world applications in the maritime industry.

This paper is structured into five sections. Section 1 introduces the relevance of process measurement variables (PMVs) in shipboard systems and highlights the importance of practical training in maritime education. In section 2 the development process of the most important professional competencies of MEs and ETOs is presented, with special attention paid to the advanced learning methods which are according to the international standards. Section 3 gives an overview of process measurement techniques and methods which are applicable in ships' measurements, with a special attention to temperature, pressure, and level monitoring. In section 4 is described implementation of the Lucas Nülle UTS in the process of maritime education with a described laboratory exercise with Type J thermocouple characterization and analysis. At the end, section 5 concludes the paper by wrapping up key findings and presenting potential directions for further educational improvement in measurements.

2. Enhancing the Competencies of Future Marine Engineers

Marine education and training processes are changing and improving together with a dynamic change in the maritime industry which are following improvements in applied technologies and in international standards (Mindykowski, 2014b).

Contemporary requirements for maritime education affirm necessity for continuous improvements of seafarers' knowledge and practical skills and competencies. Except theoretical knowledge as a background, this involves their preparedness to work in a complex and challenging shipboard environment. To achieve a high level of competencies, it is necessary to integrate new methods into educational processes, such as cotemporary laboratories, didactic systems, and advanced simulators (Knezevic et al., 2022).

Recently, the ETO became one of the most demanding officers' positions in the maritime industry due to technological improvements and implementation of highly automated electrical and control systems. Roles and responsibilities of ETO officers are described and precisely defined in the amendments to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) from 1978, with revisions in 2010. This convention provides guidance for development and improvement of educational standards which need to follow technological requirements and maritime procedures (Dževerdanović-Pejović & Dlabac, 2021).

Most important requirements of the STCW convention are related to the development and modernization of educational capacities, what includes establishment of new laboratories and modernization and improvement of existing ones, and integration of simulators in the educational process. Although simulators represent an effective tool for developing technical skills, they cannot fully replace practical training on real equipment. Real laboratory training and hands-on experience onboard remain irreplaceable elements in the process of acquiring comprehensive knowledge and competencies necessary for the effective management of ship systems (Mindykowski, 2017).

The new competency standards for ETO officers, established through the International Maritime Organization (IMO, 2011), further emphasize the importance of combining theoretical knowledge with practical training. The introduction of these standards not only represents a technical adjustment in educational programs but also opens new chapters in the professional development of seafarers. As stated by the author in (Mindykowski, 2014a), the modernization of ETO education involves not only the adaptation of existing curricula but also the creation of new educational paradigms that enable seafarers to successfully cope with the challenges of the modern maritime industry. In this sense, a crucial aspect for maritime institutions is balancing theoretical instruction, laboratory practice, and the use of simulators to ensure stronger competencies among future officers.

The first standards specifically intended for ETO officers are included in Section A-III/6 of the STCW Code, while certification requirements for electro-technical crew members are defined in the 2011 edition of the STCW Convention (IMO, 2011). These minimum standards encompass a total of 18 key competencies, divided into three functional categories: electro-technical, electronic, and automation engineering; maintenance and repair; and operation of the ship and care for persons onboard. Each of these competencies serves as a basis for the development of new educational tools and the modernization of laboratory capacities to improve the quality of practical training and prepare seafarers for onboard duties (Mindykowski, 2017).

3. Process Measurement on Ships

Ships are complex technical systems in which various PMV are continuously monitored and controlled to ensure optimal operation of ship machinery, energy efficiency, and navigational safety. The most widespread measurements include temperature, pressure, level, and flow; however, many other measurements are also performed, such as rotational speed (RPM), viscosity, gas concentration, and other parameters crucial for the management of shipboard processes.

Measurement systems onboard must be highly reliable, resistant to extreme operating conditions, and integrated into automated control and monitoring systems. The PS used for these purposes must be specifically adapted to the requirements of the maritime industry, including resistance to vibrations, temperature fluctuations, saline environments, and mechanical impacts.

Temperature measurement is one of the most critical aspects of monitoring ship systems, as temperature directly affects key ship components' efficiency, reliability, and safety. Positive temperature coefficient

resistors (PTC) are mostly used for temperature measurements onboard ship and common types of sensors which are widely implemented are Pt100 and thermocouples. They are used for different ships' systems and are vital for ships' operations.

One of the most important implementations is for main engines, where temperature sensors are used for continuous monitoring of cylinders' temperatures, exhaust gasses, lubrication oil, low (LT) and high (HT) cooling water temperatures and for turbo charger gasses temperature. In order to achieve engine performance optimization, increase efficiency and reduce risk of overheating and damaging machines, these measurements must be highly accurate and reliable all the time. Also, it is very important to have continuous measurement and monitoring of electrical motors' and generators' windings and bearings temperatures to avoid overheating which can reduce efficiency, increase electrical resistance and cause severe failures. On time detection of increased temperature levels allows preventive maintenance and extends equipment lifespan.

Temperature monitoring inside electrical cabinets and distribution boards is very important for preventing thermal failures of electrical and electronic components. By maintaining internal temperatures, we can provide optimal operating conditions and minimize the risk of overheating, which can cause damage or even fire. Temperature sensors are also widely used in HVAC (Heating, Ventilation, and Air Conditioning) systems for maintaining the desired conditions in crew areas on cargo and in crew and passengers' cabins and areas on cruise ships and ferries. HVAC system is very important for onboard comfort as well as for maintaining proper storage conditions for sensitive cargo.

Temperature control of fuels and lubricants is another important application of sensors in the maritime industry. Monitoring oil and fuel temperatures is necessary to maintain optimal viscosity, ensuring efficient combustion and reducing fuel consumption. Pressure measurement is essential for monitoring the status of working fluids in various ship systems. Ships use different types of pressure sensors, which can be classified by working principle (piezoelectric, capacitive, inductive, optical) and purpose. Pressure monitoring has broad application across shipboard systems, allowing for early detection of irregularities and effective management of operational processes.

Key applications include main and auxiliary engines, where the continuous monitoring of lubricating oil, fuel, cooling water, and exhaust gas pressure ensures optimal operation and prevents mechanical wear. Fuel and oil separation systems rely on precise pressure measurement for efficient filtration and removal of contaminants, directly impacting propulsion system performance. Reverse osmosis systems used for desalinating seawater require constant pressure control to ensure proper membrane operation and system stability.

In propulsion and ballast systems, pressure regulation in hydraulic and pneumatic circuits is crucial for manoeuvring and ship stabilisation. Pressure sensors are widely used in compressed air systems for monitoring pressure in distribution lines, ensuring the availability and reliability of pneumatic systems and instrumentation. Also, measuring and monitoring of atmospheric pressure in technical spaces is very important for proper control of HVAC system, what is creating optimal environment conditions for crew and sensitive electronic devices, as well as implementation of safety procedures in case of an emergency.

Measuring of tanks levels for different liquids stored onboard is very important and crucial for ship's stability, safety, and efficient resource management. There are different sensors technologies used for this purpose, such as floating sensors, hydrostatic, capacitive, and ultrasonic sensors, as well as radar-based sensors for precise level measurements. Monitoring of liquid levels is also important for environmental sustainability and following environmental standards and regulations. Ballast tanks require precise water level measurements to balance the ship during navigation and compensate varying load and weather conditions. Continuous supervision of fuel and oil tanks levels is very important for optimization of consumption and calculations of remaining reserves for safe ship's operations. Freshwater and technical water tanks also require regular monitoring to ensure an adequate water supply for the crew and proper operation of systems such as cooling and sanitation.Additionally, wastewater systems are subject to strict environmental regulations, making monitoring of blackwater and greywater tanks critical for proper processing and discharge in compliance with legal standards, thereby minimizing negative impacts on the marine ecosystem.

4. Utilizing the UniTrain System for Maritime Training and Education

Students in the Laboratory for Marine Electrical Engineering and Electronics at the Faculty of Maritime Studies Kotor conduct a series of experimental exercises using the modular UniTrain system, which is shown

in Figure 1 with an active course in the field of non-electrical quantity measurements (TPF), installed in the laboratory and enabling the implementation of a wide range of practical laboratory exercises.

This paper focuses on one of the key exercises—recording the characteristic of a thermoelectric cell (thermocouple) with mathematical correction. The aim of this exercise is to provide students with an understanding of the operating principles of Type J thermocouples (Fe–CuNi) and the role of temperature compensation in measurement processes.

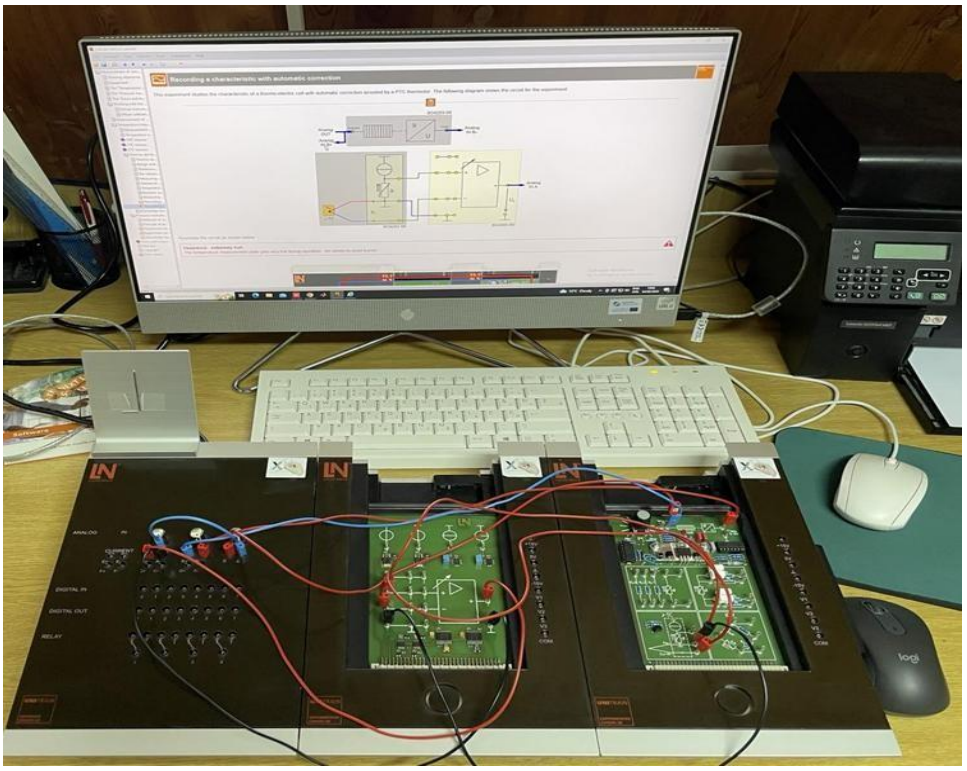


Figure 1. Experimental setup in the Laboratory for Marine Electrical Engineering and Electronics

The experiment is conducted using the UniTrain laboratory platform, which enables students to perform interactive measurements using modular didactic components. The system includes a DC power supply used to heat a metal plate to which a thermocouple is attached, as well as an instrumentation amplifier designed to amplify the very low thermoelectric voltage generated by the thermocouple. Measurements are carried out using two voltmeters: one records the voltage at the output of the amplifier (Ua), while the other monitors changes in the reference voltage corresponding to the applied heating setpoint. All components are integrated with a software application that emulates the operation of real measuring instruments, allows system calibration, and provides a tabular and graphical display of the results.

The exercise procedure begins by setting the desired heating voltage (e.g., 8 V), which heats the plate to the target temperature (e.g., 80 °C). After temperature stabilization, the output voltage Ua is measured and then divided by the amplifier gain (G = 100) to obtain the actual voltage generated by the thermocouple (Ue). Since the thermocouple measures a temperature difference, a mathematical correction is performed by adding a compensation voltage of $\Delta U = 1.019$ mV, corresponding to a room temperature of 20 °C. The resulting value represents the corrected thermoelectric voltage (Um), which is then used to determine the measured temperature by referring to the standard calibration table for a type J thermocouple. Through this process, students analyze the accuracy of the measurement and understand the importance of proper cold-junction compensation in real- world applications.

Figure 2 shows the characteristic relationship between the set and experimentally measured temperature while recording the thermocouple Type J response. A high agreement between the ideal and measured values is observed, with minor deviations typical for real laboratory conditions. These deviations can be attributed to factors such as thermal inertia, heat dissipation, contact resistance, and limitations in the accuracy of the measurement system, but remain within acceptable limits for this type of experiment.

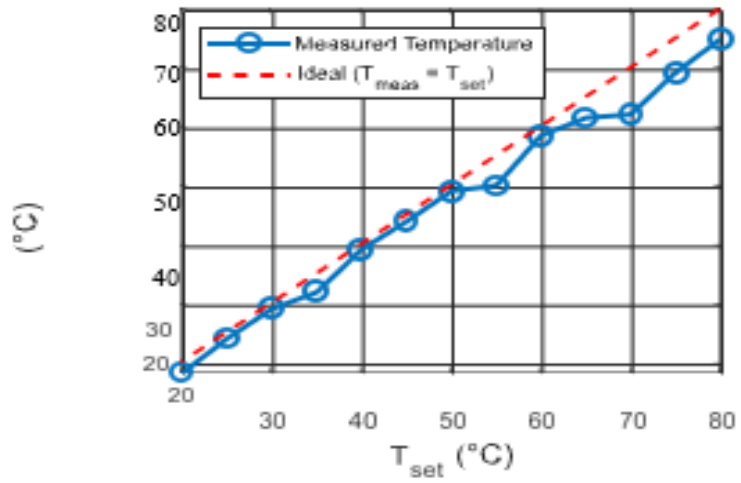


Figure 2. Comparison between set and measured temperature for Type J thermocouple characteristic

5. Conclusion

The modern maritime industry requires continuous adaptation of educational methods to contemporary technological standards, particularly in the field of process measurement. In this context, the implementation of the UniTrain system in teaching represents a significant step toward modernizing practical training in non-electrical measurements, such as temperature, pressure, and force.

Laboratory exercises enable students to acquire concrete knowledge and skills in working with sensors, transducers, and measuring instruments. Notably, the exercise involving the characterization of a Type J thermocouple covers all essential aspects of temperature measurement, including calibration, compensation, and data interpretation. The obtained results confirm the educational value of the system and its relevance for the training of future ETO and ME.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Traditional methods to determine the ships' position and Navigation Safety

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Abstract: The Russian-Ukrainian military conflict has shown the vulnerability of ship electronic navigation systems used in navigation. The Global Positioning System (GPS) may incorrectly display the vessel's coordinates both due to blocking of satellite signals by means of electronic warfare and due to cyber-attack, spoofing attack on the satellites themselves. The Electronic Cart Display Information System (ECDIS) coupled with the GPS will also incorrectly display the vessel's position and area around. The same problems we can occur with Automation Information System (AIS) data. Therefore, proper training of future navigation officers in traditional methods of determining the ship's position is gaining new momentum. The STCW Code includes celestial navigation, visual methods of determining the vessel's position and dead reckoning among the mandatory competencies for officer in charge of a navigational watch:

- Celestial navigation – Ability to use bodies to determine the ship's position
- Terrestrial and coastal navigation – Ability to determine the ship position by use of: landmarks, aids to navigation, including lighthouses, beacons and buoys, dead reckoning, taking into account winds, tides, currents and estimated speed.
- Thorough knowledge of and ability to uses nautical charts, and publications, such as sailing directions, tide tables, notices to mariners, radio navigational warnings and ship's routing information.

However, the sextant, as the main instrument of celestial navigation, is not a mandatory navigational instrument according to the SOLAS Convention. The widespread use of ECDIS has led to the fact that junior deck officer cannot determine the ship's position using traditional navigation methods.
This paper highlights the relevance of traditional navigation methods, such as celestial navigation and visual orientation using coastal landmarks, as essential backup tools for maintaining the safety of maritime operations. The necessity of preserving and developing these skills among navigators and cadets in maritime educational institutions is emphasized.
Keywords: traditional navigation, celestial navigation, coastal landmarks, backup systems, navigation safety, STCW Convention.

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1. Introduction

The global maritime industry relies heavily on satellite-based systems such as GPS, GLONASS, Galileo, and BeiDou. This dependency introduces new risks ranging from signal jamming to cyberattacks. GNSS failure may lead to severe consequences for the vessel's positional accuracy and navigational safety. In this regard, the revival of traditional navigation skills becomes strategically important. Celestial navigation and visual techniques have a proven historical track record and can serve as crucial fallback methods in the absence of satellite data. However, their effective use requires a fundamental rethinking of maritime education and the adaptation of traditional skills to modern navigation practice.

2. Threats to Satellite Navigation

From 2016 to 2024, incidents of GNSS interference in maritime transport increased dramatically, posing serious threats to navigation safety. These disruptions have been caused both by intentional actions (jamming and spoofing) and technical failures. For example, in 2019, the Center for Advanced Defense Studies [8] documented about 10,000 cases of GPS spoofing in the Black Sea, Crimea, and Syria. Other affected regions include the Baltic Sea, the Mediterranean, the Persian Gulf, and major Chinese ports [17].

Example Incidents:

- *Black Sea (2017)*: Over 20 vessels simultaneously reported false GPS coordinates, locating them at Gelendzhik Airport, 25–30 nautical miles off their actual positions.
- *Shanghai Port, China (2019)*: Spoofing incidents caused ships to transmit incorrect coordinates, placing them onshore [13].
- *Baltic Sea (2024)*: 84 hours of GNSS interference were recorded, including six major jamming events totaling 29 hours in October [12].
- *Gulf of Finland (2024)*: 145 cases of GNSS interference were registered, mainly affecting coastal navigation [11].

Consequences for Vessels:

- Loss of positional accuracy
- Malfunction of AIS systems
- Increased risk of collisions and grounding

3. Current Status of Traditional Navigation Skills

Modern generations of navigators are gradually losing both practical and theoretical skills in traditional navigation. Studies show modern officers face significant challenges operating without GPS:

- Deterioration of sextant and celestial calculation skills
- Inability to perform dead reckoning without electronics
- Poor understanding of coastal navigation by bearings
- Limited knowledge of radio navigation systems

4. Advantages of Traditional Methods

Traditional navigation provides:

- Full autonomy (no external signals required)
- Proven reliability over centuries
- Immunity to electronic warfare
- Cost-effectiveness of equipment

5. Adapting Traditional Methods to Modern Needs

With modern computational tools, hybrid backup navigation systems combining inertial, radio, and celestial components can be developed.

- Automated sextants and computer-assisted celestial systems allow fast, accurate fixes
- Optical systems and machine vision algorithms enable navigation by coastal features
- Integration enhances system redundancy during GNSS outages

Cost Justification:

Implementing such systems should be weighed against the cost of potential:

- Accidents
- Environmental damage
- Search and rescue operations

6. Global Practices and Training Standards

Leading institutions like the US Merchant Marine Academy, Tokyo University of Marine Science, Hamburg Maritime Academy, and Odessa National Maritime University incorporate practical celestial and visual navigation training using both real instruments and simulators.

International standards, particularly the STCW Convention, mandate competencies in traditional navigation methods. IMO resolutions support their retention and the implementation of backup navigation systems. IAMU promotes global harmonization of training via exchanges and research initiatives.

7. Conclusion

The study shows that adapting traditional methods to modern maritime practice is not only possible but critically necessary to ensure safe navigation. Integrating classical techniques with digital systems provides robust fallback options in GNSS-denied scenarios.

A comprehensive approach to integration should include:

- **Redesign of training standards** to ensure that celestial and coastal navigation techniques are practiced regularly alongside electronic navigation.
- **Development of modern hybrid systems** that allow for seamless transition between GNSS and traditional methods in emergency scenarios.
- **Investment in simulation-based training** to improve familiarity with traditional methods in GNSS-denied environments.
- **Continued research and innovation** in automating aspects of traditional navigation (e.g., automated celestial calculations, digital sextants, image-recognition of coastal features).
- **International collaboration and harmonization** to ensure that all seafarers, regardless of country of origin, receive standardized competency in fallback navigation.

Success depends on:

- Technical modernization with retention of classical principles
- Overhauled curricula emphasizing hands-on practice
- Investment in training infrastructure and faculty development

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Future-Proofing Nautical Sciences: Curriculum Reform at the Antwerp Maritime Academy

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Abstract: Maritime Education and Training Institutions (METIs) have faced a growing pressure in recent years to modernize their curricula in response to changes in technology, regulation, and industry requirements. At the Antwerp Maritime Academy this led to a thorough revision and update of the Nautical Sciences program. The main objective of this reform process was to maintain compliance with the STCW convention while considering the changing needs of the maritime industry. The methodology and main results of the reform process are discussed in this case study which may serve as an example for institutions facing similar challenges. The reform process was broken into four stages: conducting an in-depth needs assessment through stakeholder consultation, establishing a cross-disciplinary working group, holding workshops to identify program focus points and finally redesigning the curriculum around integrated learning pathways. This four-stage approach created a link between more traditional nautical knowledge and more recent topics like automation, cybersecurity, and sustainability. Along with the structural changes, the reform also focused on open dialogue, making the program practical and keeping it flexible for the future. The case offers insights for other METIs looking to find a balance between regulatory frameworks and the dynamic realities of the maritime sector.

Keywords: MET; curriculum reform; nautical science; learning; education

1. Introduction

The maritime world is changing fast. New technologies, stricter environmental rules, and global pressure to cut carbon emissions are changing the way a ship is operated and what is expected of the crew. Life on board is getting more complex. There are constant updates to navigation systems, alternative propulsion methods are becoming more common and autonomous ship (MASS) are starting to enter the picture (EMSA, 2024). Regulations are trying to follow this pace. The IMO is rolling out a dedicated MASS code and is pushing on its greenhouse gas reduction goals (IMO, 2024). According to the Skill Sea project, it is no longer just about knowing navigation and ship handling. Officers must understand more complex systems, take environmental responsibilities and work on a day-to-day basis in a multicultural team (Oksavik et al., 2020).

This evolution raises the question if our current training systems still fits the purpose? The STCW Convention is the framework for how maritime professionals are trained and certified, but more researchers are wondering if it can keep up with how fast things are changing on board (Bartusevičienė, 2020; Belev et al., 2021; Sharma et al., 2019). Technology is moving quickly and expectations are shifting too. For METI's it's becoming harder to stick strictly to the requirements without also updating their courses to include what's actually needed at sea today. At the Antwerp Maritime Academy, these signals led to a series of in-depth discussions among faculty members. The underlying concern was clear: is the current Nautical Sciences curriculum still preparing students effectively for the realities they will face at sea or in the diverse career paths within the maritime sector? A few recurring issues emerged: the program had become somewhat fragmented, it left little space for newer or cross-cutting topics and its structure did not always reflect the broader range of roles that graduates were stepping into. These internal reflections also aligned with broader developments in higher education, where themes like interdisciplinary collaboration, competence-

based learning and modular pathways have been gaining importance (De Wit, 2011; Kouwenhoven, 2009).

Out of these reflections grew a more formal reform initiative as a collaborative effort between teachers, students, alumni and people working in the industry. The idea was to rethink the program from the inside out: to modernize what is taught and how it is delivered so it better fits today's maritime sector. What follows in this paper is a look at how that process unfolded and what other METI's might learn from it.

2. Methodology

The reform process at the Antwerp Maritime Academy was built up gradually, shaped by internal dialogue and the practical realities of maritime education. From the start, the goal was to modernize the Nautical Sciences program without losing sight of its core strengths. To do this, the Academy worked through four main stages: identifying gaps and needs, setting up a taskforce, engaging staff through focused workshops and finally, designing a new curriculum structure based on interdisciplinary learning. Everything began with a consultation round: a detailed survey was sent out to a broad mix of people involved in the field such as industry representatives, former students, current cadets, and lecturers. The aim was to better understand where the curriculum was meeting expectations and where it was falling short (De Hert et al., 2025). Once the main issues had been identified, a reform taskforce was put together. They took the lead in reviewing the feedback, gathering the necessary background material, and setting up the next steps. By keeping everything well-organized and on track, the taskforce helped make sure the reform stayed realistic while still meeting academic and regulatory expectations. The third step was a series of workshops where faculty members came together to reflect on key developments in the industry and in maritime education more generally. The session started with an open discussion about where the sector seemed to be heading and how roles at sea were evolving (HO Gent, 2024). Another workshop focused on international benchmarking of the current curriculum. Participants looked at similar institutions abroad and how their Nautical Sciences curriculum is presented. (Achim et al., 2009; Jade University, 2025; Massachusetts Maritime Academy, 2025; NHL Stenden, 2025; University of Tasmania, 2025). As the discussions unfolded, some themes kept coming back. Clear overlaps in concerns were noticed, which helped to identify key issues. These recurring points were then unpacked in smaller breakout groups and later linked back to external quality benchmarks (NVAO Vlaanderen, 2024). The final goal of the workshops was to define different focus points of the Nautical Science program. In the last stage, attention turned to putting ideas into practice. Each focus point was given its own design session, where lecturers and experts from different departments worked together to figure out how those topics could be meaningfully introduced and developed across the program's four years. The main approach follows the tiered competency model used in the Global Maritime Professional – Body of Knowledge (IAMU, 2019), but leaves room for flexibility, applied learning and updated content. The ambition was to define learning pathways where technical skills relate to broader competences like teamwork, leadership, and decision-making (Chawla, 2015).

3. Results

The reform process at the Antwerp Maritime Academy was shaped by a mix of practical ideas to long-term priorities. Step by step, these insights helped to clarify what the Nautical Sciences program needed in order to stay relevant and effective. Rather than starting from zero, the Academy built on its strengths while opening the door to new perspectives. The initial stakeholder survey was completed by over 200 people across the maritime field. Many of them pointed to similar concerns and suggestions. They highlighted the growing role of digital tools, the importance of environmental responsibility, the need to keep up with technological change and the value of strong interpersonal skills. These responses helped the Academy define where adjustments were most needed and gave weight to the case for reform (De Hert et al., 2025). During the strategic workshops, participants were invited to take a step back and reflect on what maritime education should look like in the years ahead. These conversations helped identify a few clear priorities. There was strong support for weaving sustainability into the program from the beginning, for expanding the role of simulation and practical experience and for preserving the academic character.

The benchmarking exercise was a unique opportunity to examine similar programs worldwide. Looking into the organization of Nautical Sciences programs elsewhere highlighted strengths and areas for improvement. The focus on scientific depth and the simulator-based learning was defined as a positive aspect of the program.At the same time the exercise revealed opportunities for improvement in structure and

flexibility, making it easier to incorporate new topics more effectively.

Once the feedback from all the activities had been brought together, the taskforce set out to define the main focus points for the new curriculum. They arrived at nine broad themes that combine essential technical knowledge with topics that cut across different aspects of maritime work. These themes serve as the foundation for the next stage in designing the updated program. A visual summary of these areas is presented in Figure 1.

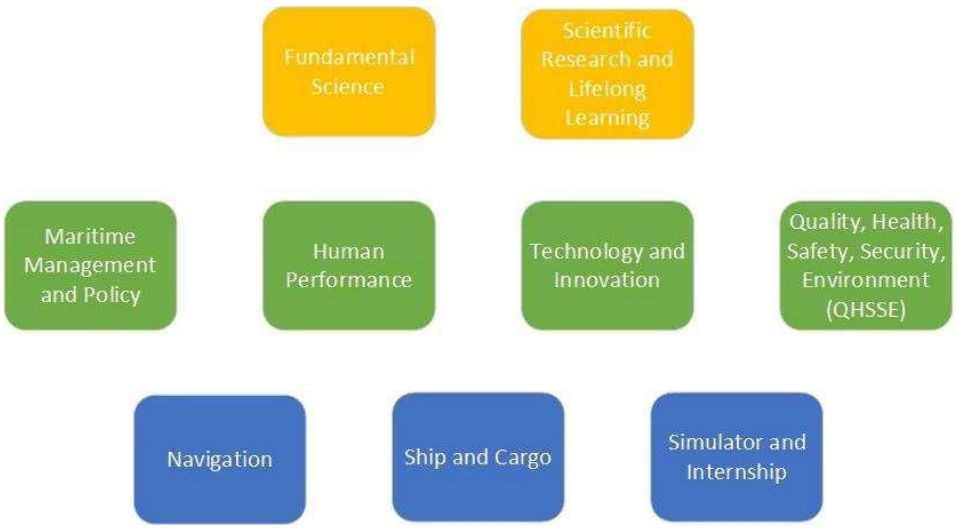


Figure 1. Focus Points of Curriculum Renewal

Each of the nine curriculum focus points represent a core domain of competence that remains essential to modern maritime operations while also offering room to address emerging challenges. These themes act as starting points for the development of integrated learning pathways, providing students with a structured and progressively layered educational experience.

The following examples show how the Academy is translating these focus points into curriculum design. The first example is the navigation pathway, where the main idea is to preserve key seafaring knowledge, such as terrestrial navigation, meteorology and collision regulations, while gradually introducing more advanced systems and technologies. In the early years, students concentrate on theoretical concepts that serve as the foundation for practical exercises. They start by learning the basic principles of navigation and by getting theoretical and hands-on experience with core navigation instruments like ECDIS and radar. In the second part of the learning pathway this basic knowledge is brought together in full-bridge simulations that recreate navigational challenges at sea. These sessions push students to combine theoretical knowledge with soft skills to think ahead and make well-reasoned decisions. Extensive voyage planning exercises are also implemented in this part of the learning pathway. In the third and final part, students get introduced to newer technologies such as dynamic positioning, MASS, and innovation in navigation. The final simulation exercises focus on teamwork, communication, and leadership in realistic bridge settings. The basis of these human performance skills is coming from a second learning pathway that is shared here as an example. In the human performance learning pathway students explore topics like resilience, well-being and working across cultures from the very first year. These topics are not treated in stand-alone courses but are woven throughout the entire program. Over time the focus changes from gaining theoretical background to putting these skills into practice, especially in situations that require sound judgment and personal responsibility. How students are assessed shifts along the way too, moving from basic checks to more reflective exercises, peer input, and group evaluations.

One issue that came up repeatedly during the reform discussions was that the curriculum felt too scattered. Over the years, extra STCW elements had been added bit by bit, which made the overall structure harder to manage. Reorganizing the future curriculum into broader themes made it easier to see where topics overlapped. Filtering out this overlap opened the door for new subjects, like specialized navigation, cybersecurity, and sustainability, to be integrated into the basic program, rather than being treated as optional

courses. Right now, the Academy is preparing to roll out these changes. Course outlines are being updated, and new teaching materials are in the works. The goal is to start using the new curriculum in 2026. Alongside the launch, an internal feedback loop will be set up so that the new structure can be adjusted over time and kept in step with what is happening in the field.

4. Lessons learned and recommendations

The curriculum reform at the Antwerp Maritime Academy offered useful lessons on how to handle change in a sector where tradition, regulation and the push for innovation are difficult to combine. One of the biggest strengths of the process was the level of involvement. From the start, the conversation was opened to a wide group, not just lecturers and internal staff, but also students, alumni and professionals working in the maritime sector. The main advantage of these different voices was that it kept the conversations open and gave everyone a sense of ownership in the process. It also kept things practical since most of the ideas came from people who know what the job is really like. Another important aspect was the value of a fact-based approach. Within the Academy, there was already a strong sense that the curriculum needed an update, but the feedback from stakeholders and the outcomes of the international benchmarking confirmed that feeling from an external perspective. Being able to rely on those insights gave direction to the discussions and proved helpful throughout the entire reform process. Gathering input early on gave the taskforce something solid to work from and helped the group move past opinions or individual preferences.

As the process moved forward, it became clear that simplifying the overall structure could really help. Taking a step back and looking at the full program in one go made it easier to spot overlaps and repetition. That review helped free up space for newer areas all while staying within regulatory limits. Perhaps the biggest shift was the decision to move toward a pathway model. Organizing the curriculum into clear learning tracks gave students and instructors a better sense of direction. It also made it easier to combine solid technical training with room for interdisciplinary themes and new teaching styles. This structure feels more in step with what is happening in the industry and gives students a better chance to connect the dots as they move through the program.

Looking back, there are a few lessons which might be useful for other maritime schools planning similar changes. Start by listening to a wide range of voices since this builds trust and keeps the focus on what really matters. Do not throw out what works, but leave room for new priorities. Soft skills, like leadership and teamwork, are important for seafarers. This research shows that they should not only be trained as stand-alone subjects but should also be integrated into (practical) training. A modular setup is an interesting approach since it helps to keep things clear and flexible while still meeting STCW regulations. Curriculum reform is a continuous process that can’t be finished overnight. It is important to build in time to pause, reflect and adjust to keep the curriculum relevant in a maritime sector that keeps changing.

5. Conclusion

This case study looked at how the Antwerp Maritime Academy approached its curriculum reform as a structured response to the changing needs of maritime education. Rather than simply updating or changing a few courses, the Academy chose to rebuild its Nautical Sciences program from the ground up. The process included benchmarking similar programs around the world, collecting input from a wide range of stakeholders and working closely with teaching staff throughout the redesign. At the heart of the new program are integrated learning pathways that combine strong technical foundations with forward-looking themes like digitalization, automation, sustainability, and soft skills. This approach allowed the Academy to stay true to its academic strengths while also preparing students for a fast-evolving industry. The reform had a broader impact within the institution as well. It encouraged departments to work more closely together, promoted flexible and open ways of thinking, and proved that it is possible to innovate while still meeting all STCW requirements. As the new program moves towards implementation, the focus is shifting to designing new course content and building a system to regularly reassess the curriculum

By sharing this journey, the Academy hopes to offer ideas and inspiration to other METIs. Every institution has its own context, but the steps taken here could serve as a helpful starting point for others looking to update their programs and stay on track in a changing industry.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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E-Learning in Maritime Education, Challenges and Opportunities: Case Study of the Black Sea Countries

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Abstract: The article deals with the challenges and opportunities of implementing electronic learning (E-Learning) in maritime education based on the case study of the Black Sea countries (Georgia, Bulgaria, Romania, Turkey, and Ukraine). In general, E-Learning offers flexible and innovative learning methods that contribute to the modernization of maritime education. The research focuses on digital transformation, innovative teaching methods (Virtual Reality VR, simulation technologies, and Augmented Reality AR), electronic platforms, quality assurance, cyber security, big data analysis, and artificial intelligence (AI) in E-Learning. The objective of the study is to evaluate the challenges and opportunities of implementing e-learning in the maritime sector. The research includes a comparative analysis of best practices in higher education institutions of the Black Sea countries to identify effective strategies for the successful integration of E-Learning.The research methodology is complex and includes a literature review, quantitative and qualitative data analysis. Data collection through online surveys, focus groups, and best practice analysis. SWOT, TOWS, and a comparative and in-depth analysis are also conducted. The research revealed that the main challenges in the implementation of digital learning are the lack of technological infrastructure, staff training, digital competencies of students and quality control mechanisms. At the same time, the research identified significant opportunities related to the use of digital learning to improve the quality of maritime education, increase accessibility, and introduce innovative methods. The conclusions and recommendations of the research aim to promote the modernization of maritime education and train qualified personnel. The study also provides valuable information to educational institutions, policymakers, and industry representatives in developing strategies for effective e-learning implementation.

Keywords: E-Learning, Maritime Education, Digitalization, AI, VR and AR implementation.

1. Introduction

Maritime education and training are an important component of the global economy, which provides a qualified workforce without whom companies cannot operate the ships of the modern fleet. Numerous macroeconomic analyses show that the training of qualified personnel in the field of maritime transport is an important component for ensuring not only maritime safety and efficiency but also the economic stability of the country. Maritime transport is the greatest mode of transport, transporting more than 90% of world merchandise trade. Therefore, the demand for qualified personnel is increasing annually in all aspects of the maritime sector, ensuring not only maritime safety and efficiency but also the economic stability of the country (Oumayma Bourhriba 2024).

Naturally, the process of digital transformation of the maritime sector affects the maritime education process. Two main areas can be distinguished: the introduction of **e**-learning in the process of maritime education, and the training of qualified personnel according to the digital transformation of the maritime sector. The role of digital learning in higher education is becoming increasingly important. The advantages of digital learning, such as flexibility, accessibility, and interactivity, are of great interest to educational institutions and students.

The high rate of technology development and the digital transformation of society have a significant impact on the education sector, changing the process of teaching and learning (Virtual Maritime Academy2024) Undoubtedly, the most noticeable impact is the impact of the COVID-19 pandemic, which accelerated the transition to online learning and the importance of its use in emergencies (Mohammed 2025, MarTID, 2018)

The region of the Black Sea is distinguished by its geopolitical and economic importance. Georgia, Bulgaria, Romania, Turkey, and Ukraine are trying to actively participate in the maritime development of digital education and maritime learning and working processes. The region of the Black Sea is an important transportation corridor, whose effective operation depends directly on the qualification of maritime personnel. In the article, we indicate challenges of digital transformation not only for the interviewed partner institutions but for the Black Sea countries in general: the lack of technological base, insufficient training of the personnel, students not knowing how to use technology properly and problems of quality control in digitalization. Top management of the maritime higher educational institutions should be aware of all these challenges, namely, make sure that innovations are fully integrated and the quality of maritime education corresponds to modern trends. The awareness of the above-mentioned things should be reflected in the strategic documents, personnel policy, institutions, and individual decision-making.

The article aims to identify and analyses the relevance, challenges, and opportunities for the implementation of digital learning in maritime education in the countries of the Black Sea region. The article addresses the necessary recommendations for the effective integration of electronic learning, which meet the needs of the modern marine industry.

The complex methodology was applied to determine the challenges and opportunities for digital learning in maritime education. A quantitative study was conducted using online surveys to gather a variety of statistical information regarding the use of digital technologies in universities, the use of platforms, academic staff, and administrative support readiness for the periods of 2015, 2025 and 2030.

Parallel to that, qualitative data was gained using focus group discussions, and an in-depth analysis of best practices was made, which enhanced our understanding of the trends. Finally, the use of SWOT and TOWS analysis enabled us to systematically analyse the internal and external factors that affect the development of e-learning, as well as the development of strategic recommendations.

2. Literature review

Digital learning has gained significance and popularity in the field of maritime education in recent years. Within the 4th industrial revolution, the use of digital and e-learning in the maritime industry is on the rise due to industry incentives and technology support. The benefits of digital learning can be summarized in four categories: flexibility, accessibility, standardization, and upgradability. Some of the challenges of digital learning are resistance to change, how effective are the virtual simulations and internet connectivity issues, particularly when learning outside of a university environment. It is noteworthy that IMO is encouraging digital learning in maritime education (Virtual Maritime Academy2024)

The Black Sea countries are actively trying to modernize their education systems using digital technologies. In this process, it is important to develop technological infrastructure and improve digital skills (Kadir Seyhan 2025) .It is also necessary to adapt education systems to the digital era and promote international cooperation in the use of digital technologies. Nevertheless, challenges remain in the region in terms of infrastructure and access to qualified personnel (Digital Education Action 2025)

The World Bank and the European Bank for Reconstruction and Development are actively cooperating with the countries of the Black Sea basin in the field of digital transformation, including in the field of education through different programs and initiatives(Stanford researchers release virtual reality simulation 2016) Thus, within the framework of the program of the World Bank “Blueing the Black Sea” (BBSEA), assistance is provided to the countries of the Black Sea basin to develop a regional framework for the sustainable management of the Black Sea. Within the Black Sea Synergy initiative, the EU supports the regional cooperation between the Black Sea countries. The Digital Education Action Plan of the EU (2021-2027) identifies priorities for the development of digital education in Europe. BSEC cooperation in the field of education uses digital technologies in the teaching process (Adithyavarman 2024)

Innovations in teaching: virtual reality (VR), augmented reality (AR), simulation technologies and other similar tools and platforms are new possibilities for creating educational programs. Part of the advantages of using VR and AR technologies are immersive Ness, interaction, and safety. The relevance of the formation of practical skills using simulation technologies (World Maritime University Dissertations 2024)

Quality assurance of digital learning and cybersecurity are critically important for the reliability and effectiveness of maritime education systems. The main standard for the quality of maritime education is the

STCW Convention. Cybersecurity risks in the maritime sector are a growing problem. Therefore, cybersecurity training is of utmost importance for seafarers. It is also important to have cybersecurity training courses in higher educational programs and in lifelong learning (LLL).

The implementation of e-learning in maritime education in the Black Sea countries is associated with several challenges. One of the biggest challenges is the lack of developed infrastructure of technologies and Internet networking. Another problem is the lack of adequate equipment in educational institutions to offer e- learning. It is mostly related to the implementation and upgrading of costly technologies (Tchanidze, K. 2020) .Also, the challenge is the insufficient level of digital skills among teachers and students. Teachers are often resistant to the introduction of new technologies, which is caused by their traditional teaching methods or insufficient knowledge of new technologies. Students' insufficient digital skills also hinder their full involvement in e-learning. In this regard, it is necessary to retrain teachers in e-learning methods and allocate financial resources to the budgets of educational institutions for this purpose.

There is still a certain conservatism and preference for traditional teaching methods in maritime education. Despite the many advantages of digital education, some teachers are still skeptical about the effectiveness of virtual simulations in terms of developing practical skills and prefer face-to-face teaching. In our opinion, one of the possible reasons is that teachers and students do not have access to modern equipment and technology outside the educational institution. A similar problem was highlighted during the COVID-19 pandemic when some students found it difficult to engage in the learning process promptly due to the lack of necessary equipment and tools (Virtual Maritime Academy2024) Still, digital education and e-learning have many opportunities for maritime education in the Black Sea countries. One of the most evident ones is the accessibility and availability of seafarers. Seafarers can learn at any time and in any place with the help of e-learning(Virtual Maritime Academy2024) .Digital education leads to better learning results because it stimulates the use of multimedia (video, audio, animation, interactive simulation, VR/AR, AI etc.) maintains stimulation during the learning and enhances the understanding of the highly specialized maritime fields.

E-learning ensures the standardization of learning materials and quality. Consistent delivery of content to all students, regardless of their geographical location, and rapid updating in line with changes in international maritime laws and technology are important advantages. Quality assurance standards can also be implemented. In the long term, e-learning can be more cost-effective. Reduction of training costs (transportation, accommodation), reduction of the need for physical infrastructure and scalability of learning are clear examples of this. E-learning allows for the coverage of more students at a relatively low cost.

3. Analysis of our Research Results

A study was conducted from April 8 to May 5 of this year, in which two maritime universities from the Black Sea countries (Bulgaria, Romania, Ukraine, Turkey and Georgia) and one official representative from the United Kingdom, a total of 11 universities, participated. The research includes 3 main periods: 2015, 2025 and 2030, according to which the obtained quantitative and qualitative data were analyzed. Information was collected through online surveys and interviews [for detailed information visit Ctrl + CLICK HERE], SWOT and TOWS analyses were also developed and analyzed.

During the research, we studied the most used digital platforms and tools that are already implemented or will be implemented by 2030. (such as: Virtual Reality (VR), Augmented Reality (AR), Simulation Technologies, Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), Cloud Computing, Blockchain, Big Data Analytics, E-commerce Platforms, Mobile Learning (M-learning), Moodle, Coursera, Canvas, Zoom/Microsoft Teams/Google Meet, and Other.)

The following information was collected and studied through the questionnaire in all three periods:

- Level of integration of digital education into existing maritime educational programs at the university.
- Assessment of the use of digital education platforms, tools, and programs.
- Readiness of academic and invited teachers in the digitalization of the educational process.
- SWOT analysis of digital education.
- Readiness of the university administration for the future development of digital education in the modernization of maritime education.
- The role and support of the state in the development of mechanisms for supporting digital education and its further development.

3.1 Diagram N1

Represents a comparative development dynamic of the digital education integration in 11 partner universities – it has increased substantially from 2015 to 2025 and by 2030, digital education will be almost fully implemented in all universities.

In 2015, the average indicator of digital education at universities was 2.4, i.e. we can say that the process of integration of digital education in the educational process was at a low level. Besides, the great majority of other universities also had a weak or partial integration in this direction.

In 2025, the level of use of digital technology has increased significantly, and the average indicator has reached 3.8. This indicates that this is due to global trends, the growth of distance learning, and technological development. According to the forecast for 2030, the average level of digital education at universities will be 4.7, which means high integration. Universities will practically fully implement interactive technologies, AR/VR systems, and the use of artificial intelligence in the teaching process.

Remarkably, all universities have a clear trend of systematic improvement of digital education. Kerch Maritime Academy, Batumi State Maritime Academy and Constanta Maritime University belong to the universities where the rate of development is especially high.

Thus, it can be concluded that in the future, digital education at universities will become an integrated and necessary part of teaching at universities and create an innovative and modern learning environment.

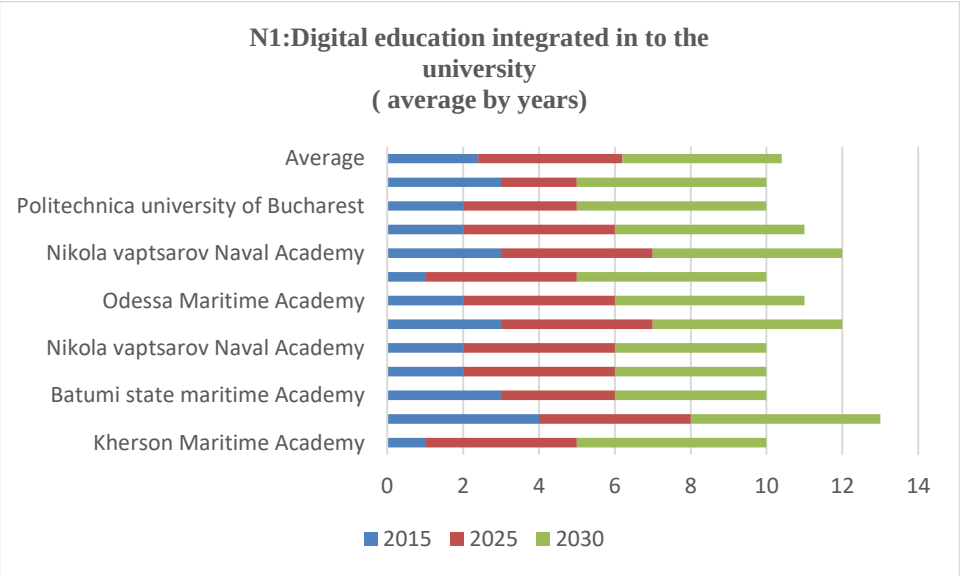


Figure 1.Digital education integrated in to the university (Average by years)

Source: Analysis of the primary results carried out by the authors. Batumi 2025

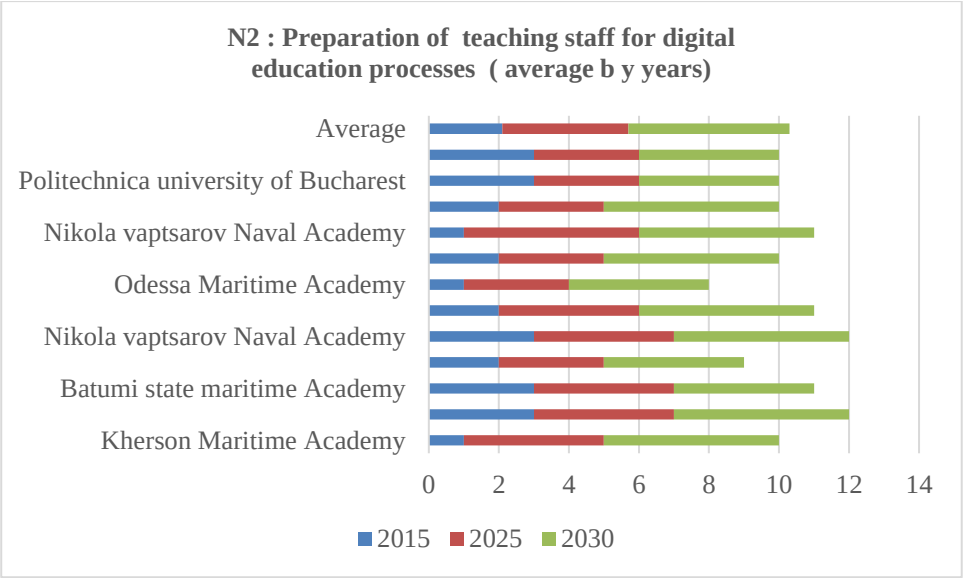


Figure 2. Preparation of teaching staff for digital education processes (average by years)

Source: Analysis of the primary results carried out by the authors. Batumi 2025

3.2 Diagram N2

The data in Diagram N2 shows that the readiness of lecturers and teachers at partner universities for the digital learning process, on average, has positive dynamics (2015-2030).

The growth of digital education integration, technological innovations, AR/VR and AI – the average indicator increases from 2.4 to 4.7 in 2015-2030. Universities also plan systemic changes related to the modernization of learning, and partner universities will periodically switch to a hybrid and digital learning model. With future trends, digital technologies will become an integral part of teaching, which will create an innovative and international environment for universities.

3.3 Diagram N3

The data in Diagram N3 reflects the dynamics of the development of digital education at universities in 2015-2023 and the transformation of various digital tools and platforms and their future integration.

In 2015, the level of digital integration at universities reached an average of 2.4, which indicates that the technological development processes were still at the initial stage at that time. In 2025, the average indicator of digital education has increased to 3.8. Universities are rapidly integrating distance learning, AR/VR systems, and hybrid models. The forecast for 2030 shows a high level of integration of digital education, and the average indicator will reach 4.7.

It is especially noteworthy that maritime and technical universities will become leaders in digital transformation. Accordingly, the pace of education integration is constantly increasing, and in the coming decades, universities will fully transition to learning models supported by digital technologies.

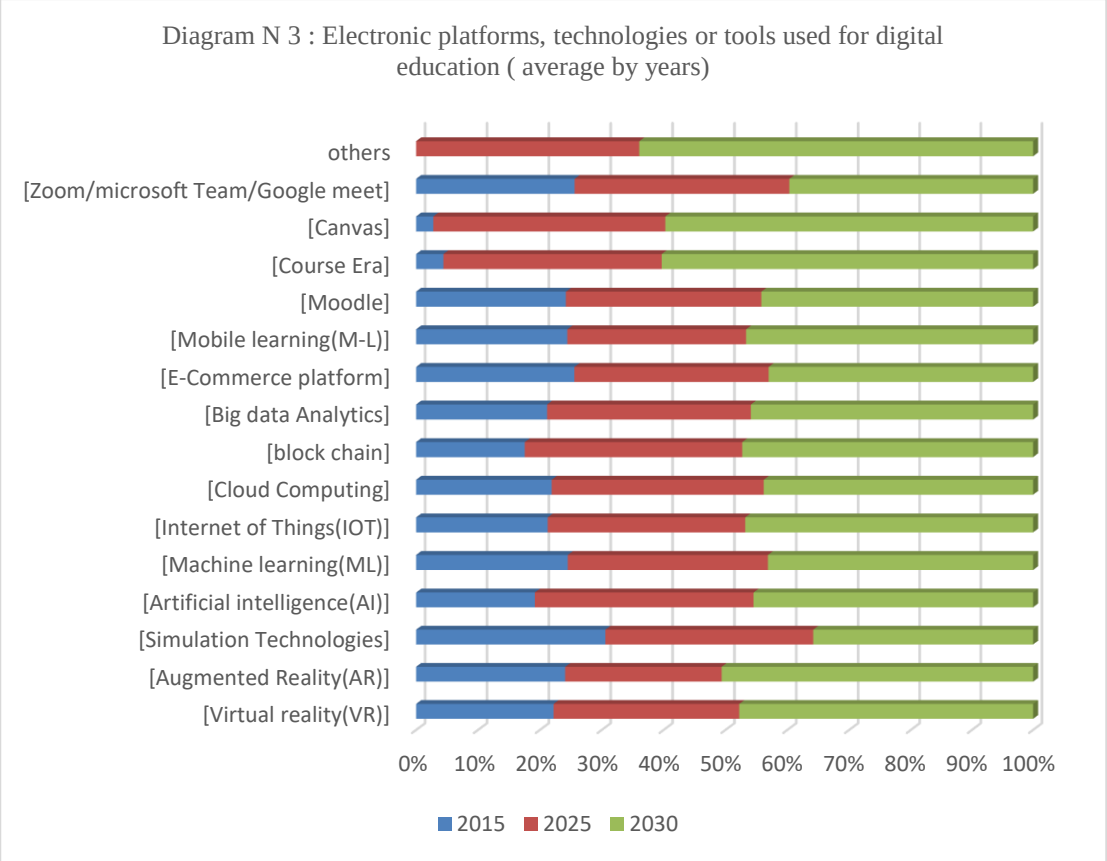


Figure.3 Electronic platforms, technologies or tools used for digital education (average by years)
Source: Analysis of the primary results carried out by the authors. Batumi 2025

3.4 Table 1

SWOT analysis of e-learning in maritime education is presented. The analysis shows that maritime education is experiencing significant progress, which is facilitated by the integration of innovative technologies, flexible teaching methodologies, and the expansion of global collaborations.

Despite the challenges, the strengthening of hybrid learning and international partnerships is pushing maritime education towards new opportunities, especially in the direction of self-education and digital literacy. According to our SWOT analysis, in future perspectives, the development of quality teaching and technology will be more intertwined. However, data security and staff shortage are still major problems that require strategic thinking and good management.

Table 1: SWOT Analysis: E-learning in Maritime Education

Factors	(Strengths)	(Weaknesses)	(Opportunities)	(Threats)
Technological Development	VR, AR, Cloud- Based Simulations, Moodle, C B T , Zoom	Insufficient technological knowledge among staff	VR and AI combined solutions to improve teaching	Total reliance on technology, which can hinder critical Thinking
Teaching Methodology	Innovative approaches, flexible procedures	Technical infrastructure problems, lack of feedback	Hybrid learning, international partnership	Excessive use of digital technologies reduces student motivation
Accessibility and flexibility	Online platforms, extended resources, logistical simplification	Financial constraints, standardization problems	Expanding global collaborations, promoting self-learning	Data security risks, digital divide problems
Human Factor	Satisfied students, experienced academic staff	Low level of digital literacy, ultra-control of teaching	Development of self- education, improvement of the teaching quality	Low resistance to technological change, staff shortage

3.5 Table 2

TOWS analysis shows the role of digital education and e-learning in maritime education, as well as the correlation of strengths and weaknesses, opportunities, and threats.

Soon, the use of VR, AR, Cloud, and other technologies will provide new opportunities for interactive and individualized learning processes, while the lack of technological knowledge and access to information technologies will be a hindrance. The hybrid learning and international cooperation will contribute to the global development of the education process; however, the overreliance on digital technologies may have a negative impact on students' motivation and critical thinking.

Modernization of learning is an opportunity that can be achieved by improving infrastructure and technological competence, as well as through more efficient financial resource management. Data security and resistance to technological innovations should be viewed as the most important management issues. According to TOWS-matrix analyses, we can conclude that the digitalization of maritime education is full of promising opportunities.

Table 2. TOWS Analysis

STRATEGIES	Strength (S)	Weaknesses (W)
	S1: VR, AR, Cloud, Moodle, CBT, Zoom S2: Innovative approaches S3: Online platforms, resources S4: Satisfied students, experienced staff	W1: Insufficient technical knowledge W2: Infrastructure problems W3: Financial constraints W4: Low digital literacy
Opportunities (O)	SO Strategies O1: VR and AI for Learning Enhancement (S1, S2, S4) O2: Hybrid Learning, Partnerships (S2, S3) O3: Global Collaboration, Self-education	WO Strategies O1: Improvement of staff technical knowledge (W1, O1) O2: Improvement of Infrastructure (W2, O2) O3: Finding financial resources (W3, O3) O4: Improvement of digital literacy
Threats(T)	ST Strategies T1: Reducing Dependence on Technology (S2, T1) T2: Preventing Overuse of Digital Technologies (S2, T2) T3: Managing Data Security Risks (S3, T3) T4: Reducing Resistance to Technological Change	WT Strategies T1: Improvement of Tech. Knowledge (W1, T1) T2: Addressing Infrastructure Issues (W2, T2) T3: Finding Financial Resources (W3, T3) T4: Improvement of Digital Literacy

Source: Analysis of the primary results carried out by the authors. Batumi 2025

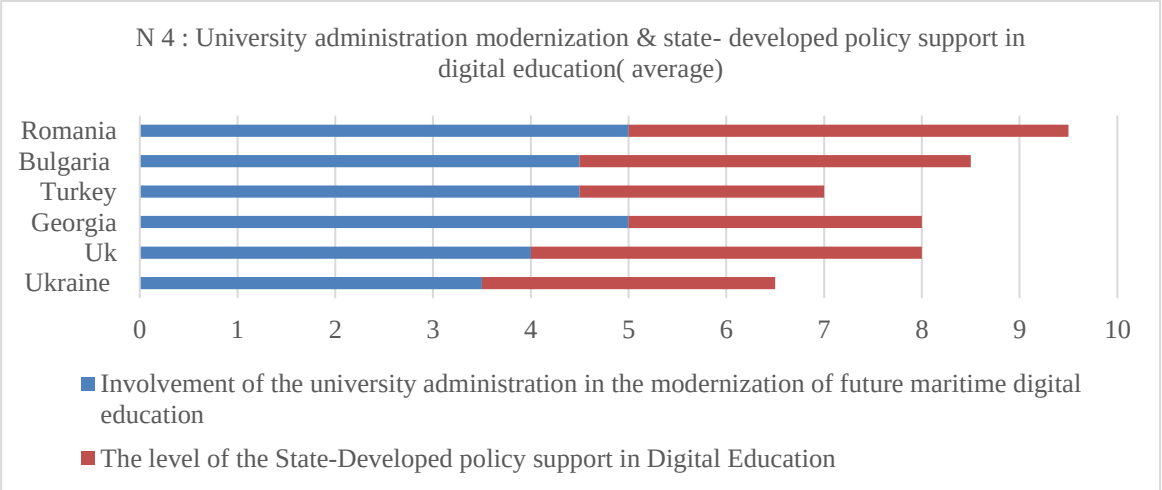


Figure 4. University administration modernization & state- developed policy support in digital education (average)

Source: Analysis of primary results carried out by the authors. Batumi 2025

3.6 Diagram 4

The data presented in Diagram 4 reflects the trends in digital learning integration in maritime education and the university approaches in terms of technological development and improvements of academic

standards.

In 2015, the level of integration of digital learning at universities was relatively low, with an average score of 2.4. In 2025, the average score has increased to 3.8, demonstrating that the integration of digital learning in the educational process is becoming more widespread. According to the forecast for 2030, the average score of digital learning will reach 4.7, which is associated with a high level of integration.

3.7 Table 3

Table 3 presents the necessary steps and existing challenges for digital education integration. The necessary steps to be taken include the recognition of innovative approaches, the development of strategic plans, the development of infrastructure, personnel training, financial support, and the provision of technological resources.

It is important to recognize the value of digital learning. Coordinate human and financial resources. Desire to increase technology, training, and electronic platforms. Reliable access to digital gadgets and the internet. Governmental funding is beneficial, but there should be further proactive governmental steps to provide financial stability and a single register to invest in infrastructure, making it more structured and effective. stable to have a unified register to invest in infrastructure to make it relatively structured and effective.

Table 3. Necessary steps and existing challenges for digital education integration

Main directions	Important issues	Level of state support
Recognition of innovative approaches	Changing old stereotypes, understanding the need for digital education	General support, but additional proactive steps are needed
Development of strategic plans	Integration of relevant strategies, allocation of human and financial resources	The need recognized by the Management; resource allocation is in the plan
Infrastructure development	Strengthening technological infrastructure, expanding online courses, supporting national and international accreditation	Support is limited, investment mostly depends on education
Staff training and digital skills development	Trainings, transition to electronic platforms, provision of quality digital products	Creation of unified registers, state initiatives aimed at digitalization, trainings with funding requests
Financial support and investments	More investment in training, promotion of technological development	Funding is mostly low, but implementation is underway
Providing access to technological resources	Access to digital devices and reliable internet	State standards have been written; widespread regulations are needed

Source: Analysis of primary results carried out by the authors. Batumi 2025

4. Conclusion

The use of digital learning in maritime education is an essential component of the Black Sea countries' ability to address the needs of the global economy and drive regional economic growth. The present study, which was conducted as a part of a literature review and experience analysis of leading maritime higher education institutions from the Black Sea countries, has revealed that high implementation of e-learning was expected to be developed between 2015 and 2025 and would be fully implemented by 2030. Digital technologies, particularly AR/VR systems and artificial intelligence, are keen on active involvement in digital learning.

Although it was clear that there had been a positive development, the following problems were also recognized: insufficient development of the technological infrastructure, problems with accessing the Internet, the level of digital literacy among teachers and students, financial constraints, and a conservative approach to traditional ways of teaching. SWOT and TOWS analyses confirmed that data security risks and the lack of qualified personnel are problems for the company.

Against this background, digital learning offers several opportunities for maritime education in the Black Sea countries, such as increased access and flexibility for seafarers, better learning outcomes through interactive learning materials, standardisation of training material and quality, and ultimately cost-effectiveness.

The study clearly shows that the challenges related to digital transformation, such as the lack of technological infrastructure, insufficient personnel training, the digital competencies deficit among students, and shortcomings in quality control mechanisms, are not only institutional but also regional problems for the Black Sea countries. A deep understanding of these challenges is essential for the top management of maritime educational institutions. The promotion of awareness should be directly reflected in strategic planning and influence institutional decisions and policies. The institutions and government should together determine priorities for the fostering of challenge.

To widely implement digital learning practices in maritime education, the Black Sea countries should invest in digital infrastructure and digital literacy programmes to enhance internet connectivity and digital skills of educators and students, simplify the regulatory framework for online courses, and support the development of learning materials. Maritime universities and colleges should widely apply innovative methods of teaching, including VR, AR, AI, and other tools.

Acknowledgements

The authors would like to thank Batumi State Maritime Academy and Black Sea Partner Universities for their contribution and support in the research.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Reading between the Waves: Improving Maritime English Comprehension through Innovative Teaching Strategies

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Abstract: Competence in Maritime English is an important skill for the Nautical Science cadets, since it guarantees efficient communication and safe operations in international shipping. But, many students have trouble with reading comprehension, and they find it hard to work through the maritime-specific lexicon since the maritime language is often technical in nature. This research was conducted at the AMET University to establish the effectiveness of maritime magazine news articles as an instructional tool to improve a cadet's reading comprehension and vocabulary. The survey was initially conducted on 320 students were based on the score 80 students with the lowest score was selected for the study. Prior to the tests, a pre-test was conducted to assess their comprehension and vocabulary knowledge at the beginning. The intervention phase consisted of an 8-week marine magazine news articles-based instruction and then practice in reading, discussion, and vocabulary. A post- test was conducted to measure changes after the intervention. The data collected were subjected to statistical analysis using the SPSS and a paired sample T-test used to determine the significance of the findings. The results indicated that there was a remarkable change in reading comprehension and vocabulary learning, the mean post- test scores proved significantly higher than the mean pre-test scores ($p < 0.001$). Secondly qualitative feedback from students showed a greater level of confidence with, and interest in, maritime texts. This research suggests that authentic maritime materials need to be incorporated into language teaching and recommends using English commercial courses as an aid in increasing the English proficiency of maritime students. The findings promote a curriculum change that fosters contextualized learning approaches using industry related texts to bridge the divide between theoretical knowledge and practical uses.

Keywords: Maritime English, Reading Comprehension, Vocabulary Acquisition, Authentic Materials, Statistical Analysis

1. Introduction

Good communication is the keystone of safety and productivity at sea. Shipping is an international industry; therefore, English as the international language of naval communication, i.e., seafaring communication, known as Maritime English, has been considerably encouraged. For Marine Science cadets, competence in this field is as much a professional necessity as a linguistic one. However, Maritime English makes it difficult for students to understand technical materials and enrich their vocabulary. These difficulties are frequently associated with a shortage of contact with natural data and a disconnection between classroom teaching and authentic maritime language. This research seeks to address this gap by utilizing innovative classroom strategies in which maritime magazine articles are a focal point for instruction to assist in developing reading comprehension mastery and vocabulary development in the future naval cadet.

"The EU Commission stated that 80% of the shipping industry explored has, over the last 20 years, a multilingual and multicultural crew" (Seafarers International Research Centre [SIRC], (1996). Nevertheless, several tragic accidents have resulted from difficulties communicating well in English (Cassar, 2012). So, students at sea academies have to unlearn their previous ways of learning. They need to apply reading to acquire knowledge, experience, and information. Reading texts is the medium for conveying vital

information aboard ships and between ships and shore (Trenkner & Cole, 2012). Regrettably, maritime students often encounter problems understanding texts due to unfamiliar maritime-English vocabulary. This "maritime English" that conveys communications between ship and ship, shore and ship, and ship and shore differs from general English. The language contains jargon, acronyms, and codewords that are often more complex than general English (IMO, 2005; Cole & Trenkner, 1998). Marine English is a strict prerequisite for all marine cadets, officers, candidates, and trainees before joining a ship's crew. Methods of teaching reading are important in the success of students' reading comprehension (Mistar, Zuhairi, & Umamah, 2016). Good reading skills (predicting, forecasting, deducing, summarizing, analyzing, and evaluating) help learners to extend their vocabulary and language skills (Gounder, 2015). The current study investigates whether marine news stories and news programs would be suitable materials for improving the reading comprehension of maritime students. These resources contain authentic language and context-specific use of language and are excellent for developing reading skills and understanding Marine English vocabulary (Bocanegra-Valle, 2010; Ziarati, 2006). This research is important for bridging the vocabulary acquisition and reading comprehension divide among the cadets, especially while dealing with the language of navigational warnings, weather reports, and operational instructions (ITF, 2020). It draws attention to the need for richer, more context-specific reading material for training students to use maritime language and language-related conventions effectively in real life.

2. Review of literature

Reading enhances learners' professional advancement in different maritime industry sectors, where they need to understand articles, reports, and instruction manuals. Learners are also expected to familiarize themselves with the manual book, log book, nautical chart, and nautical almanac. Efficient reading is a condition for the progress of industry. Reading comprehension is necessary for reading skills. Reading comprehension is defined as a process of critical reading and thinking. Making sense of factual texts requires a high degree of precision. To be proficient in reading, readers should have ample Grammar and vocabulary in the maritime domain. Three categories of vocabulary are technical, semitechnical, and core vocabulary. Vocabulary in the marine field can be mastered in the process and can contribute to reading comprehension. According to Saridaki (2023), exploring humanistic principles can be applied to reading instructions. Reading this kind of will widen their horizon about everything and may increase their humanity.

The following communicative language teaching is suggested by Ahmmed (2018). CLT enhances reading understanding. CLT is concerned with interpersonal skills, allowing students to speak with energy and accelerating their reading ability and interest. Teaching is intended to be interactive and constructive. Therefore, Kourieos (2015) suggests using demonstration and explanation techniques. Ahmmed, in contrast, also advocates for the CBI and TBLT. Content-based instruction concentrates on learning language in the context of content. Task-based language teaching is concerned with tasks associated with learning and tasks themselves. The communication TBLT will involve writing real assignments and reading reports and research papers. Marine literacy will improve learning with content learning related to reading photos and learning topics.

The best reading comprehension strategies for the nautical publication are Izza & Uchida (2022), the vocabulary list method, and the reading practice method. Several authentic materials also facilitate the advancement of reading comprehension. Kourieos (2015) stressed the significance of the journal articles/research papers. Authenticity Ahmmed emphasizes the significance of employing authentic materials. Navvaro et al. (2015) provided documentary clips, online news, and journal articles. Saridaki (2023) also reports the involvement of journal articles and some newspapers with marine content. Farida Ki (2023) also described common maritime communications phrases to understand ship behavior and safety while navigating, additionally to standardize the communication language for navigation at sea and approaching the port, waterways, and harbors with multilingual crews. They also enable marine organizations to reach their educational objectives. SMCP is designed to help avoid accidents that occur in shipping because of poor communication and language difficulties. There should be no problem about the relevance of the reading to the ongoing developments in science and technology, and it should use technological learning media. When reading technology enhances reading comprehension. Integration of technology in producing the marine language curriculum Output will enhance reading pedagogy among learners.

3. Methodology

Quasi-experimental studies are continued. The study is based on AMET University cadets of first-year marine engineering students. This research tested using specific news articles in maritime journals as an educational instrument. The selection and examination initially included 320 students, and depending on the test results, 80 students with poor results were selected and trained to be test subjects. The intervention program lasted 8 weeks and was based on using different press articles connected with the maritime field. Students are assigned multiple reading tasks, such as discussions and vocabulary activities.

3.1 Participants

The study was conducted at the Academy of Maritime Education and Training (AMET) University, Chennai. Initially, 320 first-year Nautical Science cadets were given a pre-test to assess their reading comprehension and vocabulary related to maritime topics. Based on their performance, 80 students with the lowest scores were selected for the intervention.

3.2 Pre-Test Design

The pre-test was designed to assess cadets' baseline reading comprehension and vocabulary skills in Maritime English. Three hundred twenty first-year Nautical Science cadets participated in this initial assessment at AMET University. The test was constructed using an authentic maritime reading passage titled "Ships and Shipping," which focused on the historical and technological developments in shipbuilding, including the transition from sail to steam and wood to iron and steel.

3.3. Structure of the Pre-Test

- Reading Passage: Approximately 200 words in length
- Number of Questions: 10 multiple-choice questions
- Content Focus:
- Identification of main ideas
- Understanding of factual details
- Chronological comprehension
- Vocabulary in context
- Inference and interpretation of implied meaning

Each question had four options, with only one correct answer. The test was designed to reflect comprehension and technical maritime vocabulary relevant to the student's future professional needs. The pre-test was scored out of a maximum of 10 points. A cut-off score was established to identify students with inadequate maritime reading comprehension skills; cadets who scored four or below were categorized as having low proficiency in understanding maritime texts. Based on this criterion, 80 cadets were selected from the total pool of 320 participants for the intervention and post-test phase of the study. This selection process enabled the researchers to target students who needed instructional support the most. Thus, the diagnostic assessment served as a critical foundation for identifying specific areas of reading difficulty and tailoring the subsequent instructional strategies to address the learners' needs in Maritime English effectively.

4. Pedagogical Implications

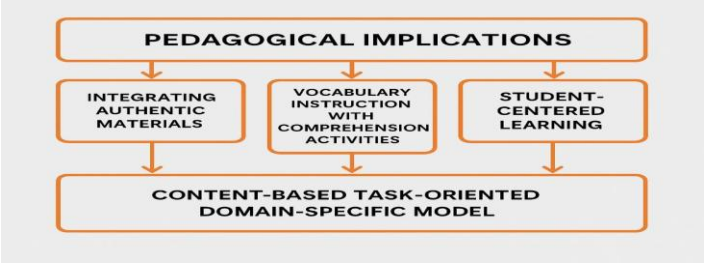


Figure 1. Pedagogical Implications

The findings of this study carry substantial implications for teaching Maritime English, especially in contexts where students must engage with technical materials and operate effectively in real-world maritime scenarios

4.1. Integration of authentic materials

Incorporating authentic materials in Maritime English teaching enhanced the students' real-world language exposure and industry-related knowledge content enormously. Utilizing critical sources from maritime magazine articles and historical accounts to technical descriptions of exemplary ships, including *The Titanic* and *The SS Great Britain*, cadets were able to learn more profound and more contextual meanings to vital terminology such as 'bulkhead,' 'propeller' and 'watertight compartments.' These materials facilitated the students' access to authentic sentence forms and advanced technical explanations, thus improving the general level of their reading comprehension. Most significantly, the genuine nature of the material created a clear sense of purpose, as students could relate admissions material to their future maritime career roles and responsibilities. In contrast to conventional textbook exercises characterized by a lack of context, these authentic resources brought the classroom closer to the shipping industry's communicative practices and discourse patterns, making the learning experience meaningful and profession-specific.

4.2 Vocabulary + Comprehension

Power the authors of this text believe that building vocabulary and developing reading comprehension are inseparable! Cadets must acquire new vocabulary as part of Maritime English and know how and where to use the particular new words in real life, from shipboard communication to documentation. Reading and vocabulary instruction are synthesized to stimulate learning and challenge students' minds. Some of the methods of instruction themselves, namely semantic map, inferencing, and contextual guess, induce 'deeper mental processing' and start to help cadets internalize and relate the new terms to everyday use before training. This method reinforces retention in the long term through repeated exposure and the use of the maritime lexicon in varied reading situations. Further, the model moves from rote learning to active output, wherein cadets can effectively read technical manuals, safety manuals, and operational reports. Consequently, students acquire the language skills necessary for precise and accurate communication in authentic maritime contexts.

4.3 Move toward Student-Centered, Task-Based Learning

The intervention deployed a student-centered, task-based learning that strongly engaged with the cadet's learning experience. In group discussions and discussion-led reading, the group elaborated interpretive readings of parts of the texts and explanations of some of the more intricate mariner terminology. It was suggested that the reflective journals provided the means through which students could articulate and develop their thinking and play a decisive role in the early stages of critical thinking and self-reflection. Most importantly, learning was aimed at facilitating cadets' meaningful application of reading materials to actual ship operation and, therefore, to connect language learning with practical and relevant applications. This method is based on the task-based learning model that considers language the function of a tool that can be used to attain meaningful communication rather than an independent concept. Through the emphasis on tasks and learner involvement, by promoting the personal autonomy of the cadets, they got the responsibility for their learning. They learned how to be proactive in how they learn.

5. Discussion and Analysis

The objective of this study was to assess and enhance the reading comprehension abilities of Nautical Science cadets in the context of maritime English using authentic instructional materials. The intervention was designed after 80 students with poor comprehension scores in the pre-test phase were identified. The following discussion interprets and analyses the significance of the statistical findings and the observed educational outcomes.

Table.1 Statistical measure

Statistical Measure	Pre-Test Scores (out of 10)	Post-Test Scores (out of 20)
Mean (M)	3.85	15.2
Standard Deviation (SD)	1.10	2.25
Variance (σ^2)	1.21	5.06
Paired Sample t-Test	—	$t = 26.89$, $p < 0.001$

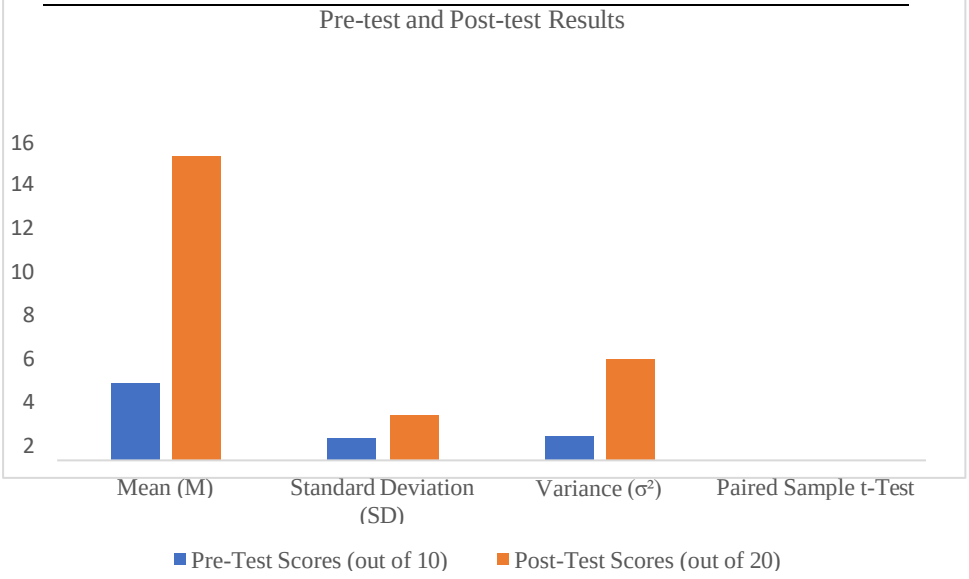


Figure 2. Pre-test and post test results

The mean value for the pre-test was 3.85 out of 10, showing a large deficiency in the student's ability to understand simple maritime texts. Given a population standing deviation of 1.10 and V 2 = 1.21, the scores are relatively narrow, meaning the underperforms are consistent overall. These findings reinforced the finding that a large portion of the students were unfamiliar with essential maritime terms and could not recognize a main idea or understand and interpret technical descriptions in maritime texts. This low base level of performance underscored the necessity of targeted instruction intervention. It also highlighted the constraints of traditional textbook-driven teaching, frequently lacking context and application in the real world, especially in specialized areas, such as Maritime English.

5.1 Post-test Performance and Instructional Effects

After the 8-week intervention that included reading structured maritime magazine texts supplemented with vocabulary tasks and discussion-based comprehension exercises, the post-test average score had increased to 15.2 out of 20. This promising effect shows that the cadets have benefited substantially by reading the true-life sea-related texts TheSS Great Britain and The Titanic. The higher standard deviation (SD=2.25) and variance (V=5.06) of post-test scores indicate a significant degree of variances in the learners' performances during post- tests, revealing that even though the majority improved, some did better than others in post-tests in language learning due to the individual differences in terms of learning rate and language acquisition. Nevertheless, all students achieved higher scores higher scores than the pre-test, indicating that the intervention was successful.

5.2 Significance: Paired Sample t-Test

The difference in the pre-and post-intervention scores was statistically confirmed using a paired sample t-test. The test resulted in a t-value of 26.89 with a p-value < 0.001, indicating that the increase in post-test scores was statistically significant and not due to chance. This large p-value does indicate a strong effect size and that the constructivist instructional strategy focusing on contextualized real-world content was the cause for the cadets scoring higher on reading comprehension and vocabulary in the post-test.

5.3 Authentic materials in the development of listening comprehension

Its success in the post-test results may result from using authentic material because authentic texts are more stimulating and cognitively challenging. Articles about real ships (such as *The Titanic and The SS Great Britain*) exposed cadets to technical terminology in naturalistic contexts to promote the learning and applying maritime language in authentic reading situations.

5.4 Authentic texts offered a twofold benefit:

- They created interest and motivation by giving cadets the opportunity to read about actual ships and incidents relating to maritime history.
- Learning was situated with new vocabulary and comprehension skills embedded in functional, domain- specific use.
- This approach is consistent with ESP (English for Specific Purposes) pedagogy, which recommends providing exposure to domain material to enhance a learner's language acquisition and professional readiness.

5.5 Qualitative Observations and Feedback

The class structure and use of course readings, even reduced by one-third, interfered with the program because practice was not effectively incorporated with theory. In addition to a quantitative increase, qualitative feedback from students indicated greater confidence in working with maritime texts and technical writing. Several midshipmen mentioned they were more likely to read material such as ship manuals, incident reports, and marine news articles without feeling intimidated. This attitudinal change is essential in attitude as confidence and motivation play a significant part in learning the language in the long term.

6. Conclusion

This research has shown that focused and meaningful instruction can majorly impact Nautical Science cadets' Maritime English reading comprehension and vocabulary development. Including real-life material, such as magazine articles from the maritime press and historical texts about the Titanic and the SS Great Britain, helped draw the line between the theoretical world and practical marine communication. These tools gave students meaningful access to specialized terminology and situational content, coupling linguistics with professional relevance. This infusion of term explanation into teaching for comprehension resulted in the potential for cadets to be more cognitively involved – to not only be exposed to term/word usage but to gain an understanding of and to use specific words in a real-world context. This combination of vocabulary and text comprehension improved retention and self-assuredness while working through technical manuals, safety documents, and operational communications. Also, the change to a student-centered, activity-based learning approach placed the learners in the center of their learning activities. Through cooperative group work, reflective writing, and task-based teaching, our cadets came to learn as autonomous, motivated individuals, using Maritime English as their active, professional tool rather than as an abstract concept in the classroom. These instructional benefits were reinforced by quantitative findings, including statistically significant post-test score improvements and highly positive student course evaluations. Overall, the paper supports revising the Maritime English syllabus, focusing on AU, authentic, subject-specific, and content-based instruction rather than on mere grammar-based practice. In this way, cadets get ready for academic attainment and become armed with those power factors for effective and safe professional operations at sea.

Cover Letter To

The Editor
WMU Journal of Maritime Affairs
Springer

Subject: Submission of Manuscript – "Reading between the Waves: Improving Maritime English Comprehension through Innovative Teaching Strategies"-reg.

Dear Editor,

We are pleased to submit our manuscript titled "Reading between the Waves: Improving Maritime English Comprehension through Innovative Teaching Strategies" for your kind consideration for publication in the WMU Journal of Maritime Affairs.

This paper explores innovative pedagogical approaches aimed at enhancing the comprehension skills of Maritime English learners, particularly cadets and seafarers. Recognizing the critical role of clear and standardized communication in ensuring maritime safety and operational efficiency, the study integrates learner-centered and context-driven strategies to foster both linguistic competence and professional readiness. The proposed approaches are designed to bridge the gap between technical content and language instruction, equipping maritime professionals with the tools needed to interpret and apply maritime communication effectively. We believe that this manuscript aligns with the journal's scope, particularly in its commitment to improving maritime education and training in line with international standards and sustainable development goals. The study offers practical insights for maritime educators, trainers, and policymakers invested in language competency and maritime communication enhancement. We confirm that this manuscript is original, has not been published previously, and is not under consideration by any other publication. All authors have read and approved the final version of the manuscript.

Acknowledgement
This research was carried out independently and did not receive any financial support from AMET University or any external funding agency.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Maritime Education for a Rapidly Changing Arctic

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Abstract: Climate change is causing rapid and accelerating reductions in Arctic Sea ice, with most of the Arctic Ocean predicted to have only small regions of multiyear ice remaining by the summer of 2050 (Jahn et al. 2024). It is likely that the Arctic will become before the end of the current decade As the Arctic becomes seasonally navigable in the coming decade (Heuzé and Jahn 2024), polar shipping routes will become viable between Asia and the east coast of the United States, along with Europe (Melia et al. 2016), saving shipping companies more than 3,000 nm and up to two weeks of travel time, with all the attendant fuel and labor cost savings. While there is a growing peer-reviewed literature catalog of sea ice decline, Arctic navigation and related socio-economic issues, there are limited pedagogical approaches to Arctic maritime training. This systematic literature review presents quantitative evidence of the state of Arctic maritime knowledge and education. The yearly count of published literature has increased by an order of magnitude in the last decade. More than 900 publications were found describing the various business cases and impacts of Arctic shipping, but less than 2% were focused on mariner education, showing that curricular approaches are currently lacking. We recommend common best practices for training mariners about a navigable Arctic. This includes the use of classroom tools and ship simulators, along with educational modules that cover the sociopolitical and environmental issues that will arise when ships start taking advantage of a navigable Arctic Ocean.

Keywords: Arctic shipping; literature review; curriculum; pedagogy; STCW

1. Introduction

The Arctic region is warming at an accelerated rate compared to the rest of the globe (Serreze and Barry 2011; England et al. 2021). Sea ice decline has been predicted for the past 45 years (Parkinson and Kellogg 1979) and been observed directly since at least the beginning of the 21st century (Bjørgo et al. 1997; Comiso 2002). Arctic Sea ice extent has been in steady decline for as long as it has been measured (Min et al. 2023). Positive feedback loops (i.e. lower albedo of open water) are hastening this trend, and it is now expected that the Arctic Ocean will reach "ice-free" status (defined by the IPCC (2021) as the September minimum sea ice extent less than 1 million km^2 for five consecutive years) within the next decade (Stroeve et al. 2007; Jahn et al. 2024; Heuzé and Jahn 2024). While the Russian Arctic coastal area has maintained commercial shipping for decades (Arctic Council 2009) and fishing fleets are the current predominant traffic in the Bering Strait and Norwegian Sea regions (Eguíluz et al. 2016), the global implication for Arctic Sea routes is complete passage through the basin connecting the Pacific and Atlantic Oceans (Fig. 1). The primary motivating factor for travel through the Arctic Ocean is the distance and time saving compared to traditional shipping routes that utilize the Suez and Panama Canals (Melia et al. 2016). A transit through the Northern Sea Route (NSR; also, sometimes referred to as the North-East Passage) or North-West Passage (NWP) has been the dream of nations since before the time of the doomed Franklin expedition in the 1840's. Given that much of the world's manufacturing is based in China (Zhang 2006) and those goods are predominantly transported by ship (Hesse and Rodrigue 2004), a shorter route between Asia and consumers in the EU and east coast of the US could fundamentally transform global trade and logistics. Countries with economic interests but not contiguous to the Arctic Circle, such as China, India and Singapore now have observer status on the Arctic Council.

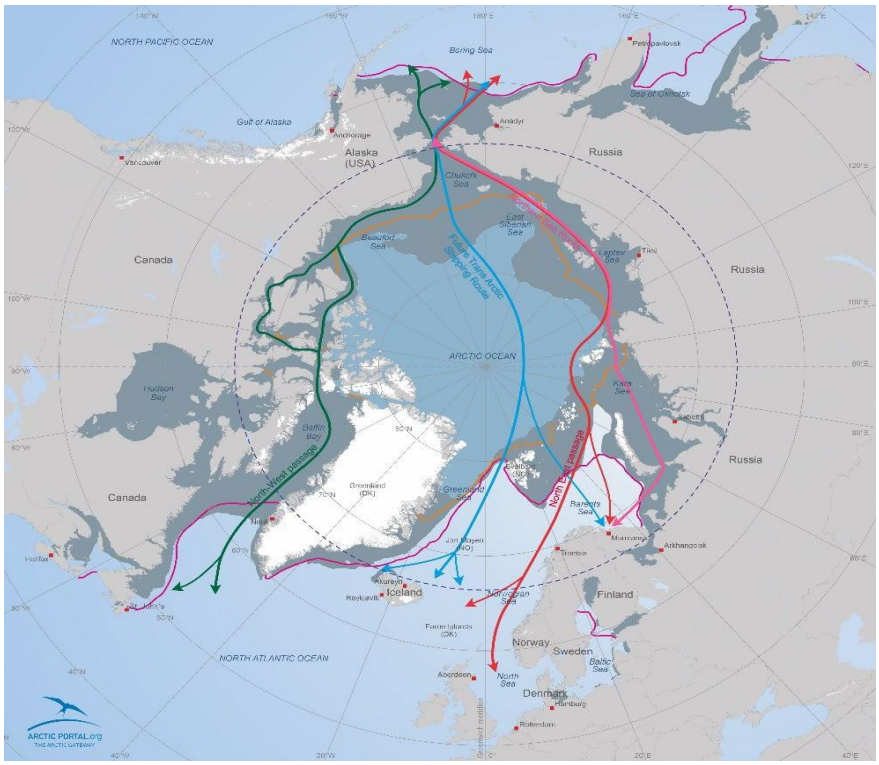


Figure 1. Map of Arctic Sea Routes**.**

This map shows the primary shipping routes through the Arctic Ocean, where mariners will require region-specific hazard training. Shown are the Northern Sea Route (NSR; pink line), an offshoot of the North-East Passage (NSP; red line), North-West Passage (NWP; green line) and the potential future Trans-Arctic Route (also known as the Trans-Polar Route: TPR; blue line). Sea ice extent from the September 2022 minimum (blue shading) and February 2022 maximum (gray shading) are shown, with the 1981-2010 median minima and maxima shown as orange and magenta lines, respectively. The dashed circle represents the latitudinal boundary of the Arctic Circle. Image reproduced from Arctic Portal (arcticportal.org).

A growing model consensus predicts that the NSR will be amenable to regular ship traffic during September within the next decade, and throughout the year by the middle to end of this century, and the NWP to follow (Smith and Stephenson 2013; Min et al. 2022; Cao et al. 2022; Chen et al. 2023; Cook et al. 2024; Zhao et al. 2024). Even the Trans-Polar route (TPR), essentially through the North Pole, will become a navigable route by the end of the century (Wei et al. 2020; Chen et al. 2021, 2023; Cao et al. 2022). The terms "ice-free" and navigable", however, do not mean that the Arctic Sea routes will be without significant hazards. There will still be sea ice and darkness for winter seasons for the foreseeable future. According to the Polar Code implemented by the IMO, "polar class" hulls will still be required to withstand ice interactions (Wang et al. 2022; Suominen et al. 2024), and icebreaker support will still be needed (Dalaklis et al. 2018). In addition to the hazards of sub-zero temperatures and sea ice, the Arctic is notorious for foul weather and poor visibility, all of which are expected to increase in future scenarios (Ghosh and and Rubly 2015; Aksenov et al. 2017; Wang et al. 2022). Additionally, modern bathymetric mapping of the Arctic Ocean basin only covers about 25% of the region, with limited coverage of eastern/Russian waters (Jakobsson et al. 2024). Outside of Russia, most Arctic nations have a small number of aging icebreakers (Drewniak et al. 2018; Dalaklis et al. 2018), and there is limited infrastructure and emergency response capabilities in the region (Benz et al. 2021).

Ecological changes in the Arctic will likely be exacerbated due to increased maritime traffic. Throughout the Arctic, shipping is likely to disturb fragile marine environments because of oil spills, plastic pollution, air and noise pollution, and the potential introduction of invasive species (Corbett et al. 2010; Dalsøren et al. 2013;

Chan et al. 2019; Qi et al. 2024; Heaney et al. 2024). Local and Indigenous communities that rely on Arctic resources will bear the brunt of these impacts, in addition to rampant shoreline erosion, infrastructure degradation, and loss of traditional sea-ice travel and hunting (Hovels Rud et al. 2011; Eerkes-Medrano and Huntington 2021; Huntington et al. 2022, 2023).

Governance, economics, environmental sustainability, and international geopolitics are all deeply impacted by declining sea ice and the potential for both resource extraction and the opening of shipping routes (Lasserre 2014; Baixada Farré et al. 2014), along with an increase in tourism and fishing fleets (Stewart et al. 2005; Troell et al. 2017).

The complexity of navigation and logistics, governance and sustainability in a new Arctic demands a training regime for mariners and the maritime industry (Dalaklis and Baxevani 2018). There are limited pedagogical approaches to Arctic maritime navigation, ecological sciences, and socioeconomic (i.e. business, legal, political, ethical) concerns. Outside of Russia or basic online courses, there are very few training programs for future Arctic mariners (Engtrø 2022), despite STCW guidelines stating the need for specialized ice navigators, who have "the knowledge, the understanding and proficiency required for operating a ship in Arctic ice-covered waters, including recognition of ice formation and characteristics; ice indications; ice maneuvering; use of ice forecasts, atlases and codes; hull stress caused by ice; ice escort operations; ice- breaking operations and effect of ice accretion on vessel stability." For international maritime universities to fill this need for polar navigators and ship operators, it must be made a coherent institutional priority to establish and share best practices and curricular approaches to a navigable Arctic. This paper conducts a systematic literature review to assess the state of Arctic maritime training and proposes a curriculum framework to fill existing gaps. We propose priority areas for research with a focus on collaborative curriculum development among international maritime universities in Arctic Council nations. Using what is already developed, the research will identify gaps in STCW education and build a curriculum map with proposed courses and individual modules to build the foundation for mariner education in a rapidly changing Arctic Ocean.

2. Methods

A literature search was performed using The Lens (https://www.lens.org/), an open-source search database for scholarly works (Jefferson et al. 2018). While The Lens provides broad coverage, future reviews could cross-validate results with other databases."PRISMA guidelines (Page et al. 2021) were followed to ensure data recording that adheres to industry standards. Search terms were selected to specifically include issues directly related to Arctic shipping, not a comprehensive reckoning of all Arctic research. Only English-language peer- reviewed journal articles from 2004 to the end of 2024 were included. No conference proceedings or book chapters were included in this analysis, in order to manage and limit the search criteria, as a test of the database struggled to accurately capture those sources. "Arctic sea ice decline", along with "melt" or "reduction" was its own search string, to account for the state of knowledge of changing ice conditions in the Arctic Ocean. All remaining search terms were filtered to include "shipping" or "maritime" terms in the title, abstract, or keywords (Table 1).

Table 1. Search terms.

List of keywords used in the systematic review of manuscripts, all of which included "Arctic" and "shipping" or "maritime' or "passage" unless otherwise noted in the text. Wildcards were used to account for alternate spellings or word truncation.

Economics	Hazard	Pollution	Biology	Indigenous	Education
Management	Safety	Emission	Ecology	People	Pedagogy
Governance	Polar Code			Society	

Wildcards (i.e. *) and logistical connectors (i.e. AND; OR) in the search, such that plural terms and other various endings of words were included. For example, a search string to find all related publications (filtered for the specified date range and type of document (i.e. journal article)) was:

(title:(Arctic) OR abstract:(Arctic) OR keyword:(Arctic) OR field_of_study:(Arctic)) AND (title:(Maritime OR ship*) OR abstract:(Maritime OR ship*) OR keyword:(Maritime OR ship*)) (1)

Sub-categories were searched with additional terms from Eq. 1 to further refine the search and then reviewed and binned according to review of the titles, keywords, and abstracts of all the papers found.

Categories were defined as follows: "Sea ice decline" refers to climate change and the predictive loss of sea ice; model intercomparisons and validation papers were excluded. Papers whose primary thrust were on teleconnections to lower latitude systems (i.e. sea ice decline impacts that extend south of the Arctic Circle, such as changes to monsoon rains or Atlantic circulation) were excluded. Note that this category is the only one here that is focused on large-scale processes not directly caused by shipping. Rather, sea ice decline is the driving causal factor in the opening of Arctic shipping channels. The remaining categories were limited to maritime issues. "Navigation" papers focused on specific discussion of Arctic shipping routes and their feasibility. "Governance" were papers focused on policy and economic issues. Search terms added to Eq. 1 were gov* business, *econ* OR manage*. "Hazards "dealt with ocean navigation hazards (e.g. ice, fog) along with search and rescue and engineering solutions (e.g. ice modeling for navigational safety; development of new materials for strength in ice conditions). For this category, the terms hazard or safety were included in addition to Eq. 1. Articles focused on narrow spatiotemporal scales of ice were included here, on the assumption that daily and/or regional ice forecasting is mostly an issue of hazards to ships. "Pollution" was the input and/or risk of introduction of chemical compounds and emissions, toxins, or noise into the environment, and included pollut* and emission terms. "Ecology" papers discussed the impacts of ship traffic on the biology or ecology of the Arctic ecosystem. And included bio* or eco* or sustain* terms. Invasive species topics were included in the ecology category. "People" were focused on shipping impacts on Indigenous populations, although general societal impacts and workers' rights were also included here. In addition to Eq. 1, the terms indigenous, people, or soci* were included. "Education" papers were focused on maritime training in polar waters and had educ* and pedagog* added to Eq. 1. To ensure that all appropriate papers were included, a further search using the term "polar code" (again, in addition to Eq. 1) was also performed.

After elimination of duplicates and non-English results from the searches, articles were filtered into author- defined categories, as described above, by reviewing the title, abstract, and keywords. If necessary, the full text was reviewed. There is a whole raft of research on the impacts of ice loss, but this analysis only included publications if they were about shipping issues specifically. Note that there are many manuscripts that cross these categories. For example, a paper that focuses on the regulatory framework for controlling the emissions of ships would qualify both as a governance and pollution issues. In those cases, the authors tried to determine the most relevant focus of the article and categorize it appropriately.

3. Results & Discussion

The total number of papers in the 2004-2024 period resulted in 1264 peer-reviewed English language papers, spanning 428 discrete journals (see Supplemental Data for a full listing of publications as categorized). Of those, 922 papers (72.9% of the total) in 375 journals (87.5%) were outside of the sea ice decline category and therefore focused on some aspect of maritime industry topics due to the diminishing Arctic sea ice extent (Table 2 lists the non-sea ice journals with at least 10 hits in our search). Categorization yielded most papers in sea ice decline (342 publications), governance (240) and hazards (282), followed by pollution (182), with less than half those counts in the remaining categories (Fig. 2).

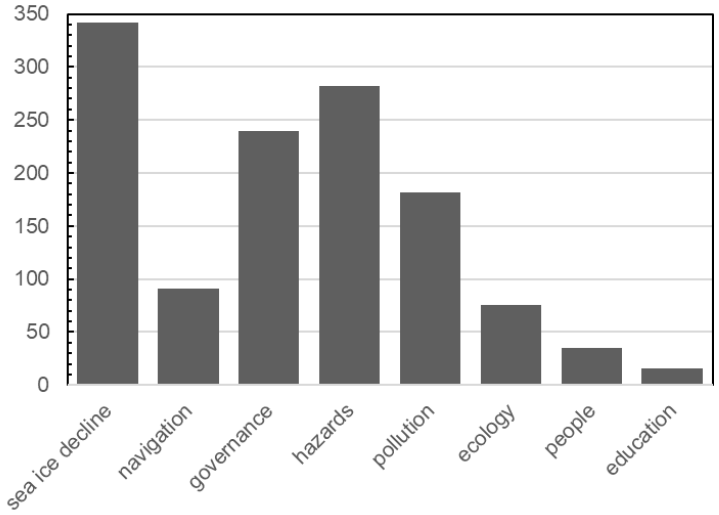


Figure 2. Total number of publications by category. Categories are defined in the text, and search terms listed in Table 1.

Papers focused on people and maritime education were by far the lowest indices in the data set, with 2.8% and 1.3% of the total papers, respectively. The various search terms yielded many duplicates, and a large proportion of sorting into sub-categories outside of the original search term(s), but which were resolved in the analysis. The "polar code" search identified papers that were almost evenly distributed between the governance and hazards (safety) categories.

Table 2. Journal count

List of the journals with at least 10 citations in the systematic review of publications, not including the sea ice decline category. The Scopus Cite Score (https://www.scopus.com/sources.uri) is listed for the journal, as of 2023. N/A indicates t h e journal does not have a score, and an asterisk is for journals not indexed by Scopus.

Journal	Count	Cite Score
Journal of Marine Science and Engineering	32	4.4
Atmospheric Chemistry and Physics	22	10.7
Frontiers in Marine Science	22	5.1
Marine Policy	22	7.6
Ocean Engineering	22	7.3
The Journal of the Acoustical Society of America	15	4.6
Marine Pollution Bulletin	15	10.2
Sustainability	15	N/A
Geophysical Research Letters	14	9.1
Arctic and North	13	*
Arctic: Ecology and Economy	13	*
Maritime Policy & Management	13	8.2
Remote Sensing	13	8.3
Polar Record	11	1.4
Environmental Science and Pollution Research International	10	8.7
The International Journal of Marine and Coastal Law	10	2.2

* Note that the two journals not indexed by Scopus are both based in Russia but publish English language versions of their manuscripts.

Within the study period, there was a marked increase in publications over the time of the study period, with a more than ten-fold increase between 2012 and 2022 (Fig. 3). From 2004-2012, the total number of papers published across all categories only exceeded 20 once, while the years 2022-2024 recorded publication totals of 193, 180 and 209 respectively. A linear regression of the papers published in each category over time reveals that the categories of governance (m=1.94) and hazards (m=2.55) had the greatest slope of increase in publication number over the study period. Every category had a higher slope for the years 2014-2024 than the prior 10-year period, with the hazards linear regression slope increasing more than 2000%! The relative lack of publications before 2013 could be a flaw in the experimental design or poor coverage of the open-source database collection, however, these results broadly follow previous literature reviews of Arctic shipping, which found the same temporal trends (Theocharis et al. 2018; Qi et al. 2024). By limiting the search to peer-reviewed literature, it is probable that we did not account for a potentially large body of work that covers the issues at hand. This is certainly true for geopolitical perspectives, as white papers, reports and books are published regularly, along with theses and dissertations from high latitude universities. Indeed, an essential reading list for Arctic maritime education starts with Part V of the book "Sustainable Shipping in a Changing Arctic" (Hildebrand et al. 2018), and specifically the chapter by Dalaklis and Baxevani (2018). Additionally, there are likely to be many Russian-language manuscripts, but this was outside the scope of our research capabilities. It is also possible that maritime education generally is not well represented in the published literature, however a search using the same database (i.e. The Lens; data not shown) produced 2,231 publications that match the search terms for "maritime AND (pedagogy) OR (education)". Of those, 243, or slightly more than 10% were delineated as in the field of pedagogy while more

than half were in the fields of engineering (690) and political science (661). These overall maritime education trends indicate robust published research (see also Manuel 2017), and therefore we do not believe a lack of published research in Arctic maritime education is indicative of a broader dearth of pedagogical research support.

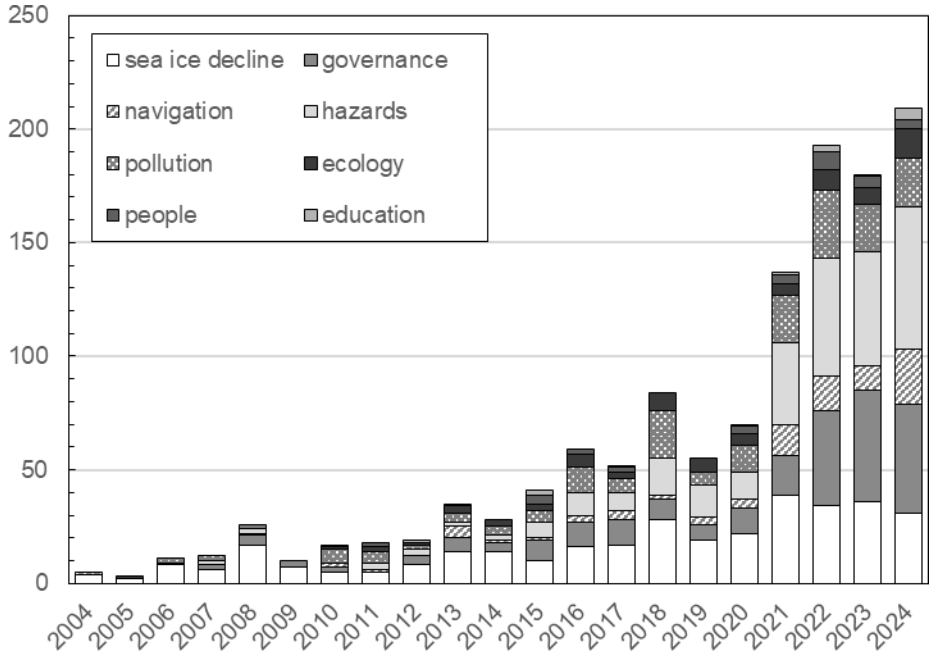


Figure 3. Publications over time by category. Categories defined in the Methods section.

There have been recent reviews on future ice conditions (Jahn et al. 2024), the navigability of various Arctic shipping routes (Melia et al. 2016; Zhao et al. 2024) along with the economic (Theocharis et al. 2018) and environmental impacts (Qi et al. 2024) of maritime traffic through the Arctic. The interest in shipping utilization has increased rapidly during the last decade (Fig. 3; Nguyen et al. 2021). We show here that there has been a marked increase in research pertaining to all the attendant issues that come along with newly industrialized spaces, especially in the areas of governance, business, and safety, closely followed by pollution and its effects on biological systems. Earlier literature may be sparse due to the more recent emergence of Arctic shipping as a research priority linked to climate change (Werner et al. 2016; Ng et al. 2018; Theocharis et al. 2018). Ironically, much of the Arctic was inaccessible to study until recently.

With the confirmation of sea ice decline, research quickly transitioned to the ability of ships to navigate through the Arctic Ocean. In 2009, the Arctic Council published their Arctic Marine Shipping Assessment (Arctic Council 2009), which acknowledged that sea ice decline could lead to potential shipping traffic, but that it was limited by safety and environmental risks, along with unknown economics and lack of infrastructure. A few years later, Smith and Stephenson (2013) found that ice was declining fast enough that the NSR, NWP and TSR would all be viable shipping corridors within the next 30-40 years; that paper has been cited over 550 times, showing the keen interest and resources being put toward understanding the Arctic Ocean routes and how the relatively short passages could upend global supply chains and the geopolitical concerns surrounding them. Governments and businesses are eager to understand the cost-benefit and risks associated with Arctic shipping, as seen in the results presented here. Professional mariners greatest concern in navigating the Arctic is safety, and there is also a robust set of literature trying to predict and mitigate navigational hazards such as ice loading and collision. This is especially true with the lack of infrastructure and search and rescue capabilities in the region. As with any commercial enterprise, ships emit combustion gases along with noise and the risk of both oil spills and invasive species introductions. Environmental research priorities are focused on how the maritime industry can reduce the risks to the environment and mitigate them.

We found a very limited publication record on the need and how to train mariners on the unique challenges presented by the Arctic working environment. Even the limited number of papers identified as in

the Arctic maritime education category here (Table 3) have only tangential application to undergraduate mariner education, as they are focused on general knowledge (Rowe et al. 2021; Wassmann 2024), cruise tourism (Manley et al. 2017), business logistics (Dinwoodie et al. 2013) or implementation of the Polar Code (Engtrø 2022). These topics are worthy, indeed necessary, components of curricula that aims to produce highly qualified mariners operating in a harsh environment… but they do not account for the breadth of required skills in navigation, safety, and environmental training. The pedagogical literature tended to be focused on teaching students (K-12) who reside in the Arctic and the issues surrounding remote Indigenous populations (Määttä and Susiati 2015, 2019; Windsor et al. 2022; e.g. Darling-McQuistan et al. 2023). There were a few that covered geopolitical issues (e.g. Boylan et al. 2021), but neither of these areas (i.e. Indigenous education, geopolitics) were included in the analysis, as they were not tied to increased shipping traffic. Of the 16 publications categorized in this study as education (which amounts to only 1.2% of the total publications included in the study), only 10 focuses principally on understanding and training the future Arctic maritime workforce. While the field of pedagogical research is vast, the specific methodologies and topics for mariners are less robust in the scientific literature (Manuel 2017). The paucity of published work, especially in an area of increasing industry demand (Lasserre et al. 2016; Koçak and Yercan 2021) highlights the need for a comprehensive and detailed research regime into Arctic mariner education, with the corollary implementation of data-backed pedagogical techniques, and a set of courses that can educate the future polar workforce on all of the issues they will encounter when operating in the hazardous and dynamic work, socioeconomic and environmental domain of the Arctic Ocean.

Table 3. List of Arctic maritime education publications

This is the complete list of papers categorized as education in the systematic review.

Author (Year)	Title	Journal
Xi et al. (2024)	Advanced human reliability analysis approach for ship convoy operations via a model of IDAC and DBN: A case from ice-covered waters	Journal of Marine Science and Engineering
Uto et al. (2024)	Formulation and validation of resistance prediction scheme for ships in ice regime described in WMO egg code	Cold Regions Science and Technology
Sætren et al. (2022)	Computer-assisted management training for emergency response professionals in challenging environments	Safety in Extreme Environments
Kim et al. (2015)	A study on northern sea route navigation using ship handling simulation	Journal of the Korean Society of Marine Engineering
Aylward et al. (2021)	Using operational scenarios in a virtual reality enhanced design process	Education Sciences
Horota et al. (2024)	VRSvalbard – a photosphere-based atlas of a High Arctic geo-landscape	First Break
Goncharov et al. (2024)	Analysis of the impact of Arctic environment conditions on the psychophysical status of navigators and the safety of ice navigation	Transportation Safety and Environment
Soper et al. (2023)	An analysis of factors influencing ice management performance in an experimental marine simulator and their application to decision support system design	Journal of Offshore Mechanics and Arctic Engineering
Manley et al. (2017)	Expedition cruising in the Canadian Arctic: Visitor motives and the influence of education programming on knowledge, attitudes, and behaviors	Resources
Segal et al. (2020)	The best of both worlds: Connecting remote sensing and Arctic communities for safe sea ice travel	Arctic
Dinwoodie et al. (2013)	Maritime oil freight flows to 2050: Delphi perceptions of maritime specialists	Energy Policy
Frydenberg and Nordby (2023)	Virtual fieldwork on a ship's bridge: virtual reality- reconstructed operation scenarios as contextual substitutes for fieldwork in design education.	Virtual Reality
Koponen (2015)	Reducing risks of Arctic operations with ice simulator	TransNav
Cemal and Burak (2012)	Simulation based training on maritime education and application on ice navigation module	Journal of Marine Technology and Environment
Rowe et al. (2021)	Integrating polar research into undergraduate curricula using computational guided inquiry	Journal of Geoscience Education
Wassmann (2024)	Syn-Arctic comprehension	Journal of Northern Studies

Engtrø (2022)	A discussion on the implementation of the Polar Code and the STCW Convention's training requirements for ice navigation in polar waters	Journal of Transportation Security

Of the education papers, experience in the Arctic region is difficult to come by, and simulators will need to employed (see references in Table 3, along with Dalaklis and Baxevani (2018) and the thesis work of Pederson (2022), the latter two which did not meet the inclusion criteria of this study so are not listed there). It is noted that ship simulators have limitations too, including fidelity, cost, and accessibility (Hontvedt 2015; see, for example Kim et al. 2021). The published research gaps in the Arctic maritime domain point to the educational priorities international maritime universities should focus on. First, there are existing courses for safe navigation based on the proficiency of the Polar Code. Model courses have been developed by the IMO and include Basic and Advanced courses in polar ice navigation and polar survival training. We recommend that these courses review and implement the latest literature on safety and navigation in the literature. Per our analysis, there were 63 peer-reviewed articles on "hazards" in 2024 alone. Safety comes first and must include Polar Code compliance and STCW requirements, but to truly operate in an environment, mariners should be aware of the geopolitical, socioeconomic and environmental issues surrounding maritime traffic in the Arctic. In addition to safety and navigation courses, the curriculum that prepares mariners for operations in the Arctic would include courses on: 1. Business and logistics; 2. Governance and regulations; and 3. Sustainability, in the sense of pollution control measures and the impacts of shipping (and sea ice loss) on the marine environment. The existence of polar navigation and safety courses indicate that there are faculty at maritime universities, especially those situated in high latitude regions, who have the requisite direct experience in the Arctic domain, but as with many fields, translating content knowledge into classroom teaching environments requires specific and proven techniques which should be represented in the scientific literature (Neumann et al. 2019). All of these issues should strive to accommodate Indigenous rights and their deep knowledge of the sea ice domain (e.g. Dawson et al. 2020).

There are a host of other issues related to Arctic shipping that are outside the scope of this study, although many will have an impact on the future training needs of mariners. In general, the shipping industry is working toward decarbonization efforts, which will have an outsized impact on the environmental impact and regulation of the Arctic (Chen and Cheng 2025). Currently, the Russian icebreaking fleet is dominant, which creates a power mismatch in navigation and search and rescue efforts (Drewniak et al. 2018). Additionally, there are many further issues that are unresolved and difficult to predict. For example, autonomous vessels, satellite monitoring, ship building, port development and management, (cyber)security, and the potential changes in global commerce are all in flux and will be important for mariners to understand how they influence polar operations, especially in terms of navigational risk. The STCW Convention is under review, with a specific area of focus on Polar Code training (International Maritime Organization; since its implementation in 2017, there has been important work done to measure its' effectiveness (Ghosh and Rubly 2015; Müller et al. 2023), despite limited training for mariners before they experience the polar environment. As shown in this work, there are an increasing number of research articles on safe and sustainable operation in the Arctic maritime environment, and that literature should certainly be brought into any curriculum. Findings from further educational research should inform the Arctic Council and IMO educational priorities. Simulator and other pedagogical resources present rife opportunities for international collaboration between nations and IAMU institutions.

Acknowledgements

The authors wish to thank the Sawyer Fund for generous support for travel, along with J. Muhlin for their procurement of those funds. J. McCamant was instrumental in use and interpretation of The Lens.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Mixed Reality Firefighting Simulator

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Abstract: In compliance with SOLAS regulations, fire drills must be conducted monthly, simulating realistic scenarios and addressing critical onboard risk areas. The sequence begins with the activation of the fire alarm, prompting crew members to assemble at designated muster stations. Assigned firefighters then proceed with suppression and rescue efforts, while reserve personnel provide support as required. If initial containment measures prove ineffective, the fixed fire extinguishing system is engaged (ACM Web3D 2024). VR fire scenarios, coupled with CFD simulations have already proven to be more realistic than standard game scenarios (Results in Engineering 2024). Furthermore, mixed reality training and task solving has proven to be up to 3 times faster than traditional methods of training (Mimica et Al). Hence, use of mixed reality firefighting training could improve crew procedural learning and overcome improvisation during drills, where, for example, fire is substituted with paper that states FIRE. Overall experience of fire drills can be more immersive and more satisfying if VR is used. To create mixed-reality firefighting drill scenarios, some special, dedicated equipment is needed. VR goggles capable of mixed reality features are a must, but the firefighting nozzles that are recognized by VR goggles add a significant improvement to overall experience. While VR goggles are found commercially available, there is no firefighting nozzle compatible with them. Here, special alterations made to a commercially available firefighting nozzle are presented. The work done included design, engineering and 3D printing components for VR controller housing that fit inside the nozzle and for the nozzle lever to activate it. Those two combined make a powerful tool for mixed reality firefighting scenarios enabling firefighting drill participants to see the fire in the desired environment if water is pouring out of the tuned firefighting nozzle. A less computer hardware demanding version can be used in any space, while a more scientific version, which employs CFD model of the fire needs workstation grade computer as hardware backup and needs to be pre modelled and pre calculated for every space individually.
Keywords: firefighting drill; VR firefighting; VR nozzle

1. Introduction and Literature Review

In recent years, the integration of mixed reality (MR) technologies into safety-critical training has garnered significant attention, particularly within the field of firefighting and emergency response. As traditional training methods often involve high costs, logistical challenges, and safety risks, MR provides a promising alternative by combining virtual reality (VR) and augmented reality (AR) into immersive, interactive environments. These environments allow trainees to experience realistic fire scenarios in a controlled and repeatable manner, enhancing both cognitive and psychomotor learning without exposing participants to real danger.

Mixed reality blends the physical and digital worlds, enabling users to interact with both virtual and real objects in real time (Milgram & Kishino, 1994). In the context of firefighting, this can include virtual fire outbreaks overlaid onto real equipment, interactive simulations of smoke behavior, and spatially accurate fire suppression tasks. The goal is to increase situational awareness, decision-making skills, and procedural accuracy—key competencies for effective emergency response.

Research on VR-based firefighting simulations has shown significant gains in engagement and knowledge retention compared to traditional classroom-based instruction (Cai et al., 2019; Tang et al., 2022). For example, Lin et al. (2021) demonstrated that trainees using immersive VR fire drills performed better in identifying hazards and selecting response strategies than those who trained with video tutorials or static diagrams. However, fully immersive VR can lack tactile feedback and physical context, which is where MR offers an advantage by combining real-world interactions with virtual enhancements (Bower et al., 2017).

Furthermore, studies such as those done by Lee et al. (2020) have emphasized the importance of

contextual realism, arguing that training systems which incorporate actual tools and environments via MR lead to higher transferability of skills to real-life incidents. This is particularly valuable in shipboard firefighting, industrial fires, and high-risk urban environments, where spatial constraints and equipment familiarity are crucial.

Despite its potential, MR-based firefighting training is still emerging and faces challenges such as hardware cost, system latency, and the need for domain-specific content. As computing power and MR hardware become more accessible, the future of fire training appears increasingly hybrid, where digital augmentation and real- world practice converge.

2. Methodology

The development of a mixed reality (MR) firefighting training scenario using FPV from a Meta headset began with the identification of real-world training needs, such as improving response behavior in confined environments, reinforcing procedural consistency, and enabling safe, repeatable practice. The project was guided by an international fire response framework, ensuring that each virtual interaction corresponded to a valid tactical element from real-life protocols.

Central to this training scenario was the creation of a custom-engineered add-on for a standard fire nozzle, designed specifically for MR integration. The goal was to retain the ergonomic and operational feel of a real nozzle while enabling digital interaction within the simulation. Using CAD software, the team designed a modular casing that could mount onto commercially available nozzles without obstructing grip or trigger movement, figure 1. The casing includes tracking markers compatible with the Meta Quest headset's spatial recognition system, and internal mounts were added to house optional haptics or Bluetooth sensors for future extensions.

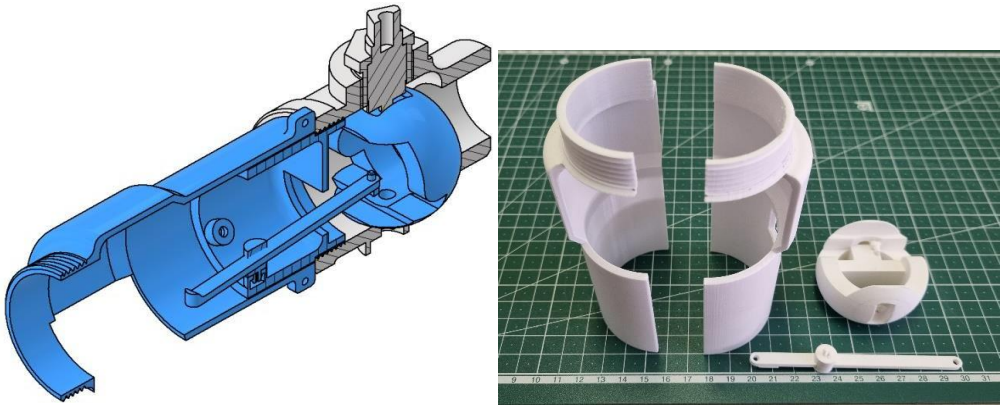


Figure 1. CAD designed (cyan color) and 3D printed parts of the firefighting nozzle add-on

The prototype was produced using high-durability 3D printing materials that can withstand repeated physical training use. Special attention was given to weight distribution, ensuring the add-on did not affect nozzle handling in a way that would deviate from actual field use. The print design underwent multiple revisions to refine balance, surface finish for glove compatibility, and structural reinforcement in stress points. The result is a robust physical prop that seamlessly blends into the mixed reality environment and enables trainees to “spray,” “aim,” and “switch flow modes” in a virtual scenario while gripping a real object.

The MR environment itself was designed using Unreal Engine, where dynamics, smoke propagation, and interactive cues flame were scripted to respond to the orientation and activation of the nozzle. When users aim the 3D-augmented nozzle toward a virtual fire source, the headset registers directional alignment, triggering suppression animations and scene progression. This spatial coordination is critical in reinforcing muscle memory and directional awareness under simulated stress conditions.

Scenario deployment takes place in a mapped physical space—such as a training facility room or mock-up ship corridor—where headset spatial scanning ensures alignment between virtual assets and real walls, doors, and obstacles. The simulation follows a semi-scripted path: users begin in a briefing zone, proceed through a fire-affected area with MR visual hazards, and conclude in a safe zone for post-exercise review. Throughout, the physicality of the nozzle and the mixed cues encourage natural body movement, intuitive response

behavior, and real-time adaptation without the risks or logistics of a live burn.

This combination of custom hardware, accurate spatial computing, and immersive interaction allows for a high-fidelity yet portable simulation system. The engineered nozzle add-on not only supports realism but serves as a modular template for extending MR into other tool-based emergency training domains.

2. Results and Discussion

Initial testing of the mixed reality (MR) firefighting training scenario was carried out by the internal development team, consisting of simulation designers, hardware engineers, and subject-matter consultants with firefighting and training experience. Although not formal trainees, the development team provided critical early- stage feedback on both technical performance and instructional integrity.

From the outset, the use of the 3D-printed nozzle add-on proved to be a successful design decision. Team members noted that its ergonomic fidelity to a real fire hose nozzle enabled immediate, intuitive interaction. The weight balance and tactile design allowed users to perform realistic sweeping, aiming, and directional control, which translated effectively within the MR environment. Even without haptic feedback or pressurized water, the nozzle's physical presence grounded the experience and gave structure to the virtual firefighting actions. Adjustments made to the nozzle casing — including reinforcement of the tracking marker mounts and slight reshaping of the grip contours — significantly improved both mechanical stability and headset recognition.

Testing sessions within the MR scenario revealed that spatial alignment between physical and virtual objects was accurate and persistent, even across longer sessions. The Meta headset’s inside-out tracking performed well in standard indoor conditions, with no major issues in drift or occlusion. Navigating through virtual smoke- filled corridors, extinguishing virtual flames with the engineered nozzle, and responding to scenario prompts felt seamless, particularly due to the natural one-to-one mapping of real movement to virtual action.

The development team also noted that the scenario structure supported iterative learning and scenario branching. Multiple rounds of testing demonstrated how the same user could experiment with different tactical decisions (entry angles, nozzle sweep patterns) without resetting physical props or room layouts. This highlighted the flexibility of MR over live drills, allowing focused repetition of decision points and real-time adjustment to user behavior without compromising realism.

The developers reported that the first-person view (FPV) recording through the headset added valuable insight during replay analysis. Reviewing sessions from the trainee’s visual perspective allowed for quick identification of strengths and errors in navigation, orientation, and response timing. This feature is planned for future integration into instructor debriefing tools.

Although the testing did not include external trainees, the team emphasized the technical readiness and educational potential of the platform. The physical-digital integration felt natural, and the MR approach avoided the disconnect often seen in purely virtual simulations. The scenario did not induce simulator sickness, and headset ergonomics were judged adequate for standard session lengths.

Overall, internal testing confirmed that the MR scenario, anchored by an engineered, trackable nozzle—offers a high-fidelity, modular platform for immersive training. The positive results lay a solid foundation for external pilot testing, where usability, transfer of learning, and instructional outcomes can be validated in collaboration with fire academies and safety institutions.



Figure 2. First person view snippets of the mixed reality firefighting simulators

Figure 2 shows four first person view (FPV) snippets from the developed MR application, illustrating the above-mentioned steps of the semi-scripted path in the scenario. An external view of a team member using the equipment during testing in an office environment is shown in figure 3.

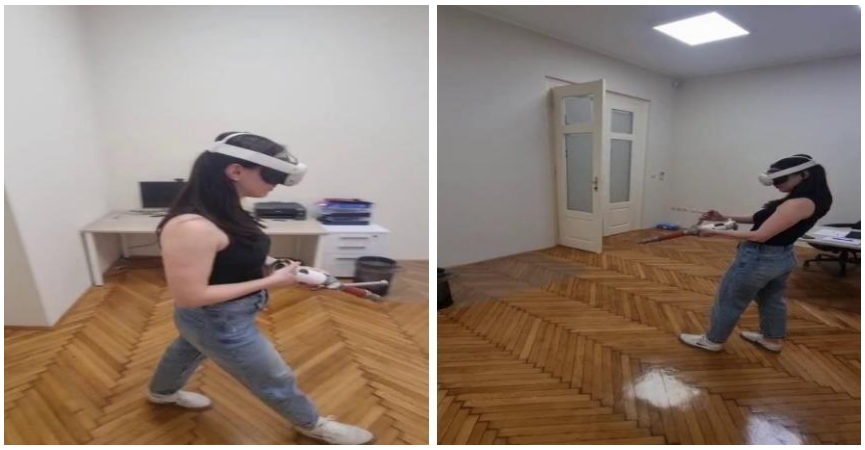


Figure 3. Third person view of simulated testing

3. Conclusion

The development and internal validation of the mixed reality (MR) firefighting scenario—featuring FPV via Meta headset and a 3D-printed nozzle add-on—demonstrated the platform's strong potential as a safe,

effective, and scalable training tool. The integration of real-world hardware with immersive virtual overlays provided realistic muscle memory reinforcement, spatial navigation challenges, and procedural immersion without the risks or logistics associated with live fire exercises.

A particularly promising application for this system lies in the maritime domain, where fire scenarios are among the most critical safety concerns due to the complex, confined, and high-risk nature of shipboard environments. Traditional fire drills aboard ships are constrained by space, equipment wear, and the inability to replicate realistic hazards without interruption to operations. The MR system addresses these challenges by enabling immersive training that can be conducted directly within actual ship compartments, thanks to the Meta headset's inside-out tracking and spatial mapping.

By digitally overlaying fire, smoke, and procedural prompts into real ship spaces (engine rooms, corridors, accommodation areas) crew members can practice navigation, suppression, and communication drills in context. The engineered nozzle, when paired with the scenario, provides tactile engagement and familiarity with key firefighting tools, while the MR system simulates conditions such as limited visibility, heat spread, and dynamic hazard zones.

Moreover, the portability of the system means it can be deployed during port stays, inspections, or voyage downtime without requiring external infrastructure. It supports both individual response training and future extensions to team-based coordination under shipboard emergency protocols (e.g. muster drills, boundary cooling, fire isolation).

Summarizing, this MR training platform has immediate relevance not only for land-based fire academies but also for integration into shipboard fire training and ISM Code–compliant drills, offering a modern, data- informed, and operationally efficient way to prepare seafarers for real emergencies at sea.

Acknowledgements

This research is funded by "UNIRI-INOVA – 4 krug" grant financed by University of Rijeka Croatia.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Gamification in Maritime Education: Bridging Traditional and Innovative Approaches at MAAP-ASTC

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Abstract: Maritime education is essential for preparing students for careers in the maritime industry, traditionally relying on instructor-led training, practical experience, and classroom instruction. With the increasing focus on modernizing educational approaches, this study evaluates the effectiveness of traditional teaching methods compared to innovative strategies—particularly the blending of both and the integration of gamification as an engagement tool—by measuring student performance through pre- and post-tests, assessing knowledge retention rates, and analyzing student engagement levels. Using a quasi-experimental mixed-methods design, the study compares the performance, engagement, and retention of students taught through traditional lecture-based methods and those exposed to innovative, technology-enhanced strategies, specifically digital gamified learning activities. These activities included point-based challenges, where students earned points for completing tasks or demonstrating mastery; leaderboards, which displayed rankings to foster a sense of competition and motivation; and interactive quizzes, which provided immediate feedback through dynamic, game-like formats to reinforce learning. Results show that although both groups exhibited improvements, the experimental group—where digital gamification elements and blended learning approaches were integrated—demonstrated significantly higher engagement, better knowledge retention, and a greater proportion of students achieving Outstanding scores. Furthermore, both students and instructors expressed a strong preference for a blended learning environment that incorporates structured digital gamification, citing increased motivation, enjoyment, and enhanced interactivity as major benefits. To further enhance maritime competence, the study recommends integrating gamification techniques into the STCW competence tables to align with modern learning strategies and industry demands. To find a good mix between traditional, game-based, and creative methods, it is also suggested to offer ongoing professional development, put more emphasis on real-world applications, and change the curriculum. This blended and gamified approach offers a more effective and engaging model for maritime education, better preparing students for real-world applications.

Keywords: maritime education; diverse student needs; engagement and retention; blended learning

1. Introduction

Students need to learn about nautical things in order to get ready for jobs in the maritime business. In the past, the major ways of teaching in this field have been through classroom learning, training guided by an instructor, and hands-on experience (Kappel, 2019; IMO, 2020). These methods have given a lot of marine professionals a strong foundation. As the business world changes and technology advances, the use of progressive teaching methods is becoming more and more popular. More and more people are using digital tools, games, and simulations to learn (Smith & Jones, 2021; Lee et al., 2022). Kahoot is an example of an interactive e-learning platform that encourages the design of fun and adaptable learning experiences that meet the needs of different learners. The AMOSUP Seafarer's Training Center (ASTC) sponsored a training session on September 16-17, 2024, to help maritime teachers come up with new ways to teach, especially by using games in the classroom. Because of these efforts, some teachers are still skeptical about how well these new methods will work, which shows that they need to be more open and eager to change. Certifying authorities should show that they are willing to accept and promote these new ideas, as their support may greatly affect

how widely these new methods are accepted. This research looks at the pros and downsides of using new teaching methods, taking into account that teachers are at different degrees of preparedness. Facing these problems might make both implementation and acceptance better. We need to compare modern training methods, such digital tools and interactive platforms, with traditional ones to see which ones help students learn better and get ready for their careers. Understanding what the maritime industry needs will help improve training programs. As digital tools and interactive platforms become more common in distance education, it is important to critically compare these methods to traditional ones to find out which ones most improve student learning and prepare them for their careers. Understanding these similarities will improve educational efforts and make sure they meet the needs of the marine sector today. There is a lack of research that directly compares the effectiveness of traditional teaching methods in maritime education with newer, more creative methods like gamification and digital tools. Modern studies generally focus on only one strategy without comparing its effectiveness to other possible methods. Also, even though more and more people are using simulation-based learning and interactive tools like Kahoot, there is still not enough real-world data to show that they work in the long term to improve maritime education. We still don't know enough about how well these tools work to get students more involved, keep them interested, and improve their practical abilities. In addition, even though new teaching techniques have been put into place, there is still a lack of awareness about how teachers feel about them and how they have changed their teaching to fit with these new methods in maritime education. Understanding the problems teachers face and their willingness to try new things is important for successful integration. The research gaps that were found show how important it is to do comparative studies. This study is even more important and urgent since it looks at gamification and different learning settings, as well as the experiences of teachers.

2. Objectives/Statement of the Problem

This study aims to compare the effectiveness of traditional teaching methods and innovative training approaches in maritime education by evaluating their impact on student learning outcomes and career readiness.

Specific questions to be answered are as follows:

1. How do the performances of the control group (taught using traditional methods) and the experimental group (taught using innovative approach) compare before and after a learning session?
2. Is there a significant difference in the performance between the control and experimental groups after they have been exposed to the same maritime learning content?
3. How does student engagement and retention differ between the control and experimental groups when using traditional versus innovative methods?
4. What challenges do instructors face in implementing innovative teaching methods, and how do these challenges impact the overall effectiveness of these methods
5. What recommendations can be made to improve maritime training programs based on the comparative results of traditional and innovative teaching methods?

3. Research Design

This study utilized a quasi-experimental mixed-methods design. Quantitative and qualitative studies revealed the efficacy of traditional and novel marine education methods. A typical non-randomized control group and an innovative experimental group were used for the quasi-experimental design. This method allowed direct performance comparisons between groups. Before and after the learning session, both groups will take a pre- and post-test to see how each teaching technique affected performance.

The qualitative component of the study addressed questions 4 and 5 of the statement of the problem. It employed an exploratory design to gain deeper insights into the challenges, perceptions, and experiences of instructors and students in adopting innovative teaching methods. This component aimed to provide a more nuanced understanding of the effectiveness of these methods beyond performance metrics.

4. Sampling

Purposive sampling was employed for selecting students for the control and experimental groups. Two training batches of the Fire Prevention and Fire Fighting component of the Basic Training offered by the AMOSUP Seafarers' Training Center will be identified as participants of the study. Each batch was composed of 21 trainees, each with basically similar demographic factors like prior knowledge, experience,

and academic level to maintain comparability. Purposive sampling was likewise used in selecting instructors based on their readiness and experience with innovative methods.

5. Results

5.1 Comparison of the Performance of the Control Group and the Experimental Group Before and After a Learning Session

Table 1. Pre-test Results of the Control Group and the Experimental Group

Scores	Description	Experimental Group Frequency	Percentage	Control Group Frequency	Percentage
26-30	Outstanding	1	4.76	0	0.00
21-25	Very Good	12	57.14	2	9.52
16-20	Good	8	38.10	11	52.38
11-15	Fair	0	0.00	6	28.57
6-10	Needs Improvement	0	0.00	2	9.52
	Total	21	100.00	21	100.00
Average Score		16.43		15.67	

Table 2. Post-test Results of the Control Group and the Experimental Group

Scores	Description	Experimental Group Frequency	Percentage	Control Group Frequency	Percentage
26-30	Outstanding	11	52.38	1	4.76
21-25	Very Good	8	38.10	8	38.10
16-20	Good	2	9.52	12	57.14
11-15	Fair	0	0.00	0	0.00
Total		21	100.00	21	100.00
Average		20.28		21.38	

Table 3. Comparative Presentation of the Performance of the Control Group and Experimental Group in the Pre-test and Posttest

Paired Samples		t	df	Sig (2 tailed)	Interpretation
Pretest Exp Grp	Posttest Exp Grp	-4.05	20	.001	Significant
Pretest Con Grp	Posttest Con Grp	-5.90	20	.000	Significant
Posttest Exp Grp	Posttest Con Grp	-1.146	20	.265	Not Significant

Table 4. Mean Ratings of the Assessment of Student Engagement by the Control and Experimental groups

Methods	Indicators (Engagement)	Mean Ratings	Composite	
		Control	Experimental	Mean
Traditional Methods	1. I find traditional lecture methods (e.g., instructor-led presentations) engaging.	3.700	3.316	3.51
	2. I actively participate more in traditional methods than in innovative methods.	3.450	2.632	3.04
	3. The instructor is effective in delivering content through traditional methods.	3.800	3.368	3.58
	4. The pace of traditional lectures is appropriate for my engagement and understanding.	3.800	3.105	3.45
	5. The materials (e.g., slides, handouts) used in traditional lectures help maintain my engagement	3.750	3.158	3.45

Composite		3.7	3.1158	3.406
Innovative Methods	6. I find innovative methods (e.g., simulations, multimedia presentations, interactive games) engaging.	3.950	3.842	3.90
	7. I actively participate more in innovative methods than in traditional methods	3.600	3.684	3.64
	8. The instructor is effective in using innovative methods to engage students.	3.950	3.842	3.90
	9. The use of innovative methods (e.g., simulations, interactive games) enhances my engagement during training.	3.950	3.737	3.84
Composite		3.8625	3.77625	3.82
Combination of Methods	10. The combination of traditional and innovative methods keeps me engaged throughout the training session.	3.900	3.895	3.51
Composite		3.395	3.0684	3.2317

t = 3.381 d = 9 Sig (2-tailed) = .008

Interpretation: significant

Legend: 3.5 – 4 Strongly Agree 2.5 – 3.49 Agree 1.5 – 2.49 Disagree 1 – 1.49 Strongly Disagree

Table 5. Mean Ratings of the Assessment of Student Retention by the Control and Experimental groups

Methods	Indicators (Retention)	Mean Ratings		Composite
		Control	Experimental	Mean
Traditional Methods	1. I find it easier to apply what I've learned from traditional lecture methods to practical scenarios	3.600	3.211	3.41
	2. Traditional methods improve my understanding of fire-fighting concepts.	3.800	3.316	3.56
	3. The feedback I receive during traditional lectures helps improve my understanding of the material.	3.750	3.421	3.59
	4. I am confident that I will remember and apply what I've learned in traditional lectures during real-life situations.	3.700	3.316	3.51
Composite		3.7125	3.316	3.5175
Innovative Methods	5. I find it easier to apply what I've learned from innovative methods (e.g., simulations, interactive games) to practical scenarios	3.800	3.632	3.72
	6. Innovative methods improve my understanding of fire-fighting concepts	3.950	3.789	3.87
	7. The feedback I receive during innovative methods helps improve my understanding of the material..	3.800	3.737	3.77
	8. I am confident that I will remember and	3.950	3.632	3.79

	apply what I've learned from innovative methods in real-life situations.			
Composite		3.875	3.6975	3.7875
Combination of Methods	9. The combination of traditional and innovative methods improves my retention of fire-fighting concepts.	3.600	3.211	3.41
Composite		3.395	3.1265	3.26075

t = 6.519 d = 8 Sig (2-tailed) = .000

Interpretation: significant

Legend: 3.5 – 4 Strongly Agree 2.5 – 3.49 Agree 1.5 – 2.49 Disagree 1 – 1.49 Strongly Disagree

6. Summary of Findings

The pre-test results showed the experimental group outperformed the control group with an average score of 16.43 compared to 15.67. In the post-test, both groups improved, with the experimental group achieving an average score of 20.28 and having 52.38% of students scoring Outstanding, while the control group had an average score of 21.38 and most students (57.14%) in the Good range. Both groups showed significant improvement from pre-test to post-test, with t-values of -4.05 (p = .001) for the experimental group and -5.90 (p = .000) for the control group. However, the post-test comparison revealed no statistically significant difference between the groups (t = -1.146, p = .265), despite the experimental group having 52.38% of students achieving Outstanding scores compared to 4.76% in the control group. The control group preferred traditional teaching methods, scoring higher for engagement (mean = 3.70) and retention (mean = 3.71) than the experimental group (means of 3.12 and 3.32, respectively). Both groups favored innovative methods, with the control group scoring 3.90 for engagement and 3.88 for retention, while the experimental group scored 3.78 and 3.70. Statistically significant differences in engagement (t = 3.381, p = .008) and retention (t = 6.519, p= .000) show that the control group preferred traditional methods, yet both acknowledged the benefits of combining teaching styles. Focus group discussions revealed that a blended teaching approach, combining traditional and innovative methods, enhances student engagement and retention. Key factors for improvement included practical applications in training, instructor engagement, interactive learning strategies, and continuous adaptability, which foster relevance and motivate students. Instructors face several challenges in implementing innovative teaching methods, including keeping up with rapidly changing technology, adapting to diverse student backgrounds, and overcoming technical and cultural barriers. Time constraints also hinder their ability to effectively integrate new approaches, highlighting the need for better training and resources to support instructors in engaging today's easily distracted students.

7. Conclusions

Both the experimental and control groups did far better on the post-test than they did on the pre-test. This shows that the teaching methods helped learners learn more. Even though the experimental group had more Outstanding students, the differences in performance between the two groups were not statistically significant. The control group liked traditional teaching methods more than new ones, which shows that they were more interested and remembered what they learned. Both groups liked a blend of old and new methods, which shows how important it is to have a balanced teaching style that can fulfill different learning needs. Focus group discussions underlined how important it is for students to be engaged and stay in school by using real-world examples, getting teachers involved, and using interactive learning methods. For learning to be relevant and interesting, a full approach to teaching that encompasses these things is needed. Teachers have trouble keeping up with technology, making sure all of their students feel welcome, and managing their time. In today's classrooms, students need to be able to stay focused and learn new things. This requires a lot of training and resources.

Recommendations

Based on the study's results, the following suggestions are given to make teaching more effective, keep students interested, and come up with new ways to educate: offer continuing professional

development programs for teachers that focus on new ways to teach and use technology. To help students learn everything, curriculum designers should mix direct instruction with hands-on exercises, real-life situations, and other activities. Training programs should stress learning by doing and using what you learn. Using simulations, real- life examples, and problem-solving in training helps people remember and learn better. By having more interactions between teachers and students, you can make the classroom a more pleasant and interesting place to study. To keep students interested, teachers should share stories from their own lives, give quick feedback, and utilize different ways to educate. Students are interested in gamified tests, leaderboards, scenario-based games, and digital simulations. They support students understand difficult marine topics and alter studying ways. Gamification may increase nautical abilities, so the STCW competency tables should incorporate it. Gamification might make learning more entertaining and useful for the workplace by helping people make decisions, solve problems, and work together. Gaming approaches that boost marine talents will be addressed in the main session. Keep an eye on the technology tools available to students and support those who need it. Consider cultural variations and alter instructional approaches, including gamification, to match students' requirements. Put in place ways to keep teaching and testing how well students are doing. Get feedback from teachers and students to make lessons better, make gamified learning elements work better, and solve problems with blended and gamified learning.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

A Comparable Corpus-Based Study of Maritime Proposal Convergence Trends for Native Chinese and English Speakers

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Abstract: To enhance China's voice and influence on the international maritime arena, it is becoming increasingly important for China to strengthen the authority and professionalism of its maritime proposals. This study establishes a set of comparable corpora with some proposals submitted by China and the United States to the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO). Guided by Toury's translation norm theory, it compares the linguistic features of maritime proposals written by native English speakers and native Chinese speakers, with the aim of providing references for China in writing and translating maritime proposals. The comparison, conducted at the lexical, syntactic and discourse levels, finds that the proposals submitted by China show a convergence trend towards the preferences of native English speakers in terms of lexical richness, sentence structure, and discourse logic. This suggests that native Chinese speakers are increasingly incorporating the language habits of native English speakers into their writing process, making the proposals closer to international standards in language style and expression.

Keywords: maritime proposals; linguistic features; MEPC; maritime translation; corpus

1. Introduction

As a means of information exchange, proposals are part of the daily work of IMO. By submitting proposals, IMO member states and related organizations can discuss relevant industry standards and legislative norms to ensure the normal operation of international shipping. For IMO member states—particularly non-English-speaking nations—to enhance the professionalism and clarity of their submissions, this study takes selected proposals submitted by the United States to the MEPC as normative references, comparing and analyzing them with Chinese proposals at lexical, syntactic and discourse levels to offer guidance for the drafting and translation of maritime proposals in China. Its core value lies in identifying convergent linguistic features across Chinese and English maritime proposals, which aligns with the argument that "strengthening participation in international maritime standard-setting requires adherence to international norms to improve the recognition of proposals (Xu, 2016)."

2. Literature Review

According to the literature visualization analysis of China National Knowledge Infrastructure (CNKI), searching with 'maritime proposal' and 'translation' as the subject terms, it is found that the translation research is mostly theoretical, lacking corpus-based empirical analysis. And the number of articles published in this research is relatively small, with a single direction, lacking empirical research. (Yu, 2021) statistically analyzed China's IMO proposals from 1999 to 2020, showing that China submitted 773 proposals, with motion-type proposals accounting for only 22%, indicating a need to improve proposal quality beyond quantity. (Sun, 2012) further pointed out that China's proposals accounted for only 3.9% of total submissions by Category A Council members from 2000 to 2011, far behind the US and Japan. However, few studies have explored the relationship between linguistic features and proposal influence, which is the focus of the present study.

3. Theoretical Foundation and Methodology

3.1 Theoretical Foundation

Toury's normative theory of translation delineates a structured approach to the translation process,

categorizing norms into initial, preliminary, and operational ones. (Toury, 2000) shows how the target orientation transforms the concept of equivalence. The "adequacy" of a translation to the source text becomes an unproductive line of enquiry, not only because shifts always occur, but because any determination of adequacy, even the identification of a source text and a translation, involves the application of a target norm. Hence, Toury seeks to describe and explain the "acceptability" of the translation in the receiving culture, the ways in which various shifts constitute a type of equivalence that reflects target norms at a certain historical moment.

The hypothesis of the present study is that, since IMO proposals prepared by China are written in or translated into English, the initial norm should subscribe to usage in the target language, and their operational norms should also align with the overall structure and linguistic characteristics of the English language, hence a linguistic convergence trend between Chinese and English Maritime Proposals.

3.2 Research Design

This study employs a comparable corpus methodology to systematically analyze linguistic features in maritime proposals submitted by native Chinese speakers (China) and native English speakers (United States) to the MEPC. Source materials were extracted directly from official IMO website, with U.S. proposals serving as the benchmark for native English conventions. The research adopts a quantitative framework, utilizing corpus analysis tools Python for automated text annotation and statistical processing. Six core metrics were derived and discussed across three linguistic dimensions. At the lexical level, the study examines lexical density and word length in the two sets of proposals. At the syntactic level, it compares differences in sentence length and syntactic complexity, while also investigating similarities and disparities between the proposals and their implications for translation practice. At the discourse level, the study explores the logical coherence of both sets of proposals and assesses the degree of explicitness in their expression.

4. Results and Discussions

4.1 Lexical Analysis

At the lexical level, analyses are conducted through lexical density, word length, and the distribution of function and content words.

First, lexical density refers to the proportion of open-ended words in the total number of words, usually, the greater the lexical density, the richer the information, and vice versa, the more homogeneous (Xiong, 2016). It is often measured via Type-Token Ratio (TTR) and Standardized Type-Token Ratio (STTR). As can be seen from Table 1, the TTR and STTR of both corpora have a similar value, indicating that Chinese proposal writers are increasingly adopting linguistic strategies characteristic of English, including a wider choice of vocabulary and a richer range of expressions.

Table 1. Lexical Density Analysis of the MEPC Proposals

Country	Total Token	Total Type	TTR	STTR
China	95397	4857	5.09%	34.5%
America	80849	4258	5.27%	34.4%

Second, average word length and its standard deviation serve as indicators of lexical complexity within the corpora. And lexical complexity can be used to measure the proportion of rare words in this register (Wang, 2023). In Table 2, both proposals exhibit similar average word lengths (5.21 for China, 5.28 for America) and comparable variability (standard deviations of 3.04 and 3.07, respectively), indicating a convergence in lexical complexity. This suggests that Chinese authors are adopting English norms, possibly to enhance the informational density and precision of their texts. However, the slightly higher standard deviation in American proposals implies greater variability in word length and a broader vocabulary range. This might reflect an effort by Chinese authors to adapt to the English-dominated maritime context, aiming to internationalize their proposals. Based on these findings, we recommend that Chinese authors enhance vocabulary diversity, particularly with specialized terms, to improve text density and precision. Furthermore, strike a balance in word length distribution to ensure readers' comprehension and readability. These strategies will help align Chinese maritime proposals more closely with international standards, thereby increasing their global impact and authority.

Table 2.Word Length Analysis of the MEPC Proposals

Country	Average Word Length	Average Word Length Standard Deviation
China	5.21	3.04
America	5.28	3.07

Third, the frequency of content words (nouns, pronouns, adjectives, verbs) and function words (adverbs, prepositions, conjunctions, auxiliary verbs) used in the maritime proposals submitted by Chinese native speakers and English native speakers. As can be seen from Table 3, the frequency of verbs in China's proposals is slightly higher than that in the American proposals, while the frequency of prepositions, adjectives and adverbs in the American proposals is higher than that in China's proposals. (Zhang, 2017) pointed out that "China's insufficient influence in technical standard-setting partly stems from imprecise technical expression." Our data shows Chinese proposals use prepositions 1.78% less frequently than American ones, which may affect the definition of terms, suggesting that more prepositional phrases should be used in technical parameters to avoid ambiguous legal interpretations.

This difference may reflect the different characteristics of the two languages in terms of expression habits. This is because English, as a comprehensive language, has a more compact grammatical structure, with a higher frequency of prepositions, adjectives, and adverbs, which contributes to the construction of more complex and precise sentence structures. Therefore, when translating and writing maritime proposals, native speakers of Chinese can appropriately use nominalized structures to replace certain verbal expressions; at the same time, increase the use of prepositions to enhance the logical relationship of sentences and the precision of expressions; and pay attention to the appropriate use of adjectives and adverbs to enhance the descriptive nature of the text and the richness of expressions.

Table 3. Content and Function Words of the MEPC Proposals

Country		China		America	
		Total Counts	Word Frequencies	Total Counts	Word Frequencies
Content Words	nouns	29704	31.14%	30618	32.9%
	pronouns	2027	2.12%	1287	1.38%
	adjectives	4933	5.17%	6325	6.8%
	verbs	20687	21.69%	11378	12.23%
Function Words	Adverbs	1178	1.23%	2082	2.24%
	Auxiliaries	1389	1.46%	1200	1.3%
	Prepositions	1695	1.78%	2434	2.62%
	Conjunctions	16847	17.66%	14971	16.1%

4.2 Syntactic Analysis

Syntactic analysis investigates sentence construction through sentence length and the distribution of sentence types. Sentence length uses mean words per sentence and standard deviation to evaluate informational density and structural variation. Table 4 shows that the average sentence length of China's proposals is 25.12, while that of the American proposals is 24.93. The difference between them is not significant, indicating that the native Chinese speakers tend to be more consistent with native English speakers in terms of syntactic structure. The standard deviation of sentence length is 27.37 and 29.14 respectively, showing that the degree of variation in sentence length of China's proposal is slightly smaller than that of the American proposal, which may imply that the Chinese proposal is relatively more consistent in terms of sentence length, while the American proposal shows greater diversity in terms of sentence length. Statistical evidence suggests that native Chinese speakers are gradually increasing the syntactic diversity in maritime proposals. However, the standard deviation of sentence length for China's proposals is slightly smaller than that for English proposals, which suggests that there may be room for China's proposals to improve in terms of syntactic diversity.

Table 4. Sentence Length Analysis of the MEPC Proposals

Country	Average Sentence Length	Average Sentence Length Standard Deviation
China	25.12	27.37
America	24.93	29.14

As to sentence structure, the ratios of simple versus compound sentences in Table 5 reflect the syntactic complexity and logical articulation strategies. The closeness between the two sets of proposals, 17.84 percent, and 18.33 percent of simple sentences, as well as 82.16 percent and 81.67 percent of compound sentences, respectively, indicates that both corpora share similar features in terms of syntactic complexity. They tend to use compound sentences to express complex concepts and logical relationships. This similarity reflects the tendency to converge in terms of syntactic structure, showing that native Chinese speakers are gradually adapting to the writing habits of native English speakers when drafting maritime proposals.

Table 5. Sentence Structure of the MEPC Proposals

Country	Simple Sentence Count	Percentage	Compound Sentence Count	Percentage
China	669	17.84%	3081	82.16%
America	594	18.33%	2647	81.67%

4.3 Discourse Analysis

At the discourse level, textual coherence is analyzed through five cohesive devices, namely, additive, adversative, causal, temporal, and conditional ones. As shown in Table 6, the frequencies of the five cohesive devices are very close, indicating that native Chinese speakers and native English speakers employ similar logical structures and cohesive devices in text organization. For example, additive conjunctions account for 60.94% of conjunctions in China's proposals and 61.64% in American ones, with negligible differences—indicating both tend to employ additive structures for information organization. The next is causal conjunctions, with 18.94% and 18.01% respectively in both sets of proposals. This confirms the argument that high-quality proposals with rigorous logic exert significant influence on IMO legislation (Jiang, 2014).

Table 6. Textual Cohesion Analysis of the MEPC Proposals

Conjunction Type	China	Percentage	America	Percentage
Additive	2384	60.94%	2009	61.64%
Adversative	198	5.06%	168	5.15%
Causal	741	18.94%	587	18.01%
Temporal	326	8.33%	260	7.98%
Conditional	263	6.72%	235	7.21%

Synthesizing the data findings, the lexical analysis reveals slightly greater lexical diversity in China's proposals, reflecting a richer range of lexical choices in these texts. The minimal word length differences between Chinese and American proposals indicate that Chinese texts have improved in aligning with the precision of English expression. The ratio of content and function words further confirms the tendency of Chinese native speakers to converge with English native speakers in their lexical choices. For Chinese-to-English translation, (Zhou, 2024) emphasized that "IMO English proposals require nominalization to replace verbal expressions" —a point that resonates with the observed lexical tendencies. The syntactic level, parallels in sentence length and sentence structure suggest that Chinese proposal writers are aligning with the syntactic norms of native English speakers. Finally, the analysis of text organization features also indicates structural convergence.

Taken together, these findings demonstrate a trend of convergence with native English speakers and gradual adaptation to international maritime discourse norms. Such developments enhance the global compatibility of Chinese proposals.

5. Conclusion

This study employs a set of comparable corpora to conduct a tripartite comparative analysis of IMO proposals authored by native Chinese and English writers. Focusing on lexical, syntactic and discourse levels, it explores the linguistic features and variations between the two sets of proposals through six detailed datasets. The analyses reveal that while Chinese proposals exhibit minor divergence in specific aspects, they demonstrate significant convergence with English norms in overall structure, syntax and diction.

In conclusion, this study sheds light on such convergence and underscores the importance of aligning with international norms. It also offers targeted recommendations for Chinese writers: lexically, enhancing lexical diversity through strategic use of prepositions, adjectives, and adverbs; syntactically, balancing sentence complexity to optimize clarity without compromising detail; and discursively, strengthening cohesive devices—particularly causal and addictive conjunctions—to reinforce coherence and logical flow. Collectively, these refinements would not only improve proposal quality but also enhance China's participation in global maritime governance by enabling clearer policy articulation.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Course of Navigation Risk Management in the Age of New Technologies: Teaching Principles and Practices

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Abstract: The introduction of autonomous and remote-controlled ships brings with them fundamentally new needs, opportunities and risks in ship navigation and requires ensuring smooth cooperation with other maritime systems. One of the most important challenges is providing appropriate training to the ship's officers and, more broadly, to specialists in other maritime sectors, who are faced with the challenge of ensuring a successful transition to digitized shipping. To achieve this goal, the Estonian Maritime Academy of Tallinn University of Technology has developed and launched the course "Navigation Risk Management". The developed course must provide relevant knowledge and skills not only to ship officers, but also to other maritime workers - for example, remote control center operators, pilots, port operators, as well as rescue ship and helicopter crews, etc. The teaching process of the course is largely aimed at solving practical exercises, i.e. the problem-based learning methodology. The simulator programs and exercises have been developed for this course that allow predicting and playing through possible situations by including in the teaching process both simulations, and a digital twin created based on a real training ship. Continuing education courses are also created based on the course.

Keywords: autonomous and remote-controlled ships; remote-controlled ships piloting; navigation risk management course; problem-based learning; digital shipping simulation

1. Introduction

We are all witnesses to the increasingly accelerating and increasingly influential digitization processes in the maritime sector. The developments in recent years in the field of the introduction of digital technologies are impressive – the first experimental fully autonomous ships are sailing at sea, albeit initially along fixed routes and not very far; the time is not far off when ships controlled from shore-based control centers will become a familiar part of maritime navigation. The development and commissioning of unmanned ships is one of the future focuses of shipping, the keywords of which must be efficiency, sustainability, and safety (Negenborn et al. 2023). All this means that the maritime industry as a whole and one of its most important parts, maritime safety, are facing new, unprecedented challenges. Traffic on shipping routes, where both manned and unmanned ships sail, requires fundamentally new, non-trivial approaches and solutions, starting with the updating of legal regulations and ending with the emergence of a new generation of seafaring actors and safety guarantors.

The importance of the human factor in ensuring maritime safety is well known (Galierikova 2019). Some authors make assumptions that as soon as artificial intelligence takes over all or at least the most important functions in controlling ships from humans, maritime safety will improve, precisely due to the exclusion of human factor from the game (Ahvenjärvi 2016; Porathe 2024). The authors of the present paper are somewhat more modest in their assessments, primarily because, no matter how highly autonomous a ship may be, the critical importance in ensuring maritime safety still lies in human actions and influences Proceedings of the International Association of Maritime Universities Conference 2025.

First, it is people who must create smart and reliable basic algorithms, regardless of whether they use the help of smart programs or even entrust the further development of these programs entirely to themselves.

Second, the safe navigation of remotely controlled ships will be mainly ensured by the operator of the shore-based control center, who will probably be a human for a long time to come. Third, even a fully autonomous, i.e. unmanned, and artificial intelligence-operated ship can encounter some difficulties at any moment for various reasons and certainly needs to establish a connection with the shore and the help of people located there. Fourth, a ship not only travels along the sea, but also encounters specialists from other maritime systems during its activities (pilotage, loading and unloading in ports, bunkering, etc.), who must also be able to cope with today's challenges.

It is clear from this that one of the main roles in the development of maritime specialists with new knowledge and skills is played by maritime educational institutions today. All technological innovations also require the training of new knowledge and skills, while the STCW 78/95 convention, which is the basis for the training of seafarers, does not yet contain requirements related to the preparation for the operation of autonomous ships. In parallel with technological development, it is vital to integrate the relevant knowledge and skills into curricula and subjects. Accordingly, a new subject “Navigation Risk Management” was developed at the Estonian Maritime Academy of Tallinn University of Technology (EMERA) in 2023-2024 within the framework of the European Regional Development Fund measure “Skills reform for the digital transformation of businesses”. One of the main goals of launching the course was to develop the necessary applied skills in addition to theoretical knowledge, based on the future needs of the digitized and automated labor market

The EMERA master's degree program "Maritime Digital Solutions" was chosen to implement and teach this course. This curriculum is suitable for teaching the course, as the goal of the curriculum is to link the fields of maritime and digitization, providing knowledge and skills about the opportunities and directions of digitization of the maritime sector. A large part of the students in this curriculum acquired their basic maritime education years ago and by the time they start their master's studies, they are working in respectable positions on ships (captains, chief mates, ship engineers) and in shore-based companies. Bringing people with such diverse and rich experience into the world of digitization seems to be optimal. The developed course must provide relevant knowledge and skills not only to ship officers, but also to other maritime workers, in cooperation with whom the relevant specialists will organize the work of future ships, including remotely controlled ships - for example, remote control center operators, pilots, port operators, as well as rescue ship and helicopter crews, etc. The learning process of the course is largely focused on solving practical tasks, i.e. problem-based learning methodology

One important teaching method and tool for achieving learning outcomes is simulation-based training. Simulators allow flexibility in training, optimizing both learning time and costs compared to practicing new types of situations in real conditions. Since such new knowledge and skills are also needed by employees in today’s maritime sector, continuing training courses are also created based on the course, so that as many as possible gain the knowledge and skills to cope with the challenges of the new digital era. One chapter of the paper describes the simulator programs and exercises developed for this course, which allow predicting and playing through possible situations by including in the teaching process both simulations, the workplace of a remote-control operator equipped with appropriate screens and a remote-control console, as well as a digital twin created based on a real training ship.

2. Course structure and general description

According to the IMO, four types of Maritime Autonomous Surface Ships (MASS) (Vakil 2022) are classified (Table 1):

Table 1. IMO classification of MASS

Degree of MASS	People on board
Degree one: Ship with automated processes and decision support	Yes
Degree two: Remotely controlled ship with seafarers on board	Yes
Degree three: Remotely controlled ship without seafarers on board	No
Degree four: Fully autonomous ship	No

In accordance with the results of previously conducted studies (Porathe 2021; Demirel 2022), the

development of the course focused on the risks and challenges associated with remotely controlled ships, as this type of autonomous ships will likely enter the seas much earlier than a significant number of fully autonomous ships will emerge. A significant part of the course is dedicated to data exchange and various information systems, with a strong focus on cybersecurity. As a result of the above-mentioned ERDF project, a course was developed in cooperation with employer representatives, which is structured as seven topics/modules, both horizontally and vertically related:

1) Opportunities and challenges of digitization in the maritime sector – the module provides an overview of the most important trends, main communication channels, operating systems, machine learning, autonomous ships, etc.

2) Overview of the needs and trends in the integration of remotely operated ships and ship and port operation systems, including risk assessment and mitigation - the module provides an overview of the needs and operating principles of a ship monitoring system. The practical part uses a digital model of the training ship "Sinilind".

3) Transition phase to remote control solution – the module provides knowledge about the propulsion and maneuvering characteristics of different ships and the influencing factors - weather conditions, human factors, communication between the ship's captain and the operators in shore center. Introduction to DP systems - understanding the relationship between ship motion, position reference systems, sensors, and other system- generated data and feedback.

4) Connection and connectivity from shore to ship (VTS, vessel traffic control and port operator cooperation) - practical use of created remote control workstations (views: ECDIS/Planning, RADAR/ARPA Conning, Fleet management, VTS) in ship navigation.

5) Cybersecurity on board, integrated approach – the module also introduces legal regulations and standards. Securing ship networks, segmentation, data leak prevention, Intrusion Detection Systems (IDS) and Security Operation Centre (SOC), backup and recovery mechanisms for crises. Software security vulnerabilities and the need for updates. Ship cybersecurity risk analysis and risk management, cybersecurity auditing and procedure review. Cybersecurity testing on board and crisis preparedness (exercises). The best practices and standards of cybersecurity in shipping. Cyber hygiene of crew members and useful tools. Psychology in cybersecurity. In addition to the focused topic, aspects related to cybersecurity are also discussed in each topic/module.

6) Ship type-based navigation risk assessment - propulsion and control equipment of different ship types, including DP equipment. Principles, handling, requirements.

7) Fleet management in crisis situations with shore-side support from the shipping company – regulations and requirements related to remote control.

In addition, 2 continuing training courses were completed based on the developed course:

1) Connection and connectivity from shore to ship.
2) Fundamentals of cybersecurity at sea and on land.

3. Methods and tools for teaching the subject

The well-known problem-based learning (PBL) method has been largely applied as one of the learning methods of the course “Navigation Risk Management”. The definition of it is “a student-centered approach in which students learn about a subject by working in groups to solve an open-ended problem” (Nilson 2010). Teaching at its best: A research-based resource for college instructors (2nd ed.). San Francisco, CA: Jossey-Bass). Based on the objectives of the course in question, the specificity of the course and the learning process, it is reasonable to focus on problem-based learning when teaching this course. In principle, the development of tasks with the characteristics of a broader cross-subject project based on interrelated problems across different subjects in the curriculum is not excluded. Such subjects in the curriculum “Digital Maritime Solutions” that allow the establishment of cross-subject problems can be, for example, subjects dealing with big data processing or cybersecurity. However, the PBL method is used when teaching this course, meaning that tasks that assume the solution of certain specific problems (preferably taken from real maritime practice) are used.

When introducing problem-based learning into the learning process, including when creating PBL tasks, the following basic principles must be kept in mind:

1) The study of a specific topic of course begins with a problem, i.e., its formulation and collection of source data; theoretical materials are always available to students from the beginning and as needed. The so-called flipped classroom principle is also often applied, where students can familiarize themselves with theoretical materials outside of classroom work before and/or after solving problems in the classroom.

2) PBL involves solving problems that resemble real-life situations or are directly derived from them. In the process of solving a problem, students and teachers integrate knowledge and skills from several subject areas. The goal of PBL is to find an exhaustive answer to the problem (there may be more than one) in an agreed format (e.g. a description of the solution to the problem, a suitable action plan, another conceptual solution).

3) In problem-based learning, students acquire both problem-solving skills and professional knowledge and skills, i.e. solving a problem must develop some specific skills, provide specialized knowledge, etc., of course, not only and not even mainly through narration by the teacher or reading textbooks, but through the students' search for and finding solutions to problems.

4) There may be different possible solutions to a problem, not just one “right” way; if a problem seemingly has only one right solution and it is known in advance (e.g. real court precedent decision), then students must still be given the opportunity to offer their own original solutions. On the other hand, the lecturer may not know the “right” solution either; in fact, there may not be one at all, but there are several, more or less realistic and suitable solutions; then an important part of completing the task is the analysis of these solutions and determining the possibilities of their implementation in real life.

5) The process of completing the task does not end with finding a solution(s) to the problem; students must evaluate the solution(s), find their positive and negative aspects, try to put together a broader picture based on the solution(s) found, and search for and find connections across and outside the problem.

The subject “Navigation Risk Management” is very suitable for the implementation of PBL in its teaching, even more so because the number of incidents that have occurred on the seas and oceans is enormous and their diversity and specificity allow to create an excellent data bank of real-life cases and use them to play through very different situations. Here we present two randomly selected cases as examples.

The first was the collision between the bulk carrier Irapua and the ore/oil carrier Topaz off the east coast of Brazil in 1991, where the Topaz was the stand-on vessel and Irapua the give-way vessel. The second was the deliberate grounding of the chemical tanker Bow Spring in the Suez Canal in 1999 to avoid risk of assumed collision with the dredger Manzanillo II. In problem-based learning, for example, these situations could be used as a basis to set tasks for similar situations, where one could investigate what could happen if a) one of the ships were a manned ship, the other an unmanned remotely operated ship, b) both ships were remotely operated ships, while analyzing the cases from different aspects: the existence and adequacy of rules, problems in decision- making and implementation, technical and algorithm adequacy issues etc.

4. Playing through remote control solutions and scenarios on a simulator

The purpose of the simulator exercise is to introduce and practice remote control of a ship. The simulator uses a ship model specially created for this purpose by the simulator manufacturer, which is a mathematical model of the EMERA training ship *Sinilind*. The remote-control operator’s workplace is in the simulator center. The operator has access to the ship’s control console, which allows him to control the ship’s maneuvering and movement. The console includes a telegraph, steering wheel, and bow and stern thrusters.

The remotely controlled ship (*Sinilind*) and other vessel traffic can be monitored on the VTS operator’s screen. The remote-control operator has an overview of the vessel traffic in the designated navigation area (Tallinn Bay). The simulator exercise scenario requires the operator to navigate the ship out of the port of departure, move through the Tallinn Bay, avoid collisions with other vessels, proceed to the port of destination, turn around there, and return to the port of departure to dock the starboard side to the quay.

To monitor the ship's maneuvering and movement, the operator has an overview of the ship's navigation equipment, from which he can view the ship's movement data.

1) On the ship's screen "CONNING", the operator sees the main maneuvering data of the ship:
    - Rudder angle
    - Engine power

- Thruster power
- HDG - heading
- COG - course overground
- SOG - speed overground - magnetic course
- DRIFT - drift angle
- ROT - rate of turn
- Ship's speed on sideway
- Wind speed and direction
- Current speed and direction
- Autopilot settings

2) The ship's ECDIS provides the operator with an overview of the ship's position and movement. Additionally, the operator can use the "predictor" function, which allows them to see the ship's predicted position based on its current speed and course.

3) The ship's RADAR provides the operator with an overview of objects that are not displayed on the ECDIS, as well as surface objects without an AIS signal. Based on this information, the operator can avoid collisions with unknown objects and vessels.

4) In addition, the operator has access to the ship's camera images, which provide a visual overview of what is happening around the ship and assist in docking the ship alongside the quay.

5. Course piloting

To test the content and structure of the subject, a pilot course was conducted for those who have previously completed simulator instructor training. During the course piloting, the theoretical part of the course was familiarized with, and the above-described exercise was performed on the simulator in the practical part of the pilot course.

The participants in the pilot course highlighted the following wishes and observations:

1) Focus and structure of the subject:
   - Only the most important ones should be addressed in the case of software and environments
   - The specific crisis situations must be specified each time (cyber-attack, piracy, technical failure, etc.)
   - Increase the section on situational awareness
   - The role of the Fleet Manager should not necessarily be discussed together with the operator of a remotely controlled vessel
   - Add the topic of the e-logbook
   - Introduce the topic of preventive maintenance of ship equipment, since it depends on how the equipment functions.

2) During the simulation exercise, the following ideas were presented for consideration:
   - During further developments, navigation on a real ship should be added to the exercise
   - It is necessary to add a more precise methodology for comparing the hydrodynamic behavior of a digital solution and a real ship
   - Develop corresponding options for all ship types

3) In addition, general questions arose:
   - General qualification requirements for a remote operator and a remote operator trainer
   - What is the universal minimum technical solution for the development of remote-control capabilities
   - Additional research and improvement are needed related to the human factor
   - Legislation

During the development of the course described one member of the course development team who is also one of the authors of this paper investigated the possibilities of remote piloting in more detail. Although the objectives of his study had a different focus, it is possible to use the risks and topics requiring further research identified in his study in the further development of this course.

This research identified the main factors influencing the development of remote piloting:

1) Technical side: compatible systems and data communication solutions (also in extreme conditions),

developed procedures in case of technical failures are necessary.

2) Legal and formal side: applied/created standards and regulations are necessary, both related to procedures (including communication) and training.

3) Human factor caused vulnerabilities:
   - Lack of knowledge and skills
   - Communication skills (including terminology and language skills)
   - Situational awareness
   - Fatigue and the associated decrease in reaction speed.

6. Conclusion

As mentioned above, this course has been developed and launched within the framework of a ERDF project in 2023-2024. Since there was not much time to complete the project, but many participants and input providers were involved in it, mainly from various maritime-related companies and institutions, coordinating the project activities and staying on schedule was not an easy task. At the same time, it cannot be ignored that the number and diversity of participants and input providers ensured the quality of the materials being created and ultimately a good result. Bringing this course, like any other subject, to a high level is an ongoing process, and in each subsequent academic year it will be enriched and the teaching materials and methods will be updated and improved.

When creating the course, both technical issues and data exchange-related topics, including cybersecurity- related topics, and the legal side were covered considering the current state of art, and the risks related to the functioning of the technical side were also considered. However, during the development of the course, the question remained as to what and how the human factor would need to be considered the most in the future and how to structure the learning process in such a way that risks related to the human factor that arise in real situations are considered, simulated, and prevented.

An important feature of this subject is that practical tasks, including those based on simulation, are of decisive importance in its teaching. This requires prior specific training for lecturers and instructors, as well as regular software updates, so one-off projects cannot ensure the long-term availability of developed solutions. In developing subjects aimed at future needs, the acquisition and continuous development of software and hardware are very important.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Managing the risk of fire from electric vehicles on board ferries: An overview of current regulations and proposals

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Abstract: Given the growth of the electric vehicle (EV) fleet and the increasing safety concerns related to fire risks when transporting EVs on passenger ferries, it is necessary to identify regulatory gaps and best practices to improve their safe carriage on ferries, highlighting the key challenges and essential safety measures. The paper aims to encourage the adoption of regulations and the implementation of all measures for the safe transport of electric vehicles on ferries in Croatia. The methodology included a systematic analysis of the normative framework, government and industry guidelines, and recommendations addressing fire risks associated with EVs, as well as mutual comparison, differences, and applicability. The results show that the current SOLAS Convention does not particularly address issues related to the carriage of EVs on vessels, and there is a lack of official IMO standards. Several industry and government guidelines have been widely accepted as a legal framework worldwide and analyzed in detail in the paper. The authors highlight two measures suitable for implementing in Croatia as a first step to contribute to navigation safety. The competent legislator should adopt the prescribed safety measures towards the classification society in its jurisdiction to make them mandatory for shipping companies. Jadrolinija's mobile application for identifying electric vehicles during the booking process would be the most significant predictive technical measure addressing potential electric vehicle fires. The gradual introduction of all recommended measures, especially on the Jadrolinija fleet, including education and training of crew, would ensure proportional risk mitigation from potential fire hazards when transporting electric vehicles on board.

Keywords: electric vehicles; ferry transport; fire risk; regulation overview; Croatia

1. Introduction

The acceptance of battery electric vehicles (EVs) worldwide is exponentially rising, with the projection to dominate the passenger vehicle fleet market in less than a decade (Jung et al. 2023). According to the International Energy Agency (IEA 2024), the total number of globally registered electric cars in 2023 was 40 million, representing an increase of 53.8% compared to the previous year. The market is highly concentrated, having more than 2/3 of all sales and total stock realized in China, Europe, and the United States, meaning that all the changes in the dynamics in these markets have severe implications on global market trends (IEA 2024). Also, based on The Association of European Vehicle Logistics data, 21,5% of new car sales in the EU were electrically charged vehicles in 2022 (ECG 2023). The fundamental reasons behind the global increase in the ownership, registration, sales, and stock of EVs arise in the current trends aimed at reducing harmful greenhouse gas emissions and the tendency to reach net-zero emissions around mid-century. These environmental incentivizes, like the European Union's Fit for 55 (European Council 2024) and the globally recognized Paris Agreement (UNFCCC 2015), are mechanisms developed for battling climate change associated with anthropogenic effects of energy-related human activities. It concerns the transportation sector especially, contributing to more than 25% of the total GHG emissions, while ¾ of the total share belongs to road transportation (Rodrigue 2024). These indicators are the results of adopting the various sustainability strategies and goals in transportation aimed at reducing the harmful effects of burning fossil fuels by introducing the decarbonization concept. The latter tends to decrease the carbon footprint of transportation and eliminate negative externalities by introducing carbon-neutral fuels According to the indicated need for the adoption of standardized regulation concerning the safe carriage of electric vehicles on board passenger ferries, this paper deals with the systematic overview of the current best practices, guidelines, and recommendations that need to be implemented within the International Safety Management Code (ISM Code) in companies operating on the coastal liner shipping in Croatia. Since the ferry transport of passengers

is mainly carried out by the national shipping company Jadrolinija, the portfolio of these recommendations is intended to establish risk assessment mechanism and awareness, adopt fire safety measures as well as the remaining technical and operational procedures for preventing, detecting, and suppressing fire accidents on board passenger ferries. Croatian coast is highly indented with numerous islands parallel to the mainland (Baric et al. 2008), where 52 out of 1.244 islands are populated (Registar Otoka 2024), so establishing efficient ferry transport is indispensable for their socio-economic development. In 2023, the national shipping company controlled around 86% of passenger and 90% of vehicle traffic (AZOLPP 2024a) without paying special attention to EV transport concerning the booking system, loading, stowing, or applying any special safety measures. By updating the risks of transporting electric vehicles on ferries, the aim of this paper is to encourage the adoption of regulations and the implementation of all measures for the safe carriage of electric vehicles on ferries in Croatia. Due to the rising trends and total share of tourist activities on the Croatian islands (MRDEU 2021) and the rising number of EVs in Croatia (CVH 2024), and with the obligation to keep sustainable development, the safety measures concerning the EV transport on ferries operating in Croatia require to be implementing on the company basis. In addition to a literature review, the methodology includes an analysis of the content of binding and non-binding regulations such as SOLAS Chapter II, IMO Iterim Guideline, and EMSA, MCA and ICS guidelines, as well as mutual comparison, differences, and applicability within regulations of Croatian legislative and Croatian ferry operators.

2. Overview of the rising challenges and potential hazards of EV transport on board vessels

Generally, vessels dedicated to carrying vehicles on board can be categorized as roll-on roll-off (ro-ro) and roll-on roll-off passenger (ro-pax) vessels (GL 2013), while some definitions also include more generic versions, which include the segmentation of ro-ro cargo and ro-ro passenger ships (Węglarz et al. 2024). These vessels are primarily used for transporting a variety of vehicles (Kang et al. 2012), from purposely constructed for transporting only vehicles to a diverse range of wheeled cargo, including also passenger ferries (Kennedy, 2023). More on diverse types of ro-ro vessels can be found in (Göksu 2024). Vehicle transport by ro-ro shipping has emerged as a significant activity within freight transport in Europe (Beizhen et al. 2022), representing a complex staged process requiring precise planning and coordination (UNCTAD 2022). As for the potential fire risks of EVs combined with severe uncertainties of related fire particularities (EMSA 2022) and the increasing demand for EVs, there is a rising concern about electrically powered vehicles transported onboard passenger and cargo ships. It relates to the risks of starting a fire from battery-operated vehicles (MSB 2023) and its consequent effects while being transported onboard, where severe implications such as casualties, vessels sinking, and material damages are possible (Lighthouse 2024). Systematic development of the EV market can be justified by the adoption of recent environmental policies (Gonzalez Almeida et al. 2023), which have influenced the rise in EV sales through governmental policy support and purchase subsidies and incentives (IEA 2024). Several regulatory bodies have adopted important environmental drivers aiming to reduce negative environmental impacts through decarbonization policy and energy transition mechanisms, including shipping, which contributes significantly to the transport of EVs (Niklasson and Allerth 2022). The EVs are based on the energy system with batteries as storing energy means, as opposed to internal combustion engine vehicles (ICEV), which use diesel or gasoline as an energy source (Węglarz et al. 2024). Electrically powered vehicles can be commonly categorized as battery electric vehicles (BEV), hybrid (HEV), plug-in hybrid (PHEV), and fuel cell electric vehicles (FCEV) (Ntombela et al. 2023). These vehicles are predominately powered by high-voltage lithium-ion (Li-Ion) batteries, which present significant challenges to fire protection (CNBOP 2023). The principal cause of a fire generated by Li-ion batteries relates to thermal runaway, usually occurring when the internal heat generated from a battery exceeds the heat dissipating into the surrounding area (MCA 2023). The latter refers to the unwanted chemical reaction, having internal cell failure and causing a chain reaction that culminates with battery fire rapidly spreading (Łącki 2020; Sun et al. 2020). Additional challenges with burning Li-Ion batteries during the thermal runaway process are associated with the ability to reproduce oxygen, preventing the influence of inert ambient air (Niklasson and Allerth 2022). The principal general fire causes and risk factors that can endanger safety operations can be categorized as thermal abuse, electrical overloading, and mechanical damage (Dorsz and Lewandowski 2022), and further specified as a malfunction of components as a result of a manufacturing process (Brzezinska and Bryant 2022), weather conditions including temperature, humidity, and saltwater (Brzezinska and Bryant 2022; Bisschop et al. 2020), collision and damage (Lighthouse 2024), software issues (Aalund et al. 2021; MSB 2020), charging (Brzezinska and Bryant 2022) and battery management systems (Erd and Stoklosa 2020). When transported on deck, EV fires can be associated with bad weather, causing shifting of the cargo, which can significantly damage the battery (DNV 2016). Besides the principal causes of fire ignition in electric cars, the characteristics of an EV fire differ from the fire in other vehicles, primarily in the creation of large amounts of heat due to the high voltage and higher energy creation, difficulty in extinguishing the fires on EVs, and the release of flammable and toxic gases (Willstrand et al. 2020; Bisschop et al. 2020), as carbon dioxide (CO2), carbon monoxide (CO), hydrogen and volatile organic compounds (VOC), and remaining gases as vapors and particulates in gases (MCA 2023). Despite the

high differentiation of fire characteristics between electric and conventional vehicles transported on board vessels and a notable number of recent ships being affected by major fires, the risk of fires associated with electric vehicles is low and undoubtedly similar to the fire effects of other cars (LASH FIRE 2022a), with unique challenges reflected in the context of the maritime environment (Zahirasri et al. 2023). The latter conclusion supports the argument that neither of the twelve recent fires on board vessels can be associated with EV failure (Lighthouse 2024). However, the fires caused by the EVs failure can last longer with the possibility of reigniting and the spontaneous burning of heated cells (Sun et al. 2020), while the severity of the fire effects and hazards are one of the most challenging risks for the crew. That is behind the adoption of normative requirements on fire fighting for detection, suppression, and extinguishing fire on board, according to SOLAS II/2 Regulation 10 (IMO 2002). Depending on the vessel carrying EVs type, the ship decks can be designed as closed, open, or weather decks, where the weather deck is completely exposed to weather and sea, and an open deck enables natural ventilation for the permanent openings (IMO 2018). The EVs are 25% heavier than conventional vehicles, which could be significant for the loading limitations and stability calculations (EMSA 2022). Regarding the stowage principle, the shipping company has the pretension from the business standpoint to perform maximal utilization of the spaces concerning the organization of the vehicles in the garages, which results in small distances between nearby ones, usually having a passage width of a minimum of 40 cm and longitudinal distance of minimum 30 cm (Węglarz et al. 2024). On the contrary, this concept provides risk challenges as the extinguishing of a potential fire incident is delayed because of the constraints in reaching the burning vehicle to prevent the dispersion of the fire on adjacent vehicles (Gonzalez Almeida et al. 2023). Besides, the height from the floor to the bottom of structural elements in the garages when passenger cars are stowed on deck should be sufficient, as the cargo decks with lower height can rapidly become filled with smoke in the case of fire, causing reduced visibility, increasing the dispersion of fire, and become difficult to extinguish (Węglarz et al. 2024). The latter also refers to the ships having ramps with diverse angles of ascent and descent, as the EVs with low clearance can lead to contact between the EV and a ramp, resulting in the damage of the battery, causing thermal runaway and eventually fire (PRS 2022). Also, as for the constructional characteristics of cargo holds on ro-ro vessels, which include large voluminal spaces without longitudinal and transverse sections and having minimal obstructions to facilitate cargo operations, the fire can rapidly disperse across the whole cargo deck (Bao et al. 2023; Todorov 2016). However, firefighting on board is the limiting effects measure, opposite to preventive measures such as an early detection system and an alarm panel (Lighthouse 2024). The most effective method of dealing with the fire of Li-Ion batteries is water supplied in large quantities (MCA 2023; GL 2013), usually in the amount of 10 m3 as opposed to 2 m3, which is needed to extinguish the fire from ICEV (CNBOP 2023; Łącki 2020), a condition which can significantly affect ship stability (Węglarz et al. 2024). The water used for extinguishing the fire is mainly seawater, which also supplies the fire hydrant and foam system on board. Despite being abundant, constant, and cold extinguishing media, the utilization of seawater has some drawbacks because it is salty and contaminated (Todorov 2016). Generally, the fundamental fire characteristics and properties of EVs were provided in (EMSA 2022), indicating the toxicity, heavy smoke and heat in the pre-ignition phase, battery heat and external heat in the ignition phase, jet flames with length up to seven meters with a duration of 1-2 minutes and 50% more of hydrogen fluoride gas from fire compared to ICEV. Fixed fire extinguishing systems on ro-pax ships primarily consist of sprinkler systems (Kima and Jeon 2023). Also, extinguishing the EV is more complex compared to a fire that occurred in a conventional vehicle. The position of the electric car battery, mainly situated in the bottom part and sealed in the hermetic case, provides difficulties in applying media directly to the source of the fire (Węglarz et al. 2024). In case of fire on a ro-ro passenger ship, the problem of locating the openings in the cargo decks arises that have the importance of preventing the smoke endangers the evacuation to lifeboats and assembly stations (LASH FIRE 2022b; Mindykowski 2022).

3. The importance of passenger ferry transport in Croatia and the relations to EV transport

Coastal liner passenger transport represents an indispensable transport modality in Croatia, considering its contribution to the coastal economic development and preventing the depopulation of the islands (Naletina et al 2018). The above constellations are the implications of Croatia's specific geographical characteristics, and numerous partially inhabited islands are considered the second most indented European coastline (Pikelj and Juračić 2013). At the same time, Croatia is recognized by the EU as one of the most important tourist destinations with a high potential for future growth (Bosnić 2014), contributing almost 20% to the national GDP in 2023 (CNB 2024). Coastal shipping significantly contributes to socio-economic development and represents the foundation for economic growth and tourism (Turk and Mirković 1993). It is one of the reasons behind the establishment of the Agency for Coastal Liner Shipping, founded to create the regulatory framework of the Republic of Croatia on the issues of liner passenger traffic on the Adriatic. The principal activity of the Agency is the provision of the selection process of shipping companies based on public tenders, which provide transportation services on state ferries and conventional and high-speed shipping lines in public coastal liner shipping (AZOLPP 2006). The primary objective of public liner coastal

shipping is to ensure the regular connection between the islands and the mainland, according to the predetermined sailing schedule and selected ports of call. In general terms, the main limitation of liner shipping in the Adriatic and particularly in Croatia is the problem of seasonality, insufficient utilization of the ship's capacity on the specific lines, and obsolescence of the ship's fleet (Hess et al. 2018). Based on the concession contracts or public service contracts, the shipping companies provide passenger and vehicle transport services on shipping lines, including 26 state ferry lines, ten state shipping (conventional) lines, 16 state catamaran (high-speed craft) lines, one additional ferry line and 16 lines (dominantly catamaran) without public service obligation (seasonal lines) in 2024 (AZOLPP 2024b).

Jadrolinija is the largest, public-owned liner shipping company in Croatia, with the business activity of liner maritime transport of passengers and cargo (MMPI 2006), providing services on the majority of state shipping lines, especially state ferry lines. In 2023, Jadrolinija's dominance in the market was confirmed by the indicator of the total traffic achieved, where it realized a share of 85,8% of passenger and 89,4% of vehicle traffic (AZOLPP 2024a). The fleet portfolio of Jadrolinija consists of 39 ferries operating on local lines, 12 catamarans, four classic passenger ships, and two ferries for international lines, dedicated to carrying more than 12 million passengers and 3,5 million vehicles yearly (Jadrolinija 2024). Besides Jadrolinija, the remaining shipping company which provides vehicle transport in coastal liner shipping in Croatia is Rapska plovidba d.d., which operates with three ferries exclusively on the short distance line between ports Stinica (on the mainland) and Mišnjak on the island of Rab (Rapska plovidba 2024). These two shipping companies have an oligopolistic status in the vehicle transport market in coastal liner shipping, with close to four million vehicles transported in 2024 (AZOLPP 2024a). All the ferries of Jadrolinija and Rapska Plovidba are sailing under the Croatian flag state, classified under the national public classification society, Croatian Register of Shipping (CRS), which, among other tasks, provides statutory certification of sea-going ships on behalf of the Flag State Administrations (CRS 2024). Primarily from an environmental standpoint, the increasing popularity of EVs is further manifested in the rise of the EV fleet, and more EVs are also transported on ferries in Croatia. It can be confirmed and argued considering the exponential trend of EV purchases in Croatia, where the total sales were up by 68% in 2023 compared to the previous year (CVH 2024), along with the current worldwide trend. So far, no accident has been recorded, not at least according to the official statements of shipping companies related to EV transport on ferries in Croatia. It reflects the current state of the highest standard in the transport services. Regardless of the continuous increase in vehicle transport on ferries in Croatia and the recent worldwide safety concerns of EV transport on board vessels, there are currently no special rules, guidelines, or recommendations considering the safe transport of EVs on ferries in Croatia. It refers to the lack of guidelines from the responsible classification society and the general procedures to be implemented in the ISM system of the ferry companies. In addition, Jadrolinija recently enabled the online purchase of tickets through a mobile application, including the purchase of a vehicle ticket, but failed to integrate EV vehicles in the algorithm to facilitate their identification and adoption of the special safety measures.

4. Normative framework, regulations issues, gaps, and recommendations for safe transport of EVs on board

As previously indicated, the regulation addressing electric vehicle transport on board ships is currently limited and scarce. However, the general regulation on dangerous goods transport on vessels is comprehensive, along with the set of standards and initiatives governing the maritime vessels transporting vehicles (Lighthouse 2024). Generally, the current normative framework addresses EV transport as a formal issue rather than an isolated matter, failing to define specific measures for annulling the risks and improving the safety measures on board in diverse cases. Currently, no IMO mandatory regulation is in effect, as the competent legal norms were entered into force before the commercial viability and public use of alternative fuel vessels (63Rodrigue 2024). It is also important to note that electric vehicles are commonly transported by different means of transport (container, PCTC, ro-ro, ro-pax, etc.), so they are simultaneously subject to diverse regulations considering the various methods of carriage. Figure 1 represents the framework of the current directives and main guidelines concerning EV transport on board vessels. Within the maritime industries' normative framework, the fire safety issues on board are primarily regulated through Chapter II-2 of the International Convention for the Safety of Life at Sea (SOLAS Convention), which defines the standards for ship stability and fire protection (IMO 2018). Despite the requirements for carriers carrying motor vehicles with compressed hydrogen or natural gas in their tanks for their propulsion, which are included in SOLAS Chapter II-2 (Regulation 20-1), the carriage of EVs is not currently addressed in SOLAS (European Commission 2023). The SOLAS convention has also been amended by different codes and guidelines. The International Code for Fire Safety Systems (FSS Code) provides the international standards for fire safety systems and equipment required by SOLAS (IMO 2019a) and the International Maritime Dangerous Goods (IMDG) code, which is also mandatory under MARPOL 73/78 and prescribes the transport of hazardous goods by sea. Besides, in 2019, the IMO prescribed the Interim Guidelines for Minimizing the

Incidence and Consequences of Fires in RoRo Spaces and Special Category Spaces of New and Existing RoRo Passenger Ships (IMO 2019b), which are primarily considered recommendatory, not mandatory norm, and are mainly focusing on the technical features of the ship. As for the scarcity of legal forms addressing the EV safety measures while being transported on board different types of vessels, several governmental and industry guidelines were created to be incorporated in the ISM Code of the shipping company providing the carriage. The principal list fundamentally includes the EMSA Guidance, Maritime and Coastal Agency (MCA) Guidance, and International Chamber of Shipping (ICS) Guidance (Rodrigue 2024), while the list of other examples of diverse initiatives from governmental authorities and similar entities can be found in (Lighthouse 2024). As the EMSA and ICS Guidance provide detailed explanations of technical, operational, and practical aspects for the safe carriage of electric vehicles, along with the elaboration on the fire properties and safety measures in protecting, detecting, and suppressing the fire on board, the recommendation is aimed at utilization of these guidance's in conjunction with IMO interim guidelines when planning, training and implementing fire control measures from EV especially on ro-pax vessels. Table 1 provides the main topics and details explained and elaborated in the relevant guidance referring only to the ro-ro passenger ships.

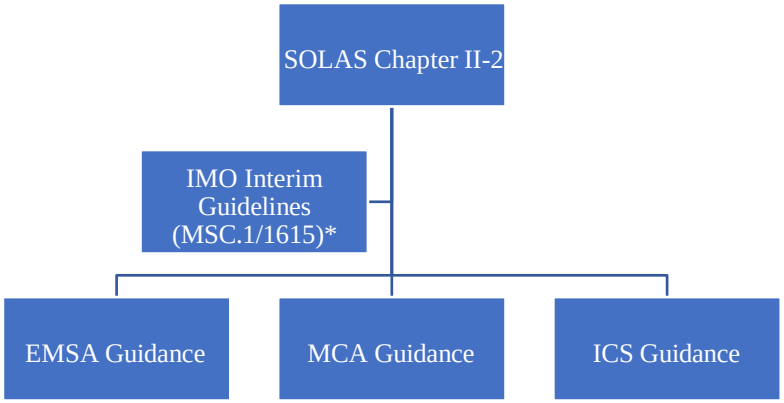


Figure 1. Normative framework of the current regulations and main guidelines concerning the EV transport on board vessels. (*Interim Guidelines for Minimizing the Incidence and Consequences of Fires in Ro-Ro Spaces and Special Category Spaces of New and Existing Ro-Ro Passenger Ships)

Table 1. Main topics covering the EV transport on ro-ro passenger vessels

EMSA	MCA
Stability and loading limitations	Identification and Vehicle Positioning
Protection against ignition	Electric Vehicle Fires – Background, Detection and Fire Prevention Measures
Fire detection	Carriage of Electric Vehicles other than cars
Fire suppression and extinguishment with a focus on EVs	Carriage of Damaged Electric Vehicles
	Design, arrangement, and location of charging equipment
	Wiring Arrangements
	Connections to the ship and charging operations

On the contrary, the handling of EVs on board ro-ro cargo vessels and PCTC is elaborated in ICS Guidance, which is, along with IMO interim guidelines, the best practice in the application of safety measures advocated by the industry organizations and companies (Maritime Mutual 2024). The fact that the governmental and industry recommendations are accepted as a legal framework worldwide primarily refers to a consequence of the fact that the current SOLAS Convention does not specially address the issues concerning EV transport on board vessels and associated with the general directive issues of lacking the specific norms and standards for safe carriage of EVs on vessels. However, based on the amendments from the IMO Sub-Committee on Ship Systems and Equipment (SSE) on the potential risks with the carriage of new energy vehicles, the Maritime Safety Committee (MSC) in 2024 adopted the proposed amendments and revised SOLAS Chapter II-2 to reduce the risk and consequences of fire in Ro-Ro and specific category spaces on new and existing Ro-Ro passenger ships. It includes the arrangement of ro-ro spaces for new vessels, the weather decks arrangement for new vessels, and water monitors on weather decks of existing ships. Also, the related amendments include the revision of the FSS Code to define new requirements for fixed water-based fire-extinguishing systems on weather decks intended for the carriage of vehicles and specifications for linear

heat detection systems and combined smoke and heat detection systems (DNV 2024).

5. Potential application of safety guidelines in EV transport on ferries in the Croatian coastal liner shipping

The magnitude of the potential fire hazards on passenger ferries in the Croatian liner shipping indicates the obliquity to apply the highest standards and safety measures when transporting EVs, especially as for the large number of passengers on board and tight passage width and longitudinal distances between stowed vehicles on board. Additionally, the constructional specifics of ship decks on Jadrolinija ferries currently in service are primarily designed as weather or closed decks, which, in both cases, requires specific procedures and safety protocols when carrying EVs on board. Figure 2 provides an example of a deck plan from Jadrolinija ferry Marko Polo, having a closed deck and cargo spaces (deck 2) when transporting vehicles.

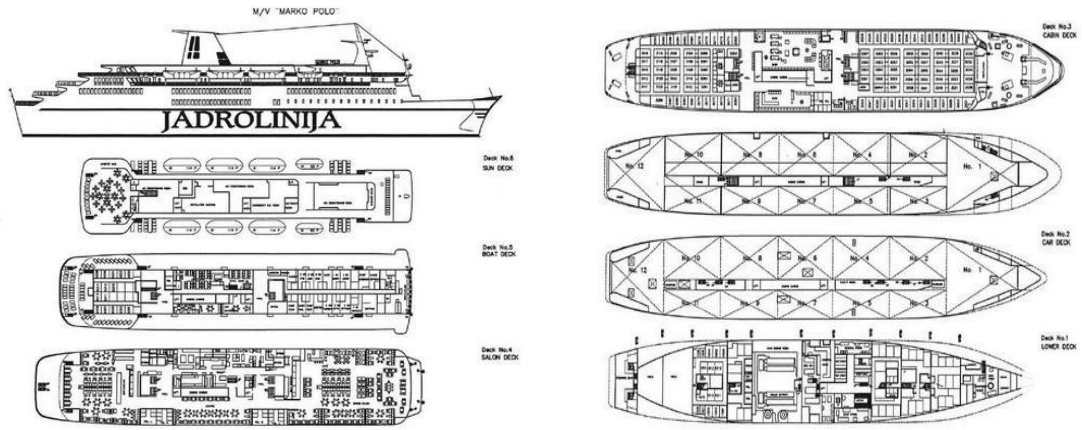


Figure 2. Deck plan of Jadrolinija ferry Marko Polo (Pinterest 2024).

Further, these constellations are taking on significant proportions during summer periods, when the share of passenger and vehicle traffic considerably increases, coinciding with the growing risk of EV and ICEV failure on board. Therefore, the proposed safety guidelines of EMSA and MCA, labeled as the industry's best practices intended to be incorporated in the ISM system of the shipping companies, provide relatively reasonable and acceptable safety requirements for the transport of EVs in ro-ro spaces of Croatian ferries operating within the coastal liner shipping and thus should be considered when adopting the specific regulation from the competent legislator. In the following pages, the overview of the key points indicated in the guidelines above will be provided and analyzed to highlight those suitable for inclusion in Croatian liner shipping based on the specifics of the voyages, vessels in service, and overall conditions.

5.1 The analysis of EMSA Guidance and overview of acceptable safety measures

The guidelines provided by EMSA first indicate the preliminary identification of vehicles depending on their energy supply before the embarkation on the ferry. It is the crucial step in adopting the stowage of EVs and remaining ICEV after the stability calculations, as it enables the crew and the company to apply the preventive measures to eliminate or decrease the risk of potential EV ignition and suitable safety measures in positioning the EVs on deck. The identification of EVs should be provided during the booking process, via mobile application, or directly on the desk. Special awareness should also be aimed at battery condition monitoring to prevent leakage and the creation of a potentially hazardous environment. As indicated in the EMSA guidance, the stowage of the EVs and other AFVs should enable direct access to the patrol while excluding the provision of any repair works and the use of naked flames, according to the relevant regulations and rules (EMSA 2022). Considering the carriage of small electric vehicles, such as e-bicycles, it is recommended to stow them on a weather deck rather than advocated cargo deck, as the majority of ferries in Croatia on shorter routes are equipped with a deck entirely exposed to weather, which

reduces the risk challenges of dispersion of fire to adjacent cargo compartments and other stowed vehicles. It implies properly assigned designated areas for vehicle storage (bike rack or parking space), separated and isolated from passengers and other cargo carried on board. Despite the possibility of implementing the charging station for EV on board ferries and the comprehensive list of risk assessment measures that should be approved before providing the service as indicated in EMSA guidance, due to the condition and age of the ferry fleet associated with the high frequency of sailings and tight sailing schedule, growing passenger traffic and the associated risks, this option should be avoided. This recommendation coincides with the standpoint of the Competent Classification Society (CRS). When dealing with fire detection on board, the cargo spaces on ferries should be equipped with fixed fire detectors and effective video surveillance, as recommended, to prompt reaction from the ship's crew. Furthermore, crew members should be regularly trained and familiarized with the fundamentals and safety aspects of the AFVs, especially on fire patrol duties. Also, the crew should be equipped with infrared (thermal) cameras and portable gas detectors in case of suspicion of gas leakage during fire patrols, and the periodical direct observation of the EV status is also needed (EMSA 2022). Efficient communication between the ship's crew and the driver of the electric vehicle is necessary to establish a successful exchange of information about any unusual vehicle behavior or previous issues. As indicated, the preferred response measure for a developed fire should be the fixed fire-extinguishing system activation or the manual means in case of situational assessment. It is significant for the ferry companies to apply all the necessary response procedures and develop contingency plans for onboard fire scenarios and fire extinguishing plans. The crew should periodically perform fire drills according to the relevant norms and using accredited protective equipment.

5.2 The analysis of MCA Guidance and overview of acceptable safety measures

The MCA Guidance reflects the best practices in EV's safe carriage and charging operations while transported on board Ro-Ro passenger vessels (Ro-pax). It is proposed primarily for the UK shipping sector. However, due to the lack of legal acts concerning EV transport on ships on a European and worldwide basis, the MCA Guidance has evolved as a referent point in setting the standards of EV-safe carriage in the industry. A considerable part of the document reflects on the possibilities and safety requirements of EV charging on board vessels, and operations of charging the EVs should not be an available option on ferries operating in Croatian waters. The recommendations considering the identification of EVs before embarkation on board and vehicle positioning correspond to the EMSA Guidance and should be a part of the pre-phase procedure of carriage. In case of fire on board caused by the electric vehicle power source, the leaked clear fluid from the Li- Ion battery should be cooled with a glycol-based automotive coolant, as recommended. Preceding the thermal runaway of the Li-Ion battery, as a principal cause of EV fire on board, the off-gassing phase occurs, releasing the toxic gasses heavier than air (VOC, CO, CO2, H2) and other vapors or particulates in the gases. So, the off- gas detectors are necessary for early thermal-runaway detection on board (MCA, 2023). As for the specifics of a high-voltage battery that can initiate rapid heating, the fire patrols on board should adopt preventive measures of continuous monitoring of possible evidence such as smoke (white vapor clouds and black smoke), heat or specific sounds, and the fire reignition conditions. It also includes the car deck inspections of trained crew equipped with thermal imaging cameras where a battery is conventionally located (e.g., underside), and the addition of closed-circuit television (CCTV) integrated with the flame recognition system can also be considered (MCA, 2023). As recommended in (EMSA 2022), the fixed fire-extinguishing system should be used as the first response measure when a fire EV occurs, especially for the disabling of spreading the fire to the other compartments and vehicles on deck. The MCA guidance indicates the use of large quantities of water for cooling the batteries and fire extinguishment in case of fire caused by the failure of Li-Ion battery as a power source of EV, as well as the potential use of vehicle fire blanket for restricting the spread of fire on adjacent deck areas, but only as a precautionary measure and primarily set on the adjacent vehicles as indicated in (Class NK 2023). If possible, the devices connected to fire hoses providing upward spray should be implemented and placed under the wheeler to achieve the direct cooling water effect, as well as other similar devices, such as portable water curtains and extinguishing lances, if available. It is of utmost importance to possess the crew's awareness of the risks involved when providing the firefighting operations, especially the challenge of electric shock, while simultaneously making available the specialized firefighting equipment for dealing efficiently with the burning fire. About the potential injuries as a consequence of a fire on board, the crew and the other respondents should be secured with personal protective equipment (PPE), including self-contained breathing

apparatus (SCBA) and other certified firefighting suits as indicated by the competent standardization agency, as the damaged battery when burning or being heated releases toxic and flammable gases (MCA 2023). Finally, the established response procedure for EV fire on board should be incorporated into the existing crew fire drills, and the response plan should be regularly reviewed and included in the vessel Safety Management System (SMS). The MCA also considers the carriage of large and small electric vehicles and procedures needed to perform in Croatian coastal liner shipping. All the recommendations for safe carriage should apply to large EVs. Small EVs have a special regime prescribed that firmly corresponds to the EMSA guidelines. The latter relates to the particularities of small EV transport on weather decks, effectively secured on board, regularly identified during the booking process, and other related propositions. The significant challenge in MCA guidance relates to the carriage of damaged EVs, emphasizing the importance of the detailed inspection with the fire risk assessment of the vehicle and the vessel. Also, these vehicles should be transported on a weather deck with disconnected battery packs to prevent possible fire ignition (MCA 2023). After the validation of indicated MCA guidelines, it is confirmed that all the above recommendations are suitable to be considered by Croatian ferry companies to improve the safety aspect of EV carriage on board based on the risk assessment of individual vessels, routes, and accompanied features.

6. Discussion and Conclusion

Considering the rise of sales, the registration of ownership of electric vehicles worldwide, as well as the fact that EVs are frequently being transported on board ferries, it is necessary to increase the level of safety measures when being carried on board based on the motivation of the user mobility, including commuting, business, tourism or any other cause of service use. The coastal liner shipping in Croatia represents a vital network of shipping routes connecting the land-based locations with the islands and respective populations, tending to satisfy the public, private, and social interests and the tourism aspect of the Croatian economy. In general, the vehicle traffic on ferries operating in the coastal liner shipping in Croatia is rising on an annual basis, which coincides with the growing share of EVs on board and the necessity to enhance the safety aspect of the carriage due to the risks of fire ignition from Li-Ion batteries as a power source. These crucial challenges of potential battery ignition on board and the insufficiency of current fire precautions and procedures are the main research questions drawn in this work. As previously indicated, there currently is a lack of regulation concerning the safety aspect of EV carriage on board vessels and the absence of official standards from the IMO, primarily argued from the standpoint of an even share of fire accidents caused by the failure of EV and ICEV. However, as the share of EVs is growing, backed by environmental incentivizes and normative frameworks aimed at reaching net zero emissions in shipping through the introduction of carbon-neutral fuels, the risks associated with potential fire accidents of vessels carrying EVs are becoming a critical factor in ensuring the safety of passengers, crew and assets. It is the reason behind the fact that the safety guidelines from EMSA and MCA are considered to be the industry's best practice when dealing with EV transport on ro-ro passenger ferries, among the other recommendations adopted by the governmental authorities and remaining classification societies. It is important to note that the Croatian Register of Shipping, a competent classification society for all the domestic ferries operating in coastal liner shipping, failed to prescribe general and specific technical guidance for the safe carriage of electric vehicles on ro-ro or ro-pax vessels. The absence of necessary guidelines from Croatian maritime legislation prevents the inclusion of essential preventive measures in dealing with the risks of fire from the carriage of EVs, despite not having any significant accidents with the failure of EV batteries reported so far. Generally, there are three main phases of intervention when planning to strengthen the general safety policy of ferry companies when transporting EVs based on the general guidance from EMSA and MCA, including embarkation, navigation, and fire occurrence, as indicated in Figure 3. Applying the prescribed propositions to the internal procedures of ferry companies operating within the Croatian coastal liner shipping is recommended.

The Jadrolinija mobile application for EV identification during booking procedures is the most significant predictive measure that deals with the potential EV fire. It is necessary to integrate this option into the current platform. Although the arrangement of the EV on board is a rather complex procedure, considering the limited space on the cargo deck and the tendency to achieve maximum share of utilization, the presence of ICEV and other vehicles powered by different energy sources, reduced passage width and longitudinal distances between wheelers, the ability to stow the wheelers on multi-level ramps, combined with the other technical and operational requirements, assigning the designated areas for EV carriage on cargo deck during the cargo plan design phase is recommended.

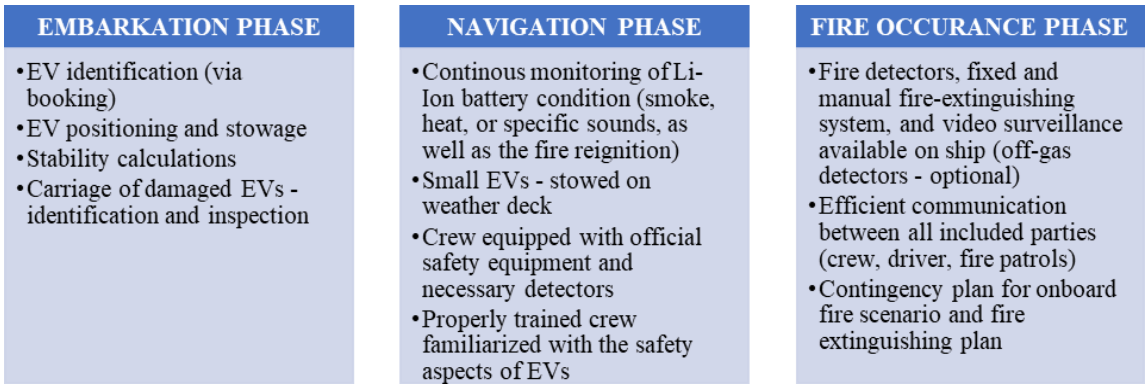


Figure 3. Main phases of intervention in dealing with the fire on board vessels.

This area should be equipped with fire detectors and the necessary equipment for effective suppression and extinguishment of Li-Ion batteries in case of ignition. For suppressing the fire of an electrically fueled vehicle, 10,000 liters of water is required (MCA, 2023), so it is necessary to consider the procedure for the disposal of contaminated fire water concerning the marine environment (Węglarz et al., 2024). The following predictive measures for combating possible fire accidents on board consist of continuous training of the ship's crew and the safety measures included in the ship's ISM system, SMS, onboard fire management plan, and similar concepts. According to the booking report, the ship's stability calculations should be made before the vehicle embarkation, while stowing of small EVs should be available at the weather deck, as indicated previously. The EV status monitoring is essential to prevent possible leakage, smoke, or other hazardous indications. Following the guidelines, it is necessary to ensure the availability of fire detection and extinguishing systems and crew safety equipment. An example of the application of a fire extinguishing system on board in case of fire ignition of an EV is shown in Figure 4.One of the water fog applicators, set underneath the vehicle and attached to the fire hose, enables the upward spray of water. It can be at the bottom of the designated areas for EV position on the car deck to secure the direct cooling water effect. The possibility of EV charging should be prevented at all costs, as for the potential risks associated with fire occurrence and the status of the Jadrolinija ferries and highly demanding everyday operations, thus mainly for safety reasons. All of the described technical measures to increase navigation safety when transporting electric vehicles on board are applicable on the ferry Marko Polo.

The original contribution of the paper consists in revealing the risks of transporting electric vehicles on Croatian passenger ferry ships, and also in identifying the lack of regulations and providing insight into safety guidelines and recommendations that could be applied with the aim of increasing traffic safety. The decision-makers, primarily the competent Ministry, should strive for the obligatory measures adopted towards the classification society under their jurisdiction to become compulsory for shipping companies, including ferry companies operating under CRS. For instance, several classification societies have already prescribed specific measures when regulating EV transport on board, such as Class NK, American Bureau of Shipping (ABS), Polish Register of Shipping, China Classification Society, and others. The safety measures integrated into the transport of electric vehicles on ferries in Croatia would ensure a corresponding risk reduction of potential fire hazards. The costs of technical modifications to Croatian ferries could be a limiting factor in implementation but the introduction of Jadrolinija's identification software, crew training, as well as the adoption of basic regulatory measures, should not be delayed.

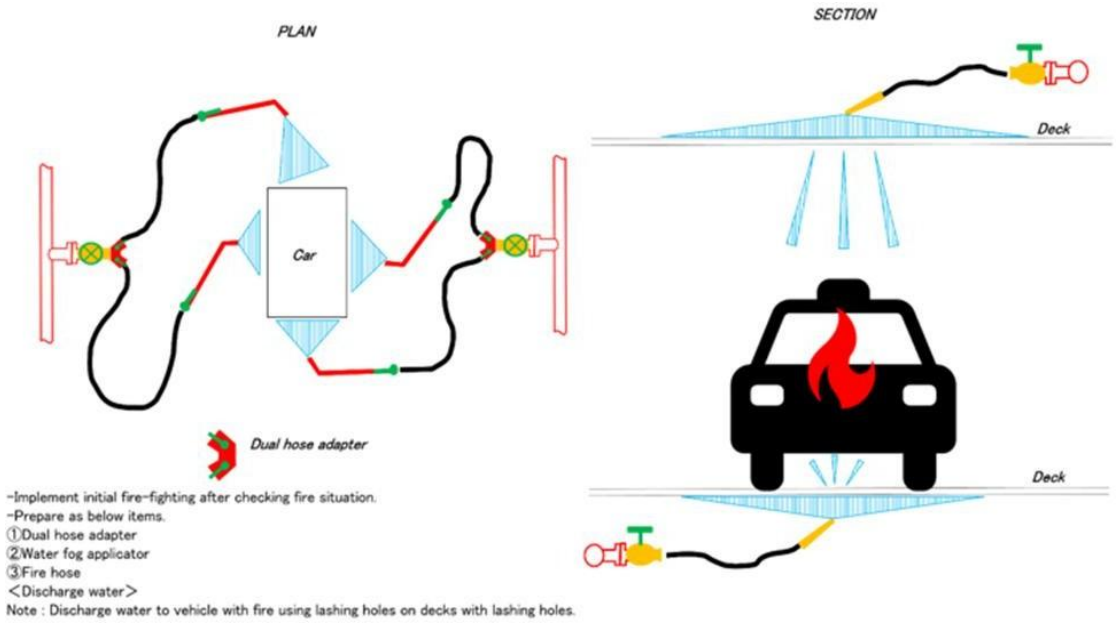


Figure 4. Application of fire extinguishing system on board in case of battery ignition on EV (Class NK 2023).

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities Conference

A Potential Framework for the Analysis of Cyber Resilience through the Perspective of Hybrid Threats

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Abstract: The way in which the response capacity of organizations in the field of critical infrastructures is tested is given by the complexity of the forms of manifestation of hybrid threats. Thus, to strengthen social resilience, in the pre-manifestation phase of the threat, it is very important to recognize the danger and strengthen the partnership between public institutions and civil society. The increase of hybrid patterns as of late, reveals, on the one hand, the multitude of combinations of methods and means used by the aggressors for the achievement of their strategic objective, which, in fact, portraits the quintessence of the hybrid war.

From this point of view, this article focuses on the need to deepen combined, institutional and academic efforts to address the issue of responding to new types of security threats. Such a model could contribute to a better understanding of the concepts we operate with – hybrid threats, national resilience and security culture – and of the elements of interdependence that result from their convergence. The rising of cyber-attacks, especially considering recent events, and the strengthening of responses in this respect, turned cyber resilience into the new favorite expression of security analysts. Therefore, cyber resilience is not just a new trend but, on the contrary, a concept that will redefine the way we look at security and business continuity, especially in the field of critical infrastructure. The article is based on an analysis of specialized literature on cyber resilience, corroborated with an analysis of the public security policies that a state is determined to apply, in the context of hybrid attacks in the cyber domain.

Keywords: Hybrid threats; National resilience; Security culture; Critical infrastructure.

1. Introduction

In the category of emerging security challenges, which require the identification of new approaches to crisis management processes at the level of state actors and the design of an efficient framework for cooperation at the regional level, also includes the events recorded in recent years in the international security environment, starting with the annexation of the Crimean Peninsula by negatively modifying the national security in the conflict zone of this country and reaching the spread of hostile actions carried out in the cyber and information fields with the aim of determining social knowledge and political processes in some Western countries, such as the USA, France and even Romania - where the events surrounding the presidential elections in November 2024 are worth mentioning.

In recent years, especially since the outbreak of the COVID-19 pandemic and the war in Ukraine, at the European Union level, efforts have been made to adopt measures aimed at strengthening capabilities to counter cyber security threats, such as NIS (Network and Information Security Directive), GDPR (General Data Protection Regulation), PSD2 (Payment Services Directive 2) and, more recently, TIBER-EU (European framework for Threat Intelligence-based Ethical Red Teaming) and DORA (Digital Operational Resilience Act).

Thus, strengthening the capabilities to counter cyber threats, according to the NIS Directive is achieved through various measures, from technical to organizational and legislative. NIS Directive 2, an updated version, imposes stricter requirements on companies and organizations, requiring the implementation of security standards, such as IEC 62443 (Consiliul European, 2024). By combining these measures, a holistic approach is aimed at providing increased resistance against cyber threats. The European Cybersecurity Certification Scheme based on Common Criteria (EUCC) defines a cyber threat as a potential circumstance, event or action that could cause damage, disrupt or adversely affect networks and information systems, their users and other persons (E.C., 2024).

Key measures to strengthen cyber threat resilience under DORA aims at a coherent set of practices aimed at ensuring the digital operational resilience of financial entities in the EU. This regulation is mandatory starting from 17 January 2025 and applies to banks, insurance firms, investment firms, third- party ICT service providers. DORA transforms cybersecurity from a technical subject into a strategic, legal and operational obligation. According to a recent study, organizations need to invest in robust prevention, detection, response and recovery capabilities, with a focus on collaboration, continuous testing and oversight at the top management level (Bruder, Yaros, Horauf, Kapotwe, & Beck, 2025).

To support their own strategic interests in international relations, most state and non-state actors use some hybrid forms of aggression that are accessible to them. A possible example would be the effect of the developments generated by the fourth industrial revolution that we are currently experiencing, due to the interconnection between the physical, digital and social domains. On the one hand, in order to influence the perception of the population in the context of polls caused by elections, malicious attackers act in such a way that most European democracies declare themselves powerless in the face of a high degree of exposure to hostile actions in the information/cyber domain. On the other hand, the hybrid nature of the new types of threats reflects the developments recorded in the crises in Ukraine, Syria and more recently in Iran.

2. Factors Determining the Emergence of Hybrid Threats to National Security

In the new security context, defined by hybrid threats exerted by state and non-state actors, the concepts of resilience and security are not only compatible, but deeply interdependent. Hybrid threats – such as disinformation, cyber-attacks, manipulation of public opinion, economic pressures or the use of proxy forces – can no longer be countered exclusively by classical means of defense. In this framework, security becomes a dynamic and multidimensional process, which involves not only prevention and defense against threats, but also the ability to absorb shocks, to respond effectively and to quickly return to a functional equilibrium – that is, resilience. Resilience is no longer a passive or secondary concept, but an active pillar of modern security. It involves an information society, protected critical infrastructures, resilient institutions, a secure digital environment and a culture of trust and cooperation between state actors and civil society.

This potential new perception of security should be much more flexible and allow the deterrence and resistance against hybrid adversities by use of a wide range of tools resulting from the interconnection of the civil (public and private) and military sectors (Frunzeti & Barbulescu, 2019).

For the first time, in July 2016, during the NATO Summit held in Warsaw, the fight against hybrid threats was identified as one of the priority areas of cooperation between the EU and NATO. After this summit, the joint report of the European Commission and the European External Action Service described the European security environment as significantly affected by hybrid actions: “hybrid activities are becoming a frequent feature of the European security environment. The intensity of these activities is rising, with growing concerns about influencing elections, disinformation campaigns, hostile cyber activities and hybrid actions performers who seek to radicalize vulnerable members of society that will become tools in their action’s implementation" (Council, 2017). In this way, basically, it is acknowledged not only that the impact of hybrid threats exceeds the territory of the member states, being felt at the European level, but also that "European security has become a matter of negotiation, contestation and struggle" (Matti, 2017) because of the new challenges derived from the actions of state and non-state actors. Recognizing the complex and cross-border nature of hybrid threats, the framework proposed in this paper provides a starting point and a suggested approach for governments in EU Member States to strengthen the overall resilience of our societies.

Hybrid threats therefore refer to the methods and tools used by a potential aggressor – which can be a state or non-state actor – to support its own interests, strategies and objectives in rapport with their attacker or adversaries (Cullen & Reichborn-Kjennreud, 2017). Current threats have multiple dimensions, and the connections between the diverse processes that define them are unclear, can be contradictory, and sometimes impossible to verify. If the aggressor's interests and objectives that uses such tactics are not reached, and especially if his actions are not detected in due time, the conflict may escalate into a hybrid war (Bach, Kaufman, Settle, & Duckworth, 2015).

Hybrid threats are not only tools of destabilization, but also a strategic framework through which international actors test and refine military and non-military tactics in an environment below the threshold of open conflict. These hybrid manifestations – combining conventional, unconventional, cyber and information methods – allow testing of new forms of coercion and influence without directly engaging armed forces in classic wars. For example, disinformation campaigns, cyber-attacks on critical infrastructure or the use of paramilitary groups in proxy conflict theaters provide opportunities to evaluate the effectiveness of tactics that can later be integrated into official military doctrine. Moreover, these forms of covert aggression allow actors to probe international reactions, measure the degree of resilience of target states and constantly adopt methods of action. Thus, the security environment becomes a space of continuous experimentation, in which tactical innovation takes place in a context of legal and political ambiguity.

An actor practicing hybrid warfare may opt for the "vertical escalation" of the instruments of power, or "horizontal escalation" by synchronizing multiple tools to achieve a greater combined effect (Bourbeau, 2015). Unlike hybrid warfare, significant to remember regarding hybrid threats is the aspect of interconnection between the different associated activities and, moreover, the difficulty of establishing the existing links between these activities prior to the period of their manifestation, consequently, beyond the framework set in terms of armed conflict or war.

The range of methods and activities associated with hybrid threats is significantly broader than in the case of conventional or asymmetric threats, as they involve a wide range of instruments – both military and non-military – used simultaneously or sequentially, depending on the objectives of the aggressor actor. The complexity and flexibility of hybrid threats make them fundamentally different – and more dangerous – than classic forms of aggression. While conventional or asymmetric warfare can be anticipated and countered within a clear normative framework, hybrid threats take advantage of precisely the gray areas – where international law, political will and the capacity to react remain limited or ambiguous.

The main factors contributing to the emergence of hybrid actions according to a recent study are (Hamilton, 2016):

1.The changing of the international order post-Cold War. Currently, malicious actors routinely use the "dark side of globalization" (Roer, 2015), with the role of a nation as an independent state being questioned, as are alliances whose norms and rules constrain responses to antagonistic actions of an asymmetric nature.

2.Technological advances in communications, globalization, and the explosion of the online environment are decisively contributing to the amplification of the capacity for influence and action for both state and non-state actors. These factors multiply the speed, range, and efficiency of hybrid operations. New technologies and globalization are no longer just factors of progress but also risk multipliers. In this context, state and non-state actors benefit from a vast, cheap, and difficult-to-regulate operational space. This makes hybrid threats harder to detect, faster, and more effective in achieving their strategic objectives.

3.The emergence of new areas of confrontation, such as the cyber environment where the rules of the game have not yet been set up.

4.The capitalizing on the potential offered by the new media technologies as well as on the new tools of social influence. Trust, one of the fundamental pillars of advanced democratic societies, is eroding under the influence of modern manipulation techniques.

5.In the contemporary context, the clear demarcation between peace and war is becoming increasingly difficult, as aggression no longer exclusively involves conventional military means, but a wide range of unconventional, opaque and difficult-to-attribute instruments. Thus, the target of a new type of aggression may not be aware that it is already involved in a conflict, which dramatically reduces the ability to react and defend.

In our opinion, in the processes designed for hybrid threats management, no satisfactory results can be achieved if the possible answers to the following essential questions are not delved into: What are the national vulnerabilities that require special attention? How could an enemy exploit these vulnerabilities? Are all levels of the organization used in defense efforts, and have they been properly trained to act accordingly against likely threats?

War no longer begins with an attack and is no longer announced on the radio. It silently insinuates itself through social networks, through elite corruption, through fake news, through invisible cyber- attacks and through manufactured economic crises. In this context, nations that do not develop their capacity for early recognition and societal resilience risk being defeated before they realize they have been attacked.

3. Steps of the Cyber Threat Analysis Framework

The evaluation of theoretical aspects, as well as the analysis of those derived from recent developments in the national and global security environment, allow us to present a potential analytical framework necessary in the process of managing hybrid threats.

This framework could include the following steps:

3.1 Identifying the tools of power the attacker might use in hybrid conflict scenarios. This stage is essential for understanding the profile and intentions of a potential aggressor. In such a conflict, a hostile actor will not be limited to military force but will use a wide range of instruments (hard & soft power) to achieve its objectives without provoking a classic military response. In this stage, we aim to analyze the power instruments (cybernetics, economic, informational, religious, cultural) that a potential adversary could use in a hybrid confrontation scenario. For example, the informational power used to control public perceptions and narrative can be represented by the following attack vectors: disinformation and propaganda campaigns (via social media, influencers, fake websites), manipulation of public opinion – polarizing society, undermining trust in institutions or deepfakes and AI- generated content for confusion and destabilization.

The analysis of the recent hybrid actions patterns indicates the following tendencies specific to the forms of threats manifestation identified typically in the informational and cyber domains and which can be found in the integrated strategies of a potential aggressor within an aggression scenario:

- The use of propaganda as predominant means of action. We are currently witnessing "the militarization and transformation of information into a war weapon", as stated in the Communiqué of the NATO Summit in Warsaw in July 2016.

- The control over the manipulated domestic media sources and with audience on wide segments of public, both inside and outside the aggressor state. Controlled media become very influential when the materials they distribute are undertaken by renowned foreign media sources, as reflected in the Joint Declaration adopted at the NATO (Summit, 2016).

- Social media undeniably offers new possibilities for a potential aggressor who intends to gain access to mass media and to the public of the intended targets.

- Widespread use of manipulated news to influence the perception of target audiences. Fabricated news is more than fake news. This includes information that deliberately distorts the objective reality in the eyes of the public and pursues a specific objective, usually associated with fulfilling the hostile interests of a potential aggressor.

- The possibility that some sites may allow the publication of data from the category of information leaks, obtained through cyber espionage actions. In this regard, we note the intervention of former British

Prime Minister Gordon Brown (Brown, 2025), who urges us to look beyond surface events. He draws attention, in an editorial in The Guardian, to the tectonic movements that threaten to demolish the entire architecture of the post-Cold War global order.

3.2 Assessing your own vulnerabilities based on the premise that in hybrid attacks, the malicious actor uses the exploitation of sensitivity within the targeted companies. This step could include:

• Identifying critical functions of society. For example, a possible direction of assessment could focus on the ways in which a government in a given region is dependent on the digital services it uses and on the vulnerabilities of these services to cyberattacks. In this regard, for maritime transport companies, we propose a method that eliminates the graphic construction that can involve graphic representation errors. The method introduces the mathematical calculation of fixed geographical coordinates, which makes it possible to identify the critical functions of a maritime transport company (Busla, 2021). A concrete and highly relevant example of the maritime domain being exposed to hybrid threats is the sabotage of the Nord Stream 1 and 2 pipeline in the Baltic Sea (September 2022) – an emblematic case of hybrid aggression against critical maritime infrastructure, with major international implications. In this situation, there was no official declaration of war or recognition of the attack, and the responsible actor was not clearly identified, which provides strategic ambiguity and deniability – classic elements of hybrid conflict (Van Soest, Black , Fine, & Retter, 2025).

• Evaluation of the vulnerability spectrum. One of them refers to geographical vulnerability. Proximity to a source of threat – be it a hostile state actor or an unstable region – inevitably amplifies the sense of vulnerability at the societal level. Even in the absence of an actual attack, this geographical proximity can generate a heightened perception of risk, with direct effects on: public opinions (increased distrust, polarization); collective behaviors (panic, radicalization, calls for military action); political decisions (militarization, emergency legislation, security populism).

3.3 Understanding the attacker's possible objectives and correlating them with the target state's actual vulnerabilities. This way, we can anticipate attack methods and build effective prevention and response measures. This is achieved in correlation with the power tools available in the group of actions directed against an identified target.

3.4 Adapting forms of reaction to hybrid aggressions, applicable to strengthening security culture. Starting from the premise that hybrid threats predominantly manifest themselves in the information space at the level of civil society, having many correlations about national security, we consider an approach focused on developing security culture useful, as a supporter of national resilience to hybrid threats.

4. Concrete Ways to Respond to hybrid warfare through cyber resilience

In December 2024, the Cyber Resilience Act entered into force to make Europe's cyberspace safer and more secure. This marks a major leap in the EU's efforts to protect its citizens and businesses from cyber threats. The Cyber Resilience Act (ARC) is the first EU legislation to introduce mandatory cybersecurity requirements for products that include digital elements. The main obligations provided by law will be enforced as of December 11, 2027. Henna Virkkunen, the Executive Vice-President of the European Commission, stated: "We are committed to making Europe a safe and secure place for our citizens and businesses to operate. This new regulation is an important step forward in ensuring that EU digital products do not pose cyber risks to EU consumers."

The Cyber Resilience Act complements the NIS2 Directive, which entered into force in 2023, forming a robust legislative framework designed to enhance cybersecurity across the European Union. These two instruments are part of a broader EU digital security strategy aimed at safeguarding the digital single market and ensuring technological sovereignty.

Companies from regulated economic areas were forced to invest in IT security since long ago and for a long time, there was an approach according to which in order to protect itself, an organization must purchase the best solution for a risk or attack vector. Often, following a cyber incident in an organization, the devastated attitude and oppressive atmosphere felt by the employees involved appear. From this point of view, a team must be prepared that has an adequate vision and is mentally prepared for the effects of a cyber-attack, otherwise, a significant loss of human resources can be a consequence. The concept of "in depth

defense" also arose, areas of solutions overlapping began to appear, machine learning based tools and artificial intelligence were born. Meanwhile, complexity also increased in the audit and compliance area, where more scrutiny came from. Cyber resilience includes all of these and focuses on mitigating risk, but from a different perspective. Basically, cyber resilience consists of the power of an organization to permanently deliver the expected result, despite opposing cyber conditions.

From this point of view, the first thing an organization needs to develop its cyber resilience is a change in mindset, meaning that top managers understand that there will be successful attacks. The offensive zone has become so complex that it is practically guaranteed that at least one service within the company will be compromised at some point. The recommendation is to shift attention to how the consequences can be reduced, so that defense against cyber-attacks can begin as early as possible, after the first signs of compromise, and the tools used by the company can prevent the next steps of the attack, to continue operations in good security conditions. Hybrid warfare encompasses a wide array of hostile actions in which military force is only a small part of a flexible strategy with long-term objectives, complemented by political, economic and information methods. For example, Russia started years ago to get involved in Ukraine's internal struggles. And also used cyber-attacks.

In 2010, for example, a malware known as Snake affected dozens of diplomatic and government systems, becoming an espionage tool that provided people behind it access to Kiev's secrets. In addition, Russia used the gas pipelines as a tool to pressure Ukrainian political leaders. In parallel, it has supplied rebel separatists in Eastern Ukraine a vast arsenal of heavy weaponry. And another essential component of the hybrid war is the disinformation campaign. All these concluded, in 2014, with the illegal occupation of the Crimean Peninsula. Russia is not the main advocate of hybrid warfare.

China, for its part, is using the same tactic in the South China Sea. And in the Middle East, Iran has invested enormous amounts of money in developing its cyber-attack capability. Moreover, it has enormous energy resources, and the media is heavily controlled. At the same time, the operations conducted by the Irish Republican Army, Hezbollah, Al-Qaeda and the Islamic State contain elements of hybrid warfare (Avarvarei, 2021).

Here are a few examples that demonstrate how hybrid threats are used to test and refine new military tactics in the "gray zone" environment (Mason, 2020):

1. In Crimea (2014) and eastern Ukraine, Russia combined "little green men" troops, cyber operations, and disinformation campaigns to foreshadow annexation, thus testing hybrid control tactics before open conflict.

2. The same model has been applied in parts of Europe (e.g., sabotage of the Nord Stream pipelines, GPS disruptions), operating in a coordinated manner below the "threshold of war" – without formal military escalation.

3. Hezbollah has used anti-tank missiles, improvised UAVs, IEDs, and decentralized cells – all in parallel with imagery campaigns, to test hybrid asymmetric tactics against a conventional army.

4. Russia and pro-Russian actors have implemented hybrid tactics in Syria and Libya: paramilitaries, cyber-attacks, mythological propaganda, to test the synchronization of unconventional power.

5. Emerging technologies in military exercises - Modern armed forces (USA, Australia, NATO) test hybrid tactics in border exercises, such as integrated drones, electronic jamming, decoys, cyber warfare. Hybrid threats serve as a testing ground for modern military tactics – a mix of conventional force, cyber-attacks, information warfare and unconventional tools – all used to assess effectiveness, adversary reaction and the threshold of international response. They allow the actors involved to experiment beyond the limit of an open conflict and to quickly adapt technologies or doctrines (drones, jamming, info-ops).

5. Conclusions

In the new security context defined by hybrid manifestations in the conduct of international actors, resilience and security are not incompatible concepts. In this framework of analysis, resilience should not be considered an alternative to national security, but, on the contrary, an innovative way to ensure it sustainably. The security of an organization's IT infrastructure and application platforms must be viewed as a strategic element in developing resilience. Implementing cyber resilience requires a redundant and flexible

infrastructure that enables the adoption of a strategy across the entire IT toolkit, so that in 3-5 years an organization can reach the optimal level of flexibility and automation - the latter, considering a major industry problem, namely the shortage of specialized personnel or significant salary costs.

In our opinion, the social dimension of security must represent a complementary function of good governance that can support the integrative strategic approach over time. In formulating response measures to hybrid threats, one of the useful options we offer is related to the need to promote policies that contribute to the development of a security culture.

A limitation of this research, which will be studied in subsequent studies on the same topic, is given by the fact that national resilience to hybrid threats does not only involve specific response measures designed at the institutional level but is a general process that includes all the component elements of a nation, including the participation of society.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Study on Behavioral Characteristics of Engineers in Engine Room simulator Using Eye-tracking Measurement Devices

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Abstract: It is important to utilize engine room simulator to improve engineer skills. Skills for engineers are divided as technical skills and non-technical skills. Non-technical skills are evaluated as Engine-room resource management which include human factor elements. Improvement on engine simulators and evaluation of behavioral characteristics for engineers' technical skills and non-technical skills such as situation awareness are required for the safety of operation.

The purpose of this study is to evaluate technical skills and behavioral characteristics by using eye-tracking measurement devices during engine plant simulator operations. The first step is to create several types of detailed animated machinery images for evaluation experiment. The second step of this study is to record and measure participants' eye-movement. Participants will operate and observe these created animated machinery images as evaluation experiment. The final step of this study is to analyze eye-movement data and evaluate behavioral characteristics such as situation awareness as non-technical skills.

The major findings of this research suggested differences in eye-movement with respect to onboard experience among the participants. As a presumption, we considered that training and education using simulator and detailed machinery animation can supplement the knowledge and experience.

Keywords: Engine room simulator, Eye-tracking Measurement, Animated Machinery, MET

1. Introduction

The 2010 STCW Convention Manila Amendments added Engine-room Resource Management (ERM) to the list of engineer competence criteria, as one of the requirements for the ability to "Maintain a safe engineering watch". Additionally, the importance of ERM training in a simulator environment has increased due to the introduction of simulator-based competence assessment for certification. In September 2024, Oil Companies International Forum (OCIMF) updated and enhanced Ship Inspection Report Program (SIRE) 2.0. This SIRE

2.0 includes the content of human resources from the viewpoint of preventing maritime accidents and engine damage accidents caused by human error. The need for resource management training is required to enhance "Situational awareness" which is included in the evaluation of non-technical skills in ERM in IMO Model course 2.07 (2017). It is necessary to consider evaluation methods based on objective data concerning this behavioral characteristic as non-technical skills and technical skills of engineers in engine machinery operation and management.

From these backgrounds, improvement on engine simulator and evaluation of behavioral characteristics for engineers' technical skills and non-technical skills such as situation awareness are required for safe operation. Therefor shipping companies and maritime education and training institutes continue to conduct improvement of engine simulator and research of evaluation method for engineer skills. There are several research done in maritime education and training utilizing engine room simulator. Zaini (2023) introduced engine room simulator as higher education tools and Laskowski et.al., (2015) suggested effectiveness for teaching and evaluating seafarers' competencies. Research on situation awareness in maritime fields remains limited but several studies have been conducted in past. Cordon et. al., (2017) suggested psychometric evidence of situation awareness is most important for the safety of shipping. Sharma

(2023) discussed situation awareness is particularly necessary in the future autonomous ship. Relation between bio signal using heart rate and eye- tracking data of entering and leaving port situation awareness for student and pilot are discussed by Khairul et. al.,(2024).

This study aims to evaluate participants' technical skills of machinery operation and behavioral characteristics such as situation awareness by using eye-tracking measurement devices during engine plant simulator operations. Engine plant simulator in Graduate school of maritime sciences, Kobe university consists of a separated engine room with monitor displays to mimic the engine plant system. Each valve, piping lines and machineries are displayed to operate M/E, D/G Engine, Boilers, purifier, etc. However, details of machinery are not included in this engine plant simulator. First step of this study is to create several types of detailed animated machinery images for training materials. Animated machinery images created, consists of three types of pump operation method, fluid movement inside machineries and explanation of each machinery. Second step of this study is to record and measure participants' eye-movement by using eye-tracking measurement devices. Participants will observe these animated machinery images as evaluation experiment and their eye-movements during evaluation experiment are recorded. Participants are selected by amount of onboard experience they possess. The final step of this study is to analyze eye-movement data and evaluate behavioral characteristics such as situation awareness as non-technical skills. Next, we discuss the participant's viewpoint, which is affected by their technical skills regarding machinery operation which in turn depends on their onboard experience.

2. Methodology

2.1. Animated machinery images

First step of this study is to create several types of detailed animated pump images for evaluation experiment. Three types of animated pump image are created by Adobe creative cloud software. Each animated image consists of a main animation, sub animation and main text. Fig.2 shows an example of animation. Main animation and sub animation describe pumps movement such as impeller, gears and other rotating parts. Also, fluid movement from suction of pumps to discharge process are described. Main text indicates explanation of pump movement and fluid movement. Explanation of main text appears every 5sec and 3 different explanation will appear in animation which means one animation duration will be 15sec. Three types of pumps "Axial piston pump", "Gear pump" and "Centrifugal pump" animations are created in this study and explanation of each pumps are shown in below.

2.1.1 Axial piston pump

1. The image shows an axial piston pump. Pistons are attached to the inclined plate. The inclined plate changes its inclination angle while rotating.

2. Axial piston pump consists of multiple pistons and cylinders. The inclined plate rotates at a constant speed. The piston stroke changes due to the inclination angle.

3. The rotation direction and rotation speed of the inclined plate are constant. The adjustment of the pump's discharge amount depends on the inclination core. The discharge direction can also be changed by reversing the inclination.

2.1.2 Gear pump

1. The image shows a gear pump composed of two gears. A space is formed between the teeth and the casing. The fluid trapped in this space is discharged.

2. The gear that is driven by the motor shaft is called the driving gear, and the gear that rotates in mesh with the driving gear is called the driven gear. The fluid serves to lubricate the meshing teeth.

3. When the fluid supply is interrupted, wear between the teeth will progress. Contamination by air or gas can also accelerate wear. Air contamination and running without fluid will reduce the pump's lifespan.

2.1.3 Centrifugal pump

1. The image shows the structure of a centrifugal pump. It connects the pump shaft end to the motor shaft end. The other end of the pump shaft is connected to the single impeller.

2. The motor rotation is directly transmitted to the impeller. The pump suction port is located at the center

of the impeller. The impeller rotates and sucks in the fluid.

3. The fluid is pushed outward to the outside of the impeller by centrifugal force. The center of the impeller has fluid moving through it, causing a drop-in pressure. Again, fluid is sucked back in there.

These created animations are all 15 seconds long. However, the number of components moving in the animation is different because the axial piston pump has eight pistons, the gear pump has two gears, and the centrifugal pump has a single impeller. Moreover, In the gear and centrifugal pumps, the flow of fluid in the pump is represented by the movement of several small spheres. In axial piston pumps, the fluid motion is explained in text only to avoid complicating the image. In the experiment, participants watch the same movie three times, with the pump type not mixed. The number of text characters in the explanation (in Japanese) is same in all animation.

2.2 Participants

In this study, eight participants are selected by the varying amounts of onboard experience they possess. All participants are provided written informed consent. Participants 1 to 3 are students of marine engineering course who has three-month onboard experiences in training ship. In three-month onboard training, engine course student will learn and experience plant operation and knowledge of how to operate machinery such as M/E, D/G. pumps, purifier and other equipment. But they did not experience overhaul or actual maintenance of machineries during three-month onboard training. Participant 4 and 5 are also engineering course students who possess one-year onboard experience on the training ship. In one year, they experienced more detailed machinery operation in training ship. M/E, D/G. pumps and purifier maintenance are carried by student with helps of engineers onboard. Participant 5 has three years on board experience as ta grade 3 engineer on board the training ship. Participant 7 has seven years onboard experience in several types of vessels and experienced as a grade one engineer. Participant 8 has 15years on board experience as chief engineer in training ship. In the result section, five groups were formed by difference of onboard experience. All participants have no prior exposure to tasks in this evaluation experiment by simulator environment.

Table 1. Onboard experience of participants.

Participant	Onboard experience
1	3month onboard training ship, student of marine engineering
2	3month onboard training ship, student of marine engineering
3	3month onboard training ship, student of marine engineering
4	12month onboard training ship, student of marine engineering
5	12month onboard training ship, student of marine engineering
6	3years onboard, Third engineer experience.
7	7years onboard, First engineer experience.
8	15years onboard, Chief Engineer experience.

2.3. Data collecting

This study utilized the View Tracker 3 (Ditect Co., Ltd., Tokyo, Japan) for eye-tacking measurement device. This eye tracking measurement device has been used in several research fields such as consumer eye tracking evaluation research (Charusiri et al., 2021), situation awareness research in nursing training (Sugimoto et al., 2024) and cognitive impairment research in medical science field (Tamura et al., 2024). View Tracker 3 show in Fig.1 consist of world camera which capture the view image of participant sight sampling by 200Hz. Eye camera is devised to capture pupils of participant sampling by 30Hz. The device is connected to portable PC by USB3 cable from end of clip shown in figure. Captured image data will be collected in original View Tracker 3 software in connected PC.

To start capturing image data, participant will carry out calibration program to adjust the initialization of the eye-tracking. Calibration program will require participant to gaze circle figure in center and each corner of monitor which will be used for evaluation experiment. The consistency of gaze point and programmed monitored points will be checked automatically. After completion of the calibration program, participants will start an evaluation experiment which is the second step of this study. An evaluation experiment detail will be explained to participant which is to observe created pumps animation. As explained in 2.1 animated machinery images above, the first animation is Axial piston pump" animation and its duration is 15sec. This 15sec animation will repeat 3 times and one pumps evaluation experiment time will be total 45sec. Evaluation experiments of the second animation, "Gear pump" and the third animation "Centrifugal pump" were carried out and eye-tracking data of eight participants are collected.



Figure 1. View Tracker 3.

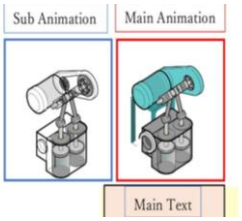


Figure 2. Example of animation and area definition

2.4. Data Analysis

The data collected via View Tracker 3 were analyzed frame by frame for the gaze points of each participants through machine learning. In the machine learning process, areas of each pump animation are defined in three locations as shown in Figure 2. The number of gaze points that fell within the defined areas of main animation, sub animation, and main text, as well as the number of gaze points outside these areas were automatically analyzed. This machine learning utilized self-created image recognition programming and analyzed the ratio of total gaze points collected from each participant's evaluation experiment. The evaluation experimental duration is fixed in 45 sec across all participants. However, due to varying operational conditions of the PCs used for data collection, the total number of frames are differed among participants. Therefore, the ratio of total gaze points was analyzed and compared for each participant. The gaze point duration is calculated by ratio times total evaluation experiment duration which is 45 sec. The determination of image collection areas was made and the reliability of gaze points are programmed 0.8 or above. If a participant gaze point reliability fell due to loss of pupil data such as blinking or other factors, those instances were excluded from the analysis data.

3. Experiment result and consideration

3.1 Experiment Result

Result of eight participant's evaluation experiment for "Axial piston pump" is shown in table 2. As mentioned in the explanation of data analysis, total number of gaze points is collected through machine learning. Ratio of gaze point that fell within the defined areas are indicated as percentage unit. Then calculated by total evaluation experiment duration 45 sec for each ratio of gaze point are indicated as second unit in the table.

Table 2. Result of "Axial piston pump"

Participant	Main Text	Main Animation	Sub Animation	Out of Area
1	21.70 sec / 48.22 %	5.08 sec / 11.28 %	14.57 sec / 32.37 %	3.66 sec / 8.13 %
2	15.32 sec / 34.05 %	9.73 sec / 21.61 %	19.95 sec / 44.34 %	1.46 sec / 3.24 %
3	18.15 sec / 40.33 %	7.88 sec / 17.52 %	1.79 sec / 3.97 %	15.81 sec / 35.13 %
4	20.79 sec / 46.20 %	16.55 sec / 36.77 %	6.90 sec / 15.34 %	0.76 sec / 1.69 %
5	12.00 sec / 26.66 %	18.25 sec / 40.56 %	11.01 sec / 24.47 %	3.74 sec / 8.32 %
6	8.00 sec / 17.78 %	17.19 sec / 38.20 %	14.93 sec / 33.19 %	4.54 sec / 10.10 %
7	25.41 sec / 56.56 %	6.01 sec / 13.35 %	12.45 sec / 27.66 %	1.14 sec / 2.53 %
8	14.47 sec / 32.16 %	25.03 sec / 55.63 %	5.30 sec / 11.77 %	0.20 sec / 0.44 %

From the result of participants 1 to participant 3 who have 3month onboard training experience, the ratio and gaze point duration of main text is higher compare to main animation. Except participant 2, gaze point ratio of main text is exceeding 40%. Taking into consideration this result, gaze point duration of main animation will be less than 10 sec which is describing machinery movement. Participant 3 analysis data resulted the gaze point ration fell within the out of defined are higher compare to other participant. The result of participant 4 who has 1year onboard training experience indicated the gaze point duration of main text is higher compared with the other defined areas. On other hand, participant 5 also who has 1year on board training experience result shows gaze point ratio of main animation is highest compared with other defined area. Also, participant 6 and participant 8 result indicate gaze point ratio of main animation is highest. Participant 7 who has 7years on board experience result indicate more than 50% of gaze point ration has fallen in main text area and only 6 sec is in main animation. Participant 8 who has longest onboard

experience resulted highest gaze point ration is fell in main animation and then gaze point ration for main text was 32 %.

The results of "Axial piston pump", "Gear pump" and "Centrifugal pump" gaze point duration is shown in Figure 3 to Figure 5. Figures indicate gaze point duration in Y-axis and X-axis indicate onboard experiences.

As shown in Figure 4, all participants fixate more on main animation compared to main text defined area. Also sub animation gaze point duration is lower compared to other defined are except several participants who have 3 month onboard experiences. Standard deviation of 3 month onboard experience group resulted 2.50 for main text, 3.20 for main animation and 4.09 for sub animation. Standard deviation of 12 month onboard experience group resulted 3.31 for main text, 0.15 for main animation and 0.64 for sub animation. The result of Figure 5 "Centrifugal pump" indicate similar result to result of "Gear pump". All participant result fixates more on main animation compared to main text. Participant who has 3 years on board and 7 years onboard experience result indicate that gaze point duration of sub animation is longer than main text. Standard deviation of 3 month onboard experience group resulted 1.51 for main text, 4.15 for main animation and 5.46 for sub animation. Standard deviation of 12 month onboard experience group resulted 1.67 for main text, 0.69 for main animation and 1.45 for sub animation. From results of three pumps animation eye tracking data indicate that "Gear pump" and "Centrifugal pump" gaze point duration patterns had similar tendency for all participants but result of "Axial piston pump" indicated in Figure3. had different gaze pattern across participants.

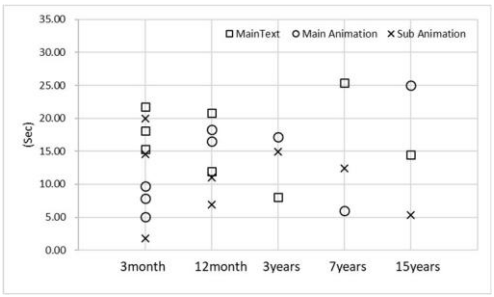


Figure 3. Result of "Axial piston pump"

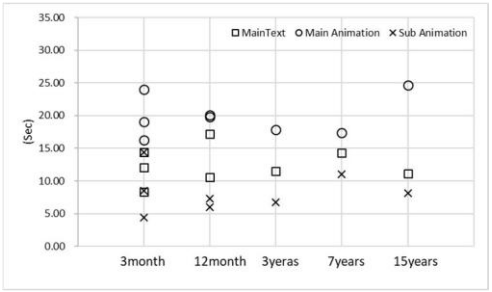


Figure 4. Result of "Gear pump"

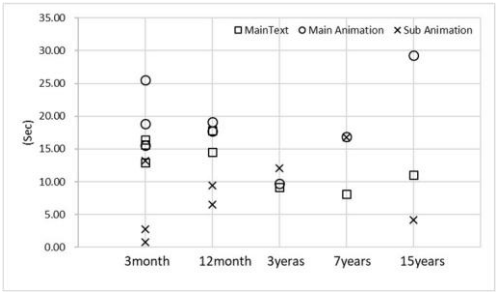


Figure 5. Result of "Centrifugal pump"

3.2 Consideration

From the results of "Axial piston pump" eye-tracking data indicated different gaze pattern by onboard experiences. If we consider participants who have 3month onboard as beginner engineers with less experience and knowledge of machinery operation, result of gaze point duration may consider that they are focused on main text to try to understand pumps operation method. Result of standard deviation will supplement this consideration, which resulted 3month group main text was 2.50 which was lowest number compare to other defined area. Participants who has 3 years and 15 years onboard experience, whom can be considered as "well trained engineers" and the participant 5 who has 12 month onboard experience, fixate more on main animation compared to main text defined area. This result may be considered as that they are already aware of machinery operation and their interest is focused on animated machinery movement such as piston and inclined plate rotation movement.

From the result of "Gear pump" and "Centrifugal pump" eye tracking data, it is evident that the consideration of onboard experience differences which suggested the above "Axial piston pump" gaze point

duration which showed different pattern. For these two types of pump animation resulted that all participants fixate more on main animation compared to main text defined area. This result may suggest that these two types of pump operation is more simple compare to axial piston pump and participants are aware of its operation experience. Further, the beginner engineers as students of marine engineering course have several chances to learn about operation and fluid movement in class and training ship experience. These knowledge and experience of beginner participants may result in the same tendency compared with well-trained engineers. In this study we did not collect subjective data such as questions or comments from participants and eye- tracking data were collected and analyzed by purpose of objective data. Participants eye-tacking data are assumed as behavioral characteristic and situation awareness. The result of "Axial piston pump" may suggest difference of onboard experience and their technical skill and situation awareness by gaze point duration. The result of "Gear pump" and "Centrifugal pump" may suggest that fixation of main animation for all participants and their interest as situation awareness was described by eye-tracking data analysis.

4. Conclusion and future study

This study focused evaluate participants' technical skills of machinery operation and behavioral characteristics such as situation awareness by using eye-tracking measurement devices. In this study, we attempted to detect the knowledge and situational awareness based on their onboard experience by measuring gaze point ratio and duration. Endsley (1995) defines model of situational awareness as "Level 1: Perception of the elements in the environment, Level 2: Comprehension of their meaning, and Level 3: Projection of the status in the near future". Regarding this model, the findings of this study suggest that level 1 and level 2 could effectively measure by conducting evaluation experiment and using eye-tracking measurement devices. Perception of the elements were measured and evaluated by participants eye movement during observations, which created different types of pump animations. Comprehension of meaning were suggested from the result considered by difference of defined areas with different group of onboard experiences and their knowledge.

For the future study, it is necessary to establish a method of presenting information that suggest the areas to focus on and the amount of information received do not fluctuate to implement effective training and education. Additionally, the defined area of machinery learning used in data analysis is necessary to configure for gaze point ratio of out of area. Furthermore, it is essential to increase that participant who have different onboard experiences to increase robustness of this study's findings. In conclusion, we consider that training and education using simulator and detailed machinery animation that supplements the knowledge and the experience gained from onboard sea service would be useful in improving the technical skills and situational awareness to provide safe machinery operations for engineers.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Safe operator dependence on automation in MASS 1 and MASS 2: A systematic review on the interaction between perceived risk and trust calibration

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Abstract: Maritime Autonomous Surface Ships (MASS) will transform seafarer roles and redefine human responsibilities. Despite reduced onboard personnel, human involvement remains essential across all levels of autonomy, making trust in automation pertinent to the safety of MASS. Trust is influenced by perceived risk and predicts an operator's willingness to depend on automation. Poor trust calibration can manifest as over- trust or under-trust in automation and can lead to safety-critical failures. Across all degrees of MASS autonomy, understanding the relationship between perceived risk and trust in automation is critical to reduce incidents caused by human misuse or disuse of automation. However, conceptual and methodological inconsistencies have returned fragmented findings on the risk-trust interplay, limiting the application of existing research. The safety and resilience of MASS will rely not only on system intelligence and design but also on the training and competence of human operators. There is urgency for maritime training solutions to maintain and recover trust calibration in dynamic, high-risk scenarios. The findings of this systematic review identify gaps in maritime research, highlighting the need for empirical studies to investigate how perceived risk affects human trust in automation. This will support proactive strategies, regulations, and policies to ensure safe and effective human- MASS integration.

Keywords: Human-Automation Interaction; Maritime Autonomous Surface Ship; Perceived Risk; Trust calibration

1. Introduction

While the aviation, automotive, and rail industries have rapidly advanced in automation, maritime technology adoption and related regulatory frameworks have progressed more slowly (Mallam et al., 2019). Despite this slower pace, ships have continuously integrated technological innovations, including automated radar plotting aids (ARPA), global positioning systems (GPS), automatic identification systems (AIS), global navigation satellite systems (GNSS), and electronic chart display and information systems (ECDIS), which significantly transform navigation tasks previously reliant on manual processes. Historically, seafarers have demonstrated resilience and adaptability to these technological shifts, prompting mixed opinions over concerns about human adaptation to Maritime Autonomous Surface Ships (MASS). The preliminary definition for a MASS, as stated by the International Maritime Organization (IMO), is a ship which can operate to varying degrees, independent of human interaction (IMO, 2022). However, as onboard human presence diminishes under Degrees 1 and 2 of MASS autonomy, prior to the complete removal of seafarers envisaged in Degrees 3 and 4, interdisciplinary research is essential to understand and manage the evolving dynamics of Human- Automation Interaction (HAI) and the transformation of seafarer roles.

Automation has the potential to create new error pathways and can delay error detection and recovery (Lützhöft and Dekker, 2002). Trust is a significant determinant of human dependence in HAI, therefore inappropriate trust, whether in the form of misuse (over-trust due to overestimating automation capabilities) or disuse (under-trust leading to rejection of automation), frequently results in significant operational risks and costly, adverse outcomes (Parasuraman and Riley, 1997). Historically, seafarers' trust in automation has shaped the usage and safety of newly adopted automated systems in maritime operations (Harati-Mokhtari et al., 2007). A prominent example is the grounding of the Royal Majesty cruise ship in 1995,

which remains a highly relevant case study in HAI failure. The vessel grounded after a failure in the GPS antenna cable caused the receiver to revert to Dead Reckoning mode yet continued to display position data as if satellite input were still active. The bridge crew's reliance on the inaccurate GPS display without cross-checking the data illustrates excessive trust in automation, likely influenced by low perceived risk of failure due to the system's proven reliability and reputation (Lützhöft and Dekker, 2002).

Inappropriate trust in HAI has contributed significantly to maritime incidents. For example, following the 2005 mandate for AIS use under the IMO's Safety of Life at Sea (SOLAS) Convention, unfamiliarity, inadequate training, and low trust in automation affected seafarer dependence on AIS, resulting in at least three collisions that year (Harati-Mokhtari et al., 2007). In contrast, recent groundings involving vessels such as *Priscilla*, *MV Kaami*, *Lauren Hansen*, *Ruyter*, and *Lysblink Seaways*, illustrate the dangers of excessive trust toward systems such as autopilot and ECDIS, exemplifying the consequences of inappropriate trust in automation (Chan et al., 2023). However, attributing HAI failures solely to individual human error, risks overlooking broader systemic issues including inadequate organisational safeguards, insufficient training, and error-intolerant system designs that fail to compensate for human misjudgement. Reason (2000) describes how a seemingly minor event can trigger a cascade of communication and management failures between human operators and automated systems, calling this the Swiss Cheese Effect. Human error is an inevitable part of maritime operations (Lützhöft et al., 2019), which reinforces the need for research into new competencies, training, and HAI educational strategies to ensure a safe transition toward greater levels of maritime autonomy.

Trust acts as a mechanism through which humans manage risk and uncertainty (Li et al., 2019). According to Hoff and Bashir (2015), HAI research commonly identifies two trust components: 1) subjective trust, an attitude encompassing cognitive and affective dimensions; and 2) behavioural trust, which occurs when an individual actually takes a risk. Trust in automation correlates strongly with perceived risk (He et al., 2022; Li et al., 2019), defined as beliefs regarding the likelihood of positive or negative outcomes beyond considerations specific to the relationship with a particular trustee (Mayer et al., 1995). Perceived risk comprises two constructs: 1) Perceived Relational Risk (PRR), the belief that an interaction with a technology, system, or person may have negative outcomes; and 2) Perceived Situational Risk (PSR), the belief that a specific task or context may lead to negative outcomes (Stuck et al., 2022). Consequently, individual risk tolerance significantly influences dependence on automation (Naiseh et al., 2025). As described in Figure 1. trusting automation involves willingly accepting risk by delegating responsibility to the system (Lee and See, 2004).

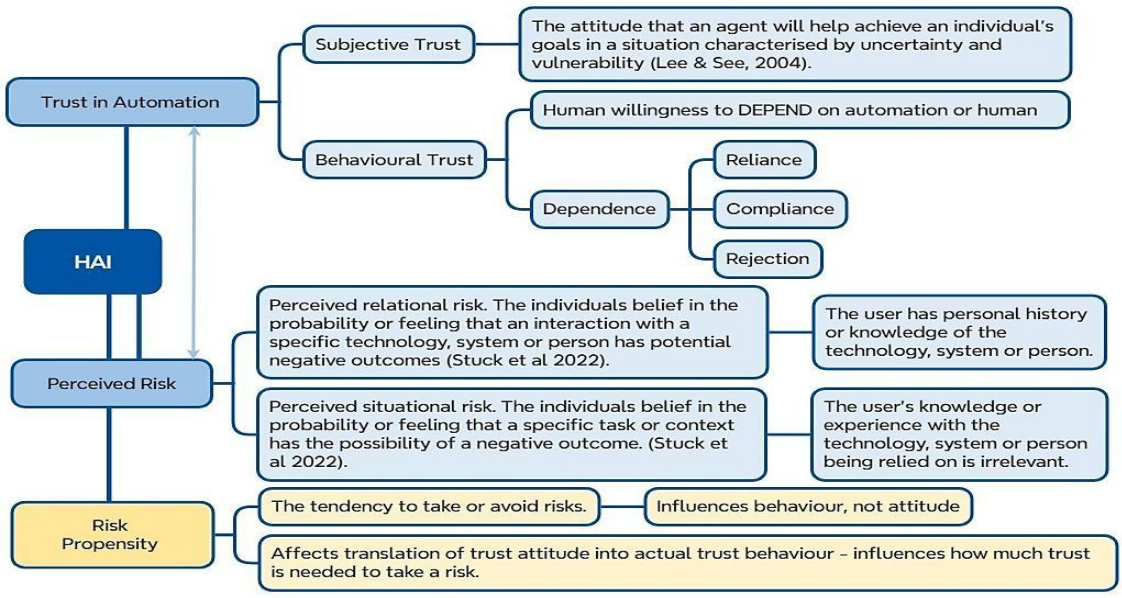


Figure 1. Constructs of trust and perceived risk in human-automation interaction.

Maintaining trust that accurately reflects an automated system's capabilities, termed trust calibration, is essential for safe and effective dependence in complex environments (Parasuraman and Riley, 1997). Understanding the dynamics between risk perception, trust, and HAI is critical for mitigating the human factor risks of MASS. However, research on how perceived risk influences operator behaviour during

interactions with automated systems remains limited (Fahnenstich et al., 2024; Hu et al., 2024). Additionally, existing studies often inadequately address the distinct dimensions of risk and trust that shape operator behaviour, resulting in fragmented understanding and inconsistent guidance.

2. Rationale

Seafarers operating MASS must prioritise safety, adhere to established procedures, and maintain confidence in their decisions. Effective team interaction depends on appropriately calibrated trust in automation, especially as MASS progresses to higher degrees of autonomy and remote operation centres (Madhavan and Wiegmann, 2007). Trust is not static but an emergent property that evolves in response to new information and changing circumstances (Hoffman, 2017). The mixed-autonomy maritime environment introduced by MASS generates novel situations in which various actors perceive risk differently, reflecting the inherently subjective nature of both risk perception and trust.

Understanding how perceived risk influences trust behaviour in high-stakes decision-making requires analysing how seafarers evaluate the capabilities, reliability, and performance of autonomous systems, PRR's, and how this shapes trust attitudes and subsequent behaviours (Stuck et al., 2022). It is equally important to examine how environmental or contextual risks, or PSR's, affect seafarers' dependence on automation. To date, these constructs have not yet been empirically isolated or assessed.

Most research uses static measures of trust and risk, overlooking the dynamic cognitive processes involved in real-time decision-making, particularly in time-critical emergencies. This is particularly relevant in MASS contexts, where seafarers must interact with multiple autonomous systems operating at varying levels of autonomy. In such settings, the perceived risk fluctuates, influencing decisions to comply with, rely on, or override automation. The absence of a comprehensive framework to explain how perceived risk influences trust, and affects decision-making, poses a significant threat to operational safety (Stapel et al., 2022).

The literature review presented in this paper identifies studies that examine the relationship between perceived risk and trust in automation across safety-critical industries. Specifically, it assesses whether existing research provides insight into dynamic trust calibration processes, which are essential for adapting to fluctuating risk conditions and maintaining appropriate trust levels across diverse MASS operator profiles and contexts. The review presents a synthesis on how perceived risk constructs influence trust in automation, while also mapping relevant theories and methodological approaches. These insights support the development of practical and scalable frameworks to inform seafarer decision-making in MASS 1 and MASS 2 operations, where human autonomy is progressively diminished.

3. Method

3.1. Research Methodology

This review adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. PRISMA is widely recognised for enhancing the transparency, rigor, and reproducibility of systematic reviews (Aromataris et al., 2024). PRISMA's structured approach and guidelines support the synthesis of heterogeneous evidence, which is particularly suited to this review given the diversity of study designs, contexts, and measures used to investigate the multidisciplinary dimensions of trust and perceived risk in HAI. The PICO (Population, Intervention, Comparator, Outcome) framework (Methley et al., 2014) was applied to develop search terms based on the following concepts:

Population: Seafarers operating MASS with varying levels of autonomy.

Intervention: An increase in perceived risk during HAI, whether sudden or anticipated.

Comparator: Routine operational conditions with low perceived risk and calibrated trust in automation.

Outcome: Trust calibration, appropriate dependence, and safe decision-making in risky situations.

3.2. Inclusion Criteria

Studies were included in the primary search if they met the following criteria: 1) published between January 1, 2012, and the present, aligning with the commencement of the MUNIN project; 2) published in English; 3) empirical in nature (quantitative or mixed methods), explicitly addressing perceived risk and trust in automation; and 4) conducted in safety-critical industries, such as military, maritime, aviation, healthcare,

and automotive sectors. Non-empirical studies (e.g., theoretical papers, literature reviews, or purely qualitative research) or outside safety-critical contexts (e.g., general technology acceptance in smart devices, social media, public acceptance, or chatbots) were excluded to maintain focus and relevance to MASS.

3.3. Search Strategy and Screening Process

Owing to multiple synonyms describing MASS, perceived risk, trust in automation, and human-automation interaction, the search strategy was developed following PRESS electronic search guidelines (McGowan et al., 2016). To capture both peer-reviewed and grey literature, searches were tailored to database- specific syntax, including Boolean operators, wildcards, and proximity functions. Searches were conducted in multidisciplinary databases (Scopus, Web of Science, ProQuest, and EBSCOhost), computing and automation databases (ACM Digital Library, and IEEE Xplore) and APA PsychInfo to access the literature from human factor research. Maritime-specific sources included the World Maritime University (WMU) Digital Repository.

A comprehensive search combining all four PICO concepts (MASS, Risk, Trust, and HAI) returned 24 records, of which only one remained after manual screening. To broaden the scope, a second systematic review was conducted without the maritime restriction (i.e., Risk, Trust, and HAI). Following de-duplication manual screening of 82 results from the WMU Repository (71 excluded) and exclusion of 46 grant-related records, 1,524 documents remained. Of these, 181 were deemed potentially relevant and the full texts were retrieved.

Using Endnote, an electronic keyword search for 'risk' AND 'trust' narrowed the records to 119, which were then manually screened to include only those addressing risk and trust in automation. Owing to the varied terminology, this could not be done electronically. A final screening excluded studies not in safety-critical domains, lacking empirical data, and omitting perceived risk/trust measures or behavioural dependence. This process resulted in 15 retained records from the second review, combined with the initial review result for a total of 16 records for analysis. Manual review was essential to ensure that relevant insights into risk, trust, and HAI, often embedded in broader studies, were not overlooked by automated tools.

4. Results

4.1. Studies investigating perceived risk and trust in human-automation interaction

The reviewed literature demonstrates substantial variability not only in the findings but also in the methods, theoretical frameworks, and empirical approaches employed to investigate trust and risk within HAI contexts. Table 1 summarises the reports retrieved from the systematic review.

Table 1. Systematic review results on the interaction between perceived risk and trust calibration.

Study	Variables Independent & Dependent	Key Findings
Ajenaghughrure et al. (2020).	I – risk. D - trust, delegation.	Risk negatively affects trust in automation. As risk increases users delegate less control to automation.
Azevedo-Sa, Zhao et al. (2021)	I – reliability, visibility. D - trust, monitoring.	High reliability increases trust and decreases operators' monitoring. Low visibility increases monitoring and does not influence trust.
Azevedo-Sa, Yang et al. (2021)	I – reliability. D – trust.	Trust dynamics are slow to change.
Cummings et al. (2021).	I – controllability, observability. D - perceived risk, trust, performance, confidence.	Perceived risk negatively correlates with trust & self-confidence, which are highly correlated with each other. Perceived risk increases with task complexity. Risk-taking behaviour increases with higher trust, and lower perceived risk.
Elder et al. (2022).	I - reliability. D - trust behaviours, trust in AI.	Reliance is higher in high reliability conditions. Negative outcomes attributed to AI decrease trust.
Fahnenstich et al. (2024).	I - human vs. AI support, risk. D - trust attitude & behaviour.	Trust behaviour increases under higher risk. Human support agents are perceived as more responsible for negative outcomes.
He et al. (2022).	I - risk D - perceived risk, trust	Trust is moderated by experience & cognitive load. Event criticality increases perceived risk & reduces trust.

Hoesterey and Onnasch (2023).	I - situational risk. D - trust attitude & behaviour.	Trust attitude increases with reliability and is not affected by risk. Trust behaviour is lower under high-risk conditions.
Hu et al. (2024).	I – event risk. D - perceived risk, behaviour, trust.	Increased perceived risk affects psychological state and behaviour and leads to lower trust. Trust behaviour decreases as risk increases.
Li et al. (2019).	I - reliability, situational risk. D – PSR, PRR, trust.	High-reliability information & low situational risk increase trust while decreasing PRR. Low trust will result in high PRR.
Liehner et al. (2022).	I - context, risk, reliability, D – trust, reliance.	Context and risk impacts reliance; personal risk reduces reliance more than property risk. Reliability increases trust and reliance.
Pearson (2019).	I - analytical risk, affective risk. D – trust, reliance.	Trust is more predictive of reliance at higher analytical risk levels. Trust and reliance increase as affective risk increases.
13. Sadler et al. (2016).	I - transparency, risk. D – trust, reliance.	Trust and reliance increase with higher transparency. Increased risk reduces trust, leading to higher automation rejection.
Sato et al. (2020).	I - task load, risk. D – trust, perceived risk, performance.	Perceived risk elevates trust (performance & process) under high- load conditions. Perceived risk increases trust despite reliability.
Simon et al. (2024).	I - transparency, risk. D- trust, perceived risk, compliance.	High perceived risk with low trust increases compliance. Environmental transparency increases perceived risk.
Stapel et al. (2022).	I - automation, conditions. D - trust, reliance, perceived risk.	Trust is higher in monotonic conditions than in engaging conditions. Post-drive trust & perceived risk are positively correlated.

The studies presented in Table 1 adopted diverse experimental setups, including driving simulators (study's 1, 2, and 3), real-world vehicle testing (study 16) and decision-support models in AI-assisted operations (study 5). Trust in automation was inferred through self-reported ratings, behavioural compliance, and physiological indicators (e.g., heart rate, galvanic skin response, eye tracking). Trust has been shown to be dynamic, shifting with system performance (study 3) task demands (study 5), and environmental conditions (study 1). Risk conceptualisations varied, with some studies emphasising PSR (context-specific threats) and others focussing on PRR (confidence in the system). Azevedo-Sa, Zhao et al. (2021), distinguished between internal (system reliability) and external (visibility) risk. Li et al. (2019), also noted differing impacts of risk types, revealing clear distinctions between PRR and PSR. Hoesterey and Onnasch (2023) and Fahnenstich et al. (2024) were the only authors to clearly differentiate subjective trust (attitude) from behavioural trust (actual reliance on automation).

Individual differences, such as risk propensity, automation experience, and cognitive load, were influential in shaping trust dynamics. He et al. (2022) quantified personal characteristics and found that inexperienced drivers and female participants were more sensitive to risk. Cummings et al. (2021) reported risk-taking increased as participants neared their goal, calling this phenomenon "get-home-itis". Trust in automation tends to increase under high-stakes conditions (Fahnenstich et al., 2024), although Liehner et al. (2022) noted that trust varied by context, with the highest automation reliance in warehouse scenarios and the lowest trust in medical environments. A recurring trend was the emphasis on automation transparency and reliability as a mechanism to foster trust (study's 4, 6, 11, 13, and 15). However, Simon et al. (2024) cautioned that the influence of transparency on operator compliance must be critically assessed across diverse operational contexts.

While some studies addressed decision-making (study's 4 and 11) they did not investigate how perceived risk influences trust and dependence over time. Trust dynamics vary significantly across industries (aviation, maritime, and healthcare) and operational contexts (e.g., high-risk vs. routine operations). Pearson (2019) reported that cognitive risk types (analytical vs. affective) affect delegation decisions across automation stages: analytical risk reduces reliance, whereas affective risk increases it. Hu et al. (2024) observed that while efforts have been made to model trust dynamically, the literature lacks robust quantitative frameworks capable of capturing the abstract, subjective, and probabilistic nature of trust in automation.

4.1. Interaction Between Perceived Risk and Trust

Perceived risk was manipulated through task difficulty, environmental uncertainty, and the potential for adverse outcomes. Across the 16 studies, a consistent relationship was observed between perceived risk and trust in automation. Several studies have reported strong negative correlations between perceived risk and trust in automation; some positioned perceived risk as an antecedent of trust, while others presented it as a consequence (He et al., 2022). Interestingly, moderate levels of risk, especially under high workloads, were associated with an increased reliance on automation, suggesting that cognitive overload may shift trust dynamics (Sato et al., 2020). The directionality of the trust-risk relationship and its behavioural implications require further investigation (Fahnenstich et al., 2024). Enhancing trust in automated systems requires addressing users' perceptions of risk and reliability, as these significantly affect their willingness to delegate tasks to machines (Liehner et al., 2022).

4.2. Gaps Identified by the Systematic Review

A recurring concern among authors is the absence of cohesive scientific literature on human factors and automation and the need for foundational contributions to guide future research on human-autonomy trust and risk perception in decision-making (study's 1, 3, 6, 7, 9, 12, 13, 14, 15, and 16). Several authors emphasised the need to clarify the dynamic relationship between perceived risk and trust, including how constructs such as situational risk, relational risk, and individual risk propensity interact with subjective and behavioural trust (Azevedo-Sa, Yang et al., 2021; He et al., 2022). Sato et al. (2020) called for practical recommendations to enhance seafarer training, automation design, and regulatory policies to support safe human-automation collaboration. Cummings et al. (2021) advocated for research on trust calibration in mixed-autonomy environments, focussing on how operators adjust behaviour in response to biases shaped by perceived risk and trust. Finally, Hu et al. (2024), stressed the importance of bridging the gap between theory and practice by developing dynamic and quantitative trust models to produce actionable insights.

5. Discussion/Conclusion

In high-stakes environments involving autonomous agents such as MASS, ensuring calibrated trust is critical (Chancey et al., 2024). The findings by Simon et al. (2024) indicated that risk perception can override trust in high-stakes scenarios, suggesting that trust alone is insufficient to drive decision-making under uncertainty. While this highlights the importance of developing a robust theoretical framework for future empirical studies, the interaction between perceived risk, trust attitude, trust behaviour, and ultimate reliance on or rejection of automation is more complex than current research often reflects.

Perceived risk is a multifaceted and affectively driven construct, and its role in shaping trust and behaviour in HAI deserves greater empirical scrutiny. Affective responses to risk are foundational to human survival and decision-making, influencing both how individuals assess automation and how they behave in operational settings (Visschers and Siegrist, 2008). Studies must account for both perceived relational risk (internal/system- based) and perceived situational risk (external/context-based), while recognising that individual traits such as risk propensity, personal experience, personality, and cognitive state also influence outcomes (Jin et al., 2020).

The variability of findings across HAI studies points to limited consensus on the roles and determinants of trust. While trust has long been considered a predictor of decision-making (Hoff and Bashir, 2015), its affective dimensions remain underexplored (Wildman et al., 2024), and its role in mediating or moderating perceived risk remains contested. Building on broader risk-perception work, Sjöberg (2001) identified beliefs about unknown consequences as the primary factor influencing perceived risk, suggesting that behaviour should be studied as a function of the situation rather than within a situation, emphasising cognitive expectations over trait-based explanations.

Other studies, such as Wang et al. (2020) have revealed that risk-taking behaviours can fluctuate with operational duration and conditions, such as sleep deprivation and reduced stimulation during extended container voyages. These insights highlight the importance of theoretical and methodological models grounded in the realities of cognitive and affective human behaviour in high-risk environments. As such, the absence of a unified framework that integrates perceived risk, trust, and decision-making presents a significant challenge. The current literature tends to emphasise static correlation analysis and qualitative mechanisms, with insufficient integration of real-time trust calibration or behavioral modelling (Hu et al.,

2024). There is a critical need for more comprehensive research integrating real-time trust assessments with trust attitude, trust behaviour, and perceived risk across varying autonomy levels and situational contexts. Without such frameworks, strategies for proactively managing human factors in autonomous maritime operations remain limited.

In conclusion, this review reveals that despite increasing interest in trust and perceived risk within HAI, the literature remains fragmented and limited, particularly in contexts relevant to MASS. Notably, only one maritime-specific study was identified: Simon et al. (2024), which examined risk and trust in relation to automated predictive maintenance tools for maritime engineers. This highlights a significant knowledge gap in understanding how seafarers perceive, interpret, and respond to risk during interactions with systems of varying levels of automation. Addressing this gap requires both theoretical consolidation and empirical research focused on the maritime domain. Such work is essential for developing evidence-based frameworks that can guide training, regulation, and system design for MASS operations that retain a human operator's critical role in ensuring safety under autonomy.

Acknowledgements

The authors acknowledge the financial support of the Blue Economy Cooperative Research Centre (BE CRC), established and supported under the Australian Government's Cooperative Research Centres Program, grant number CRCXX000001. The authors acknowledge Glenn Mulcaster and Nat Enright, research librarians from the University of Tasmania, for their guidance and peer review of PRISMA protocols and procedures.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Considerations for the Experience of Multilingual MET Students using Virtual Reality

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Abstract: Research indicates that Virtual Reality (VR) can be used as a beneficial experience-based learning platform for education. This disruptive technology has the potential to create new opportunities and enhance Maritime Education and Training (MET). However, most of the research completed on best practices and design for VR based experiential learning has been focused on monolingual, English only, speaking participants. Since most mariners worldwide are multilingual, this gap in research has created the potential for misinformed design practices for those creating and using VR learning resources (Gilmartin, 2024).

This paper discusses the implications on future use of VR considering the findings from an interpretive phenomenological (Heidegger et al., 1962) study by Gilmartin (2024) that explored the experience of both monolingual and multilingual MET students when using a VR Learning Experience. The study used interviews, observations, and think-aloud responses to interpret the experience of students at two MET institutions, one in the United States and the other in Croatia. While focusing on the self-view of the participant's experiences, this study identified that although the participants did not recognize an influence of language upon their experience, individual cultural and personal backgrounds did influence the way the participants approached and interpreted their experience using the VR Learning Experience.

Keywords: virtual reality, maritime education and training, multilingual students, cultural influence

1. Introduction

Maritime Education and Training Institutions (METs) rely heavily on a variety of experience-based learning opportunities within their training programs. Much of this is due to the Standards of Training, Certification, and Watchkeeping (STCW) regulations outlining sea time requirements and use of simulator training. However, METs generally wish to integrate more experience-based training than the minimum required by STCW. Unfortunately, it is difficult to arrange for time onboard commercial vessels, and it is expensive to run a training vessel. Simulators are a little more flexible, but they are also extremely expensive and most METs are limited in how many simulators can be purchased and maintained.

Virtual Reality (VR) is a disruptive technology that provides new opportunities for experience-based learning. VR tends to be less expensive and more flexible when compared to traditional experience-based learning platforms (Gilmartin, 2024). There has also been a considerable amount of research identifying that VR can be a beneficial experience-based learning platform (Kenna & Potter, 2018; Lau et al., 2018; Long et al., 2020). However, most of this research was conducted on monolingual, English only speakers. This created a significant gap in understanding how to use VR to support MET programs for experienced-based learning, particularly since most MET students are multilingual.

In the dissertation, *VR and Language: Investigating the experience of multilingual learners who use virtual reality*, Gilmartin (2024) investigated how multilingual MET students viewed their experience of using VR to learn by exploring the research question, "What is unique about the experience which multilingual learners have when using VR for experiential learning when compared to monolingual English only learners?". There were several findings from this study, indicating that the question of whether language has an impact on the experience of an MET student using VR is complicated. The findings indicated that the entire social identity of the student, including language, culture, and prior experiences, shapes the way that an

MET student views their experience. These findings have significant implications for MET professors and institutions that intend to use this disruptive technology within their programs.

2. Study Methodology

The study conducted by Gilmartin (2024) used an interpretive phenomenological (Heidegger et al., 1962) approach to explore the experience of a multilingual MET student using VR to learn maritime related subjects by focusing on their own self-view of their experience. The data was collected using observations, a pre and post experience interview, and a think-aloud protocol to encourage the participants to speak their thoughts aloud while engaging with the VR learning experience. This allowed Gilmartin to identify the experiences observed by the student before, during, and after they used the VR learning experience. The sessions began with a pre- interview, continued with the participant using the VR Learning Experience while Gilmartin used the think- aloud protocol to ask probing questions to keep the participant speaking their thoughts and feelings aloud, and ended with the post-interview. The sessions were recorded using a video camera and recording the screen view of the VR headset. This allowed Gilmartin to align what the participant was saying and doing with what they were seeing within the VR headset (see Figure 1).



Figure 1. Alignment of screencast and video recording for observations (Gilmartin, 2024)

These video recordings were used to collect observations and a transcript that was turned into memos and coded using the Cognitive Affective Model of Immersive Learning (CAMEL) model (Makransky & Petersen, 2021). The CAMEL model was chosen to identify the codes for this process because it is a currently accepted model used when designing and creating immersive VR learning experiences. The CAMEL model explains that VR Instructional Design should focus on using the technical factors (immersion, control factors, and representational fidelity) to create the VR affordances (presence and agency). When these are designed correctly, the affective and cognitive factors (interest, motivation, self-efficacy, embodiment, cognitive load, and self- regulation) are engaged, directing the student towards learning. This model was designed after conducting research on monolingual students using VR to learn so it is possible that it does not consider the unique needs of multilingual students. The codes identified from the CAMEL model were “interest”, “motivation”, “self- efficacy”, “embodiment”, “cognitive load”, and “self-regulation”. During this coding process, the codes of “background information”, “language”, and “culture” were added as it was identified as common themes during the coding process.

The participants were recruited from two METs, one from the United States, SUNY Maritime College (SUNYMC) and the other from Croatia, University of Dubrovnik (UNIDU). The sample was limited to students in an MET program were beyond their first year in the program and felt comfortable using Maritime English. This ensured that all participants had the required baseline knowledge to understand and learn from the VR learning experience they were interacting with. The participants included six participants from SUNYMC and five participants from UNIDU. Three participants were monolingual speakers, and the remaining eight participants were multilingual. Two participants had no experience using VR before, five participants had some experience using VR before, and three participants had a lot of experience using VR before. These participants were given a pseudonym to protect their identity for the study (see Table 1).

Table 1. Participant Demographic Breakdown (Gilmartin, 2024)

Pseudonym	Institution	Age	Gender	Race/ Ethnicity	Language(s)	Previous VR Use
Robert	SUNYMC	19-25	Male	White	English	Some
Joseph	SUNYMC	Prefer not to say	Prefer not to say	Prefer not to say	English and ASL	A lot
Jacob	SUNYMC	19-25	Male	No Response	English	Some
Brian	SUNYMC	19-25	Male	White	English	None
Jessica	SUNYMC	19-25	Female	White	English, French	A lot
Faizan	SUNYMC	19-25	Male	Middle Eastern	English, Arabic	A lot
Marko	UNIDU	19-25	Male	No Response	Croatian, English	None
Ivica	UNIDU	19-25	Male	Croat	Croatian, English, German	Some
Tomislav	UNIDU	19-25	Male	Croat	Croatian, English	Some
Ilija	UNIDU	19-25	Male	No Response	Croatian, English	Some
Tvrtko	UNIDU	19-25	Male	Croat	Croatian, English	None

3. Study Findings

The findings from the study indicated a complicated answer to the research question. Although most participants responded that they did not believe that language impacted their experience, the coding showed an interesting picture. The coding that included only CAMIL codes (self-efficacy, motivation, interest, self-regulation, embodiment, and cognitive load), the comparison between monolingual and multilingual participants showed a very similar experience. However, when the additional codes of language, culture, and background information were added, a difference between the groups of multilingual and monolingual participants began to be indicated (see figure 2).

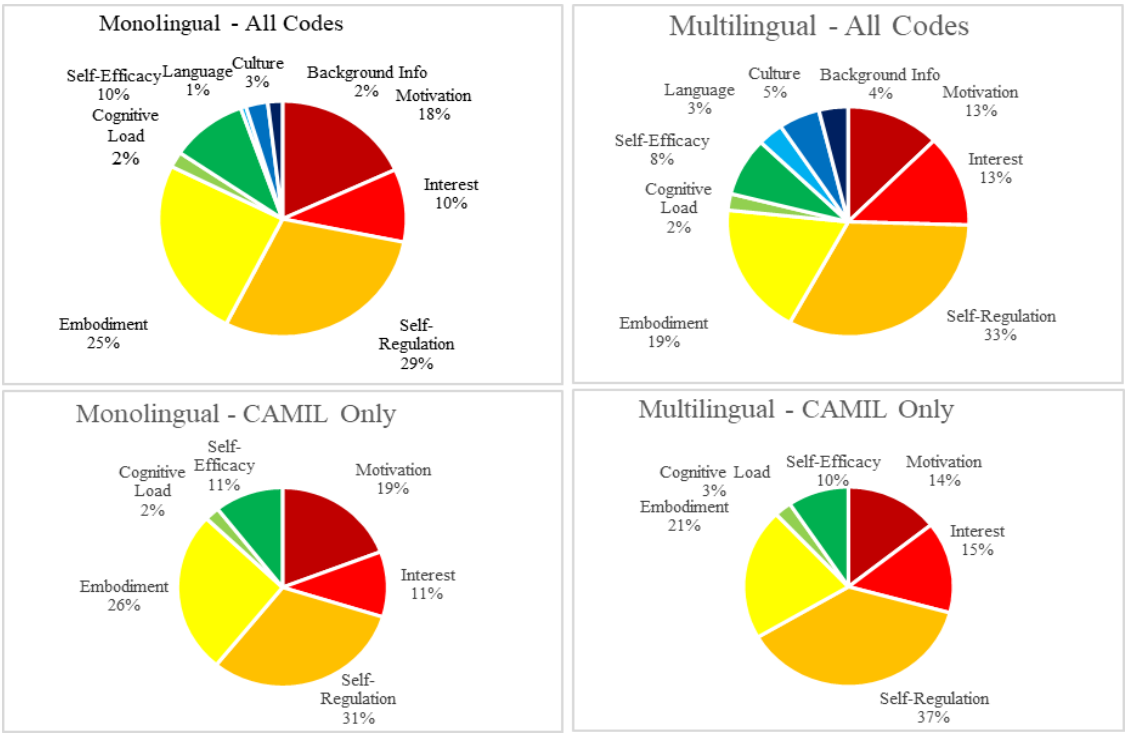


Figure 2. Coding - Comparison between Monolingual and Multilingual Participants (Gilmartin, 2024)

When the participants were compared between the two institutions, an even greater difference could be identified. The participants from SUNYMC had very little identification of codes for culture, language, and background information whereas the participants from UNIDU showed a greater inclusion of culture, language, and background information being identified during the coding of their sessions (see figure 3). Gilmartin (2024) noted that she shared the same cultural background as the participants from SUNYMC whereas the participants from UNIDU had a different cultural background from Gilmartin. Gilmartin identified two possible reasons for this difference with the first being that having a shared culture with SUNYMC made it difficult to identify unique cultural codes that might have existed within the SUNYMC experiences and with the second being that the participants were proud and excited to share their cultural identity with Gilmartin. When looking at the comparison of codes, there are indications that difference of culture influences a student's self-view of their experience more significantly than whether they are monolingual vs multilingual.

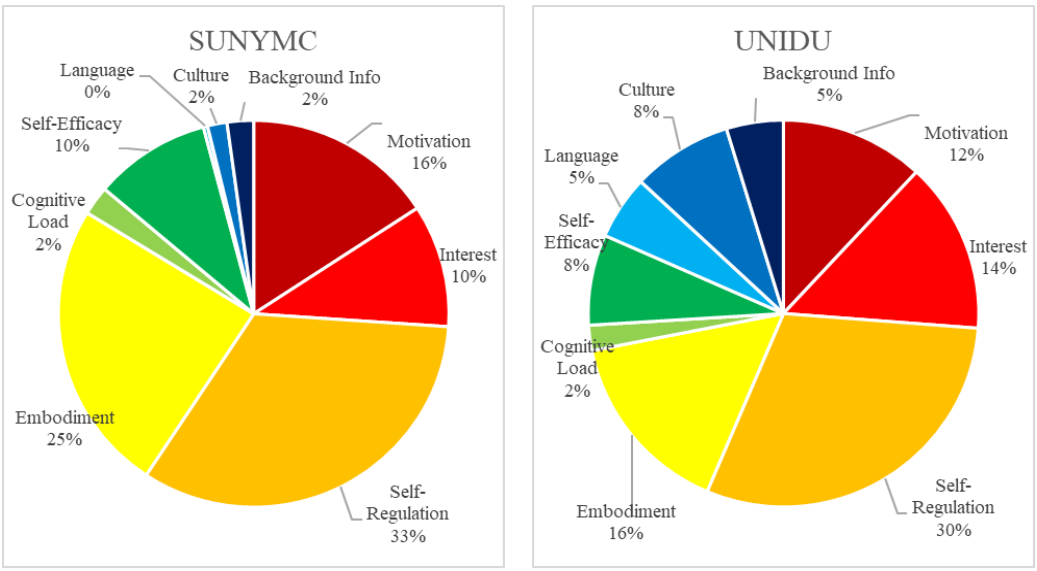


Figure 3. Coding - Comparison between SUNYMC and UNIDU (Gilmartin, 2024)

Gilmartin also noted that although the multilingual participants stated that language did not impact their experience, this was usually alongside an explanation that they were very comfortable with the English language. This was particularly true of the UNIDU participants who went on to explain that their cultural identity relates to tourism and having a strong English-speaking ability. This shows the interconnected nature of culture, language, and identity and how all three impacted the participant's self-view of their experience using VR to learn. This aligns well with sociocultural theory (Vygotsky, 1978) that explains that a student's learning and development is heavily shaped by their culture and that language, culture, and social identity are strongly intermixed. This means that despite the participants stating otherwise, their social identity, which includes language, had an impact on the way the participants viewed their experience.

In addition to the coding, a difference in interpretation of the participant's experience using VR due to cultural differences was indicated in cultural responses to research process and the think-aloud protocol. One example was the cultural reaction to the informed consent form that is required to conduct research in the United States. The participants from SUNYMC (Brian, Faizan, Jacob, Jessica, Joseph, Robert) did not show much reaction to this aspect of the research process and reacted to it as if it was commonplace. However, the participants from UNIDU (Ilija, Ivica, Marko, Tomislav, Tvrtko) had a strong reaction to this process, finding it comical and noting the cultural differences between the United States and Croatia while explaining that this was not necessary as a part of their culture. One of the required aspects of the Informed Consent discussion was to mention any potential harm and the possibility of VR sickness and exposure to electromagnetic radiation. The participants from UNIDU found this very comical as well and indicated that they were not concerned whereas the participants from SUNYMC indicated a neutral response to this information. The largest cultural difference identified was shown in the participant's responses during the post

interview. When they were asked if they thought that VR could be used as a part of the learning process for MET programs, the SUNYMC participants (Brian, Faizan, Jacob, Jessica, Joseph, Robert) all indicated strong enthusiasm and indicated a desire to make this a reality. The UNIDU participants (Ilija, Marko, Tomislav, Tvrtko) initially indicated excitement which then became subdued and indicated that they did not believe this would happen. Gilmartin (2024) pointed out that both institutions were working on integrating VR into their programs at the time, so this response was not due to an issue of accessibility for the technology but was more likely due to a cultural response to change.

4. Implications for MET

As METs consider using VR for learning, the findings of this study have noteworthy implications on how MET students will interpret their experience using this technology. The comparison of the CAMIL codes between monolingual and multilingual participants showed similar results, indicating that their experiences are comparable when it comes to engaging the CAMIL model while using Virtual Reality. This indicates that the CAMIL model is equally effective for both monolingual and multilingual students in engaging the learning process when using an immersive technology to learn. However, the findings that culture and other social identity factors impact the self-view of the experience of a student using VR is not currently addressed in the CAMIL model. Although the CAMIL model is effective at engaging learning for both monolingual and multilingual learners, it does not address the cultural and social identity needs of the students using the platform. This is an issue considering the nature of METs. The maritime industry is international and includes cultures from all around the world. These findings indicate that there could be strong differences in how each student interprets their interaction due to their different cultures and self-identities.

This study only looked at two cultures and has not considered the cultural diversity which exists amongst students in MET programs world-wide. Most MET students are like the participants in this study as they are all required to be comfortable with Maritime English and must pass the Standard Maritime Navigational Vocabulary (SMNV). However, the cultural connection with English and their own self-view of their ability to understand English may vary depending upon culture and personal experience. This means that the impact of language and the self-view of a student's own ability of understanding English may influence the way that a student may interpret their use of VR for learning when it uses English as the language for instruction. This study was aimed at illuminating the unique needs of multilingual students using VR for learning and although the results initially indicate that language is not a factor, a deeper look at the results highlight the need for educators and instructional designers to consider the unique cultural, linguistic, and historic factors that influence a student's personal identity and the way that their experience is interpreted from their point of view.

5. Future Research and Considerations

The findings of the study by Gilmartin (2024) highlight the unique cultural and linguistic needs of MET students when designing experience-based learning opportunities. As explored in this study, the cultural and linguistic self-identity of a student influences their self-view of these learning experiences. However, this is not just true of experiences provided through VR. This is true of any experience-based learning opportunity including experience gained on commercial vessels, training vessels, and in the simulator. There is currently very little research on the impact of culture or self-identity and how it influences these experience-based learning opportunities for MET students. Since MET programs are regulated by the IMO and these cultural and self-identity influences are not outlined in the regulations, it is important for MET institutions to research these influencing factors, identify the unique needs of their students, and implement best practices based on these findings.

Additionally, cultural differences may influence the way students and professors react to this new technology. If culturally, VR is not commonplace or is seen as unnecessary, it might not be embraced or supported by those that would use VR in the classroom. This lack of support could hamper the long-term adoption of this new platform and prevent it from becoming a common tool for learning. Cultural differences toward new technology might also impact the self-view of the experience and the benefits of using VR for learning. If the student does not see the benefit of using VR for learning, this could also impact the effectiveness of using this tool for learning. The different cultural views of VR and technology along with adoption and the impact on the self-view of using VR for learning should be researched and considered by

those who hope to adopt it into their programs.

The study by Gilmartin (2024) provided a complicated answer to the question focused on exploring the experience of multilingual MET students using VR for experience-based learning. The participants did not feel that language impacted their experience, but the data indicated their cultural and self-identities impacted the way they viewed their experience using VR. These findings raise questions about the impact of self-identity, including language and culture, on all forms of experience-based learning. As MET institutions look toward using VR, it is critical that we explore this impact of self-identity on the self-view of learning experiences.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Enhancing Cyber Resilience in Critical Maritime Infrastructures

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Abstract: As critical maritime infrastructures become increasingly digitalized and interconnected, their exposure to sophisticated cyber threats grows, raising urgent concerns for operational continuity, supply chain integrity, and national security. This paper examines the key criteria for assessing and strengthening cyber resilience within maritime critical infrastructure by synthesizing international standards, regulatory frameworks, and industry best practices. Through a literature review, the study identifies essential resilience factors—including robust governance, layered technical and organisational controls, incident detection and response capabilities, continuous training, sectoral collaboration, and comprehensive risk assessments that account for system interdependencies. Resilience must be approached from multiple perspectives and across all organisational levels, with a comprehensive understanding of how it can prevent cascading negative effects. Cyber risk management should therefore begin at the preventive stage and these findings underscore the necessity of a proactive cyber risk management.

Keywords: critical maritime infrastructures; cyber resilience; resilience criteria

1. Introduction and Theoretical Background

The maritime sector must maintain high readiness when addressing cyber threats due to digital transformation in the sector – integration of information communication technology (ICT), digitalization of operations. Digital technologies have become essential to the operation and management of numerous systems which are critical to the safety and security of shipping and the protection of the marine environment (IMO 2022). Enhancing protection against cyberattacks requires maintaining the highest possible standards of safety and security (Dimakopoulou & Rantos 2024).

The IMO has recognized cybersecurity threats as an issue of utmost importance and has therefore issued a comprehensive framework and guidelines aimed at improving resilience (International Maritime Organization 2018). Supporting this view, (Progoulakis et al. 2023) noted that maritime sector today is more frequently affected by cyber risks than ever before. ENISA has also published guidelines intended to strengthen the cyber resilience of the maritime sector (Drougkas et al. 2019). According to Araujo, Machado & Passos (2024) and Dimakopoulou & Rantos (2024), as well as Setola et al. (2016), cyber threats are on the rise, and the maritime sector should invest significantly more effort in building the resilience of its critical infrastructure. Such an increase is also confirmed by the database MCAD (NHL Stenden University of Applied Sciences, n.d.), further reinforcing the need to assess the current situation and define future preventive measures aimed at improving the resilience of critical infrastructure in the maritime sector.

Resilience is commonly described as the capability to continue performing regardless of the of external hazards. Interpretations of resilience drawn from multiple sources, collectively consider it to be a dynamic, adaptive, and enduring quality, particularly relevant to systems exposed to complex and evolving threats (Araujo, Machado & Passos 2024).

Cyber risk management is the process of identifying, analysing, assessing and communicating a cyber- related risk and accepting, avoiding, transferring or mitigating it to an acceptable level, considering costs and benefits of actions taken to stakeholders (International Maritime Organization 2018). Cyber risk management relies on the “CIA triad”: Confidentiality, Integrity, and Availability, and failure in any of these areas can disrupt operations, harm reputation, and expose organisations to serious risks (International Organization for Standardization 2022). The growing adoption of cyber-physical systems and distribution must consider the perspective of cyber resilience as a way of complementing a traditional assessment of

physical resilience, this point of view being a central issue for critical infrastructures, considering the potential social and economic consequences an incident can cause (Araujo, Machado & Passos 2024).

Critical maritime infrastructure (CMI) specifically refers to the assets, systems, and services within the maritime domain whose disruption, degradation, or destruction would have impacts on overall security, stability, and safety. Its components are shown in Illustration 1. (Rehak, Senovsky & Slivkova 2018).

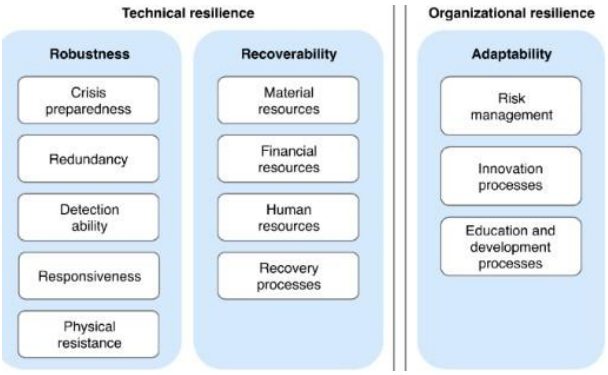


Figure 1. Components and variables determining the resilience of critical infrastructure elements

Critical infrastructure subsystem resilience can be understood as a condition formed by three types of factors: (1) Factors determining resilience (i.e., components of technical and organizational resilience); (2) factors limiting resilience (i.e., statutory regulations, available financial resources); and (3) factors affecting resilience (i.e., threats, resilience strengthening instruments) (Rehak, Senovsky & Slivkova 2018).

The aim of this paper is to explore the key criteria for assessing and enhancing cyber resilience within maritime critical infrastructures by examining current international standards, regulatory frameworks, and industry guidelines. The research addresses the question - what are the key criteria for assessing cyber resilience in maritime critical infrastructure. This paper applies a qualitative, integrative literature review method, analysing academic publications, international standards, incident databases, and industry case studies. The methodology synthesises key sources addressing CI resilience (Setola et al., 2016), maritime cyber risk management (Dimakopoulou & Rantos 2024; International Maritime Organization 2018), and cyber incident analysis (Diaz 2020; NHL Stenden University of Applied Sciences, n.d.), to identify essential criteria for assessing cyber resilience in maritime critical infrastructure.

2. Overview of International Guidelines and Standards

2.1. International Association of Classification Societies (IACS)

To address increasing cyber vulnerabilities in maritime transport, IACS has issued two new Unified Requirements as a strategic response. These requirements, UR E26 and UR E27, effective for new ships contracted as of 1 January 2024, focus on integrating cybersecurity measures throughout the design, construction, and operational phases of a vessel (Dimakopoulou & Rantos 2024). The primary objective of UR E26 - *Cyber resilience of vessels* is to establish and maintain a secure onboard environment. On the other hand, UR E27 - *Cyber resilience of onboard systems and equipment*, aims to support manufacturers and the administration framework of onboard operational systems and equipment in evaluating and improving their cyber resilience (Inmarsat 2024). These steps represent a significant advance in maritime safety, as UR E26 and E27 establish a consistent methodology for incorporating cybersecurity from design to decommissioning of vessels. By addressing both organisational and technical aspects of onboard resilience, these requirements directly respond to the digital threats facing a maritime industry.

2.2. IMO Guidelines

The International Maritime Organisation's best practices situate cybersecurity as a priority, alongside other safety risks, under the International Safety Management (ISM) Code (Dimakopoulou & Rantos 2024). IMO has issued MSC-FAL.1-Circ.3-Rev.2 Guidelines on maritime cyber risk management. The guidelines aim to strengthen cybersecurity in shipping by offering broad recommendations for managing maritime-related cyber
risks. The Maritime Safety Committee also adopted Resolution MSC.428(98) - Maritime Cyber Risk

Management in Safety Management Systems. The resolution encourages administrations to ensure that cyber risks are appropriately addressed in existing safety management systems (International Maritime Organization 2018). As per International Maritime Organization (2022) these Guidelines present the functional elements that support effective cyber risk management and consist of the following: identify responsibilities, protect processes, detect cyber risks, respond to threats and recover.

2.3. European Regulatory Frameworks

The EU has recognised the importance of enhancing the resilience of critical infrastructure. The European Commission has introduced the Green Paper on a European Programme for Critical Infrastructure Protection (CIP). At the same time, the European Council, through its directive, defined critical infrastructure (CI) as any asset, system, or component considered essential for sustaining vital societal functions (Council Directive 2008/114/EC). The European Programme for Critical Infrastructure Protection (EPCIP) aims to enhance the protection of critical infrastructure across all sectors within the EU, addressing a wide range of disruptions affecting CI, from natural disasters to terrorism. In short, it seeks to provide an all-hazards cross-sectorial approach (Setola et al. 2016). After 2016, a new Network and Information Security Directive - NIS 2 was published in 2022 (Directive (EU) 2022/2555) as the European Union's response to growing cyber risks, aiming to enhance security by focusing on the protection of network and information systems to prevent the negative impact of potential incidents (NIS 2 Directive n.d.).

2.4. ENISA Guidelines

The European Union Agency for Cybersecurity (ENISA) has a central role in guiding member states and industry stakeholders toward enhanced cybersecurity resilience. It has presented a range of reports and guidelines addressing vulnerabilities in critical infrastructure sectors, including the maritime sector. These guidelines support stakeholders in enhancing their ability to respond effectively and swiftly to cyber crisis situations through a series of procedures and continuous monitoring. Emphasis is placed on raising overall awareness of cyber risks and attacks in order to secure both information technology and operational systems.

According to Drougkas, Sarri, Kyranoudi & Zisi (2019), ENISA clearly highlights simulations as a foundation for strengthening system resilience, while also providing concrete guidance on developing a Disaster Recovery Plan to restore operational functions in the shortest possible time, as well as a Business Continuity Plan to ensure uninterrupted operations. The Agency places special emphasis on the importance of having a strong governance framework.

2.5. RUSI Europe Recommendations for Maritime Cybersecurity

According to Polemi & Van Maele (2023), RUSI states that it is necessary to establish specialised teams dedicated exclusively to cybersecurity, including the regular implementation of risk assessments in order to identify vulnerabilities, risks, and threats that could hinder or disrupt the functioning of critical infrastructure. The adoption of international standards is a baseline for cyber risk governance, and in this regard, it has provided valuable guidelines, with particular emphasis on the need to integrate cybersecurity into the maritime sector.

2.6. ISO/IEC 27001 and ISO 22301 Standards

Information Security Managements Systems (ISMS) in any business sector follow the guidelines defined by ISO/IEC standards in order to establish and maintain a high-quality information security management system. Implemented ISMS is a tool for risk management, cyber-resilience and operational excellence (International Organization for Standardization 2022). ISO 27001 Annex A is a list of controls designed to address risks to information security and suggestions on how the controls could be implemented. The controls have now been structured into 4 domains: organisational controls, people control, physical controls and technological controls (International Organization for Standardization 2022).

ISO 22301 Standard on the other hand, aims to establish guidelines that enable operations to continue smoothly even after unexpected incidents. It helps in identifying risks, preparing for emergencies, and improving recovery time (International Organization for Standardization 2019). Its objective is to provide post- disruption business continuity (e.g., after natural disasters, man-made disasters, etc.) through business impact analysis and risk assessment. The philosophy behind ISO 22301 is based on impact assessment and risk management by identifying the most important activities and the risks that may affect them

(Tikanmäki, Savolainen & Ruoslahti 2024). In the maritime industry, ISO 22301 strengthens cyber resilience against increasingly complex threats by supporting the adaptation and recovery phases of the resilience cycle. It ensures that organisations are able to respond to cyber threats and to quickly restore critical operations. By focusing on business impact analysis and continuity planning, the standard complements technical cybersecurity frameworks with a broader organisational readiness.

3. Cybersecurity Risks and Key Assessment Criteria

The seamless operation of port facilities, shipping lanes, vessels, offshore platforms, and supporting systems such as navigation aids, communication networks, and traffic management systems is essential for ensuring the continuous flow of maritime transportation and maintaining the integrity of global supply chains. Critical maritime infrastructures encompass the essential physical and digital assets, systems, and services that enable the safe and efficient operation of maritime transportation, logistics, and offshore activities.

Survey data collected from practitioners and academics specialising in maritime security, demonstrates that 81% agreed or strongly agreed with the statement „*cybersecurity in the maritime sector lags behind cybersecurity in other areas of critical infrastructure*", while 15 % answered neutrally (Fenton 2024).

The digital transformation of the maritime sector has led to an increase in cyberattacks, as evidenced by the growing number of reported incidents over the years. This transition to the future and to concepts, such as Smart Ports, brings along cybersecurity challenges that need to be met in order for future ports to fully unlock the potential of new technologies (Drougkas, Sarri, Kyranoudi & Zisi 2019).

Incidents such as an escalation of Houthi attacks on shipping through the Red Sea, blockage of the Suez Canal by MV Ever Given in 2021 and the paralysing malware attack on shipping giant Maersk in 2018, underscore both the critical importance of the maritime transportation system (MTS) to global supply chains and its acute vulnerability to disruptive kinetic, cyber, or cyber–physical attack (Fenton 2024). Likewise, the cyberattack on the IMO in 2020 disrupted its website and intranet services (Diaz 2020).

The Maritime Cyber Attack Database (MCAD) compiled by researchers at NHL Stenden University, Netherlands, provides an interactive global representation of open-source discrete cyber-attacks on the maritime transportation sector (NHL Stenden University of Applied Sciences n.d.). Until mid - 2025., researchers have catalogued around 295 cyber incidents involving the maritime sector including incidents impacting vessels, ports and other maritime facilities worldwide, with further attacks being added through continuous updating. See Illustration 2. (NHL Stenden University of Applied Sciences n.d.). Such episodes have profound financial implications, and can present disruptions to operations, reputational damage, and potential threats to safety (Dimakopoulou & Rantos 2024).



Figure 2. Map of cyber incidents in maritime sector

Figure 1. (Fenton 2024). illustrates a pronounced upward trend in reported maritime cyber incidents from 2001 to 2023. This sharp increase not only reflects the growing digitalisation of maritime operations but also highlights the sector's escalating exposure to cyber threats.

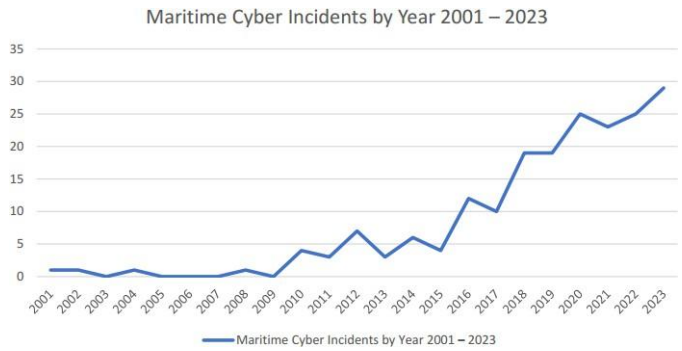


Figure 3. Maritime Cyber Incidents by Year 2001–2023.

Critical maritime infrastructure system resilience can be understood as a condition closely related to the performance function of individual subsystems (Rehak, Senovsky & Slivkova 2018). It is not easy to manage all aspects of cybersecurity management without using help and guidance from existing standards and guidelines. Therefore, cybersecurity management should use policies, processes and procedures on technical controls and employee awareness to manage cybersecurity in ports and aboard ships. Expert advice from maritime consultants who can help implement cybersecurity in the port and ship environment is important to avoid mistakes (Polemi & Van Maele 2023).

Ensuring cyber resilience in critical maritime infrastructures requires a holistic approach, combining technical, organisational, and human factors. Key criteria identified include the integration of cyber risk management into existing governance structures, supported by robust technical controls and systematic risk assessments (International Maritime Organization 2018; ISO/IEC 27001 2022). Equally important are the development of effective incident detection, response, and recovery capabilities, along with regular testing and updating of these procedures (Drougkas, Sarri, Kyranoudi & Zisi 2019). Risk assessments are of critical importance in preventing cyber threats and establishing the highest possible level of resilience, particularly in an era when such threats are rapidly evolving. This includes not only information technology, but also operational technology (Aghazadeh Ardebili, Lezzi & Pourmadadkar 2024; Polemi & Van Maele 2023). According to Polemi & Van Maele (2023), the human factor is a key element in building resilience, and regular, high-quality training of personnel combined with familiarisation with risks, operational procedures, and exercises is essential.

4. Discussion and Conclusion

The maritime sector plays a vital role in global trade and logistics, encompassing all key components such as ships, ports, navigation systems, and logistics networks, which together form the Critical Maritime Infrastructure (CMI). Given the importance of the sector, it is essential to identify potential risks and threats in a timely manner and to protect both physical and cyber systems from increasingly frequent attacks. Cyber resilience of CMI is of strategic importance, and this research has demonstrated that cyber resilience has become an imperative in today's maritime operations. It requires continuous updating and addressing of the sector's unique operational, regulatory, and technological complexities. Protection and resilience are prioritised due to the growing complexity, interconnectivity, and systemic dependencies of infrastructure, which increase its vulnerability to cascading disruptions across various sectors.

Given the inherently international nature of the maritime sector and its unavoidable reliance on both digital and physical systems, it is essential to adapt and continuously improve approaches to strengthening resilience. This research has highlighted the importance of CMI, and even more so, the importance of its cyber resilience, considering the maritime sector's impact on global trade, logistics, and ultimately, the economy.

This study has identified seven key criteria for assessing and strengthening cyber resilience in CMI:

1. Integration of cyber risk management into governance structures - ensuring cybersecurity becomes a core element of organisational risk management and decision-making.
2. Implementation of technical and organisational resilience measures - providing layered defence across both IT and OT environments.

3.Development of incident detection, response, and recovery capabilities - ensuring the ability to quickly mitigate and restore operations after cyber incidents.

4.Training, awareness, and clear operational procedures - addressing the human factor as a critical element of resilience.

5.Continuous testing, auditing, and improvement of resilience measures - ensuring adaptive capacity in the face of evolving threats.

6.Sectoral collaboration and engagement with cybersecurity experts - enabling information sharing and access to up-to-date best practices.

7.Comprehensive risk assessments incorporating system interdependencies - recognising cascading effects within complex maritime systems.

The benefits of applying these criteria are multifold. They help organisations shift from simply reacting to cyber threats to actively managing them, which boosts preparedness and lowers the risk of major disruptions. On the other hand, building resilience across all parts of the organisation helps maritime stakeholders better handle cyber incidents in a way that they ensure operations to continue as well as minimize economic impacts. Culture of continuous improvement reduces systemic vulnerabilities during longer period of time and that is possible by integrating lessons previously learned.

International standards and industry frameworks show that the maritime sector is making progress in strengthening cyber resilience. With rising threats and complex operations, there is an urgent need to enhance cyber resilience in CMI. It's clear that resilience isn't just a technical issue but is also an organisational priority. Building stronger resilience in critical maritime infrastructure will require better international cooperation, ongoing staff training, and learning from past incidents.

This research faces several limitations because of the length constraints, mainly the absence of deeper analysis of the role of different stakeholders in cyber-attacks in maritime infrastructures and the analysis of actual case-studies, which will be the topic of future research.

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The 25th IAMUC
Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Dependence of the thrust and power of wind propulsors on the speed of the vessel

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Abstract: The IMO Strategy for Decarbonization in Shipping encourages the use of alternative energy sources, in particular auxiliary wind propulsors (WP). In this work mathematical modeling of aerodynamic forces and power of WP depending on the relative speed of the vessel (in relation to the true wind speed) and the direction of the true wind is conducted. A significant dependence of the energy output of WP on the value of ship speed is shown. The dependences of the thrust and power of WP on the relative speed of the vessel at different values of the WP aerodynamic quality have been obtained. The dependences of the relative speed of the vessel at which the maximum power of the WP is achieved on its aerodynamic quality and the direction of the true wind are also obtained. The relationships between the true wind direction and the relative speed of the vessel are found, at which the WP power will reach its maximum value at different values of the WP aerodynamic quality.

Keywords: wind propulsor, thrust and power, speed of the vessel, wind speed and direction.

1. Introduction

Many works have been devoted to various aspects of the use of sailing equipment on marine vessels (Yunlong Wang et al. 2022, Kramer J. V. et al. 2022, Ariffin N. I. B. et al. 2020, Cairns, J. et al. 2021). In particular, the aerodynamic characteristics of a segment rigid sail were studied utilizing computational fluid dynamics analysis and a virtual wind tunnel (Atkinson, G. M. 2019). The performance of a commercial vessel with various wind-propulsion systems was also studied (Fujiwara T. et al. 2005, Reche-Vilanova et al. 2021, 2023). A significant number of works are devoted to the general formulation of the problem of optimal control of a ship with a wind propulsors, including mathematical models of the ship's propulsion system (Miyusov M. V. 1996, Kryvyi O. F. et al. 2016, 2019, 2021, 2023). This work is devoted to the study of the dependence of the thrust and power of wind propulsors on their aerodynamic characteristics, vessel speed and true wind parameters.

2. Modeling the aerodynamic characteristics of wind propulsors.

A special feature of auxiliary wind propulsors (WP) is their joint operation with the traditional propulsion plant, which ensures the transfer of effective power from the main engines to the propellers. An increase in the speed of the vessel causes a change in the speed and direction of the apparent wind, and, as a result, aerodynamic forces on the WP. Aerodynamic characteristics of a WP (soft or rigid sail, Flettner rotor, etc.) are usually obtained as a result of wind tunnel tests. As a result of the tests, the dependences of the three main dimensionless characteristics of the WP are determined: the coefficients of aerodynamic forces of drag C_x, lift C_y and moment C_m on the angle of attack α of the air flow on the ship's WP. The aerodynamic characteristics of a ship's sail are most clearly reflected by the dependence of C_y on C_x, that is, the function $C_y = f(C_x)$, which is depicted graphically with a mark on the curve of angles of attack. Fig. 1 shows the function $C_y = f(C_x)$ of a single sail, the triangle of wind speeds and aerodynamic forces on the sail (Miyusov M. V., 1996). Note that in Fig. 1 α is the angle of attack of the air flow on the ship's sail, this is the angle between the apparent wind direction and the conventional plane of the sail, and β_{ia} – is the angle of installation (setting) of the sail, that is, the angle between the conventional plane of the ship's sail and the diametrical plane of the ship. Obviously, the following formula is valid:

$$\alpha = \gamma_a - \beta_{ia} \quad (1)$$

where γ_a – is the apparent wind heading angle, i.e. the angle between the ship's heading and the direction of the apparent wind.

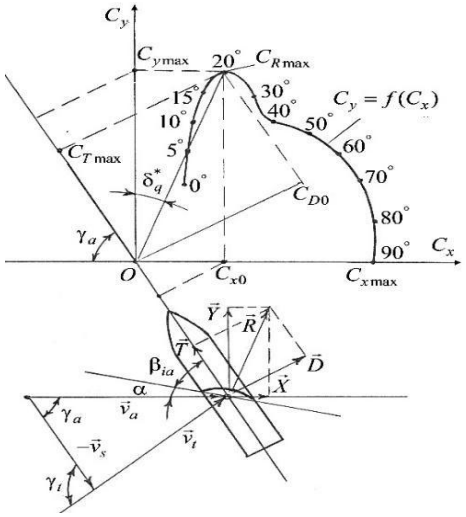


Figure 1. The function $C_y = f(C_x)$ of a single sail, the triangle of wind speeds and aerodynamic forces on the sail.

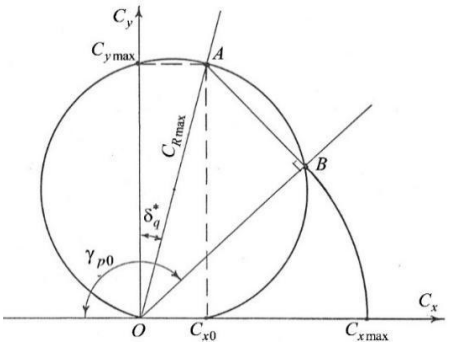


Figure 2. Determination of the angle γ_{p0} of change of sail operating mode.

The value *X* of the aerodynamic drag force $\vec{X}$ and the value *Y* of the lift force $\vec{Y}$ can be expressed as follows:

$$X = 0.5C_x(\alpha)\rho S v_a^2, \quad Y = 0.5C_y(\alpha)\rho_1 S v_a^2, \tag{2}$$

where ρ_1 – the air density; S – the characteristic area of the WP; v_a – the apparent wind speed.

The value *T* of the aerodynamic thrust force $\vec{T}$ and the value *D* of the aerodynamic drift force $\vec{D}$, according to Fig. 1, are related to the values (2) by the following relations: $T = Y\sin\gamma_a - X\cos\gamma_a$, $D = Y\cos\gamma_a - X\sin\gamma_a$. Using formulas (2), it is not difficult to establish the relationship between the dimensionless coefficients $C_x(\alpha)$, $C_y(\alpha)$ and the dimensionless coefficients of aerodynamic thrust C_T and drift C_D:

$$C_T = C_y(\alpha)\sin\gamma_a - C_x(\alpha)\cos\gamma_a, \quad C_D = C_y(\alpha)\cos\gamma_a - C_x(\alpha)\sin\gamma_a. \tag{3}$$

It should be noted that the sum of both pairs of aerodynamic forces $\vec{Y}$ and $\vec{X}$, $\vec{T}$ and $\vec{D}$, is equal to the resulting aerodynamic force on the WP, i.e. $\vec{R} = \vec{Y} + \vec{X} = \vec{T} + \vec{D}$.

The speed of the apparent wind $\vec{v}_a$ on a moving vessel is equal to the vector difference between the speeds of the true wind and the speed of the vessel on course $\vec{v}_s$, i.e.: $\vec{v}_a = \vec{v}_t - \vec{v}_s$. All three speeds form a triangle of speeds (see Fig. 1), from which it is not difficult to obtain expressions for determining the magnitude of the speed and course angle of the apparent wind:

$$v_a = \sqrt{v_s^2 + v_t^2 + 2v_s v_t \cos\gamma_t}, \quad \gamma_a = \arccos\left((v_t + v_s\cos\gamma_t)v_a^{-1}\right), \tag{4}$$

where γ_t – is the heading angle of the true wind, v_s, v_t – are the velocities of the ship and the true wind, respectively. Let δ_q – the angle between the vector of the resultant aerodynamic force $\vec{R}$ and the lift force $\vec{Y}$ (the aerodynamic quality angle), and C_R – the dimensionless coefficient of the resultant force, which can be defined as $C_R = \sqrt{C_x^2 + C_y^2}$, then the dimensionless coefficients of aerodynamic thrust C_T and drift C_D can also be determined by the formulas:

$$C_T = C_R^2 + C_y^2\sin(\gamma_a - \delta_q), \quad C_D = C_R^2 + C_y^2\cos(\gamma_a - \delta_q). \tag{5}$$

The aerodynamic quality of a WP is characterized by the value $K = K(\alpha)$ and the angle of aerodynamic quality δ_q

$$K(\alpha) = C_y(\alpha)/C_x(\alpha), \quad \delta_q = \operatorname{arcctg} K(\alpha). \tag{6}$$

3. Choosing the optimal WP (sail) setting angle

One of the main parameters of a WP when used on ships is the WP (sail) setting angle β_{ia}, which together with the course angle of the apparent wind, according to formula (1), determines the angle of attack α of the air flow on the ship's sail. The angle β_{ia} changes during operation and should provide maximum efficiency of the sail, which is determined by the dimensionless coefficient of aerodynamic thrust C_T. One way to determine the optimal angle of sail setting is a graphical method using the function $C_y = f(C_x)$, characterizing the aerodynamic characteristics of a WP (look at Fig. 1). Indeed, on the curve $C_y = f(C_x)$ you can always find such an angle of attack α of the air flow on the ship's sail, denoted by $\alpha_{\max}$, at which the value *Y* of the aerodynamic lift force $\dot{Y}$ and the lift force coefficient C_y will be maximum. It is obvious that for the curve $C_y = f(C_x)$ depicted in Fig. 1, the angle of attack $\alpha_{\max} = 20^\circ$ corresponds to the maximum value of aerodynamic lift. Let us introduce the notations $C_{y\max} = C_y(\alpha_{\max})$, $C_{x0} = C_x(\alpha_{\max})$, $C_{R\max} = C_R(\alpha_{\max})$, then we write:

$$C_{R\max} = \sqrt{C_{x0}^2 + C_{y\max}^2}\,\mathrm{arcctg}\,K(\alpha_{\max}) = \mathrm{arcctg}(C_{y\max}/C_{x0}). \quad (6)$$

where δ_q^* – the aerodynamic quality angle for the maximum value of the lift coefficient $C_{y\max}$.

According to formula (1), the angle of attack α of the air flow on a ship's sail significantly depends on the course angle of the apparent wind γ_a. Depending on the angle γ_a, the ship's sail can switch from the "wing" operating modes, in particular, at the close-hauled, close reach, beam reach (beam wind, half-wind), reaching courses, to the "parachute" operating mode at the broad reach (quartering wind) and downwind courses. The last courses are called full course angles, which satisfy the condition $\gamma_{p0} \le \gamma_a \le \pi$, where γ_{p0} – the course angle of the apparent wind, at which the sail switches from the "wing" mode to the "parachute" mode.

When $\gamma_a > \gamma_{p0}$, the dimensionless coefficient of aerodynamic thrust C_T can be considered equal to the maximum value of the drag coefficient $C_{x\max}$, the value of the latter is determined experimentally and can be found in the characteristics of a particular WP. The value of the angle γ_{p0} can also be determined graphically in the coordinate plane (C_x, C_y) (Fig. 2), in which we plot point A with coordinates $(C_{x0}, C_{y\max})$, and construct a circle of diameter *OA* and an arc with center at point *O* and radius $C_{x\max}$. Through the intersection point *B* of the circle and the arc, we draw a ray *OB*. The angle between the negative semi-axis of the abscissa axis and the ray *OB* will be equal to γ_{p0}. Its value is easy to find from the right triangle *OBA*:

$$\gamma_{p0} = \pi/2 + \delta^* + \arccos(C_{x\max}/C_{R\max}). \quad (7)$$

Therefore, taking into account the above and formulas (5) and (6), for the maximum values of the dimensionless coefficients of aerodynamic thrust $C_{T\max}$ and $C_{D\max}$ drift, we write the following expressions при $\delta_q^* < \gamma_a < \gamma_{p0}$:

$$C_{T\max} = C_{R\max}\sin(\gamma_a - \delta_q^*), \quad C_{D\max} = C_{R\max}\cos(\gamma_a - \delta^*). \quad (8)$$

4. Determination of the dependence of the thrust and power of wind propulsors on the speed of the vessel.

The obtained mathematical model (8) for the coefficient of aerodynamic thrust makes it possible to investigate the dependence of the values of aerodynamic thrust *T* and the power N_w of the wind propulsors. In particular, at the close-hauled, close reach, beam reach (beam wind, half-wind), reaching courses (the "wing" mode), that is, when the condition is met: $\delta^* < \gamma < \gamma_{p0}$, we obtain the following formulas: $T = 0.5C_{R\max}\sin(\gamma_a - \delta_q)\rho_1 S v_a^2$, $N_w = Tv_s$. Let us turn to dimensionless quantities

$$\tilde{T} = \kappa^{-1}T, \quad \tilde{N}_w = (\kappa \cdot v_t)^{-1}N_w, \quad \tilde{v}_s = v_s v^{-1}, \quad \tilde{v}_a = v^{-1}v, \quad (\kappa = 0.5C_{R\max}\rho_1 S v^2). \quad (9)$$

Using formulas (4), (5) and (9) for the dimensionless values of WP aerodynamic thrust $\tilde{T}$ and power $\tilde{N}_w$, we obtain the following expressions

$$\tilde{T} = (\tilde{v}_s^2 + 1 + 2\tilde{v}_s\cos\gamma)\sin(\arccos((\tilde{v}_s + \cos\gamma)(\tilde{v}_s^2 + 1 + 2\tilde{v}_s\cos\gamma)^{-0.5}) - \delta^*), \quad \tilde{N}_w(\tilde{v}_s, \gamma) = \tilde{v}_s\tilde{T}(\tilde{v}_s, \gamma). \quad (10)$$

The results obtained allow us to conduct a numerical study of the behavior of the WP thrust and power depending on the relative speed of the vessel. The value of the angle δ_q^* for the main types of ship auxiliary

WP, as a rule, belongs to the range: $\delta_q^* \in [10^\circ;30^\circ]$, and can be determined using the results of aerodynamic tests (Miyusov M. V., 1996), in particular, for the NKK (Nippon Kokan K.K.) type rigid sail $\delta_q^* \approx 20^\circ$. Calculations of dependencies (10) were carried out at different values of the angle $\delta_q^* \in [10^\circ;30^\circ]$ for the relative speed of the vessel, varied from 0.2 to 2.0, which corresponds to a range of the vessel speed change from 8 to 20 knots and the true wind speed from 5 m/s to 20 m/s. The calculations showed that the nature of the change in the WP thrust from the speed of the vessel is determined by the aerodynamic quality of the WP. In particular, Fig. 3 shows how the WP thrust depends on the speed of the vessel $\tilde{v}_s$ at $\delta_q^* = 10^\circ$ ($K = 5.67$). In this case, curve 1 corresponds to the value of the true wind $\gamma_t = 150^\circ$; curve 2 – to the value $\gamma_t = 30^\circ$; curve 3 – to the value $\gamma_t = 120^\circ$; curve 4 – to the value $\gamma_t = 60^\circ$; curve 5 – to the value $\gamma_t = 90^\circ$. Therefore, in this case, for most heading angles of the true wind, the WP thrust increases with increasing vessel speed and does not reach a maximum. Fig. 4 shows how the WP thrust depends on the ship speed $\tilde{v}_s$, at $\delta_q^* = 20^\circ$, $K = 2.75$. In this case, curve 1 corresponds to the value of the true wind $\gamma_t = 30^\circ$; curve 2 – to the value $\gamma_t = 150^\circ$; curve 3 – to the value $\gamma_t = 60^\circ$; curve 4 – to the value $\gamma_t = 120^\circ$; curve 5 – to the value $\gamma_t = 90^\circ$. In this case, with increasing ship speed, the WP thrust decreases but has almost horizontal sections in which the rate of thrust decrease is insignificant. Fig. 5 shows how the WP thrust depends on the ship speed $\tilde{v}_s$, at $\delta_q^* = 30^\circ$, $K = 1.73$. In this case, curve 1 corresponds to the value of the true wind $\gamma_t = 60^\circ$; curve 2 – to the value $\gamma_t = 150^\circ$; curve 3 – to the value $\gamma_t = 90^\circ$; curve 4 – to the value $\gamma_t = 120^\circ$. In this case, with increasing ship speed, the WP thrust rapidly decreases.

The research conducted explains the reason for the qualitative differences in individual traction characteristics, the description of which is known now. An increase in the speed of the vessel in crosswinds leads to an increase in the speed of the apparent wind, and at the same time to a decrease in the course angle of the apparent wind. These factors have the opposite effect on the change in the thrust of WP. In this case, the ability of the WP to adjust to acute course angles of the apparent wind is of decisive importance. This ability is characterized by the aerodynamic quality of the WP. The results of numerical simulation of the behavior of the WP power are shown in Figure 6 for $\delta_q^* = 30^\circ$: curve 1 corresponds to the value of the true wind $\gamma_t = 60^\circ$; curve 2 – to the value $\gamma_t = 150^\circ$; curve 3 – to the value $\gamma_t = 90^\circ$; curve 4 – to the value $\gamma_t = 120^\circ$. Here the maximum power is achieved at relatively low dimensionless vessel speeds: $\tilde{v}_s = 0.8 \div 1.2$.

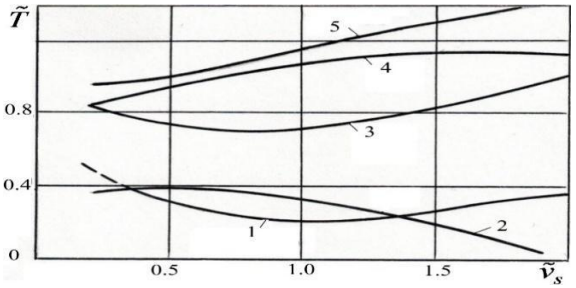


Figure 3. Dependence of WP thrust on vessel speed, at $\delta_q^* = 10^\circ$, $K = 5.67$

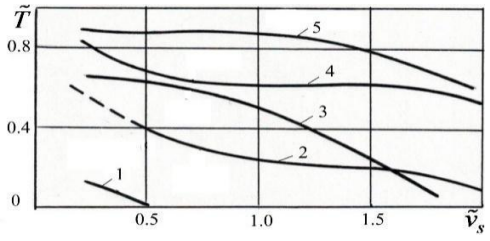


Figure 4. Dependence of WP thrust on vessel speed, at $\delta_q^* = 20^\circ$, $K = 2.75$

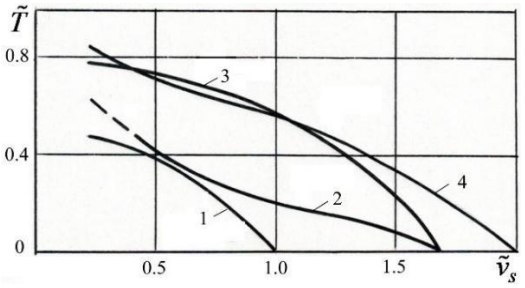


Figure 5. Dependence of WP thrust on vessel speed, at $\delta_q^* = 30^\circ$, $K = 1.73$

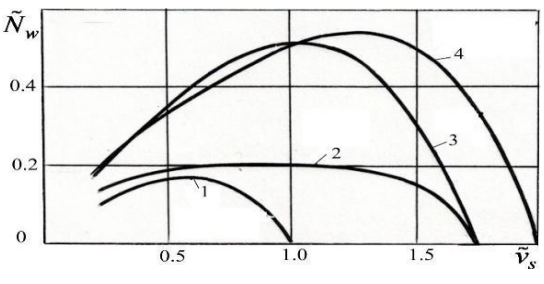


Figure. 6. Dependence of WP power on ship speed, at $\delta_q^* = 30^\circ$.

5. Study of the thrust and power of a WP for extremum.

To determine a more general picture of the change in thrust and power of the WP with different aerodynamic quality and under different wind conditions depending on the speed of the vessel, it is advisable to conduct a study of functions (10) for the extremum, while the course angle of the true wind will be considered a constant. For this, we will use the first formula in expressions (3), which, considering the representation (6), we will write as follows $C_T = C_x(\alpha)(K\sin\gamma_a - \cos\gamma_a)$. Using formula (4) to determine γ_a, we obtain:

$$T_s(v_s, \gamma_t) = \kappa_0(K\sin\gamma_t - \cos\gamma_t - v_s)\sqrt{v_s^2 + 1 + 2v_s\cos\gamma_t}, \quad N_w(v_s, \gamma_t) = v_s T_s(v_s, \gamma_t), \quad \kappa_0 = 0.5C_{x0}\rho S v^2. \tag{11}$$

Analysis of dependencies (11) shows that a WP can create positive thrust and power only if the condition $\tilde{v}_s < K\sin\gamma_t - \cos\gamma_t$ is met. Let us find the derivative of thrust (11) with respect to the relative speed of the vessel $\tilde{v}_s$ and equate it to zero:

$$\frac{\partial T(\tilde{v}_s, \gamma_t)}{\partial \tilde{v}_s} \equiv \kappa_0 \frac{-2(\tilde{v}_s + \cos\gamma_t)^2 + K(\tilde{v}_s + \cos\gamma_t)\sin\gamma_t - \sin^2\gamma_t}{\sqrt{\tilde{v}_s^2 + 1 + 2\tilde{v}_s\cos\gamma_t}} = 0. \tag{12}$$

Analysis of the obtained roots of equation (12) allows us to conclude that the thrust of the WP $T(\tilde{v}_s, \gamma_t)$ can have extrema only when the aerodynamic quality of the WP satisfies the condition: $K > \sqrt{8} \approx 2.83$. At the same time, if the relative speed of the vessel v_s is related to the value of the heading angle of the true wind γ_t by the following expression: $\tilde{v}_s = 0.25K_- \sin\gamma_t - \cos\gamma_t$, where $K_\pm = K \pm \sqrt{K^2 - 8}$, then the thrust will reach a minimum, and if so: $\tilde{v}_s = 0.25K_+ \sin\gamma_t - \cos\gamma_t$, then a maximum. Condition $\tilde{v}_s > 0$ makes it possible to impose restrictions on the value of the heading angle of the true wind γ_t at which the dimensionless thrust 3 can reach extrema. In particular, the thrust of the WP can have an extrema only when the condition $\gamma_t > \text{arctg}(4K_+^{-1})$ is met, for example, curve 1, which is obtained at $\gamma_t = 60^\circ$ and $K = 5.67$, as well as curve 2 ($\gamma_t = 120^\circ$, $K = 5.67$) in Figure 7. In the opposite case, the thrust of the WP (11) will be a decreasing function, for example, curve 3 ($\gamma_t = 120^\circ$, $K = 2.75$), curve 4 ($\gamma_t = 60^\circ$, $K = 2.75$) and curve 5 ($\gamma_t = 30^\circ$, $K = 3.73$) in Figure 7. If $\gamma_t > \text{arctg}(4K_-^{-1})$, then the thrust of the WP has only a maximum, for example, curve 1 ($\gamma_t = 60^\circ$ $K = 5.67$) in Figure 7. If $\gamma_t > \text{arctg}\,4/K$, then the thrust of the WP can have both a maximum and a minimum – curve 2 ($\gamma_t = 120^\circ$, $K = 5.67$) in Figure 7.

To study the power of a WP, we find the derivative of power (11) with respect to the relative velocity of the vessel $\tilde{v}_s$ and equate it to zero. After simple transformations, we obtain a cubic equation with respect to $\tilde{v}_s$:

$$3v^3 + (5\cos\gamma_t - d)v^2 + (2 - 3d\cos\gamma_t)v - d = 0, \quad (d = K\sin\gamma_t - \cos\gamma_t). \tag{13}$$

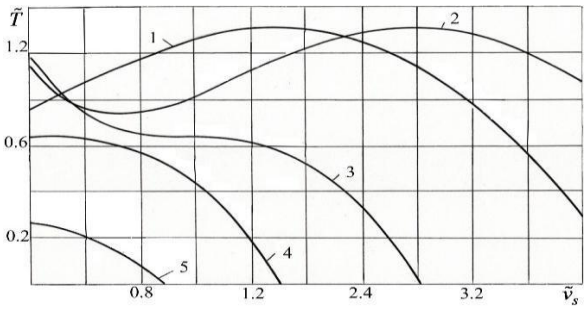


Figure 7. Dependences of the thrust of the WP on the speed of the vessel.

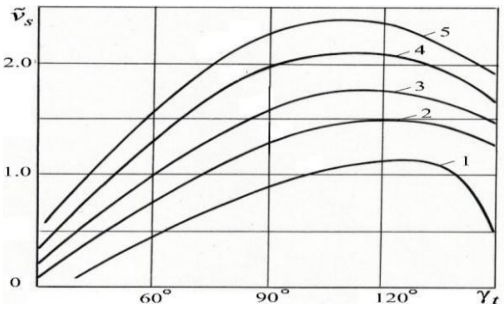


Figure 8. Dependences of the speed of the vessel, corresponding to the maximum power of the WP, on the angle of the true wind

The solution of equation (13), performed using Cardano's formulas, made it possible to find the extrema of the WP power and establish the relationship between the relative speed of the vessel $\tilde{v}_s$ and the heading angle of the true wind, at which extreme values of the WP power are achieved.

In particular, if $D \geq 0$, where $D = 27^{-1}p^3 + 0.25q^2$; $p = b - 3^{-1}a^3$; $q = 2\cdot 27^{-1}a^3 - 3^{-1}ab - 3^{-1}d$;

$a = (5\cos\gamma_t - 2d)\cdot 3^{-1}$; $b = 0.6667 - d\cos\gamma_t$, then the power of the WP will have only one max, which is achieved at $\tilde{v}_s = \sqrt[3]{0.5q + \sqrt{D}} + \sqrt[3]{0.5q - \sqrt{D}}$ if $D = (q/3)^3 + (a/3)^2 \geq 0$, then the power of the WP has three extrema, max: $\tilde{v}_s = 2\sqrt[3]{\beta}\cos(0.33\varphi + 0.67\pi) - 0.33a$; $\tilde{v_s} = 2\sqrt[3]{\beta}\cos(0.333\varphi) - 0.333a$, and min: $\tilde{v_s} = 2\sqrt[3]{\beta}\cos(0.33\varphi + 1.33\pi) - 0.33a$ were $\beta = 3^{-1}\sqrt{3^{-1}p^3}$; $\varphi = \arccos(-0.5q\beta^{-1})$.

Calculation shows that the presence of three extrema is observed when the aerodynamic quality of the WP exceeds 1.6 at heading angles of the true wind close to the downwind course: $\gamma_t = 150^\circ \div 165^\circ$. Fig. 8 shows the results of calculating the relative speed of the vessel, at which the power of the WP has a maximum, depending on the angle of the true wind γ_t for different values of the aerodynamic quality of the WP *K*. Curve 1 was obtained at *K*=1.5, curve 2 at *K*=2.0, curve 3 at *K*=2.5, curve 4 at *K*=3.0 and curve 5 at *K*=3.5.

6. Conclusions

So, as a result of the research, the main patterns of the behavior of the thrust and power of WP depending on their aerodynamic characteristics, wind conditions and ship speed were obtained, namely: the possibility of effective use of the WP on relatively high-speed ships is substantiated, and ways to increase the efficiency of using wind energy by the ship's auxiliary WP are indicated; the relatively high speed of modern transport vessels determines the high probability of the operation of WP on beam wind and close-hauled courses. In this regard, the WP must be adapted to effective operation on these courses, that is, have high aerodynamic quality; the relationship between the ship's speed and the heading angle of the true wind was found, at which the WP thrust and its power reach extreme values; when assessing the efficiency of the WP, it is necessary to take into account the ship's speed and the characteristics of the probability distribution of winds in the area of the ship's operation. The latter should be the direction of further research when using the auxiliary WP.

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The 25th IAMUC
Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Green Technologies and Evolving Role of Seafarers in the Future of Shipping Industry

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Abstract: With the adoption of green technologies, the shipping industry is undergoing a significant transformation. Innovations such as energy-efficient propulsion systems, alternative fuel engines, and emissions monitoring tools are redefining the onboard vessel operations for seafarers. By introducing the emerging green shipping technologies, this study explores how the integration of these technologies is reshaping the seafarers' role, and what competencies they need to effectively operate ships. The study employed concept mapping technique to provide a structured approach for visually representing the interrelationships among the green shipping technologies, the resultant changes in vessel operations, and the required competences for seafarers to handle these operational changes. The findings highlight the critical importance of environmental stewardship, digital literacy, and leadership capabilities in addition to technical expertise for seafarers. Furthermore, the study underscores the necessity of enhanced training programs, interdisciplinary collaboration, and targeted investment to up-skill seafarers for the successful implementation of green shipping technologies. Thus, the findings of this study contribute to a deeper understanding of the human dimension in ocean sustainability. The study would also guide policymakers, maritime educators, and industry stakeholders to advance green shipping practices and help the IMO to achieve its decarbonization goals under UN SDG-13.
Keywords: Green shipping; MASS; Seafarers, Maritime Education and Training (MET), Human element; Decarbonization, Digitalization

1. Introduction

Green shipping refers to the adoption of environmentally friendly practices and technologies in shipping transportation to minimize environmental impacts and promote sustainability (Lun *et al.*, 2016). The green shipping practices (GSPs) encompass a range of strategies which aim to reduce emissions, improve energy efficiency, and enhance overall environmental performance of shipping companies. Designing energy efficient vessels, using clean energy, employing emission reduction techniques such as slow steaming, and managing resources effectively are the central themes of GSPs (Lun et al. 2016; Chang and Danao 2017). Along with the increasing environmental pollution from the shipping industry, the concept of green shipping has received significant global attention during the last few decades. Scholars and policy makers suggested a number of green shipping practices (GSPs) to reduce the environmental degradation from the shipping industry (Prokopenko and Miśkiewicz, 2020).

Traditionally the shipping industry focused on operational efficiency and profit maximization even at the cost of environmental degradation. However, situation started to change after the inception of the concept of *sustainable development* by Brundtland Report in 1987. The concept emphasized the need to balance economic, social, and environmental goals for all economic activities. The United Nations' Earth Summit in 1992 further solidified the importance of integrating environmental protection into global policies including maritime activities. Subsequently, the UN introduced its Sustainable Development Goals (SDGs) in 2015. The SDGs, particularly SDGs 6, 7, 13, & 14, provide a comprehensive framework that highlights the critical role of the shipping industry in achieving the SDGs. It is estimated that the international shipping industry is responsible for 15% of NO_X and 13% of SO_X emissions annually (Walker et al., 2019; IMO, 2014). Besides, approximately 3% of the annual CO_2 emissions can be attributed to shipping. The International Maritime Organization (IMO) predicted that the shipping industry will account for approximately 15% of worldwide

CO_2 emissions by 2050 (IMO, 2018) if the industry continues operating in the traditional manner.

Recognizing the severity of the situation, the IMO has adopted several mandatory and non-mandatory regulations and strategies to minimize environmental impacts from the shipping industry (Chircop and Shan, 2020; Bach and Hansen, 2023). For instance, the IMO introduced the Ship Energy Efficiency Management Plan (SEEMP) in 2013 and the Energy Efficiency Design Index (EEDI) in 2015. Subsequently, the worldwide Sulphur cap regulation on fuel composition of 0.5% entered into force in 2020. Besides, the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) were introduced in 2023. Since environmental regulations are gradually becoming more stringent, shipping companies are compelled to adopt more green technologies and practices in their operations.

Seafarers onboard are playing a significant role in adopting and implementing green shipping technologies and practices (Dewan and Godina, 2023b). The adaptation of these green technologies which subsequently helps to comply with the regulations, changes the vessel operations onboard (Baum-Talmor and Kitada, 2022). As a result, seafarers need new skills that are crucial for adopting sustainable shipping practices, particularly in the context of energy efficiency and environmental stewardship. Several studies (Baum-Talmor and Kitada, 2022; Dewan and Godina, 2023b, 2024c; Kitada *et al.*, 2023) highlighted the significant role of seafarers in implementing GSPs. However, these studies fail to suggest how these technologies change seafarers' traditional work paradigm onboard, and what skills are required for seafarers to adapt the evolving work domain. This study aims to fill this gap by introducing a logical relationship among the green shipping technologies, changes in vessel operations, and the required skills to operate those technologies effectively. Thus, this study addresses the following research questions- *i) What are the current and emerging green shipping technologies? ii) how does the adoption of green technologies change the vessel operations of seafarers onboard? iii) what are the skills and competencies required for seafarers to adapt to these changes?*

2. Green Shipping Technologies and Evolving Operational Paradigm of Seafarers

Technological and managerial innovations are the perquisites for the successful implementation of GSPs (Mallouppas and Yfantis, 2021). Technologically, several measures have been adopted by the shipping industry including efficient hull designs, propulsion systems, slow steaming, and alternative fuels (Papanikolaou *et al.*, 2023). Managerially, the survey and assessment of ships have become more stringent by the maritime regulatory bodies (Ng, 2018). The IMO mandated that mid and top-level managers on shore as well as senior managers on board (captains, chief-engineers, chief officers, etc.) must formulate and implement appropriate strategies to comply with the regulatory tools, such as SEEMP, CII, Sulfur Cap, EEXI. These technologies and regulatory tools are significantly changing the operations of vessels and role of seafarers onboard. In this section, we highlight the green shipping technologies, and the changing operational paradigms of seafarers. We then discuss the skills which they need to perform their jobs effectively aligning with the technological advancement in vessel operations.

2.1 Efficient Ship Design

Efficient ship design refers to the optimization of a vessel's structure, hydrodynamics, and energy systems to maximize vessel performance while minimizing fuel consumption, emissions, and operational costs (Papanikolaou *et al.*, 2023). This involves advanced engineering, innovative materials, and AI-driven performance monitoring systems to improve energy efficiency, reduce environmental impact, and comply with stringent regulations, particularly EEDI. Hull optimization, use of lightweight materials, and air lubrication systems are the most common technique used to reduce friction with water, improve propulsion efficiency, and thus reduce fuel consumption and emissions (de Kat and Mouawad, 2019; Papanikolaou *et al.*, 2023).

Changes in the hull shape directly impact the onboard operations of seafarers as it alters the hydrodynamic performance, operational efficiency, and behaviour of vessels in areas such as ship handling (de Kat and Mouawad, 2019). A more optimized hull reduces water resistance and enhances fuel efficiency, but it changes how the ship responds to steering and impact of wave. In turn, it impacts the stability of vessels, especially during docking and navigating in confined waters or adverse weather conditions (de Kat and Mouawad, 2019). Optimized hulls often demand adaptive load distribution and draft adjustments to maintain its stability. As a result, seafarers need to develop new skills to adapt to these modifications.

The altered hull dynamics requires seafarers to learn advanced ship handling techniques to navigate efficiently. Additionally, with the integration of AI-driven ship performance monitoring systems, seafarers

need to develop data interpretation skills to analyse real-time efficiency metrics, including hull resistance, fuel consumption and voyage optimization strategies. Furthermore, understanding new hull maintenance technologies, such as low-friction coatings and air lubrication systems, is essential, as these changes require periodic inspection, troubleshooting, and upkeep to sustain long-term efficiency.

2.2 Alternative fuels and treatment systems

The adoption of alternative fuels and treatment systems is reshaping some of the job description of seafarers, requiring them to shift from handling conventional fossil fuels to managing alternative fuels such as LNG, methanol, ammonia, and hydrogen (Dewan and Godina, 2023, 2024). Each of these novel fuels have their own distinct properties, safety concerns, and operational requirements. For example, ammonia is toxic and corrosive, hydrogen requires cryogenic storage and leak detection system, while LNG poses flammability risks that demand strict handling procedures (Mahmud, Sheikh and Chowdhury, 2025). As a result, seafarers must develop expertise in the novel alternative fuels' storage, bunkering, and combustion monitoring to ensure safe and efficient fuel usage while complying with strict safety and environmental regulations.

Moreover, the integration of after-treatment technologies like SCR (Selective Catalytic Reduction), CCS (Carbon Capture and Storage), and exhaust gas scrubbers adds new complexity to vessel operations. Seafarers require monitoring emissions levels, managing treatment systems, alternative fuel management, and conducting regular maintenance to ensure compliance with IMO regulations (Dewan and Godina, 2023). Many of these systems rely on automated controls and real-time data analytics. Hence, seafarers must become proficient in data monitoring, troubleshooting automated emissions control systems, and interpreting environmental performance reports (Dewan and Godina, 2024). The increasing reliance on AI-driven optimization for fuel efficiency also means that seafarers must understand smart energy management systems and adjust fuel usage based on real-time performance data.

2.3 Propulsion Systems

The key technological advancements in propulsion systems are transforming the traditional to complex technology-driven ship operation (Bui, Perera and Emblemsvåg, 2022; Inal, Charpentier and Deniz, 2022). For example, the integration of digital twin technology means that seafarers must transition from reactive troubleshooting to proactive data-driven decision-making, analyzing real-time system diagnostics, and collaborating with shore-based teams to prevent failures (Simion *et al.*, 2024). On the other hand, wind-assisted propulsion technologies, such as Flettner rotors or kite systems, introduce a new dimension to voyage planning (Inal, Charpentier and Deniz, 2022), requiring seafarers to optimize routes based on wind conditions while seamlessly integrating wind power with conventional propulsion. Moreover, advancements in highly efficient propellers, contra-rotating propulsion systems, and energy-efficient rudders demand a refined approach to ship maneuvering, requiring seafarers to adjust to new hydrodynamic behaviors and automated control systems.

Seafarers must possess new skills and competencies to deal with these changes in propulsion systems. These skills include digital system proficiency, predictive maintenance analytics, and advanced ship handling techniques. Proficiency in interpreting data from automated diagnostics and adjusting hybrid propulsion settings to maximize energy efficiency are crucial skills for seafarers in this respect. Overall, as ships are becoming more automated and data-driven, seafarers need to be more technology-savvy system operators.

2.4 Power Systems

The introduction of DC power grids, hybrid power system, battery storage, and WHRS (waste heat recovery systems) are changing the work requirement of seafarers, particularly the engineers. The conventional diesel-powered operations are moving towards energy-efficient and hybrid power management systems (Liu *et al.*, 2020; Pan *et al.*, 2021). As a result, seafarers need to manage more complex and integrated power networks compared to traditional engine-driven generators. With the shift toward hybrid propulsion, seafarers need to understand energy flow optimization, battery management, and power distribution systems to ensure efficient use of electricity. In some ships, the traditional diesel-powered generators are being replaced by automated energy storage systems which require constant monitoring and control. The deployment of WHRS requires seafarers to monitor and control waste-heat recovery boiler (WHRB) and organic rankine cycle (ORC) generators to maximize energy efficiency and reduce fuel

consumption (Senary *et al.*, 2016; Liu *et al.*, 2020). Additionally, seafarers must adapt to AI-driven diagnostics and real-time performance monitoring of automated power management systems that require the skill of data analytics. Moreover, seafarers also need to integrate inputs from multiple energy sources into the overall power grid, adjust load balancing and optimize energy storage. As a result, seafarers need electrical engineering competencies, digital monitoring skills, and expertise in hybrid propulsion technologies to effectively operate these advanced power systems.

2.5 Ship Operation

Ship operation is significantly being transformed by the integration of smart navigation systems, AI driven voyage optimization, and real-time weather routing. Consequently, seafarers now largely rely on advanced digital tools to enhance fuel efficiency, reduce emissions, and ensure safe navigation (Dai et al., 2024; Venkatesan et al., 2025). The widespread adoption of slow steaming which requires precise speed adjustments for optimal fuel consumption, demands a greater understanding of engine load management and predictive maintenance. The use of remote monitoring and ship performance analytics requires seafarers to adapt to collaborative decision-making with shore operators (Emad and Shabakhsh, 2022; Emad, 2020). Furthermore, the integration of autonomous and semi-autonomous technologies is gradually shifting seafarers' focus from traditional vessel handling to supervising intelligent systems, troubleshooting AI driven systems, and ensuring cybersecurity against potential cyber threats (Emad, Enshaei and Ghosh, 2022).

3. Methodology

This study adopts the concept mapping technique to explore the skills and competencies of seafarers to cope with the technological advancement in vessel operations. The concept mapping is a visual and analytical tool which enables the exploration and representation of relationships between complex ideas (Novak and Cañas, 2008; Moon *et al.*, 2011). Thus, it is an effective approach for understanding the interplay among technological advancement, changes in vessel operations, and corresponding competencies. Concept mapping technique systematically breaks down the core themes of a study and arranges them into a structure to visualize the themes (Weinerth *et al.*, 2014). This method allows to identify and analyze key elements of our study, such as green shipping technologies, changes in vessel operations, and the associated competencies of seafarers. This study uses the following steps in concept mapping-

Step-1. Defining the scope and objectives: The scope of our study is limited to green shipping technologies, corresponding changes in vessel operations, and associated skills for seafarers.

Step-2. Data Collection: This study utilizes secondary data from existing literature, IMO guidelines, and industry reports on green shipping technologies and their implications for seafarers.

Step-3. Developing concept map: In this study, we have map out three core themes or primary elements

a) Green shipping technologies (e.g., *efficient ship design, alternative fuels and treatment systems, propulsion systems, power systems, ship operation, etc.)*

b) Changes in vessel operations onboard

c) Required skills and competences for seafarers to cope with changes.

Using these three key themes, this study describes their relationships and highlights the influence of these technologies on the vessel operations and skill-requirement of seafarers.

Step-4. Analysis and Interpretation: Using the final concept map, this study identifies patterns and insights regarding the impact of green technologies on seafarers' roles and skills.

Thus, concept mapping offers a clear framework that captures the interconnectedness of technological advancement, operational changes, and associated competencies. The visual framework will facilitate the understanding of maritime educators, policymakers, and industry stakeholders regarding future role of seafarers in the shipping industry. The framework also provides a roadmap for targeted interventions in maritime education and training (MET). Furthermore, the adoption of concept mapping technique will facilitate the replicability of this study in future research (Emad & Oxford 2008; Kitada *et al.*, 2023).

4. Results and Findings

Based on the discussion on previous studies, the concept mapping technique reveals a structured relationship among green shipping technologies, the evolving work patterns of seafarers, and the competencies required to operate in this evolving landscape. The analysis identifies five major technological domains: *efficient ship design, propulsion systems, alternative fuels and treatment systems, power systems,*

and ship operation. The technological development under each of the domains contributes to substantial operational changes onboard. For example, optimized hull forms and air lubrication systems require adjustments in ship handling and fuel efficiency monitoring while dual-fuel propulsion and wind-assisted technologies require seafarers to manage more complex navigation planning, engine configurations, and power switching techniques. Similarly, the adoption of alternative fuels such as LNG, ammonia, and hydrogen introduces new safety procedures, chemical handling, and emissions control techniques. Across these technological domains, a clear shift is observed in the work paradigms of seafarers, such as shift from manual to digital operations, from single to multi-system management, and from isolated onboard decision-making to integrated, shore-based collaboration. Correspondingly, the required skills of seafarers also to expand to areas such as technical proficiency in advanced propulsion and power systems, digital literacy for AI-driven navigation planning, environmental compliance knowledge, and strategic leadership. These findings underline the necessity for comprehensive and future-oriented training frameworks that align competency requirement of seafarers with the operational demands of implementing GSPs.

The above conceptualizes the evolving role of seafarers in response to the increasing integration of green shipping technologies. Based on the previous literature, it identifies five key technological domains (*efficient ship design, propulsion systems, power systems, ship operation, and alternative fuels*) as the most critical areas transforming vessel operations. These advancements have led to a significant shift in vessel operations for seafarers, characterized by transitions from *manual to digital operations, from traditional fuel handling to alternative fuel management, and from compliance awareness to proactive environmental stewardship*. Additionally, the framework highlights the growing complexity in onboard vessel operations, requiring seafarers to *manage multi-system integration and engage in continuous collaboration with shore-based operation centers.* To effectively navigate these changes, the proposed framework outlines four essential competency domains. These include- (1) *Technical and Operational Expertise*, emphasizing proficiency in advanced propulsion and energy systems as well as emissions control technologies; (2) *Digital Literacy*, encompassing knowledge of AI tools, cybersecurity, and autonomous-system management; (3) *Environmental Awareness and Commitment*, reflecting regulatory knowledge and a behavioral shift toward sustainability; and
(4) *Management and Leadership,* covering strategic planning, resource management, team management, and change management. Collectively, the framework underscores the need for a multidimensional upskilling strategy for seafarers to keep pace with emerging green shipping technologies and ensure the successful implementation of GSPs.

5. Conclusion

Seafarers are at the forefront of implementing GPSs and reducing environmental impacts from the shipping industry. The decisive role of seafarers in implementing GSPs is also highlighted in previous literature (Dewan and Godina, 2023b, 2024). However, this study for the first time presented how the technological development is changing the operational landscape onboard vessels, necessitating a significant shift in the skillset of seafarers. To effectively manage these technologies, seafarers must possess a blend of multidisciplinary competencies. Therefore, continuous professional development and targeted training are imperative to equip the seafarers with the capabilities required to operate safely, efficiently, and sustainably in the era of green shipping.

This study provides a foundation for aligning maritime training and education with emerging green shipping technologies. Future studies may seek to empirically validate the proposed competency domains, assess training effectiveness in real-world settings, and explore the behavioral and cognitive adaptation processes of seafarers. Moreover, the investigation of long-term career impacts and the psychosocial challenges of green shipping technologies will be instrumental in future.

Future policy efforts should focus on integrating green competencies into international training frameworks (i.e., STCW), developing certification pathways for new fuel systems and digital tools, and supporting seafarers through retraining, mental health services, and smooth career transition programs. Policy initiatives must be taken to ensure a resilient, skilled, and environmentally conscious workforce as they are critical for achieving the long-term sustainability goals of the shipping industry.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Artificial Intelligence and its Transformative Impact in Shaping the Maritime Industry

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Abstract: The fourth industrial revolution's advanced technologies is reshaping the maritime industries' operational models and services to achieve greater efficiency. Among all advanced technologies, artificial intelligence (AI) is promised to have a profound effect on shaping the future role of seafarers and marine operators. By utilizing AI, equipment and systems are becoming intelligent enough to be able to collaborate with humans in areas such as collision avoidance, route optimization, reduction of fuel consumption, and preventative maintenance. To achieve this, AI employs other advanced technologies such as the Internet of Things (IoT). Modern ships integrate IoTs (advanced sensors) in the ships' hull, machinery, and navigation systems. Data collected by IoTs is then processed and analyzed by AI and presented to humans for decision making processes. Although AI as an intelligent agent provides measurable results, the question remains how the workforce and human agent can trust, validate, measure, and correctly interpret AI results and integrate them into different sectors of the shipping industry. With the emergence of remotely operated and autonomous ships, answering this question is becoming more critical. Although AI provides a great opportunity for integration of human and machine operations however, AI, like all other advanced technologies, has its own shortcomings. These require the maritime industry—and more importantly, its leading regulators, such as the international maritime organization (IMO)— to be watchful of how AI is getting integrated into the sector and how it will be used in the decision-making processes. It is required to ensure safe and ethical use of artificial intelligence and provide a foundation for the necessary training scheme for the marine workforce to adopt and work alongside AI.

This article aims to use a systematic literature review to provide a brief overview of AI's role and its effect on the human element in the maritime industry, along with its utilization in the remotely operated and autonomous shipping. The results show that despite the limitation of AI, in its current condition (narrow AI), it has great potential to revolutionize the industry. However, care has to be taken as it presents many risks and vulnerabilities. The authors suggest that it is crucial for the maritime industry to avoid sleepwalking into a no return state where the entire industry becomes overly reliant on AI and AI generated results without fully understanding AI structures, behaviors, and the critical role of human operators in the future of the shipping industry.

Keywords: Artificial Intelligence; Maritime Industry; Human Factor; Remotely operated and autonomous ships; Sustainability; Maritime Education and Training, MASS, Seafaring

1. Introduction

Industry 4.0 is revolutionizing all industries, including maritime, by changing the entire operational model and services. In the shipping industry, this is being realized by introduction of Maritime Autonomous Surface Ship (MASS) that allows remote or autonomous operation of ships. Technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Machine Learning (ML), Big Data, and Cloud Computing are being used to implement Industry 4.0. However, although all the advance technologies has a role to play, AI has a unique role as its main aim is to reach an intelligence level that can simulate human intelligence (Aiello et al., 2020; Banerjee et al., 2021; Jan et al., 2023; Shahbakhsh et al., 2021).

So far AI and its other Industry 4.0 advanced technology has been utilized to achieve sustainability, reduce greenhouse gas emissions, and improved automation however, its effect on human element and role of maritime workforce has not been adequately investigated. For instance, the role of seafarers, terminal and port operators, marine engineers and those involved with remotely operated and autonomous ships will be dramatically affected by AI however, there is not much research on how they need to be trained and what it takes for them to go through reskilling, upskilling, and even in some cases, de-skilling (Emad & Ghosh, 2023; Emad et al., 2024; Kamble et al., 2018; Khabir et al., 2020; Lokuketagoda et al., 2018). One reason might be that there is a misconception that intelligent technology will replace human in the workplace for example in MASS shipping. However, ideally the idea of implementing AI is to augment human operators' capabilities. This research, through a systematic literature review, focuses on AI, its potential opportunities and risks, and suggests how we can benefit from AI while remaining watchful of its shortcomings in the maritime industry.

2. Method

This paper utilized a systematic literature review (SLR) to develop a better understanding of the outcomes of the scientific research done about implementation of Industry 4.0 and it technologies such as AI, IoT, and cybersecurity in the maritime industry and how they affect the role of the human element in current and remotely operated and autonomous ships. Our study involved using academic search engines such as Scopus, ScienceDirect, and Web of Science to review peer-reviewed articles from academic journals, conference proceedings, industry paper, and books. Moreover, white papers from the industry on the impact of the next generation of AI and its revolutionary effects on our society, jobs, and the interaction between AI and human operators were explored. The goal is to understand how maritime education should evolve toward a technology- oriented model (Dinter et al., 2021; Lame, 2019; Nightingale, 2009). The combined search results from all search engines and industry papers produced 153 articles. The results were filtered for duplication, relevancy, and quality of the papers through the screening and eligibility process. The total number of articles used for this research paper was narrowed down to 63.

3. Artificial Intelligence (AI)

Artificial Intelligence (AI) is designed to mimic human cognition in functions such as reasoning, learning, and problem solving. There are different definitions for AI; however, all of them share some common aspects, namely the aim to create a product that resembles human intelligence to perform tasks autonomously or augment human decision-making.

The field of AI has been introduced in 1956, by Dartmouth Summer Research Project on Artificial Intelligence. AI initially existed in a very primitive form however during decades of research and development it is getting to the stage that is revolutionizing all aspects of society and most industries (Fetzer, 1990; Kelly et al., 2023; McCarthy et al., 2006; Sheikh et al., 2023).

3.1 AI developmental Wave and Taxonomy

AI development has gone progressed through three distinct waves, resulting in two AI winters—the first and second—during 1970s and 1980s. This period is characterized by limited progress, technological limitations, and failure to meet expectations mainly due to lack of adequate funding. After its inception in 1956, the first AI systems in the lab were able to perform simple tasks like playing checkers and solving logical puzzles. The excitement fueled the assumption that AI would soon be capable of performing the tasks that human does however, it soon proved to be overly optimistic they were—we are experiencing similar optimism today, where many believe that advanced AI will soon replace humans. However, around 1970, the first AI winter began. The second wave started in the late 1980s when personal computers became popular. However, after a few successful projects, the second wave of AI subsided. It was not until the late 1990s that AI flourished and matured to the stage that characterized AI Spring. AI growth has continued to expand mainly due to ease of access to the internet, immense processing power, and the availability of large pools of data (Gordon, 2023; Haenlein & Kaplan, 2019; Sheikh et al., 2023).

AI can be grouped into three main categories, types, and sub-branches sometimes referred to as the

AI hierarchy as outlined below (Kelly et al., 2023; Shreya, 2023):

Artificial Intelligence:

1. Artificial Narrow Intelligence → Machine Learning
2. Artificial General Intelligence → Deep Learning
3. Artificial Super Intelligence → to be invented

Artificial Narrow Intelligence, also known as Weak AI, is designed to be capable of performing specific tasks such as playing games that generally proved to be better than humans at those tasks. Artificial General Intelligence, also known as Strong AI, still in developmental stage, would be capable of thinking like human and learning to perform tasks or anything that a human can do. Originally, it was predicted that Strong AI would become a reality by 2060, however recently report published by Google DeepMind is suggesting that Strong AI could become a reality as soon as 2030, highlighting upcoming changes across all industries, including the maritime industry. The key difference between Narrow AI and Strong AI, which focuses on performing a single task through learning algorithms, is that it cannot apply knowledge gained from one task to other unrelated tasks or jobs. This is entirely different from Artificial General Intelligence, which is assumed to be capable of replicating complex and challenging human thinking (Güner, 2022; Rouse, 2023). In contract Artificial Super Intelligence is set to determine its own goals without humans intervention to understand or even be aware of them (Kuusi & Heinonen, 2022; Shah et al., 2025).

4. AI Application in the Maritime Industry

The addition of AI to equipment and systems enabling data-driven decision making leading to operational efficiency. The maritime industry is responsible for transporting approximately 11 billion tons of cargo annually is increasingly being criticized and put under the spotlight due to facing challenges such as high fuel costs, human errors caused by fatigue, climate change concerns and challenges, and pandemic-related crises. In response to these challenges the maritime industry is undergoing transformation aiming to improve efficiency, sustainability, and resilience. This is being pursued through the introduction of green shipping and remotely operated and autonomous ships (MASS) as sustainable solutions (Poongavanam et al., 2023; Shahbakhsh, 2025b). The maritime industry, by integrating Machine Learning (ML), as a subset of AI along with digitalization that can produce streaming data will be capable of instant analysis of the data to identify patterns that support data-driven decision-making. As the shipping industry shifts toward MASS and remotely operated and autonomous ships, incorporating AI-empowered systems is becoming increasingly important. It is predicted that the market for AI incorporated equipment and systems reach $5.01 billion by 2028 (Ceyhun, 2019; Güner, 2022; Portley, 2023; Shahbakhsh et al., 2023).

4.1 Route Optimization and Energy Efficiency

The maritime industry is currently employing AI-enhanced systems to optimize routes by analyzing real- time meteorological data, the ship's hydrodynamics, and surrounding traffics resulting in considerable efficiency. The provided speed management further enhances efficiency by recommending dynamic speed profiles that minimize fuel consumption and thus emissions without compromising arrival schedules. AI also contributes to weather and sea condition forecasting by processing remote sensing data, aiding in safe navigation and route planning (Lisowski, 2022). Such intelligent voyage planning system not only lowers operational costs but significantly reduces greenhouse gas emissions, making a strong case for decarbonization (Khabir et al., 2020; Pribyl, 2023; Saafi et al., 2022).

4.2 Engine Performance and Maintenance

In the engine department the AI-powered engine performance monitoring system with its predictive maintenance schedule is revolutionizing how ships manage their critical machinery. AI-driven systems optimize fuel consumption and reduce emissions by analyzing navigational data and vessel performance. IoT sensors embedded in propulsion systems continuously monitor engine health, identifying early signs of wear and inefficiency. The real-time condition monitoring enables proactive maintenance, preventing suboptimal combustion, and ensuring peak engine performance. Furthermore, AI-enhanced energy

consumption analytics identify inefficient energy use across systems like HVAC and lighting, allowing automated adjustments that curtail auxiliary power demand (Emad et al., 2020; Plaza-Hernández et al., 2021).

4.3 Ports and logistics

Ports and logistics have also seen remarkable AI integration. AI-optimized port is coordinating vessel arrivals with berth availability through digital twin simulations, thereby reducing idle times and auxiliary engine usage. Container terminals with autonomous cargo handling systems, such as robotic cranes and automated guided vehicles, expedite loading and unloading, shrinking port stays and associated emissions. Remote monitoring and control are facilitated through AI-enabled digital twins, providing real-time insights and decision support for shore-based operators. In near future the autonomous berthing and docking will be achieved using AI algorithms that process environmental data to execute precise maneuvers in congested ports (Cai et al., 2024). Advanced port gate systems alleviate truck congestion, while smart documentation handling reduces administrative delays, both of which contribute to a greener and more efficient port environment (Cranai Infotech LLP, 2023; Kumari, 2021; Tsiulin & Reinau, 2022).

4.4 Emissions Monitoring and Alternative Fuels

AI also plays a central role in emissions monitoring and compliance of ships. IoTs through sensor networks installed onboard ships measure exhaust gas composition in real-time, sending data to centralized systems for analysis triggering corrective actions, such as engine recalibration or adjustments to exhaust scrubbers, ensuring compliance with environmental regulations. Most significantly, AI accelerates the adoption of alternative fuels through enhancing research and empowering simulation platforms. These tools model the operational viability of new fuels such as ammonia, hydrogen, and methanol under diverse scenarios, reducing testing costs and speeding up deployment. Emissions trading integration platforms, powered by AI, help fleets align with carbon credit markets and reinvest savings into sustainable technology (Durlik et al., 2024; IMO, 2020; Mahajan et al., 2023).

4.5 MASS and Autonomous Shipping

AI is pivotal to the advancement of autonomous shipping by enhancing navigation, safety, maintenance, and operational efficiency. In navigation, AI algorithms like Proximal Policy Optimization (PPO) and Probabilistic Roadmaps (PRM) enable Marine Autonomous Surface Ships (MASS) to make real-time decisions in complex maritime environments, accounting for dynamic obstacles and adhering to International Regulations for Preventing Collisions at Sea (COLREGs) (Guan et al., 2024). For collision avoidance, Deep Q-Networks (DQN) combined with velocity obstacle methods allow vessels to proactively manage potential collisions by learning optimal maneuvers through reinforcement learning (Li et al., 2025). Object detection and classification are enhanced using multi-scale deep learning models, such as improved YOLOv8 and Faster R-CNN, which accurately identify and track maritime objects under varying conditions (Haijoub et al., 2024). Predictive maintenance leverages machine learning techniques to analyze sensor data, forecasting equipment failures and optimizing maintenance schedules to prevent downtime (Simion et al., 2024).

5. AI Risks in the Maritime industry

While AI is offering significant benefit to the maritime industry, there is a dire need for careful consideration of its risks including misuse, errors, ethical concerns, cybersecurity vulnerabilities, regulatory gaps, and structural challenges (Durlik et al., 2024; Kim et al., 2022). Comprehensive risk assessment and pilot testing is essential ensuring the safe and reliable AI integration. The IMO—as the main regulatory body of the maritime industry—can playing a critical role in defining the risk assessment criteria and enforcing data governance and mandate safety and security testing to ensure that AI, meet all safety, ethical, and reliability requirements (Biolcheva & Valchev, 2023; Shah et al., 2025; Shahbakhsh, 2025a; Sheikh et al., 2023).

Another crucial factor is the human element and how operators interact with collaborate AI and managing the misconception that AI will replace humans. For the foreseeable future AI is in need of human oversight, monitoring operation and intervene when necessary. However, there is significant gap in

training program for how maritime workforce should interact with AI. The training programs should provide seafarers with the knowledge and competencies for monitoring, diagnosing and manual override of AI systems when necessary (Emad & Shahbakhsh, 2024; Shahbakhsh et al., 2021; Srisorn et al., 2023).

6. Seafarers Engagement with AI and the Role MET

Seafarers and the entire maritime workforce soon will need to directly or indirectly engage with AI and Ai-driven intelligent systems and equipment to analyze vast amounts of data and provide actionable suggestions to human operators. However, resistance to adopting AI, driven by distrust in AI or concerns over job displacement, highlights a critical training gap. The maritime industry should support Maritime Education and Training (MET) institutions to address this gap by equipping seafarers with AI literacy, cybersecurity skills, and ethical judgment to avoid over-reliance on AI-generated results. This is necessary for building an informed trust with AI in order to cooperate with AI in the form of Human-AI teaming (Amershi et al., 2019; Odedina, 2025; Sheikh et al., 2023; Wang et al., 2020). The availability of competent, AI capable workforce may help reducing the current resistance to AI integration to the maritime sector (Emad et al., 2023).

Maritime Education and Training Institutes (METs) are playing a critical role in training and assessment of the maritime workforce and preparing a new breed of seafarers (Emad & Oxford, 2008; Emad et al., 2007; Narayanan et al., 2023). The future seafarers who, in addition to their seafaring and technical skills, need to be equipped with AI literacy and ethical judgment to avoid blindly over-relying on AI-generated results for decision-making (Emad & Shahbakhsh, 2022; Emad & Ghosh, 2023; Emad & Shahbakhsh, 2024; Sharma, 2023).

AI is also transforming maritime education and training through adaptive learning and technologies such as immersive simulators. The researcher in the field of MET are expanding our understanding of the potential and challenges of employing AI and other Industry 4.0 techno0logies. Projects such as i-MASTER that employs AI-driven simulators that dynamically adjust scenarios based on trainee performance, optimizing skill acquisition (Bhagat & Munim, 2024). Some countries are also pioneering in utilization of AI in their educational systems. For instance, in Singapore, AI-enhanced bridge simulators analyze trainee decisions, generate automated feedback, and produce performance analytics, improving training efficiency (Koh et al., 2023). Institutions in the Black Sea region leveraging AI for competency-based curriculum design, aligning MET with emerging industry needs (Colak et al., 2024). However, global MET system lags AI advancements as the STCW convention lack the mandatory requirement for AI training. A proactive maritime industry is required to sync between AI progress, IMO regulations, and its MET system to synchronize with the AI progress to prepare maritime workforce for an AI-integrated future (Emad, 2021; Shahbakhsh et al., 2023).

7. Current State of Changes

Despite an ongoing revision, the STCW struggles with the keeping up with the development and implementation of AI in the maritime industry. Additionally, the current application of AI primarily involves narrow or weak AI, which has its own shortcomings in terms of safety, regulation, ethics, and bias. Delaying the workforce training while AI is being integrated entails immense risk particularly with the potential potential integration of Artificial General Intelligence (AGI) in the near future (Duzenli et al., 2025; Kizilay & Çelik, 2025; McLean et al., 2023; Pazaver & Kitada, 2025; Yi et al., 2025).

The MET institutions need to proactively develop the AI-resilience competencies for seafarers to understand AI behavior, interpret safety aspects of AI-generated results, recognize failures, and respond to anomalies. AI is not just merely a tool in a seafarer's or maritime operator’s toolkit but a transformative system revolutionizing the maritime operations (Biolcheva & Valchev, 2023; Emad & Shahbakhsh, 2022; Lee & Lee, 2024). While technology providers are responsible for designing AI systems with safe design patterns, interpretability, and alignment with safety and security requirements, users also need to be trained to understand the system's limitations and receive updates as AI systems evolve. AI is and will continue playing a massive role in augmenting human activities across the maritime sector—especially onboard ships. Seafarers, as the frontline of the shipping industry, are no longer isolated from the digital and cyber world. Therefore, they need to build AI-resilient competencies along the traditional maritime skills. Technology providers must design interpretable and secure AI systems, while MET programs should

leverage AI-driven tools, such as simulators, to prepare seafarers for evolving operational realities.

8. Conclusion and Recommendations

AI is revolutionizing the maritime industry to make it more resilient, sustainable, green, and environmentally safe contributing to digitalization and decarbonization. However, the integration of AI present many challenges to the maritime industry including workforce readiness and regulatory alignment. It is therefore necessary to adopt a balanced approach when integrating AI at any scale. Understanding the new system's capabilities and limitations is essential to build trust, and to be able to validate, measure, and correctly interpret AI-generated results before integrating it into the decision-making process. While some industries are still trying to address the current shortcomings of narrow AI, researchers and pioneers are warning about the potential emergence of Artificial General Intelligence (AGI) within the next decade.

The IMO is working on developing a new code to address changes related to remotely operated and autonomous ships and is also revising STCW to include these technological advancements. Meanwhile, MET institutions must proactively leverage AI-driven tools to design new training programs and advanced simulators for seafarers to experience and learn to working alongside AI, focusing on AI literacy, cybersecurity, and ethical decision-making. To guide future research, this paper proposes the following questions:

- What are the gaps in MET training programs, tools, and facilities regarding AI integration?
- What are the potential opportunities and risks of AI use in MET?
- What is AI-based training competencies that can foster trust in AI-generated output while addressing safety, ethical, and security concerns?
- What are the recommended amendments to STCW to address AI-related training?
- What skills and competencies are required for maritime trainers to effectively train learners for AI-Driven workplaces?
- Which IMO regulation, beyond STCW, needs amendment to address the emergence of AI in the maritime sector?

While the AI and other advanced technologies under the framework of Industry 4.0 are maturing the maritime industry should remain alert, vigilant, and watchful, and maintain active oversight of AI implementation. More importantly, the maritime industry should stablish the boundaries for human-AI collaboration, ensuring seafarers retain a supervisory role. By aligning IMO regulations, MET programs, and industry practices, the maritime sector can harness AI's potential while safeguarding safety and operational integrity.

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The 25th IAMUC

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Proceedings of the
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Autonomous and AI-Driven Hydrography: Innovations for Sustainable Maritime Practices

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Abstract: The hydrographic data processing with integration of artificial intelligence (AI) is enhancing the quality and is also time-efficient in data collection, data processing, and interpretation of maritime data. This innovative technology changed the efficiency, accuracy, and paved solutions for environmentally sustainable survey operations. The AI-enabled autonomous bathymetric system can handle real-time bathymetric mapping, onboard real-time data processing, and it will reduce human interventions. As an example, the AI-based CARIS Mira Cloud platform enhances the hydrographic data processing, which includes noise filtering, anomaly detection, and accuracy, and it helps to minimise manual post-processing. A case study conducted in Sharm Obhur underlines the benefits of the AI-based CARIS Sonar Noise Classifier (CARIS Mira) in data processing, such as quality improvement and efficiency. This study, compared with traditional methods, shows that AI-based data processing results in a 92% boost in data accuracy and substantially reduced operational costs. This confirms the growing role of AI in an effective, cost-effective, and more intelligent future for hydrographic surveying

Keywords: Autonomous Hydrography; Artificial Intelligence; Sustainable Maritime Practices; Smart Navigation; Marine Data Analytics

1. Introduction

Maritime industry is now undergoing notable changes with the enablement of artificial intelligence (AI) in the different sectors of industry. The AI-enabled hydrographic operations also cause a significant transformation in the maritime industry. The AI changes the traditional methods used in the hydrographic data acquisitions and processing, which offer enhanced precision, operational efficiency, and support for sustainable marine navigation. The AI- enabled hydrography helps improve workflow automation, cost reduction, and environmental responsibility, while also building on traditional navigation practices that have long supported maritime safety **(**Walling & Hill, 2014). To demonstrate the practical implications of these innovations, a case study by Alahmadi & Elsobeiey, 2025, conducted in the Sharm Obhur creek in the Red Sea is referred in this paper. This study highlights the applications of AI- enabled hydrographic data processing and interpretations and their benefits in marine survey operations.

2. AI in Hydrographic Surveying

The improvement of recent technology like artificial intelligence (AI) plays major roles in the hydrographic data collections, data processing, and interpretations, and makes marine survey techniques efficient and environmentally sustainable maritime operations (Specht et al. 2021). The present study deals with AI-enabled bathymetry data processing, mapping, real-time data interpretation in hydrographic survey, and their applications (Lin et al. 2022). AI-enabled data processing techniques enhance efficiency and reduce the time required for data processing. There are many AI-enabled hydrographic data processing software tools available commercially, and among them, CARIS Mira is one that helps improve noise filtering, feature detection, and anomaly detection, thereby reducing time for data processing (Pavlis & Romeiser, 2019). Traditional practices in the maritime sector require more time, manpower, and high operational costs. Hence, AI helps reduce all these and results in effective survey, mapping, and safe navigation (Marrable et al., 2020).

The most recent cloud-based AI data processing technology, including CARIS Mira, offers better real- time hydrographic data filtering, and this enables surveyors to enhance maritime decision-making and reduce

computation time (Table 1). For this reason, the Hydrographic Survey Department (CAT A accredited) at the Faculty of Maritime Studies adopted AI-based data processing methods to improve survey methods, accuracy, efficiency, and marine environmental sustainability. AI technology has changed the hydrographic survey efficiency, data accuracy (92%), and reduction in survey costs (50%) compared to traditional survey methods (IHO & GEBCO, 2021) (Figure 1). All these data show improved efficiency and cost-effectiveness of AI-powered hydrographic survey techniques (Specht et al., 2021; Lin et al., 2022).

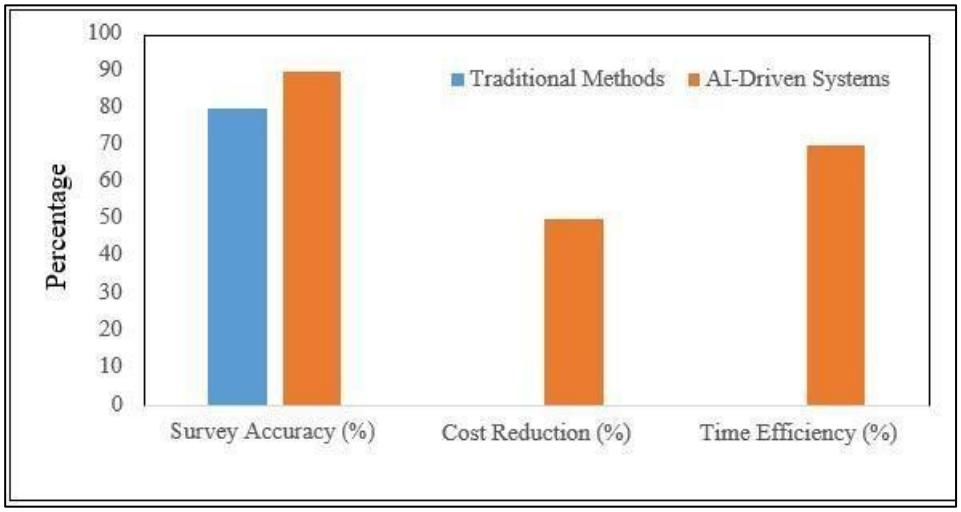


Figure 1. Comparison of Traditional vs. AI-Driven Hydrography

3. AI for Sustainable Maritime Goals

There are few studies that show AI-enabled hydrographic survey systems offer major operational benefits, reducing survey and processing duration and survey-associated errors (IHO & Nippon Foundation-GEBCO Seabed 2030 Project, 2021; Specht et al., 2021; Lin et al., 2022). These systems will support sustainable marine ecosystems by utilizing AI-enabled real data acquisition, data processing, and navigation, and they also help with fuel efficiency. Different studies associated with AI-enabled hydrographic systems also underline the effectiveness of the system in utilization of underwater mapping, detection of underwater hazards, and enhancing the accuracy of nautical charting, etc. (IHO, 2017).

The studies show the AI-enabled survey solutions in the maritime sector are essential for global maritime sustainability goals. Even though challenges like cybersecurity risks and regulatory compliance show the need for standard practices for AI use and applications in the maritime sector (Svilicic, Rudan, Jugović, & Zec, 2019), this research underlines the need for collaboration in different sectors like education and training, industry, private sectors, and the IMO to ensure the modernization and fair and responsible use of AI in hydrography.

4. Case Study: AI-Driven Hydrographic Data Processing

In a practical application of artificial intelligence in hydrographic workflows, Alahmadi & Elsobeiey (2025) conducted a focused case study at Sharm Obhur, a coastal lagoon near Jeddah, to assess the performance of the AI-based CARIS Sonar Noise Classifier in cleaning bathymetric data. Utilizing the SeaBat T50-P multibeam echo sounder on the KAU Hydrography 2 vessel, the study collected high-resolution depth data from relatively smooth terrain. Following acquisition, datasets were processed using CARIS HIPS and SIPS software, including georeferencing and generation of noisy and cleaned surfaces. The classifier, a pre- trained convolutional neural network, effectively identified and removed erroneous data points by assigning confidence scores, significantly reducing noise while preserving critical seabed information. As illustrated in Figure 2, the raw data contained surface artifacts, which were subsequently eliminated in the cleaned result shown in Figure 3. A differential surface analysis (Figure 4) confirmed successful de-noising, especially across flat terrain. The cleaned data conformed to over 63% of IHO Special Order accuracy standards, validated by Total Vertical Uncertainty (TVU) calculations. Importantly, AI processing took only 30 seconds compared to 40 minutes via manual editing—demonstrating significant efficiency gains. This case underscores how AI integration can

transform hydrographic data workflows, reduce processing time, and meet international accuracy standards, particularly in controlled bathymetric environments like Sharm Obhur.

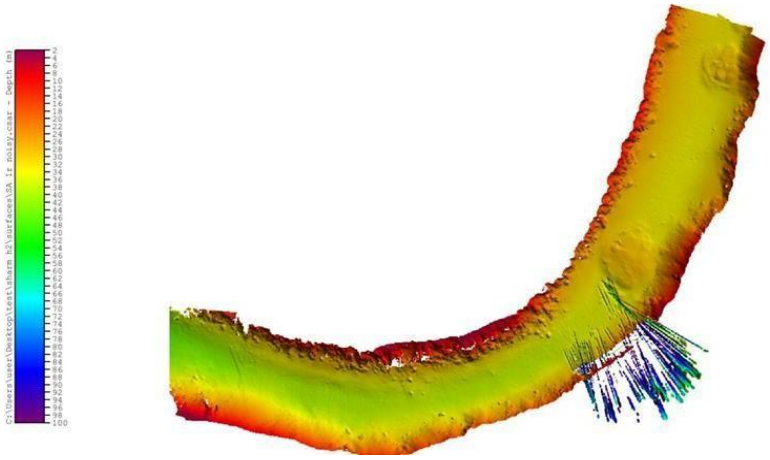


Figure 2. Noisy base surface for Sharm Obhur (Alahmadi & Elsobeiey, 2025)

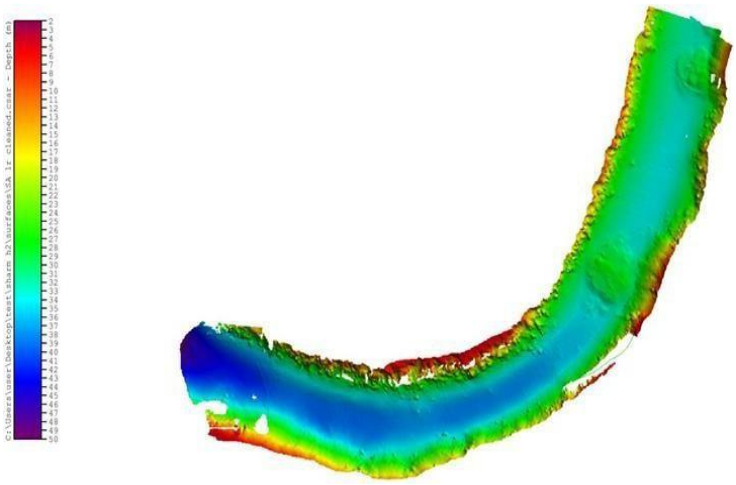


Figure 3. Cleaned base surface for Sharm Obhur (Alahmadi & Elsobeiey, 2025)

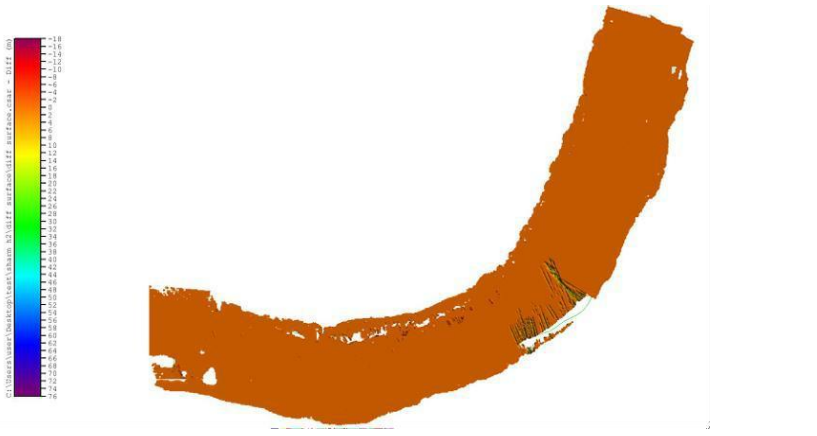


Figure 4 2D view of the difference surface between the noise surface and clean surface for Sharm Obhur data *Alahmadi & Elsobeiey, 2025)*

5. Conclusion

The role of AI in hydrographic surveying is to improve the data acquisition techniques, data processing

techniques, and data interpretations, leading to notable improvements in efficiency, accuracy, and environmental sustainability. The referred study conducted in our institute highlights the role and impact of AI- enabled tools like CARIS Mira and the CARIS Sonar Noise Classifier in enhancing data processing methods and interpretation, and reducing the processing time from 40 minutes to 30 seconds. The case study in the Sharm Obhur shows how AI-enabled systems effectively remove noise, detect seabed features, and comply with international hydrographic accuracy standards. This study shows AI potential to help sustainable maritime operations by reducing manual labor and minimizing ecological footprint. The advancement of AI technology and AI-enabled hydrographic systems will play a major role in the future of smart, efficient, and responsible marine surveying. Though ongoing collaboration in academia, science, technology, industry, and regulatory bodies will be important to ensure ethical use and long-term success of AI in this industry.

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Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Exploring a Framework for Maritime Education and Training Tailored to Professionals in Underwater Robotics

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Abstract: The modern maritime industry is undergoing a profound transformation of its operational concepts influenced by growing disruptive technologies such as digitalization, decarbonization and intelligent systems. This transformation requires qualified experts skillful at operating sophisticated technologies. The market demands a redefined skill set from future maritime professionals, with an emphasis on competencies such as data control, automated systems understanding, decision-making using artificial intelligence and expertise in high-tech environments. The objective of this paper is to formulate programs and competencies with particular regard for professionals in remotely operated vehicles (ROV) by adapting educational frameworks to technological innovation. This paper investigates the current application of underwater robotics in the maritime industry by means of a SWOT analysis. This analytical framework will reveal strengths, weaknesses, opportunities and threats associated with the use of robotics. The paper critically evaluates existing curricula, training initiatives and academic Master's programs, while considering technological, ecological, safety and societal challenges associated with the application of underwater robotics. The findings of this paper illustrate specific learning outcomes, subject areas and competencies necessary for ROV professionals. Special emphasis is put on acquiring new skills and knowledge through the application of advanced solutions in robotics, with a focus on adapting these competencies to the international standards in order to adequately respond to the demands of the maritime labor market. The paper demonstrates that the education of ROV professionals requires programs which integrate knowledge of numerous different subjects such as maritime sciences, technology, engineering, mathematics and social sciences, especially in the domains of team work, time management and communication. This interdisciplinary approach ensures greater competence of professionals in maritime operations, further increasing efficiency, environmental protection, safety and safety standards compliance. The paper highlights that learning frameworks based on robots are adapted to the preferences of new generations who are extremely familiar with experience-based learning and digital literacy. Future research stemming from this paper's findings will be aimed at the development of curricula which optimally combine theoretical knowledge with practical applications. Future research will combine state of the art tools with teaching methods, i.e. incorporate virtual reality simulations in ROV trainings, in order to encourage even more effective skill acquisition. This will result in the acquisition of fundamental knowledge of underwater robotics while simultaneously practicing transversal skills such as analytic thinking, innovation and interdisciplinary cooperation, which will ensure a professional workforce ready to face different scientific and industrial challenges within the maritime society 5.0

Keywords: underwater robotics; maritime education and training (MET); remotely operated vehicle (ROV) professionals

1. Introduction

According to Schumpeter's concept of creative destruction, disruptive technologies are the technical innovations that make existing technologies and social relations obsolete or significantly changed. Today, the attention of the academic and professional public is focused on several interconnected technological fields, including nanotechnology, biotechnology, artificial intelligence, quantum computing, robotics, the Internet of Things, blockchain, geoengineering, and Earth Systems Engineering (Thomas, 2019).

The literature highlights advanced manufacturing methods, digitalization, automation, and new smart materials (Thomas, 2019; Agarwala, 2022) as the key disruptive technologies in the maritime sector. The development of extensive databases has enabled the application of artificial intelligence in autonomous ships, cloud computing for data processing and storage, and digital twins for predictive maintenance of ship

equipment and systems. Drones and unmanned aerial vehicles (UAVs) facilitate inspections, while augmented and virtual reality improve training and simulations in the maritime sector (Agarwala, 2022).

Robotic systems, including remotely operated vehicles (ROVs) and autonomous robots, enable sophisticated missions in ocean exploration, sampling, and monitoring of marine life. These robots are equipped with advanced guidance, navigation, and communication systems that enable operation in extreme conditions and significantly contribute to the development of marine robotics and research capacities (Zereik et al., 2018).

Over the past two decades, ROVs and AUVs have become indispensable tools in scientific and commercial underwater exploration, while human submarines are increasingly used for specialized tasks (Zereik et al., 2018). Robotics, as a key disruptive technology in the maritime sector, offers innovative solutions for underwater exploration, offshore operations, port logistics, and vessel maintenance (Sahoo et al., 2024).

Underwater robots are widely applied in science, industry, and the military. ROVs are particularly important for the inspection and maintenance of underwater infrastructure, while AUVs are increasingly employed in mapping and exploration tasks (Sahoo et al., 2024). Robotics has also contributed to aquaculture, where automated systems contribute to greater profitability and efficiency of farming (Yue & Shen, 2022).

Larson (2014) emphasizes that unmanned underwater vehicles (UUVs) represent a disruptive technology with the potential to transform naval warfare. Additionally, there are significant opportunities for the use of underwater robotics in archaeological missions and industrial maintenance. This indicates the need for developing advanced human-robot communication systems in complex underwater environment (Mišković et al., 2016).

The value of global remotely operated underwater vehicle (ROV) market is estimated at US$1.8 billion in 2024 and is expected to grow at a compound annual growth rate (CAGR) of 7.3% by 2034, reaching US$3.6 billion (GMI, 2024). The market growth is driven by an automation increase in industries such as oil and gas, marine exploration, infrastructure maintenance, and inspection, where remotely operated vehicles (ROVs) are becoming essential for efficient and safe operations in challenging environment. Technological innovations, such as artificial intelligence and advanced sensors, improve the performance of ROVs, enabling the performance of complex tasks with minimal human intervention. The main challenges in the market include regulatory barriers and high maintenance costs. However, the advancements in technology and the growing need for safer operations are expected to contribute to continuous growth. North America dominates the market, while Europe and Asia are witnessing significant growth, especially in industries such as underwater archaeology and mining. The ROV market comprises various sectors, including aquaculture, rescue diving, utilities, military, oil and energy, and others (see Fig. 1). The oil and energy sector dominated the market with a market share of 35% in 2024 (GMI, 2024). Trends and challenges in the offshore ROV market indicate extensive oil and gas exploration and offshore wind power, but also high capital and operating costs, especially for smaller companies (Bali, 2025).

The report on the observation of mini ROVs market describes the growth and forecasts for small underwater robots used for visual inspections and scientific research in aquatic environment. This market is projected to grow with an estimated increase from USD 11.98 billion in 2024 to USD 12.65 billion in 2025, at a compound annual growth rate (CAGR) of 5.6%. By 2029, the market is expected to reach USD 15.88 billion, growing at a CAGR of 5.8% (The Business Research Company, 2025). The statistics on the remotely operated vehicle (ROV) market show a significant need for personnel training in this industry, particularly due to market growth and technological innovations.

In the maritime industry, disruptive technologies necessitate the formation and update of regulations, as in aviation and automotive industries. These technologies affect not only operational processes but also human resource management (IMAREST, 2023). Given the growth of technology and automation, the education system must be adapted to prepare people for new challenges and provide professionals with the skills that are necessary for work in a technologically advanced society, both at sea and on land. Three key areas for this transformation are the development of STEM skills for seafarers 4.0, ethical use of new technologies to the benefit of humanity, and a wider access to maritime education based on innovative teaching methods (Simmons & McLean, 2020).

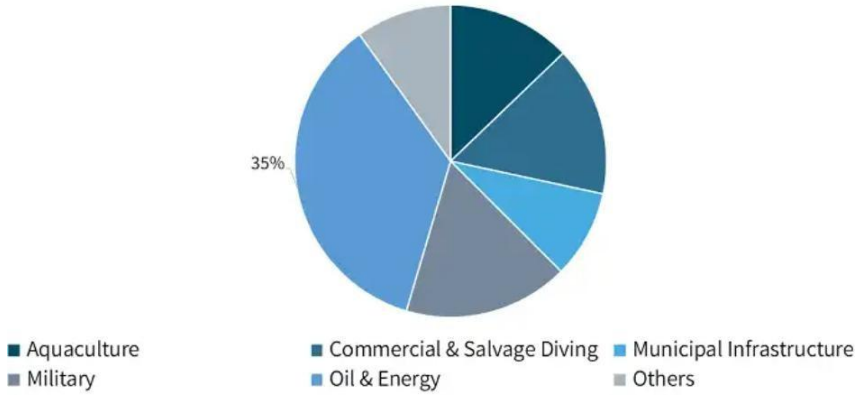


Figure 1. Remote Operated Vehicle (ROV) market analysis based on application (GMI, 2024)

Disruptive technologies in education significantly transform learning and teaching methods. These technologies include (Gejendhiran et al., 2020):

- Online Learning
- Chat-based Collaboration Platforms
- Competency-Based Education (CBE)
- Virtual Reality (VR) and Augmented Reality (AR)
- Artificial Intelligence (AI)
- The Internet of Things (IoT)
- Digital Twins
- Gamification
- Case-based Instruction
- STEAM (Science, Technology, Engineering, Arts, and Mathematics)
- Immersive Experiential Learning.

Education should provide all the conditions for the development of highly competent seafarers. The proposed skills should include leadership, data processing, teamwork, automation understanding, change management, lifelong learning, stress management, and effective communication. This modern approach to learning promotes students' autonomy and develops research skills. On the other hand, individualized learning, including mentoring and coaching, is becoming increasingly important, despite high expenses (Maghoromi, 2023).

Implementing disruptive technologies in the maritime sector requires a blend of specialized and transferable skills for the successful adoption and integration of new technologies. Employers should consider the skills they need and the skills that will be needed in the future. Artificial intelligence (AI) calls for the skills such as data analysis, business modeling, IT skills, and interdisciplinary knowledge. For autonomous systems, key skills include systems engineering, functional safety, software development, communication, and cybersecurity. The combination of AI and autonomy necessitates a broader vision, willingness to adapt, and a passion for innovation. Sustainable energy and decarbonization require multidisciplinary thinking, training in hazardous processes and safety, as well as design and integration within the system (IMAREST, 2023). Cybersecurity skills are essential for protecting autonomous systems and other digital systems

Additionally, specialized skills in energy systems and sustainable solutions for ship operations, as well as the development of soft skills, are also significant (Harris & Sunley, 2021). All these skills are developing slower than robotics, and therefore automation represents a challenge for the workforce. The prior education of the existing workforce, which traditionally focused on specific engineering fields or business sectors, does not facilitate the adaptation and transition to automated operations (Zuo et al., 2023).

This paper will examine the role of disruptive technologies in the transformation of the maritime industry, with a specific focus on the application of underwater robotics in addressing contemporary technological, operational, and environmental challenges. The study relies on a SWOT analysis to identify the

trends associated with the deployment of robotics in the maritime sector. The paper proposes potential draft topics for the basic level of ROV operator training, aligned with modern industry requirements and educational standards. The paper further highlights the skills necessary for effective ROV operations. Special emphasis will be placed on the need to integrate these educational requirements into university transformation processes to align university education with the characteristics and expectations of younger generations of students (Thomas, 2019; IMAREST, 2023; Zereik et al., 2018).

This paper comprises several chapters. The first chapter is introductory while the second chapter presents the research methodology. The third chapter provides an overview of underwater robotics in the maritime industry with the proposal of SWOT analysis. The fourth chapter discusses the skills and competencies of professionals, whereas the fifth chapter provides concluding remarks.

2. Methodology

To review the current state and potential of robotics application in the maritime and related industries, this paper employed a systematic review of relevant scientific and professional literature. Such approach provided a comprehensive insight into the current practice and development directions in the application of underwater robotics, thereby identifying the nature of this growing disruptive technology.

Based on the key findings from the literature, a SWOT analysis was conducted to systematically address issues in the broader implementation of these technologies in industrial practice. This method facilitated a structured review of various aspects of underwater robotics, encompassing technical, organizational, and regulatory factors.

Additionally, the literature analysis identified a strong need for the development of specialized educational and training programs adapted to the needs of the modern labor market. In that sense, the paper identified the key skills and competencies required for future ROV operators, thereby contributing to the definition of the educational framework for this specialized profession.

3. An Overview of the Application of Underwater Robotics in the Maritime Industry

The maritime sector is adopting a new generation of disruptive technologies, which will improve efficiency, safety, connectivity, and meet environmental goals like the reduction of carbon emissions. However, there are challenges, such as the need for updated regulations that follow technological developments and encourage innovation. The impact on employees should be considered in the process of the adoption of the disruptive technologies. Companies must ensure that their employees are included in the technological transformation through an effective process of recruitment, retraining, and retention of skilled personnel. Additionally, the inclusive work environment that supports employee development and fosters greater innovation and satisfaction will ultimately reduce staff turnover and loss of expertise (IMAREST, 2023). This paper presents a SWOT analysis of underwater robotics applications in the maritime industry in accordance with the review of relevant literature (see Table 1).

Among the advantages, it should be noted that the rapid development of data enabled the integration of artificial intelligence (AI) for autonomous ships, cloud computing for data storage, and digital twins for predictive maintenance of ship equipment. In the field of management and decision-making, advanced technologies such as voice control, chatbots, big data analytics, and real-time computer modeling (Edge Computing) enable more accurate and faster decision-making (Agarwala, 2022).

The opportunities for the application of robotic technology, particularly marine robots, are becoming crucial for the efficient exploration, exploitation, and monitoring of the marine environment. Due to the harsh conditions in the oceans, such as high pressure, low temperatures, and communication challenges, human labor is insufficient for the performance of complex tasks. Robotic systems, such as remotely operated vehicles and autonomous robots, enable advanced ocean exploration missions, sampling, and monitoring of marine life. These robots must be equipped with advanced guidance, navigation, and communication systems, as well as the ability to operate in extreme conditions, thereby contributing to the advancement of marine robotics and research missions. Their market presence has significantly increased due to greater availability and decreased costs. The advantages of robotic networks are reflected in their ability to efficiently perform complex tasks, especially in research and environmental missions. Heterogeneous robots contribute to greater flexibility and adaptability at work. At the same time, marsupial robotic systems enable faster distribution and coordination

between the main and supporting robots, which is crucial in demanding and hazardous environment (Zereik et al., 2018).

Table 1. The SWOT analysis of the application of underwater robotics in the maritime industry

Strengths	Weaknesses
• enables efficient execution of complex tasks in the maritime industry, especially in research and environmental missions • provides greater flexibility and adaptability at work • enables faster distribution and coordination in demanding, dangerous, and inaccessible environments • wide application • reduces the risk to human lives • enables precise and rapid decision-making	• there is insufficient reliability and efficiency of these systems in real conditions, so the methods of perception, control, and communication should be further advanced • navigation in open areas beyond the range of acoustic transmitters remains problematic due to the lack of precise pre-prepared maps • initial cost and expertise required for the development of these technologies • the deficit of trained ROV operators
Opportunities	**Threats**
• Increased availability and affordability of underwater robotics. • underwater robotics is an indispensable tool in scientific and commercial underwater exploration, unlike humans • greater autonomy, cost reduction, and development of hybrid systems that combine the best features of ROVs and AUVs • greater collaboration between organizations, institutions, and the maritime industry to better integrate the technology into MET programs	• technical, regulatory, and ethical threats, including issues of safety, cybersecurity, legal norms, and social acceptance • mismatch between the skills of the existing workforce and the rapid development of robotics • isolation of employees, which can affect mental health and social skills

Source: Authors

However, the implementation of robotics in the maritime brings specific challenges related to technical, regulatory, and ethical aspects, including issues of safety, cybersecurity, legal norms, and social acceptance (Sahoo et al., 2024).

Navigation in open areas beyond the range of acoustic transmitters remains problematic due to the lack of precise pre-prepared maps. Additionally, the development of advanced methods of perception, control, and communication still requires further research to ensure the reliability and efficiency of these systems in real- world conditions (Zereik et al., 2018).

In maritime industries, the development of soft skills poses an additional challenge. On ships with less numerous crews, where only a part of the crew is permanently active, opportunities for interpersonal connections are often limited. As ships become increasingly autonomous, the maritime industry may exacerbate worker isolation, which might jeopardize mental health. These difficulties can pose a challenge for workers transitioning to shore, where stronger social skills are required (Harris & Sunley, 2021).

The demand for robotic systems in the energy sector, both onshore and offshore, is increasing, which might result in reduced operating costs and protect workers from hazardous working conditions. However, there is a mismatch between the skills the workforce possesses and the rapid development of robotics. Engineers must have significant experience and a thorough understanding of multidisciplinary robotic systems to successfully operate robots and effectively implement them in various tasks (Zuo et al., 2023).

The specificity and complexity of ROV training are recognized through the existing standards of reputable institutions. For example, the IMCA (International Marine Contractors Association) standards in the training process outline several modules, including operational safety, familiarization with various ROV systems, maintenance, ROV operations, and education on the application of different types of sensors (IMCA, IMCA R 004 rev. 4, London: IMCA, 2022). Furthermore, NORSK standard U-102 provides structured training for ROV pilots, pilot technicians, supervisors, and superintendents. In addition to the necessary experience for

individual training, the necessary health and safety certificates, work on a simulator, troubleshooting, and operational requirements that include control, navigation, handling manipulators and cables. Training is also required in conflict management, communication, and the management of specific demanding operations (Norsok, U-102, Oslo: Norsok, 2012).

Birk (2022) investigates the interaction between humans and robots in underwater environment. Underwater human-robot interaction is an area with great potential and many challenges due to the specific underwater conditions. The key problem is communication because traditional methods, such as speech, are not practical. Such issues led to the development of systems based on gesture recognition. These systems utilize computer vision and deep learning (DL) to help robots to understand and respond to the diver's movements. At the same time, robots can use visual cues, body movements (kinematics), or underwater displays to send information back to divers. Advances in sensor technologies have enabled more precise tracking and detection of divers, which improves collaboration in missions such as underwater archaeology, research, or industrial maintenance. Despite the significant progress, full integration of these technologies still requires the harmonization of different communication methods and the development of more robust systems that are more resistant to underwater interference. In that regard, publicly available datasets such as CADDY and SCUBANet play a crucial role in the training and testing of AI models, thereby further stimulating innovation in this field (Mišković et al., 2016).

Mancer (2010) underscores a concern regarding the training of new operators of underwater vehicles to become effective leaders capable of performing all aspects of a "typical" mission. There is a global shortage of trained operators, and as systems become increasingly specialized, operators and support personnel must possess a higher level of skills. Currently, many operators come from other fields or through other academic studies without specific knowledge of underwater vehicles and their environment. It is necessary to develop an effective training method and determine the appropriate level of education that will allow the exploitation of the previous knowledge and skills of the operators, as well as continuous improvements and innovative solutions of ROV manufacturers, industry requirements (fishing, shipping, oil, and gas industry, etc.) as well as the regulatory framework established by national and international governmental and non-governmental organizations.

4. Maritime Education and Training Tailored to Professionals in Underwater Robotics: Skills and Competences

In terms of the development trends of maritime universities focusing on disruptive technologies, the literature review indicated initiatives exemplified by joint master programs at universities in France, Norway, Portugal, and Spain. Their students have an opportunity learn about technical and technological systems, controls, autonomy, safety, and environmental protection, as well as transferable skills such as teamwork, innovation, communication, and project management in a technical-technological context (Marxer et al., 2021; MIR – EMJMD, 2022).

The MATE (Marine Advanced Technology Education) model is particularly beneficial in this context, as it explains in a step-by-step manner the acquisition of practical skills in underwater robotics through classes and competitions, thereby directly preparing students for work in ocean-related industries. There are several phases of the MATE model:

- Researching industry needs to determine employers' requirements,
- The incorporation of practical marine technologies into curriculums,
- Organizing student competitions in underwater robotics (ROVs – remotely operated vehicles), and
- International competitions in collaboration with industry and academic institutions (Zande & Brown, 2008).

Patterson et al. (2012) report on a project supported by the National Science Foundation that involves a collaboration between the Virginia Institute of Marine Science at the College of William & Mary and the Watermen's Museum, an informal educational institution. This project provides schools with professional remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) to explore the wrecks from the last major battle of the American Revolution.

Participants worked in teams and performed the tasks that simulated real expeditions, such as the ROV system deconstruction, measuring currents on wrecks, biota photography, and maintenance of the

robots. During the experiment, students took on various duties, including vehicle operation, navigation, and mission control. The results showed a positive impact on student's attitudes toward science and their participation in "citizen science".

Recent technological advances necessitate a reform of educational methods and curricula to foster STEM education and the skills required for the 21st-century workers. Educational robotics is considered a powerful tool for developing not only programming but also soft skills such as problem-solving, creativity, and collaboration (Gratani & Giannandrea, 2022).

The core of the curriculum is based on the integration of STEM principles through work with ROVs. The curriculum is designed to provide the students with hands-on learning experiences through engineering, design and solving real-world problems by means of technology (Wright et al., 2014). This paper proposes a draft of topics for the curriculum that is being developed for "Encouraging innovative capacities and skills for the application of maritime robotics in monitoring and protection of the marine environment" - "MARROBO" project (15/07/2024 - 14/07/2026).

There are several topics for curriculum development:

- Topic 1: How can maritime regulations, sustainable development principles, and foundational knowledge of oceanography be integrated to effectively support and advance the Blue Economy in a way that ensures long-term environmental, social, and economic sustainability?
- Topic 2: How do current national and international regulations and Classification rules influence the development and deployment of various types of Remotely Operated Vehicles (ROVs), and what are their present and potential applications across maritime industries?
- Topic 3: How have underwater drones developed throughout history, what types and equipment do they use, and what support systems do they require to function effectively in modern underwater missions?

Topic 4: How do the proper use and maintenance of various types of ROVs contribute to the efficiency and safety of underwater missions, based on planning operations with divers, basic control and navigation, the use of VR applications, and data collection and processing?

- Topic 5: How does the application of virtual reality (VR), through basic equipment and setup, ROV assembly and testing, underwater navigation, task execution, and object retrieval, improve training and operational efficiency in the use of remotely operated vehicles (ROV)?
- Topic 6: How does the scanning and exploration of underwater areas, control exercises at underwater training sites, and the collection and processing of video material achieve effective practical application of ROVs in real operational conditions?
- Topic 7: What are careers and skills related to ROV?

When defining curriculum, relevant educational institutions and experts should specify learning outcomes in terms of the skills required for the use of underwater robots (Barnier, 2024). Upon completion of training, a candidate should demonstrate:

Technical expertise - for the successful operation of ROVs and AUVs, candidates must possess the skills necessary for the operation, management and maintenance of these complex devices.

Analytical thinking - candidates should be able to analyze collected data and draw precise conclusions because the quality of processing and interpretation of this data is of paramount importance.

Problem-solving skills - working in underwater conditions often brings unforeseen situations. Candidates must have abilities to diagnose problems and effectively and quickly resolve technical challenges during operations.

By the end of the MARROBO project, this curriculum should be aligned with the standards of the International Marine Contractors Association (IMCA). IMCA is a global organization that provides training and certification for operators and technicians in the underwater industry, including ROV management. Their standard ROV Pilot/Technician Level 2 course covers the basics of electronics, optical fibers, sonar and safety, as well as an introduction to the offshore industry. Training can be conducted in person, online, or in a hybrid format, using IMCA Class B simulators with realistic scenarios and functions. The course lasts for at least 10 days and is aligned with IMCA guidelines. Access to the course is possible for candidates with appropriate technical qualifications or industry experience. In cases of poor results, candidates may not obtain the corresponding certificates (IMCA R002, 2022; MECDCO, 2023).

Instead of a simulator, the training program would incorporate a VR application that replicates all phases of operator training, including knowledge of robotics, systems, and sensors, as well as the performance of specific maritime tasks and skills in digital recording and data analysis. The tests and quizzes, simulation of specific tasks and VR applications assess the trainees' theoretical knowledge, skills, and performance in specific tasks before the trainees start operating ROVs in real-world conditions.

Rahman (2019) explores metrics and methods for the evaluation of learning outcomes in robotics and STEM education. Various criteria were proposed for assessing outcomes in robot-based STEM education, including educational, scientific, behavioral, intellectual, cognitive, and social aspects. The most used criteria are test scores along with motivation (internal and external), level of engagement in class, and teamwork skills. Teachers also emphasize the importance of problem-solving skills, time management, and regular attendance, as well as laboratory skills and the ability to conduct experiments while minimizing cognitive load during the learning process. Less common but important criteria include confidence in robotics, computational thinking, the formulation of research strategies, and commitment to lifelong learning.

The students are also evaluated based on their engineering vocabulary and practical skills. Online learning makes education more accessible, even to those who cannot attend traditional training, while chat and online collaboration platforms enable global interaction between students and professors. Technologies like VR enable immersive experiences that combine the best aspects of in-person and online education. At the same time, AI personalizes the learning experience by analyzing student behavior and facilitating adaptive learning. Augmented reality (AR) facilitates the understanding of complex concepts through 3D models, while the Internet of Things (IoT) enables the tracking of the student data and provides greater flexibility in learning. STEAM education encourages creativity through an interdisciplinary approach, whereas gamification makes learning more engaging by incorporating gaming elements. Mixed reality tools sustain experiential learning that blurs the boundaries between the real and virtual worlds, while blockchain enables secure storage of data and documents, such as diplomas and certificates (Gejendhiran et al., 2020). All the technologies enable personalized, flexible, and engaging educational approaches that facilitate learning, increase access to education, and integrate theory and practice.

Progress in robotics education prepares the next generations of engineers and workers through early education and promotion. While the early initiative successfully engages students and stimulates their interest, an integrated educational path should be developed to lead the students from elementary school to academia. This path should be based on early experiences and provide opportunities for progress across different age groups. The key to the success of robotics programs for all ages lies in hands-on, exciting activities with adequate professional support, which allows the students to learn in frustration-free environment (Page et al., 2020).

Educational robotics programs in higher education, K-12, and at informal levels have grown significantly over the recent years, which is evident in programs such as the U.S. FIRST Robotics and FIRST LEGO League. Many organizations develop and promote underwater robotics programs and encourage the students to participate in competitions and other educational initiatives. Robotics is highly motivating for the students because it combines STEM skills with practical experience in problem-solving, teamwork, creativity, and innovation. While most K-12 robotics programs focus on land-based competitions, a smaller number of programs utilize the underwater environment for unique challenges. While there are common principles across different underwater robotics curricula, such as competitions and careers, differences arise in learning objectives, tools, age groups, and assessment (McGrath et al., 2014).

Skills for emerging maritime technologies encompass several areas that will be critical to the future development of the sector. Primarily, the skills are related to autonomous systems, including autonomous vessels, sensors, and drones. This technology requires expertise in robotics, electrical software, and advanced platforms. Additionally, autonomous vessels will rely on advanced power systems to enable long-term seafaring. Another important segment is data use and cybersecurity, as practical analysis and management of digital data is essential for maritime and seaport operations. In that sense, cybersecurity skills are crucial for protecting autonomous systems and other digital systems. There is a need for technologies that can reduce carbon emissions, support the research of alternative fuels such as hydrogen and ammonia, as well as the development of efficient energy management systems. Such technologies require specialized skills in the field of energy systems and sustainable solutions for ship operations. Similarly, many of these skills are not specific to the maritime sector but intersect with other industries, such as aviation, automotive, and aerospace.

These cross- sector skills facilitate the exchange of knowledge and innovation, which is crucial for advancing maritime technologies. Soft skills, such as problem-solving, self-management, socio-emotional and communication skills, are equally important.

In the era of challenges such as climate change and sustainability, it is important to develop a passion for engineering and innovation in young people. SeaPerch is a program that allows children to explore engineering, construction, buoyancy, and other STEM fields through underwater robots. SeaPerch II expands this program by adding soft robots and Arduino microcontrollers and helps the students of all ages to explore new technologies and develop an interest in STEM careers. RoboNation organizes an international competition each year in which teams all over the world solve thematic challenges with their underwater robots. Recent challenges included deep-sea mining and the collection of hydrothermal data to solve real-world problems through innovative solutions.

In collaboration with RoboNation, MIT Sea Grant integrates SeaPerch II components into these competitions. Popular modules, such as touch sensors and soft robotic grippers, are widely used in competitions due to their dexterity and ability to manipulate various shapes (Sullivan et al., 2024). Yim et al. (2024) investigated how underwater robotics competitions can be an effective means of promoting integrated STEM education. Through project-based learning and engineering design processes, the students develop key STEM skills, including problem-solving, teamwork, and critical thinking. Underwater robotics competitions allow the students to apply interdisciplinary knowledge to solve real-world challenges. Bloom's Taxonomy is also used to assess participants' cognitive development and encompasses various levels of learning, from basic knowledge acquisition to complex problem-solving. Research results showed that such competitions are an effective and engaging preparation of the students for careers in STEM fields.

5. Conclusions

Disruptive technologies are significantly changing the business and educational fields in the maritime sector. This paper explored the development of an educational framework for specialization in the field of underwater robotics, focusing on the needs of the labor market and the remarkable technological progress in the maritime sector. The analysis revealed the need for education and training in the field of ROV (remotely operated vehicle) technology, as current educational systems are still not fully aligned with these requirements.

The research findings identified the lack of a defined and specific curricula that would enable professionals to acquire practical and interdisciplinary knowledge in line with the rapid development of disruptive technologies in the maritime sector. The SWOT analysis detected significant advantages and opportunities of underwater robotics. There is also a notable deficiency in trained ROV operators. These findings should lead to the development of new courses or the enhancement of current study programs.

Although the paper is based on an analysis of existing literature, additional empirical research and consultations with industrial partners are necessary to further validate the educational models. Strengthened cooperation between the academic community and the maritime industry would be a solid basis for the development of the sustainable educational solutions that will shape personnel capable of responding to the challenges and the future needs in the field of underwater technologies.

Acknowledgements

This work is supported by the project "Fostering the innovation capacities and skills for marine robotics deployment for monitoring and marine environment protection" (MARROBO), which has been approved for funding under the First Call of the Interreg VI-A IPA Program Croatia – Bosnia and Herzegovina – Montenegro 2021 – 2027, from July 15, 2024, to July 14, 2026. The MARROBO project aims to boost research and innovation in marine robotics for monitoring and protecting the marine environment. It focuses on the development of advanced robotics and modern skills that would measure microplastics and metals in seawater as well as noise pollution. The project aims to encourage smart investments in robotics, enhance biodiversity protection in the Adriatic Sea, reduce pollution, and promote a sustainable blue economy.

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Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Multimodal CLIL and Sustainable Maritime Education: Leveraging Disruptive Technologies for Future Seafarers

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Abstract: The evolving maritime industry, driven by digitization, automation, and environmental sustainability imperatives, necessitates innovative approaches to maritime education and training. This study investigates the effectiveness of a multimodal Content and Language Integrated Learning (CLIL) framework augmented with disruptive technologies namely Artificial Intelligence (AI) and Augmented Reality (AR) in enhancing maritime cadets' language proficiency, technical competency, and sustainability awareness. A mixed-methods research design was employed involving 120 cadets across four instructional groups, each exposed to varying degrees of technological and pedagogical integration. Quantitative results revealed statistically significant improvements in English language acquisition, simulation-based technical performance, and environmental literacy, particularly in the cohort receiving AI and AR-enriched multimodal CLIL instruction. Qualitative feedback further indicated heightened learner engagement, contextual understanding, and real-world readiness. These findings underscore the potential of technology-enhanced CLIL as a scalable, future-ready educational model capable of equipping seafarers with the interdisciplinary competencies demanded by the maritime industry's global digital and ecological transition.

Keywords: Multimodal CLIL, Maritime Education, Artificial Intelligence, Augmented Reality, Sustainability

1. Introduction

The shipping sector is on a threshold of change, characterized by comprehensive and complex mutation which is reverberating the conventional operational model. They are fundamentally powered by three interwoven forces: automation, digitization and environmental sustainability. Combined they herald a new era, Maritime 4.0 with intelligent systems, data-informed decision-making and higher environmental responsibility. Projects including the International Maritime Organization's (IMO) "GreenVoyage2050," Energy Efficiency Existing Ship Index (EEXI) and the ambition for zero-emission shipping by 2050 are informing the shift in the skills needed for seafarers of today and tomorrow. Moreover, the development of unmanned ships, powered by Artificial Intelligence (AI), the Internet of Things (IoT) and machine learning algorithms, requires qualified personnel with a solid foundation in high technical and complex expertise as well as strategic decision making in digitally enabled surroundings.

Indeed, these older types of maritime training that have historically valued rote technical training and procedural knowledge are minor in comparison to the new type of training required for today's maritime educators. These old paradigms of teaching language, sustainable development, and vocational training are constricted and compartmentalized methods that no longer work in the modern and inter-disciplinary world. In an age where the character of the maritime domain is intensifying in complexity and globalized its high time education frames become straightforward and propped up by the industry and military. Content and Language Integrated Learning (CLIL) is an example of a pedagogical trend that is receiving more attention in vocational and higher education settings. Developed in European language education policy, CLIL

prioritizes the concurrent acquisition of content knowledge and language. In maritime, with English as a medium of language for communication, documentation and regulation, the strategic application of CLIL is at an advantage. It allows cadets to receive domain-specific content from engine room procedures to environmental management systems in English and thereby enhancing technical and linguistic knowledge in a realistic working environment.

Yet, the traditional practice of CLIL is tied down to textbooks to teach content and it does not fully exploit the capabilities of new technologies to improve the process of learning. Acknowledging this lack, the present research presents an extended model of Multimodal CLIL which also includes disruptive technologies such as; Adaptive learning systems that are AI driven and individualized to each learner's profile & performance data; Augmented Reality (AR) simulations where trainees are immersed in virtual engine rooms, navigation bridges, safety drills; Interactive digital tools through which blended learning can occur, ranging from virtual classrooms and gamified assessments to multimedia content for different learning types. This union of CLIL pedagogy with these technological advances signals a new paradigm in maritime education, leading not only to cognitive goals including knowledge retention, but also affective outcomes comprising liberating learners by enhancing motivation, engagement and cultural awareness and finally, not forgetting interrelated skills needed for sustainable maritime practice. Consequently, the following is a central question of this study: Could a multimodal, technological-aided CLIL methodology contribute towards a blended learning environment that prepares maritime cadets in the fields of language, technology, and sustainability skills to meet the future underlying their maritime profession?

Through an empirical investigation on the topic it is hoped that the study may contribute to the field of Maritime Education and Training (MET), most poignantly to expose some of the actions MACs can benefit from taking towards strategic management of Language – Technology – and -Sustainability when educating future seafarers.

2. Literature Review

The revolution in Maritime Education and Training (MET) driven by the digital age, the sustainability imperatives, and the rise of immersive technologies, has led scholars and practitioners to re-consider pedagogic models and curriculum structures. Leading this debate is the Content and Language Integrated Learning (CLIL) approach, which has been receiving growing attention in the field of Maritime English teaching and maritime professional competence building. CLIL is understood as a bilingual educational method in which students develop both the contents of a particular subject and another language (a second, foreign one). Since English is the working language of global navigation, the CLIL pedagogy not only amplifies maritime cadets' communication skills but also language-rich technical and regulatory knowledge (Shvetsova & Bondarenko, 2023; Coyle, Hood, & Marsh, 2010). At the same time the training they receive is aimed to shape them into professional mariners who have a global understanding and ability to communicate both on the bridge and ashore in a common business language, not a mother tongue, and 'learning is a task'. More recent research takes it broader and applies CLIL to multimodal and multilingual learning settings. Lo and Lin (2015) call for MMCLIL models that are more open and flexible, that can support that design of different modalities including visualisations, simulations and authentic media to promote learning activities and cognitive processes, especially for EFL learners. In maritime education, this is particularly pertinent as cadets are frequently exposed to schematic diagrams, navigational software and safety manuals, that prompt a multimodal reading of text and visual images as well as spatial literacy. Simbolon and Febrianti (2020) also underscore the instructional significance of collection and curation of digital content, including YouTube-based videos, for Maritime English teaching, demonstrating how collection, curation of resources could situate learning and make language learning within technical contexts meaningful. If, on the one hand, the development of CLIL has caused MET to overcome its traditional limitations, one the other hand the technological developments of the Fourth Industrial Revolution (4IR) have transformed it by bringing in tools such as Augmented Reality (AR), Virtual Reality (VR) or Artificial Intelligence (AI) to the learning space. These innovations change not just how we teach maritime operations but how learners experience, cognitively and sensorially. The potential applicability of immersive technologies to Maritime training in improving situational awareness, safety preparedness and operational confidence is emphasized by Mallam, Nazir and Renganayagalu Mallam et al., 2019). They contend that the application of AR and VR promotes experiential learning, especially in high-risk, low-frequency situations, such as escape training or engine room fault finding. Likewise, Shah (2024) and Jain (2024) underscore the AI-enabled platforms charms to offer individualized learning paths through adaptive feedback, self-assessment in real time, and automated language correction systems, features that are particularly useful in competency-based learning modules. These findings converge with more general views on digital infrastructure as supporting the improvement of the quality and accessibility of vocational education.

University of Toronto Scarborough, and it is great for gaining and developing understanding of many topics. Ideally, all of these technologies are used for more than simple novelty and can play an

important role to enhance sustainability education in MET. The initiatives of the International Maritime Organization in regulation and the UN Sustainable Development Goals (not least SDG 4 on Quality Education and SDG 13 on Climate Action) require that sustainability literacy be developed in coming generations of seafarers. Im et al. (2023), it becomes clear that it is necessary to design MET frameworks that are robust to technological and environmental disruptions (and as we have seen even to epidemiological disruptions). Their study shows that sustainability in maritime education should be approached not only on a parallel level, but as an in-built principle to the technical and language training. This is supported by Nalupa (2022) which highlights the toolkits and challenges in the world of the 4IR and its vast opportunities in lifting sustainability practices in MET. The incorporation of sustainability concepts into CLIL modules using case studies, simulations, and AR scenarios is an effective way to make it possible for the cadets to interact on 'meaningful' issues of the environment as well to mould attitude coupled to knowledge. Taken as a whole, the literature reveals an emerging consensus that the future of maritime education is in integrated, technology-enhanced pedagogies, and that both 'content aware' and – increasingly – 'context aware' instruction are the educational goals. A multi-modal CLIL approach, enhanced by disruptive technologies and underpinned by sustainability demands, emerges as a feasible, scalable and pedagogically sound option to prepare maritime professionals for tomorrow. This paper extends the utility of these realisations by examining how, in practice, such a model can be successfully implemented in a maritime training environment.

3. Research Methodology

This research utilized the convergent parallel mixed methods research design to examine the effect of a multimodal CLIL framework used with disruptive technologies on the language, technical competence and sustainability awareness of maritime cadets. This design was chosen in order to have a mixture of quantitative and qualitative data, collected and analysed at the same time, in a process of triangulation and identification of the positive and negative aspects of different instruction modes on the part of learners. The experimentation was carried out at the Academy of Maritime Education and Training (AMET), India over an academic semester. One hundred and twenty cadets from the Nautical Science and Marine Engineering programs were involved in the study. The cadets were intentionally assigned to one of four equally averaged among level of academic background and proficiency in English based on their levels of proficiency. Group A acted as the control group and was taught by traditional CLIL (print-based) and through teacher-centred lectures. CLIL combined with digital materials (e-books, video presentations, online tests) were added to class instruction in group B. Group C was taught through a CLIL-based approach that was combined with an AI-adapted learning system integrated with an LMS (Moodle in combination with ChatGPT plugins), featuring personalized feedback, automatic progress monitoring and real-time language support. Group D underwent combination of experimental intervention multimodal CLIL model based on AI adaptive system, AR by means of RemoteSpark™ and interactive DMs and on a set of maritime topics (e.g. navigation, safe-bounding measures, and sustainability practices).

A variety of assessment instruments and tools were used to determine the effect of these teaching modifications. Quantitative data had been obtained from pre- and post-tests on language between the two groups (using the MARCOM Maritime English Proficiency Scale), technical task performance assessments, carried out in simulator-based actions, and a sustainability awareness questionnaire instrument based on the UN Sustainable Development Goals (SDGs), including the main goal of SDG 13 (Climate Action). These tools assessed learning, procedural correctness and attitudinal changes towards sustainability. In addition, qualitative data were collected through FOs, instructor observation logs, and cadets' reflective journals, which offer in-depth information on the learning experience, level of engagement, and barriers perceived by cadets. The quantitative parts were processed descriptively, inferentially (paired sample t test, ANOVA) to assess the significance of the effects between the groups. Thematic analysis was applied on the qualitative data the emerging themes in learner motivation, perceived efficacy of multimodal tools, and the merger of language and technical content were coded in NVivo software. Ethical issues Statement of ethics was met throughout the study. Written consent was obtained from every patient and the study protocol was approved by the institutional ethic committee. The stringent methodological process followed by the study not only ensured internal validity but also contextual applicability of the results in larger maritime education and training (MET) environments.

4. Results

The study results are presented in this section with reference to the three main dimensions of evaluations: linguistic competence, technical competence, and sustainability literacy. Data were obtained using standardized questionnaires and analysis was performed with SPSS (v27) in order to test group differences.

4.1. Language Proficiency Improvement

Language proficiency was assessed using a pre- and post-test aligned with the MARCOM Maritime English Proficiency Scale, focusing on vocabulary, reading comprehension, technical writing, and oral communication. The percentage improvement was calculated for each group.

Table 1. Language Proficiency Scores (Pre- and Post-Test)

Group	N	Pre-Test Mean (%)	Post-Test Mean (%)	Mean Difference	% Gain	p-value
A	30	61.4	69.5	8.1	13.2%	0.043
B	30	60.9	72.2	11.3	18.6%	0.031
C	30	62.2	79.6	17.4	28.0%	0.017
D	30	60.8	83.3	22.5	37.0%	0.005

Group D, which received the full multimodal CLIL instruction including AI and AR, exhibited the highest improvement in language proficiency with a 22.5-point gain (37.0% relative increase), statistically significant at $p = 0.005$. The gains were comparatively lower in the other groups, with Group A showing the least improvement (8.1 points, $p = 0.043$). This highlights the efficacy of multimodal and tech-augmented CLIL in maritime English development.

4.2. Technical Competency Performance

Cadets were assessed on simulation-based tasks such as engine maintenance, fire drill response, and navigation chart plotting. Each task was scored out of 100 based on accuracy, time efficiency, and procedural adherence.

Table 2. Simulation Task Performance Scores

Task	Group A	Group B	Group C	Group D
Engine Maintenance	63.2	68.4	76.1	84.7
Fire Drill Response	59.0	65.2	74.3	86.1
Navigation Charting	66.5	72.3	81.6	88.3
Mean Total Score	62.9	68.6	77.3	86.4

Group D consistently outperformed the other groups across all technical tasks. The highest score was in the Navigation Charting task (88.3), indicating strong spatial and procedural comprehension facilitated by AR simulations. The average technical performance of Group D was 86.4%, representing a 37.4% improvement over Group A. The integration of immersive technologies such as AR appears to have enhanced situational awareness and practical task execution.

4.3. Sustainability Awareness Assessment

Sustainability literacy was measured through a 25-item questionnaire aligned with the UN SDG 13 framework, covering environmental regulations, energy efficiency, waste management, and climate adaptation practices in shipping.

Table 3. Sustainability Awareness Scores

Dimension	Group A	Group B	Group C	Group D
Energy Efficiency Practices	61	70	78	89
Marine Pollution Prevention	59	67	74	85
IMO Environmental Regulations	60	69	76	87
Climate Change Awareness	58	66	73	83
Mean Awareness Score	59.5	68.0	75.3	86.0

Group D demonstrated the highest level of awareness across all sustainability dimensions, with a mean score of 86.0%. This suggests that embedding environmental themes within multimodal CLIL modules, supported by scenario-based AR experiences and AI-driven content customization, significantly influences learners' ecological literacy and attitudes.

4.4 Summary of Statistical Significance

A one-way ANOVA confirmed statistically significant differences between groups across all variables (language proficiency: $F = 12.73$, $p < 0.01$; technical performance: $F = 15.46$, $p < 0.001$; sustainability awareness: $F = 11.29$, $p < 0.01$). Post-hoc Tukey tests revealed that Group D's performance was significantly higher than the other groups ($p < 0.05$ in all comparisons), reinforcing the superiority of the multimodal CLIL approach.

5. Discussion

The findings from this study are compelling that adding a symbiotic emergence of Multimodal Content and Language Integrated Learning (CLIL) with disruptive technologies namely Artificial Intelligence (AI) and Augmented Reality (AR), presents as a disruptive momentum and a powerful new framer for environmentally sustainable maritime education. The results indicate a meaningful increase in the cadets' language proficiency, technical competence, sustainability literacy as well as Group D cadets' competencies when being exposed to the entire multimodal treatment. This validates the fundamental assumption of the study, i.e., that a carefully designed technology-facilitated CLIL model enables the development of 21st century mariners, ready to overcome the multifaceted challenges of Maritime 4.0 and the global sustainability requirements. One of the major contributions of this research is the confirmation of pedagogical viability of multimodal CLIL in a nautical setting. CLIL Introduction CLIL (see Coyle, Hood, and Marsh 2010) includes a combined focus on content and form, and has mostly been implemented in regular education and bilingual education. However, the use of MET in vocational technical education is less explored. Shvetsova and Bondarenko (2023) note that with English being the working language in the maritime sector, CLIL provides clear gains through placing language within technical content. The present research expands on this by not only adopting CLIL but also extending it via multimodal means (visual, textual, interactive, spatial etc.) enabling different learning styles.

The significant increases in language ability among Group D are consistent with those of Lo and Lin (2015), who propose in a multimodal CLIL model for EFL learners as it relates to depth of processing. Maritime cadets frequently face voluminous technical documents and need to become articulate in high pressure situations. Conventional language training separated from technical education doesn't solve this — and our challenges are complex. By employing AR simulations of bridge operations and AI based feedback for maritime communication tasks, we were able to show that learners can apply language in authentic and simulated environments to aid retention and functional fluency. As a technical training-from-the-perspective of learning, the AR-based learning had better effects. Being that Group D consistently scored higher on simulated tasks (i.e., fire drills, engine maintenance, and navigation) – one might argue that experiential learning supports procedural comprehension. These results support Mallam et al. (2019) who argue AR and VR technology provide a controlled and immersive training setting which results in better risk perception, quicker reaction times, and improved decisions. AR technologies allowed cadets to perform safety protocols and technical duties in virtual engine rooms and simulated bridge operations in a low-risk high-fidelity learning environment that meets or exceeds the traditional classroom learning experience without real-world hazards. The encouraging trend of the increased awareness of sustainability among the Group D cadets strengthens the rationale for the incorporation of environmental education in maritime education. Im et al. (2023) stress the importance of incorporating sustainability in MET curriculums, particularly following the adoption of IMO regulations and the maritime sector's ambitions for decarbonisation. In both CLIL modules and AR learning scenarios, sustainability content (e.g., ballast water management, energy-efficient navigation, and the prevention of marine pollution) was integrated. Such an approach enabled the cadets to connect abstract concepts with physical and visualized events and to further develop their environmental literacy and sense of responsibility. The finding that Group D had the highest scores on sustainability awareness adds credence to the conclusion drawn by Nalupa, (2022) who maintains that developing maritime professionals of the future should be proficient in technical matters and be ecologically minded.

Furthermore, the data from the groups C and D, presented in table 5 and 6, the use of AI-aided adaptive learning systems, permitted to develop type of individualized instruction that is widely recognized and researched in educational literature (Luckin et al., 2016). These systems tracked cadet progress, detected learning deficiencies, and gave real-time feedback on English usage and procedure terms. Such customization is important in crowded nautical classrooms, where teachers have difficulty catering to individual learning needs. AI can democratize learning by "ensuring that slower learners get that help levels of dropout levels of competency (Shah, 2024). The present research also contributes to a better knowledge of how teaching

innovations, such as educational technologies, may fit in a maritime CLIL context. The work by Simbolon and Febrianti (2020) has shown the effectiveness of curated videos on YouTube for the teaching of Maritime English, and we take this a step further by combining interactive, immersion and adaptive technologies to interplay with one another to give a high-quality learning experience. This coming together of multimodality, context-based relevancy, and instant performance feedback, shifts passive uptake to active, learner-centred participation. But the quarter system can only work if an institution has the capacity, the faculty are trained and the institution is prepared. And although Group D had access to a well-equipped lab with AR devices, others maritime academies, especially in developing countries, may not possess such facility. Hence, scalability and cost-effectiveness are still to be addressed. (http://www.ejisdc.org in trying to understand elements for sustainable adoption on eLearning and EdTech, it is often mentioned (by Jain 2024) that eLearning and EdTech should be viewed as a part of institutional ecology. This debate supports the fact that multi-modal CLIL combined with AI and AR is not a supplement but an inevitable value for contemporary maritime learning. It facilitates understanding, gives a sound base of knowledge and ideas enabling practice and mutations of attitudes which is essential need for seafarer of the 21 st century. The papers recommend a change of system when it comes to the design and implementation of maritime education, towards the interlacing dual challenges of digital transformation and global sustainability.

Recommendations

Based on the findings and implications of this research, certain recommendations that maritime education institutes, curriculum developers, and regulatory agencies, intending to globalize and contemporize the education of seafarers, are proposed to consider keeping in view sustainability and technological trends are as follows:

7.1. Multimodal CLIL and its Institutional Embedding

Multimodal CLIL in maritime universities and training academies should be established as an instructional approach. This involves making language learning more communicatively enriching in contexts ranging from navigation, marine engineering, environmental science, and safety operations. Curriculum changes should to be made to emphasize interdisciplinary studies that mimic how the maritime sector functions in practice.

7.2. Utilisation of AI and AR Techniques

Institutions of learning need to adopt AI-powered adaptive learning platforms and AR simulation solutions to enable a personalised learning environment and immersive technical training. These tools provide flexible solutions to the provision of personalized feedback, scenario-based learning and learning language integrated with technical tasks. Strategic relationships with EdTech developers and marine simulation vendors can facilitate such integrations in a cost-efficient and context-ready environment.

7.3. Teaching Training and Faculty and Digital Pedagogy Coaching

Effective dissemination will require a strong faculty development program. Teachers need to prepare in CLIL and in digital pedagogy, specifically in the use of AI dashboards, virtual simulators and content creation tools. This will enable them to provide interactive, student-focused and technology-mediated learning opportunities.

7.4. Integrating sustainability into each module

Sustainability content should not remain the domain of separate environmental subjects, but should be integrated across curricula, beginning with ship operations and engineering systems, and extending into the logistics of maritime transport. This is in line with the IMO's sustainability drive and will enable cadets to develop a mind-set of sustainability during their time at sea as future seafarers.

7.5. Policy Changes and Financial Assistance

Multimodal CLIL and technology integration be included as standard competencies in maritime education policies at national and international levels (e.g. IMO and DGS). Funding models and incentives should be established to support infrastructure improvements, research and demonstration projects in this area.

7.6. Longitudinal and Multi-Institutional Study

Additional large scale longitudinal studies are advised in order to follow-up on the long-term effects of multimodal CLIL on cadet academic performance, retention and career progression. Cross institution international research will explore best practice, cultural relevance and the scale of the model to develop new insights.

Acknowledgement:

This research was conducted independently without any financial assistance from AMET University or external agencies.

Thank you for considering our submission. We look forward to your feedback.

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Maritime Rescue Drones

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Abstract: The ships are un-avoidable mode of transport, which is responsible for almost 80-90 % of trade all over the world. The ships are generally operated by experienced sailors including her captain. The condition of ships required to be kept in sea-worthy state particularly the hull to avoid major loss due to any accidents. The Hull surface inspection and maintenance is a part of sea-going members' responsibility. For such an activity, the exposure of crew members to the sides of ships are inevitable. The risk of falling overboard is increased if the crew does not follow the correct safe operational procedures. The statistics shows the causality rate due to Man overboard incidents maximum. In today's practices, if any crew member or passenger identified as fallen overboard, the team of trained manpower deploy the rescue boat at the incident location. They perform the search operation to identify the victim and follow the safe rescue methods to recover the sufferer. The drone, a pilot free aircraft developed to perform high risk unmanned tasks are right choice in this scenarios too. At present small drones are used to do the tank inspection without human entry state in the maritime application. This paper aims to provide a solution for this problem of search and rescue (SAR) with modern drone technology.

Keywords: Rescue; UAV; Thermal image; Man overboard; Drone

1. Introduction

1.1 Background

Modern day sea-faring includes lot of technology advancements. Apart from the technology, new management practices also ensure the safe and efficient ship operations. The technology assistance including auto navigation and un-attended machinery space during night hours improves the crew members relaxed and focused work environment. Despite these developments, Man overboard(MOB) is an un- avoidable incident in maritime industry. The crew member fall in to sea is a dangerous event and difficult to survive particularly in nights and unfavorable weather conditions. The recovery rate is much influenced by the time taken for the identification, sea condition and time of incident (International Maritime Organization [IMO], 2019; Golden & Tipton, 2002). The MOB recovery exercise has been segregated as following different stages, Identify the victim, ship turnaround and rescue boat operations. All these acts are exhaustive in nature (US Boat, 2012). Originally developed for military operation, the drones are influenced in every industry including maritime (Floreano & Wood, 2015; IAPH, 2021). The drones use during search and rescue incidents are much convenient in the large ocean. The quick adoption of this technology for this application is due to their inherent advantage of fast transport, autonomous operations and easy to add new sensors with them.

1.2 Problem Statement

Despite advancements in technology and regulation, MOB accidents continue to rank high among maritime fatalities. A conservative estimate of 1,000 people falls overboard annually across the world, according to Proceedings of the International Association of Maritime Universities Conference 2025 Selmy (2016), and a vast majority of those accidents result in fatalities due to delayed detection or rescue. The study conducted on American coast states around 24% of MOB incidents resulted to fatal among all deadly incidents recorded, as published by Boat US (2012). The present day rescue operations highly depend on the human power and which is inefficient during inclement weather conditions. This recovery procedure increases the risk factor on ships' employees by exposing added crew to the sea while rescuing the victim (IMO, 2019).

The drone has been found as a useful technology for SAR operations, still its application for MOB events are reduced due to the uncertain regulation, limited innovations in maritime applications and no use of drones in vessel's current safety system (CLIA, 2021).

2. MOB a Review

2.1 Man Overboard (MOB) Incident

A man overboard (MOB) incident is either crew/ passenger fall into sea purposely or accidentally from ship. A high fatal rate incident among the maritime accidents, MOB kills the victim if ships team's inaction when the incident has been identified. The death during MOB is due to exposed to drowning, hypothermia, attack by sea life or injury by the impact on the vessel structures (Golden & Tipton, 2002). The quick action by on-board team certainly improves the recovery rate of Victim. The data collection and classification of MOB incidents are poor which has been identified by various safety agencies and researchers (IMO, 2017; MAIB, 2020). Added with the above, there is huge scarcity of in-depth statistics that focuses on the mechanism, timelines and the consequences of such events.

2.2 Shortcomings of Traditional MOB Rescue Practices

Conventional rescue methods can usually include manual visual location, alarm systems, and Rescue boat deployment. These are usually slowed by adverse weather, poor visibility, or the absence of real-time tracking, which have a great loss effect on survival (Vanem et al., 2008). Furthermore, rescue boat deployment presents additional risk by putting more crew members into the open sea's peril (Wang et al., 2020).

Research has established that the initial 10 minutes following a MOB accident are determinative of survival, especially in cold water where rapid onset of hypothermia can occur (Golden & Tipton, 2002). Existing shipboard technology is not effective enough in recognizing an overboard occurrence immediately, most importantly when it goes undetected by the crew.

3. Man Overboard (MOB): The Hidden Crisis

The phenomenon of a Man Overboard (MOB) is one of the most serious emergencies on board ships. While maritime operations have become increasingly safer through regulation and technology, MOB incidents remain alarmingly frequent and often fatal. Despite advancements in shipboard safety protocols and equipment, the response time, detection delay, and challenging environmental conditions continue to contribute to poor survival rates.

3.1 Classification of MOB Incidents

MOB incidents can be broadly classified into three categories:

Unintentional Falls – Occur due to accidents such as tripping, slipping on deck, loss of balance during rough weather, or during operations close to the edge of the vessel (e.g., mooring, inspections).

Intentional fall – A crew member or passenger falls overboard due to his unstable or disturbed mental state. These kind of events are difficult to monitor on thousands of passengers stay in cruise vessels and much prevalent on these ships (Lloyds Register Foundation, 2020). Apart from mental health, the emotional distress and intoxication are also influence them to perform such an act.

Suspicious or Undetermined Circumstances – There are few incidents, which unable to ascertain the reason for the fall and have no clear explanations. The law enforcing agencies takes these cases for investigation. MOB incidents involved on large vessel is difficult to be identified. If identified later, the location recognition has limited choice and impossible in few cases.

3.2 Statistical Overview of MOB Fatalities

Although global data collection on MOB incidents is fragmented and inconsistent, available reports suggest that these accidents are far more common and deadlier than often perceived.

According to BoatUS (2012), in the United States alone, Man Overboard events accounted for approximately 24% of fatal marine accidents on coastal waters. Most of these occurred in recreational boating, small fishing vessels, and some on commercial and passenger ships.

Globally, Selmy (2016) estimated that an average of 1,000 individuals fall overboard annually, though the exact number may be significantly higher due to underreporting and classification issues. For instance, many unexplained disappearances on cruise ships may never be officially recorded as MOB incidents.

Cruise Lines International Association (CLIA) data from 2010 to 2020 shows an average of 19 overboard incidents per year on cruise ships. While this number may appear small, the survival rate is reported to be less than 25%, primarily due to delays in detection and the vessel's inability to reverse course in time for an immediate rescue (CLIA, 2021).

Additionally, Maritime Accident Investigation Branch (MAIB) reports highlight the fact that even in commercial shipping, MOB fatalities are often linked to:

- Failure to wear personal flotation devices (PFDs)
- Poor safety culture and crew fatigue
- Inadequate response drills and training

One key concern raised in multiple reports is the low use of MOB detection technologies. Despite the availability of motion sensors, CCTV, radar tracking, and wearable MOB alarms, implementation remains low due to cost concerns, technical integration challenges, and resistance to change.

3.3 MOB Detection and Rescue Difficulty

Despite regulatory improvement and technological progress, detection and recovery of individuals that go overboard are some of the most challenging safety matters on the seas. Successful rescue of a man overboard mission relies on a number of factors stated below

i. Delayed Detection

The U.S. Coast Guard (2019) writes that delayed response is a primary cause of deaths in MOB situations. Even delayed by a few minutes, the individual can get far away from the boat, and visual or radar observation becomes more and more difficult.

ii. Environmental Factors

A dangerous problem is hypothermia in colder seas, where a survival time is merely 15 to 30 minutes (Golden & Tipton, 2002). Severe waves or storms may also impair the visibility of the victim and hinder the launching of rescue boats safely.

iii. Human Lookout and Manual Search Limitations

The observers may not always be vigilant, and their field of view is often obstructed by ship design or obscurity. Furthermore, search protocols depend significantly on the validity of the last-seen-position (LSP) data, which is often unknown or unreliable in MOB scenarios (IMO, 2019).

iv. Rescue Crew Risk

The rescue boat is a primary vehicle used in the recovery of MOB incidents. This act exposes addition crew members (Rescue boat team) to sea and increases the risk of causality or injury. If the incident occurred in high seas or poor weather conditions, the risk probability is further increases and have occasionally resulted in secondary casualties, BoatUS (2012) observes, citing the need for safer alternatives.

v. Insufficient Training and Procedures

As a part of emergency preparedness, regular emergency drills are conducted which includes MOB drills. Due to the vessel’s commercial preferences, these MOB drills are not reflected the reality accurately. Particularly MOB drill in night time environment is difficult to replicate (CLIA, 2021). In the absence of regular and realistic drills, even technology-rich ships can be incapable of executing successful MOB rescues.

4. Current Rescue Procedures for Man Overboard (MOB) Incidents

4.1 Rescue Boat operation during MOB incident

Man Overboard (MOB) is the high rate of causality accidents in ships. The sailing team follows safe procedures while working near to the sides to avoid MOB incidents. If such an incidents occurred, the efficient detection and continuous lookout increases the survival rate. The training for rescue boat maneuvering / operation helps the team to successfully recover the MOB victim. The table-1 explains standard working procedures for MOB incidents for merchant ships.

Table-1 Rescue Boat Operations

Step	Action	Details
1.Incident Detection and Alarm Initiation	Detection of Man Overboard	Crew or passenger fall overboard and identified by any person.
	MOB Alarm Raised	Shout "Man Overboard!", press MOB button on instruments.
	Life Buoy Deployed	Life buoy with smoke and light thrown to mark location.
	Bridge Alerted	Ship's position, speed, and course noted.
	Automatic MOB Devices	Some ships use wearables or AIS beacons for auto-alarm.
2. Maneuvering the Ship	Williamson Turn	Used when MOB location is unknown; returns to original track.
	Anderson Turn	Quickest turn when MOB is visible on one side.
	Scharnow Turn	Used if ship has traveled far beyond MOB point.
	Considerations	Choice depends on visibility, sea state, and speed.
3. Search and Observation	Visual Search	Observers with binoculars deployed.
	Use of Equipment	Radar, AIS, thermal imaging used if available.
	SAR Activation	Search and rescue initiated if MOB not found quickly.
4. Launching Rescue Boats	Launch Conditions	Launched only if weather/sea conditions permit.
	Rescue Team	Typically 3–4 crew with rescue gear (lifebuoys, harnesses, etc.).
	Risks	Heavy seas make rescue operations hazardous.
5. Recovery and First Aid	Onboard Medical Aid	Immediate treatment for trauma, hypothermia, CPR if needed.
	Lifting Victim	Use cradles, stretchers, or lifting devices for unconscious.
	Monitoring	Medical Officer monitors until professional help available.

4.2 Drone based Application for rescue

The Figure 1 show pioneering drone-based solutions for man overboard (MOB) rescue scenarios, as they illustrate how latest unmanned aerial vehicles (UAVs) can significantly enhance emergency response times and minimize human risk. In the Figure 1 (a), a quadrotor drone is observed delivering a life-ring to save a person in distress in the water directly. This system utilizes GPS, onboard sensors, and potentially real-time video to pinpoint the victim and deploy the flotation device precisely. These UAVs are especially useful in situations where sea conditions render conventional rescue boat deployment hazardous or delayed (Floreano & Wood, 2015; Reinhold et al., 2020).

In the Figure 1 (b), a second drone carries a sling-type rescue harness. This is a more sophisticated UAV use, where the UAV can hover and stabilize over water and drop a retrieval system. These systems are already in testing and pilot implementation by maritime safety agencies and global coast guards. UAVs such as these have great potential in unmanned SAR operations by minimizing the number of human rescuers entering dangerous terrain, thus preserving lives at both ends of the rescue chain (Silvagni et al., 2017; CLIA, 2021)



Figure 1. Drone based rescue.

The rising rate of Man Overboard (MOB) incidents in marine environments has led to the critical demand for efficient and effective rescue solutions. Conventional response techniques, i.e., Rescue boats and visual lookout-based detection, tend to be ineffective due to slow response times, harsh sea conditions, and poor visibility. The use of Unmanned Aerial Vehicles (UAVs) for maritime search and rescue (SAR) is a revolutionary change.

4.3 Comparative Drone Evaluation

To select the most suitable platform for MOB rescue application, six parameters including payload capacity, range, speed, power source, flight time and total weight were evaluated for five commercially available drones. These are the Volocopter (Volocopter GmbH. (2022)), Ehang 184 (EHang. (2021)), Griff Aviation 300 (Griff Aviation. (2020)), FB3 Heavy Lift (FB3 Heavy Lift. (2021)), and Flowcopter (Flowcopter. (2023)).

Table-2 Comparative Table of Heavy-Lift Drones for Maritime Rescue

Type of Drone	Range (Nm)	Power Source	Max Payload (Kg)	Speed (Nm/s)	Total Weight (with_Payload)	Flight Time (Min)
Volocopter	18.9	Battery	200	59.3	700 Kg	30
Ehang 184	8.63	Battery	100	54	360 Kg	23
Griff Aviation 300	8.1	Battery	225	32.39	300 Kg	45
FB3 Heavy Lift	1.35	Battery	100	58.3	170 Kg	60
Flowcopter	486	Engine (Hydraulic)	95–100	Not specified	150 Kg	360

Recommendations

Following the above analysis and design rationale, the Volocopter is found to be the most viable platform for an autonomous MOB-drone rescue system. It meets the essential design parameters: large payload capacity (200 kg), good speed (59.3 Nm/s), and tested stability through its 18-rotor design. Its balancing between operational range and endurance makes it highly suitable for quick deployment near ships or coastal bases.

Even Flowcopter leads in range and endurance, its hydraulic system, reduced payload, and complexity limits its versatility for accurate, sensor-based missions. Similarly, while Griff 300 provides weighty lifting capability, its slow speed is disadvantage and less suitable for emergency SAR response. This analysis presents a drone-supported MOB rescue strategy grounded in comparative study of existing drone technologies, with the culmination being a design developed from the Volocopter platform. The strategy seeks to facilitate real-time identification, quick deployment, and secure recovery of MOB victims utilizing an autonomous multi-rotor drone system.

5. Autonomous MOB Detection and Rescue

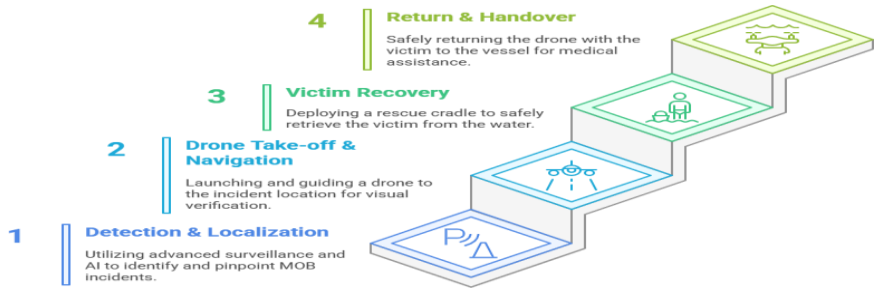


Figure 2. Proposed rescue operational flow

5.1 Detection and Localization of MOB

The first phase is focused on the real-time monitoring of a ship's perimeter with thermal imaging and high- resolution optical cameras. These are coupled with computer vision algorithms trained on machine learning capable of identifying abnormal motion near railings and overboard incidents. Once detected, AI systems triangulate the MOB's position using GPS, on-board cameras, the ship's telemetry and environmental factors such wind and current.

Perimeter Surveillance (Step 1-1) The vessel surroundings are installed with both thermal image cameras and high resolution optical cameras. These comers are positioned such that any segment of the vessel sides are not overlooked. The thermal images are developed by the body heat in the human and easy to pick up during night and low visibility environments.

Real-Time Video Analysis with AI (Step 1-2) The feed from the cameras are send to the Machine learning computer for analysis. The Algorithm developed based on computer vision identify the human movement patterns near to the vessel sides. The sudden changes in the human movement, particularly moving away from the safety barriers are captured using algorithm.

Detection (Step 1-3) Any abnormal human movements is recognized e.g., a person slipping, leaning precariously, or falling. This signal will be considered as a potential MOB incident. The AI employs time-series behaviour analysis, comparing patterns of typical movement to remove the false alarms in pattern changes identified.

MOB Position Triangulation (Step 1-4) Once the fall has been detected through analysis, immediate recording of the following data is essential for forecast the drift. GPS coordinate, ships speed, direction of the vessel, along with wind and current vectors. The analysis from the video data captured reveals the direction of fall.

5.2. Drone take-off and Navigation

Drone pre-flight Check (Step 2-1) The ships' power distribution system feeds the batteries installed in the drone without interruption. The status checks are significant act prior to its fly. There are monitoring system in place to check the drone's operational, navigational systems including battery condition continuously. Once MOB incident alarms, the drone automatically perform its pre-flight checks.

Autonomous Take-off (step 2-2) The ships deck has multiple obstructions such as crane and antenna installed for the vessel operations. These structures limit the runway or ramp kind of an arrangements for aircrafts take-off. The drones, capable for their vertical lifts move up from either of its launch pad or helipad even in inclined vessel positions.

Navigation to Target Zone (Step 2-3) Drone's flight control system navigates the UAV to the targeted victim's position. The GPS feed help the integrated navigation system to pre define the path. Any obstruction on the drone path can be identified and corrected using the LiDAR or Radar sensor mounted on the drone. Any variations of the designated path due to the changes in the wind speed and direction be amended in the stability control algorithms of flight control system. The drone arrives to its designated location (Latitude, Longitude and altitude) with possible maximum speed. It stays remains above crests of waves and sea spray.

Descent and Hover for Visual Verification (Step 2-4) Before the flight control changes to its recovery stage, the camera mounted for downward image confirms the MOB victim. Based on the image collection, drone correct its positions which help in scooping the victim easily.

5.3. Victim Recovery Mechanism

Water Landing and Positioning (Step 3-1)

With the initiation of recovery phase, The drone lowers in altitude and lands on the water surface. The buoyant hallow structure made on carbon-fiber reinforced material helps this whole vehicle in floating state. **Deployment of Rescue Cradle (Step 3-2)**



Figure 3. Proposed maritime rescue drone

The rescue kit made of waterproof and flexible polyester fabric structure works as a cradle helps to hold the victim while lifting. For the immersion of this cradle 300 mm tungsten rod (high density material) is mounted in the four corners. The amphibian legs height allows the human body to position on the cradle without getting disturbed by the buoyant structure. The rectangular cradle frame of 2700 x 2100 mm guarantees it can support a human in conscious as well as unconscious spread position securely.

Victim Loading and Securing (Step 3-3)

The multiple sensors mounted all around the drone helps to identify the victim's spread position. This position identification assists in the drone's maneuvering which helps the victim movement to the cradle center. The water current and the wave movements due to the drone landing helps the victim to be positioned on the cradle if the victim is unconscious. The tension cords of netting arrangement keep the victim in steady state and prevent displacement during the flight mode.

5.4. Return and Handover

Lift-off with Victim (Step 4-1)

When the drone lifts its total payload of 120 kg (80 kg person +40 kg gear) the stability on the horizontal plane is important. The gyroscope and balance sensor mounted on the drone feeds the data to make the required thrust adjustments. This adjustment keeps the mass in center position.

Autonomous Return Flight (Step 4-2)

The drone plans its return course with considering the following: Resistance to wind and wave motion, closest distance to ship or rescue deck, collision avoidance through onboard sensors.

Safe Docking and Transfer (Step 4-3)

On arrival, the drone either descends onto the ship or hovers over a robotic lift platform on deck. The rescue team retrieves the victim using safety nets or stretchers. Medical teams begin first-response treatment immediately upon arrival.

6. Conclusion

Maritime seafarers' safety continues to be an essential issue in maritime activities, and Man Overboard (MOB) accidents are among the most life-critical emergencies offshore. Conventional rescue strategies, although proven with time, are frequently disadvantaged by delays, bad weather, poor visibility, and high operating hazards on the rescue team. In such a scenario, the implementation of autonomous aerial systems presents a revolutionary solution to maritime search and rescue (SAR) operations. This research sets forth an innovative, technology-based MOB rescue system with a Volocopter-inspired multi-rotor drone platform. The approach prioritizes a four-step process: live MOB identification by AI-powered computer vision, GPS and LiDAR-based autonomous drone launch and navigation, victim hoisting with an amphibious cradle system, and safe return for medical transfer. Each stage uses modern developments in UAV design, machine learning, and sensor fusion to develop a quick-response system that reduces rescue time and increases survivability— in high-risk or low-visibility environment.

The Volocopter has the most well-rounded capabilities in payload, speed, range, and safety while comparing with existing available drone platforms. While other models such as Flowcopter and Griff Aviation 300 have their strengths in respect of range or lifting ability, the redundancy of the Volocopter, amphibious

suitability, and short-to-mid-range mission handling make it the ideal choice for conversion.

The new system can revolutionize maritime emergency response as it can offer an autonomous, modular, and scalable solution. Through additional validation with simulation and real-world tests, the design can be incorporated into current maritime safety procedures to lower the reliance on manual rescue methods and end up saving lives.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

The Utility of Extended Reality in Maritime Education and Training: A Bibliometric Review

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Abstract: Extended Reality (XR), encompassing Virtual Reality (VR), Augmented Reality (XR), and Mixed Reality (MR) technologies, is rapidly evolving and holds the potential to transform Maritime Education and Training (MET). Although XR technologies are increasingly applied, there is no systematic interrogation of the educational utility within MET. This study addresses that gap by conducting a bibliometric analysis.The analysis gives an overview of trends, influential research articles, and literature sources. Furthermore, a co-occurrence analysis highlights research topics and their connections, and finally, a co-citation analysis indicates scholarly networks and future research directions. The results reveal that XR research in MET spans diverse topics, discourses, and research clusters, which indicates the viability of the research area. However, improved contextualization and frameworks are needed to support both research and industry applications.

Keywords: Extended Reality, Virtual Reality, Augmented Reality, Mixed Reality, Maritime Education and Training

1. Introduction

Extended Reality (XR) applications are developing rapidly in Maritime Education and Training (MET). XR is an umbrella term encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality technologies (MR) (Guo et al. 2021; Kim et al. 2023) (see Figure 1).



Figure 1. Virtual reality example to the left, where navigation students at HIMT in India are immersed in a ship simulation. Augmented Reality example to the right, where WMU students are exploring a ship overlaid in the real world. Mixed reality adds an additional dimension by enabling the manipulation of real-world objects as part of the simulation.

In MET, such novel technologies are making their way into training and education for technical competencies as per the International Convention on Standards of Training Certification and Watchkeeping (STCW) requirements. XR technologies also have the potential for educational applications for the Knowledge, Skills, and Attitudes considered in the Global Maritime Professional Body of Knowledge (GMP-BoK) learning outcomes (IAMU, 2019), which broadens the scope of the STCW competency requirements. This study is part of an International Association of Maritime Universities (IAMU) research project that will

situate XR applications within the taxonomy of GMP Knowledge, Skill, and Attitudes. The project intends to expand research on the impact of XR technologies on Intended Learning Outcomes in the cognitive, affective, and psychomotor domains.

The aim of this study is to provide an overview of XR research related to MET, including its overall applications and research directions. For this purpose, a bibliometric review (van Eck and Waltman, 2010) is used to analyze the metadata of published research.

2. Methodology

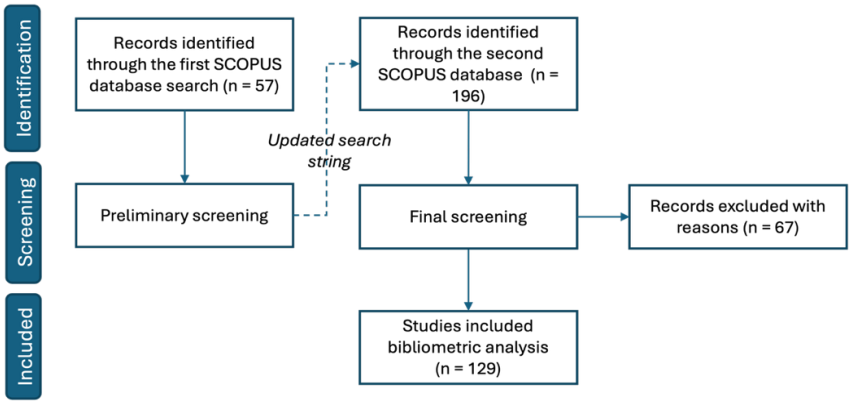


Figure 2. PRISMA flow diagram

A basic version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol[1], which is commonly used for systematic literature and bibliometric reviews, guided the identification and screening of articles (See Figure 2). To identify articles, the literature database SCOPUS was used, which has a wide variety of publications in the humanities/social field that was particularly useful for the purpose of the present study. Article titles, abstracts, and keywords were included in the search. The search string was divided into two parts. The first part focused the search string on Extended Reality technology and its different variants. We choose not to include “simulators” as a search term. Simulators are an established training category in MET, which can be referred to as a form of VR technology, and would have generated substantial results. However, our primary objective was to explore novel XR applications. But this is not a clear-cut distinction, and became one of our main issues of reflection (see Section 3.1). The second part of the search string linked the search to Maritime Education and Training. Two search strings were explored: the first one defined the relationship between “maritime education” and “maritime training”. It identified 57 articles. After a preliminary screening, the search string was updated to not fix the relationship between “maritime” and “education”, to also capture results with, for example, “education in maritime”. The final search string is shown below. It identified 198 articles. Although the first search string yielded more targeted results, we determined that the second one was preferable to capture articles more broadly.

("extended reality" OR xr OR "virtual reality" OR vr OR "augmented reality" OR ar OR "mixed reality" OR mr OR "immersive technologies")

AND

(maritime AND (education OR training))

Four of the authors conducted a complete screening of the articles independently, and the results were then synthesized by the first and second authors. The main screening criteria were the relation to MET. Our assessment was inclusive to gain a broad overview, but there were boundary cases where different interpretations were possible. One such issue was the exclusion of articles that were deemed to focus too much on technology development in its own right. Another issue was military applications, where articles that, for example, focused on navigation similar to civic applications were included, but where warfare applications were excluded. Furthermore, several articles that were introductions to conference proceedings were excluded. Finally, 129 articles were deemed eligible for the review.

There are several limitations to our approach: snowballing and manual identification could have been used to find articles that have not been indexed in SCOPUS; additionally, other databases, such as Web of Science, could have been utilized to potentially identify more articles. Following the identification and screening of the articles, VOSViewer (van Eck and Waltman, 2010) and Excel were used for the bibliometric analysis, as detailed in the following section.

3. Findings

The analysis focused on capturing key overall insights from the articles, which are visualized and described below.

3.1 Overview and trends

Figure 3 illustrates the overall interest in XR technologies, characterized by a sharp increase after 2017. The articles from early on show the career of the XR concept and the evolution of technologies and applications. Especially, the early articles refer to VR in the established categories of simulation in MET. There are also examples of gamified learning using PC desktop or web-based applications. The increasing trend broadly coincides with the time when major market players such as META started to release their versions of the Oculus Quest headsets, which also came with the new programming environments that made it easier to develop and distribute applications. There are, however, also other novel modalities such as AR applications on smartphones. Our assessment, therefore, is that while XR applications using headsets will continue to rise, application development across various platforms will be an important feature going forward.

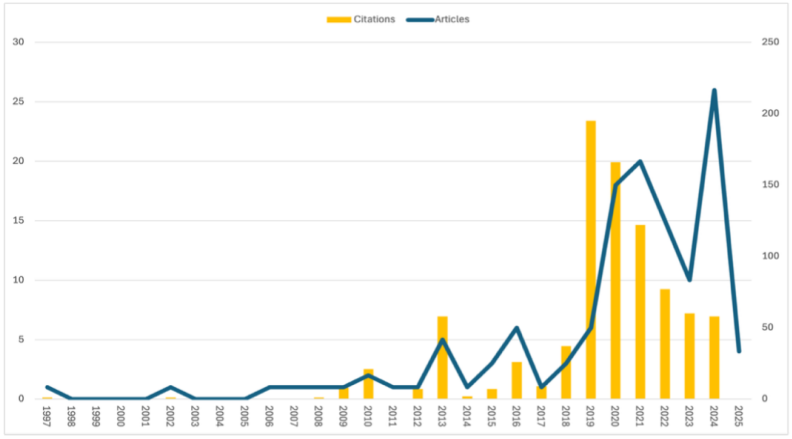


Figure 3. The line diagram and the left legend display the number of articles per year. The column diagram and the right legend display the citations of the articles per year.

3.2 Influential articles

The most cited article, Mallam et al. (2019), provides an overview and makes a connection between the essential component of simulation in MET and emerging immersive technologies, subcategorized into VR, AR, and MR (see Table 1). Other articles, among the most cited, illustrate a common research focus where a specific XR technology is explored in relation to a MET application.

The journals of the most cited articles also illustrate the spread of discourses, ranging from education in general to those specific to maritime and technology. The spread of research is also confirmed by the number of journals and conference proceedings where the articles are published. In total, the 129 articles used in this research are published in 87 different literature sources, with 36 articles appearing in 36 distinct journals. As indicated in Table 2, the single most common source is the CEUR workshop proceedings, which are free open- access proceedings for computer science workshops. The IAMU AGA proceedings and WMU JOMA journal rank 8 and 10, respectively (see Table 2).

Table 1. The ten most cited articles

Rank	Authors	Title	Year	Source title	Cited by
1	Mallam S.C.; Nazir S.; Renganayagalu S.K.	Rethinking maritime education, training, and operations in the digital era: Applications for emerging immersive technologies	2019	Journal of Marine Science and Engineering	101
2	Shen H.; Zhang J.; Yang B.; Jia B.	Development of an educational virtual reality training system for marine	2019	Computer Applications in Engineering Education	50
3	Kim T.-E.; Sharma A.; Bustgaard M.; Gyldensten W.C.; Nymoen	The continuum of simulator-based maritime training and education	2021	WMU Journal of Maritime Affairs	41
4	Markopoulos E.; Lauronen J.; Luimula M.; Lehto P.; Laukkanen	Maritime Safety Education with VR Technology (MarSEVR)	2019	10th IEEE International Conference on Cognitive Infocommunications, CogInfoCom 2019 -	39
5	Makransky G.; Klingenberg S.	Virtual reality enhances safety training in the maritime industry: An organizational training experiment with a non-WEIRD sample	2022	Journal of Computer Assisted Learning	38
6	Jung J.; Ahn Y.J.	Effects of interface on procedural skill transfer in virtual training: Lifeboat launching operation study	2018	Computer Animation and Virtual Worlds	35
7	Markopoulos E.; Luimula M.	Immersive safe oceans technology: Developing virtual onboard training episodes for maritime safety	2020	Future Internet	29
8	Dewan M.H.; Godina R.; Chowdhury M.R.K.; Noor	Immersive and Non-Immersive Simulators for the Education and Training in Maritime Domain—A Review	2023	Journal of Marine Science and Engineering	24
9	Luis C.E.M.; Mellado R.C.; Díaz B.A.	PBL methodologies with embedded augmented reality in higher maritime education: Augmented project definitions for chemistry practices	2013	Procedia Computer Science	23
10	Bukhari A.C.; Kim Y.-G.	A research on an intelligent multipurpose fuzzy semantic enhanced 3D virtual reality simulator for complex maritime missions	2013	Applied Intelligence	22

Table 2. The most common Journals and conference proceedings

Rank	Source title	Count
1	CEUR Workshop Proceedings	7
2	Advances in Intelligent Systems and Computing	6
3	IOP Conference Series: Earth and Environmental Science	4
4	Journal of Marine Science and Engineering	3
5	Procedia Computer Science	3
6	Applied Sciences (Switzerland)	3
7	Journal of Physics: Conference Series	3
8	Proceedings of the International Association of Maritime Universities , IAMU Conference	3
10	WMU Journal of Maritime Affairs	2

3.3 Topics

The spread can be further understood from the point of view of topics and how they cluster. Figure 4 shows a co-occurrence analysis based on author keywords. VR is prominently positioned at the center, indicating that it is the most frequent and interconnected XR topic within MET research. Additionally, the surrounding clusters suggest diverse yet interrelated themes. Following VR, AR is the next modality, which is a focus of the red cluster, including human factors in its application. Overall, the research encompasses XR applications for both navigation and marine engineering, where the latter has some precedence. In addition, there is research on both technical and soft skills, where maritime safety training is also highlighted. Furthermore, there are linkages to gamification and serious games, which are long-standing and cutting-edge research directions, as well as blended learning. These connections also indicate the overlap between XR and established simulator categories.

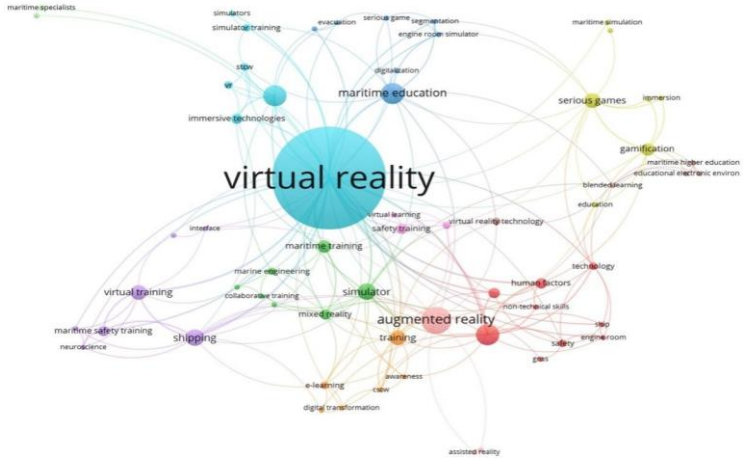


Figure 4. Co-occurrence – Author keywords

3.4 Scholarly networks

Finally, it is possible to gain insight into past and future research directions by mapping scholarly networks. VOSViewer has provisions for analyzing past directions through bibliographic couplings (a link between two articles that cite the same article) and future directions through co-citations (a link between two articles that are both cited by the same article). These linkages can be analyzed on an article level and synthesized through literature sources, including journals and conference proceedings, or by individual authors. Figure 5 displays a co-citation analysis by authors.

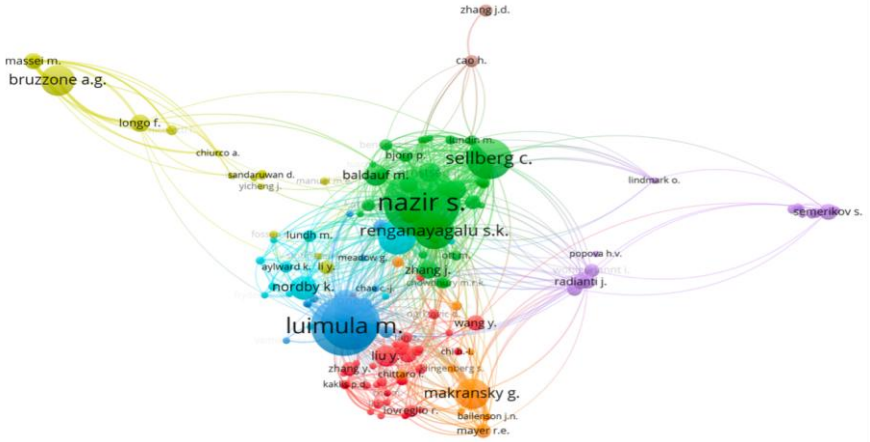


Figure 5. Co-citation - cited authors

It is possible to deduce different clusters of linkages. One cluster (blue) centers around linkages to Markopoulos and Luimula with colleagues who have published a review on The Effectiveness of Immersive Learning in Maritime Education and Training (2020) and on Maritime Safety Education with VR Technology. Another cluster (green) centers around linkages to Sellberg, who publishes extensively on simulators in Education and Training, and Nazir, who researches on various aspects of simulator performance (see for example Nazir et al. 2019; Sellberg 2018). It is also interesting to view the distance between the linkages, where Semerikov in the purple cluster is active in the software engineering discourse and research, for example, methods of assessment, using mobile internet devices for training, and sustainability issues.

4. Discussion, concluding remarks, and future work

The results show the multifaceted nature of XR research relating to MET across multiple discourses, topics, and clusters of researchers. In general, this shows the viability of the research area. We also identified emerging areas in the database search results, but that were not eligible for inclusion in the review at this stage. One such area is AI, where there were articles that were too technical to merit inclusion at this stage, but where MET applications are likely to be developed in the future, given the rapidly developing interest and capabilities of this technology.

At the same time, it is important that there is a framing of the research, in order to be able to systematically interrogate the utility and support dissemination, which is also important for industry applications. We hope that going forward our research will contribute to this end by mapping the utility of XR applications within the GMP framework and the taxonomy of Knowledge, Skills, and Attitudes learning areas, as well as their relations to the STCW competencies.

Our next steps are to expand this bibliometric review into a systematic literature review to gain a more in- depth understanding. The results will also be input into the needs analysis phase of action research cycles, where we will develop new XR applications.

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Proceedings of the
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Fast Time Simulation and Dynamic Manoeuvring Prediction – towards Integration of Disruptive Technology for Training of Navigators of the Future

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Abstract: Maritime education and training must continually evolve to meet the needs of shipping companies and maritime service providers. Modernization requires the incorporation of the latest technological developments relevant to safe, sustainable, and efficient ship operations. MET institutions must develop new education programs and courses to address changing conditions in the maritime labour market.

This paper introduces approaches to use new technologies based on Fast Time Manoeuvring Simulation to improve teaching / training and also conning of real ships:

Case studies include simulation-based manoeuvre training using fast-time simulation for ship motion predictions to be used for full dynamic manoeuvre planning, consumption analysis and collision avoidance. Initial experiences and feedback from students and instructors are summarized, and the pros and cons are discussed. This technology helps to improve new study courses and training methods to educate future navigators, who will become marine pilots, and might also support operators in remote-control centres for Maritime Autonomous Surface Ships (MASS) and VTS operators.

Keywords: Ship-handling, Manoeuvring Prediction, Simulator Training, Fast-time simulation, energy efficient operation

1. Introduction

Maritime universities, academies, and training institutions aim to provide qualified and well-trained mariners for shipping companies worldwide. Graduates from MET institutions often continue their professional careers in various maritime sectors ashore, including classification societies, bridge equipment manufacturers, MET institutions, national waterway and shipping administrations, as well as marine pilots or VTS operators. These secondary market institutions value the seafaring experience and expertise of mariners.

New shore-based services, such as Vessel Coordination Centres and Remote Operation Centres for Maritime Autonomous Surface Ships (MASS), are in development or being established. However, the secondary market is experiencing a shortage of applicants who meet the traditional profiles of experienced navigators ready to become marine pilots or VTS operators. Consequently, new education programs and study courses must be developed to address the changing conditions in the maritime labour market. This paper provides some examples for a new course for maritime pilot education and training.

Historically, ship handling skills were acquired through extensive practice. Nowadays, simulation technologies have revolutionized training methods. Full Mission simulators, though effective, are costly and time-consuming. Fast Time Simulation offers efficient ship motion prediction for mental model preparation in training and onboard conning assistance. Various manoeuvring prediction technologies provide better insights into ship motion. The following overview covers conventional and new methods, from single to multiple predictions and step-ahead predictions, extending the decision horizon for improved ship handling training. For these purposes a dedicated software system (SAMMON: “Simulation Augmented Manoeuvring Design, Monitoring & Conning) has been created and is continuously enhanced. The toolbox provides features for predicting ship motions. For detailed information refer to (Benedict et al. 2009 and 2016))

The next sections will introduce various new features, focusing on dynamic path predictions and

efficiency and safety considerations.

2. New Manoeuvring Prediction Features using Fast Time Simulation

2.1. Expanding the Horizons of Manoeuvring Prediction for Two Steps Ahead

While existing dynamic predictions offer foresight for the next manoeuvre only, real- life scenarios often require corrections to previous manoeuvres, making subsequent ones challenging to execute. To address this, the "Edit Mode" feature in the Planning tool allows revising commands at earlier manoeuvring points (MPs). By presenting predictions for at least two manoeuvring segments ahead, Figure 1 exemplarily showcases the approach to Rostock Port's turning area black shapes depict predictions from current position (MP0) with command settings: Rudder Midships and both engines at EOT +30%. The red shapes indicate predictions for the next manoeuvre, planned from the blue shape for a turn into the side arm, pre-planned with split engines and rudders at 20° PT. Both predictions are calculated simultaneously, so adjustments at MP0 influence the entire manoeuvre chain. For example, changing the rudder (centre figure) adjusts the entire prediction, or altering the engine will move the starting position of the next manoeuvre closer, allowing for EOT reduction (right figure). This feature is useful when external forces like wind impact the scenario.

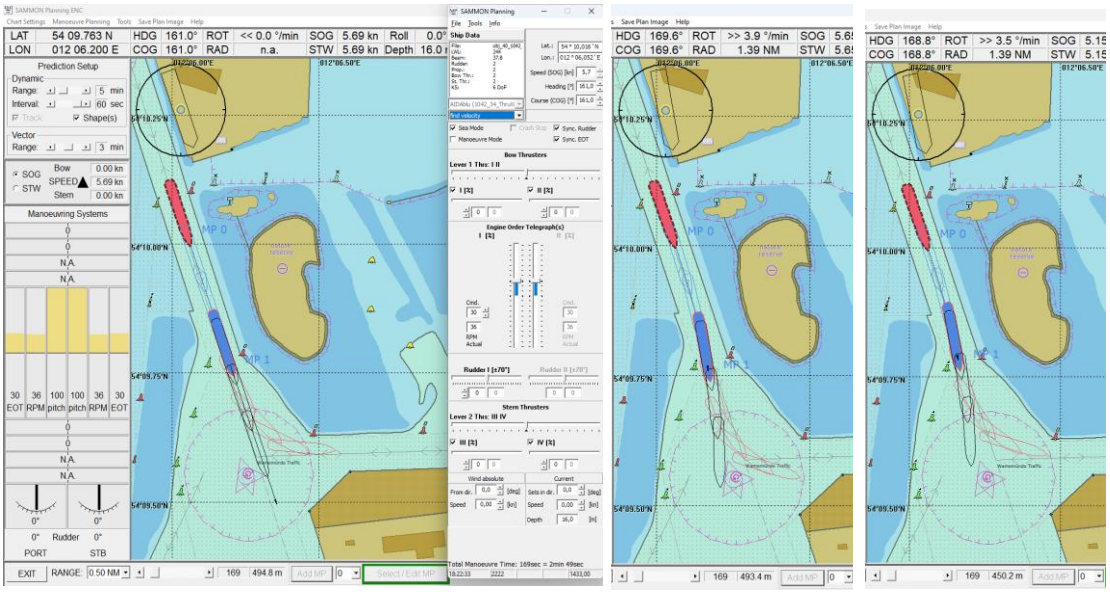


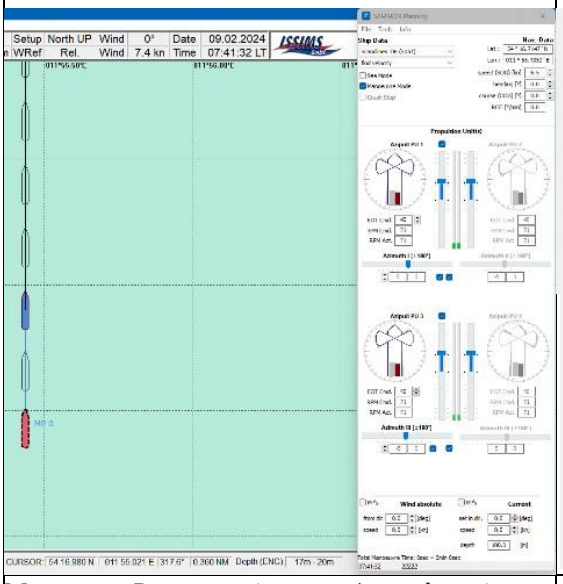
Figure 1. Intelligent predictions with two simulated steps ahead approaching a port area The left figure's

These examples illustrate how preparing a comprehensive manoeuvring plan is straightforward, providing valuable insights into the ship's manoeuvring behaviour for a wider horizon. The operational interface is user-friendly on a laptop, making it beneficial for lecturers, trainees, and onboard use.
In future this Two Step Prediction will be a new element of the Manoeuvring Monitoring & Conning Module to be available during manoeuvring to allow for innovative support in the ship handling process.

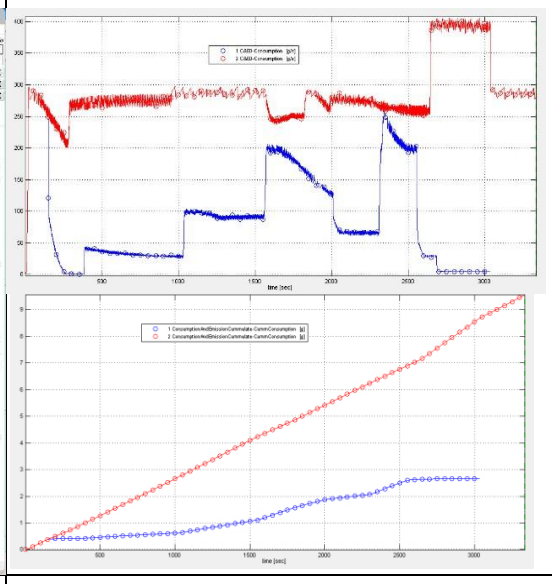
2.2. Prediction for Efficiency Consideration during Manoeuvres

Efficient ship operation relies not only on technical equipment but also on handling. Measurements on real vessels showed that different manoeuvring concepts have a big impact on the resulting consumption. Simulated environments demonstrated that proper assistance tools lead to effective manoeuvring with fewer engine orders and rudder commands, reducing energy consumption. Figure 2 illustrates two samples for demonstrating result for consumption using new features of the SAMMON toolbox:

On the left side the handle panel of SAMMON Planning is shown, visualizing initial manoeuvring conditions for a double-end ferry with four azimuth propellers. The required power (in kW) at MP0 is shown in the green bar display: with both pairs of azimuth propellers at EOT 40%, the power is equally distributed, resulting in a speed of 6.5 knots. Future studies aim to simulate drive train energy as measured onboard, integrating the power of installed azimuthal drives. In this way, innovative assistance to nautical crews will reduce total energy consumption during manoeuvring.



Momentary Power requirements (green bars, in kW) for a double-end ferry with 4 azimuth propellers: both pairs of azimuth propellers EOT 40%,



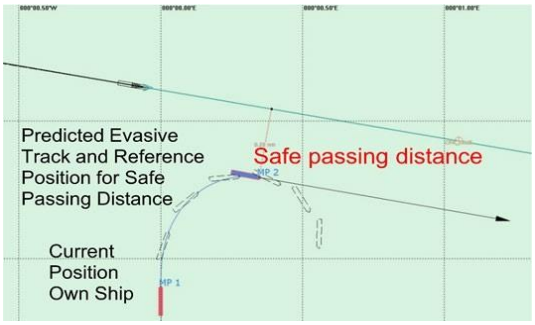
Consumption plots for two manoeuvring strategies (Top: separate for manoeuvring segments; Bottom: cumulative consumption)

Figure 2. Display of power requirements in SAMMON handle panel (left) and comparing results for consumption during manoeuvres in SIMDAT analyzing software (Right)

On the right side the comparison of consumption for two complete manoeuvring plans can be seen: the blue graph represents the results for using conventional POD strategy,
i.e. speed changes were made by reducing POD revolutions; the red graph shows the results for an alternative strategy where speed changes were made by turning both PODs inward.
These samples proof the great potential of the software to achieve improvements in efficient ship handling concepts.

2.3. Prediction for Decision-making in Collision Avoidance Situations

Moreover, predictions help the Officer of the Watch (OOW) make decisions during potential collision situations. There are three main applications: determining when to initiate maximum rudder angle for safe passage, identifying the "Last Line of Defence" for collision avoidance, and visualizing manoeuvring zones for steering control options. Besides providing information about latest time for initiating an avoidance manoeuvre for safe passage, new features support situational awareness by displaying navigable space and predicting paths with maximum rudder angles. This is valuable for simulation training, demonstrating risk models and collision avoidance strategies to cadets. Additionally, visualizing the escalated risk of collision based on the ship's own manoeuvring capabilities at the prevailing circumstances enhances maritime education and training.



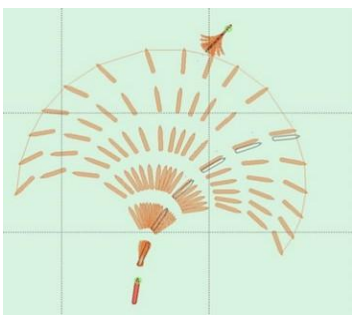


Figure 3. Visualising lower action limit for "Stand on Vessel" (left) and manoeuvring zones (right)

Figure 3 (left) shows an encounter situation in an electronic chart environment. The own ship (red shape) is on a north-easterly course, approaching another vessel on a south- easterly course, crossing the bow

at a short distance. The prediction highlights the closest approach when the own ship's heading equals the target ship's course over ground. To ensure a minimum passing distance of 0.25 nm at the CPA, the hard wheel over command must be initiated at MP 1, reaching MP 2 (Baldauf et al., 2017; Gil et al. 2020).
An alternative concept for situation assessment and decision-making is to use multiple predictions to visualize all potential positions of a manoeuvring ship within a given timeframe (Figure 3 (right)). Manoeuvring zones can be calculated and displayed, representing areas a ship may cover using various control settings for the exact situation. This concept may enhance situation assessment for collision avoidance on board (Mehdi et al., 2019) as well as monitoring from a VTS (van Westrenen & Baldauf, 2019).

3. Application of Fast Time Simulation in Master Course of Maritime Pilotage - Module Manoeuvring

3.1 Traditional Career Path of Sea Pilots in Germany and new Approach

Traditionally, seafarers in Germany had to be vessel masters for an extended period before allowed applying to become a pilot. However, declining applicant numbers with that experience level led to considerations how to cope with lowered entrance experience and therefore to be balanced by increased training needs. Today, pilot training in Germany follows three paths (named LA1, LA2 and LA3) depending on participant experience levels:

- Career Path LA3: For those with a master's license and 24 months sea experience in the last 5 years. It requires 12 months of in-house training and an exam.
- Career Path LA2: For those with a master's license but lacking sea experience. Participants undergo an additional 6 months training before starting LA3.
- Career Path LA1: For those without a master's license, a selection process and a new, dedicated degree program "Master of Maritime Pilotage" in Warnemünde is required, covering content and training for all three steps (LA2-LA3).

A wide range of simulators it used to handle the different levels of sea-time experiences and ship types. Especially the problem of students' heterogeneity is very crucial. This, however, can be very well addressed by applying FTS-tools. This could be observed when teams elaborated manoeuvring plans together in teams.

3.2 The use of SAMMON Fast Time Simulation for lecturing in Pilot Education & Training

One element of the Manoeuvring Module in the new course is to apply knowledge of different propulsion and manoeuvring aids to create and prepare a detailed manoeuvring plan. Participants were divided into four groups, each tasked with developing a departure manoeuvre for their vessel type with various types of propeller and thrusters.

All vessels were defined to be 200m in length, with no current or wind conditions, and operated in a wide manoeuvring area with a simple pier. Each group had to depart from the same berth but with different vessels. The goal was to focus on the propulsion and thruster performance, allowing participants to present and discuss their detailed manoeuvre plans.

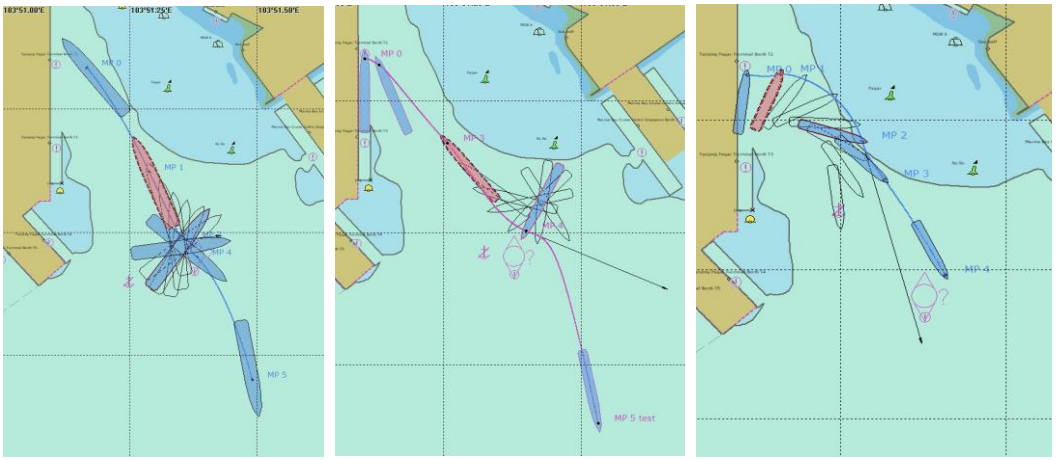


Figure 4. Three different departure Manoeuvres created by group of participants.

- Left: departure with right-handed fixed propeller and bow thruster,

- Middle: shows departure with two inward turning propellers and bow thruster,
- Right: shows vessel with two podded propulsion and bow thruster.

The discussion within the groups fostered a rich exchange of knowledge and experience. When presenting their results, participants detailed their manoeuvres, and the lecturer used the SAMMON Planning tool to illustrate the outcomes Figure 5. This had three key effects:

- Participants took the manoeuvre descriptions seriously.
- Incorrect assumptions were quickly corrected through simulation of alternatives.
- Other groups benefited from moderate exchanges and knowledge specific to each propulsion setup.

Afterwards, reshuffled groups planned a departure from same pier under same conditions, focusing on accurate detailing and identifying limits. The Fast Time Simulation tool demonstrated several advantages:

- Enhanced knowledge of propulsion setups, particularly double propeller and podded propulsion.
- Quick correction of wrong assumptions through immediate simulation feedback.
- Efficient demonstration of well-prepared plans versus reactive manoeuvring.
- Focused manoeuvre planning without distractions like handling errors or visuals. Final discussions revealed the existing great potential of the software and suggestions for future software feature extensions were made.

4. Conclusions

Prediction of ship motions is essential for navigation safety, particularly in coastal or narrow waters and during berthing operations. Fast Time Simulation (FTS) technology enhances maritime education and training by predicting future ship motions, improving manoeuvre planning, and increasing efficiency and sustainability in shipping.

This paper presents the latest advances in FTS, including Two Step Ahead prediction, simulation model extensions for consumption and multiple predictions to visualize complete manoeuvring zones representing all potential positions of a manoeuvring ship within a given time period.

FTS technology supports the new Maritime Pilotage master course, making theoretical content more engaging and practical, also as preparation of full mission real time simulation.

Students and lecturers / instructors widely accept FTS as a reliable simulation tool, enhancing both individual exercises and group discussions. It complements, rather than replaces, real-time training methods, improving lecture and training preparation where other options may be less effective or unavailable.

Acknowledgements

The authors thank the lecturers, pilots, and navigators who shared their insights during interviews and questionnaires. This research was partially conducted within the national research project "Expert system as an Assistant for Manned and Autonomous Shipping (EBAS)" funded by the German Federal Ministry of Digitalization and Transportation (BMDV). It is supervised and surveyed by DLR Projektträger Bonn. Further research was part of the SimpleShip project, supported by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) and overseen by the German Research Centre Jülich (PTJ). Additionally, materials from the LEAS project ("Shore-side decision support for traffic situations with highly automated or autonomous vessels using AI"), funded by the German Federal Ministry of Education and Research (BMBF) and supervised by VDI Technologiezentrum Düsseldorf, are included. ISSIMS GmbH provided the SAMMON software tool used in this study.

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Proceedings of the
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Geo-Spatial Visualization of Multi Beam Echo Sounder Data to Explore the Submerged City of Poompuhar

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Abstract: The main objective of this article is to explore the maritime activity and the trade routes from the ancient submerged harbour Poompuhar. Poompuhar is a port city during Chola dynasty in Tamil Nadu, southern part of India, which was vanished due to natural disasters, sea level changes or tectonic movements of earth surface. Digitally reconstructing the maritime harbour is essential to preserve the cultural heritage and for the archeological research. The Sangam literature describes the location of the Poompuhar Port, habitation and town planning. This Study discover the hidden remains at the offshore region using the MultiBeam echo Sounder Data (MBES) and Remote operated vehicle (ROV) data acquired by the Sagar Tara vessel of National Institute of Ocean Technology (NIOT), funded by Department of Science and Technology (DST), Govt of India. The submerged Port City is mapped based on the ancient Tamil Sangam literature and the MBES data. The MBES Data is preprocessed and the submerged structures are visualized to reconstruct the ancient shoreline and its past geographical features.

Keywords: Port city, Geo spatial, Multi beam echo sounder, Underwater exploration, Maritime data portal.

1. Introduction

This paper focuses on Poompuhar, a historic site in south India also known as kaveripattinam or puhar is believed to have been destroyed by a combination of natural disasters and possibly human factors. According to historical documents and archaeological research, this port city was submerged and eventually destroyed as a result of tsunami and sea erosion. The research highlighted that the preservation of archaeological evidence has been affected by rapid shoreline changes caused by human interventions such as the construction of jetties, groins, breakwaters, and port infrastructure, which have intensified dynamic coastal processes over time. To explore the submerged heritage sites of Poompuhar, advanced marine techniques were employed, particularly the Multibeam Echo Sounder (MBES), a widely used hydroacoustic instrument for measuring water depth (Bhattacharya et al., 2022). It generates high-resolution bathymetric maps of underwater terrains by determining the vertical distance to the seabed or objects on it, using multiple beams directed in various directions, as illustrated in Figure 1. In addition to conventional geospatial survey methods Artificial intelligence techniques will be utilized to enhance data processing, visualization, and anomaly detection, significantly improving the precision of underwater mapping. Machine learning algorithms enable more accurate identification of submerged features and anomalies within large datasets, thereby enhancing data interpretation efficiency. The AI-assisted methods pave the way for future applications of intelligent systems in marine archaeology (Mishra et al., 2021). This study highlighted on maritime research and geospatial analysis in submerged areas. It also provides geospatial data for exchanging information in marine conservation. The historical culture of Poompuhar is represented in this paper which offers submerged sites and conservation efforts. This study examine the hidden areas of Poompuhar using cutting edge remote sensing and geospatial techniques to highlight its historical significance. The research focuses on the hidden aspects of Poompuhar through the application of remote sensing and geospatial techniques. It further aims to document the historical significance of Poompuhar and support the development of effective preservation strategies for its submerged heritage sites.

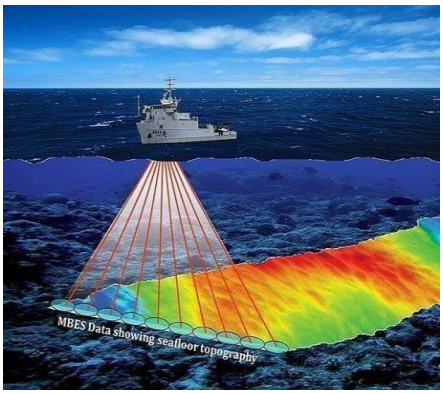


Figure 1. Data Collection using Multi-Beam Eco Sounder

2. Exploration Site

At the mouth of the Cauvery River, the port city of Poompuhar is located. The port extension of marine archaeological explorations around Poompuhar, along with brick, stone and pottery structure found in the area and provide evidence of the existence of heritage sites. The site spans a latitude from 10°57′0″N (southern boundary) to 11°18′0″N (northern boundary) and a longitude from 79°48′0″E (western boundary) to 80°12′0″E (eastern boundary). This coastal region is crucial for researching long-term changes in the Earth's surface because of its dynamic coastal processes and vulnerability to erosion and tsunamis. The study provides a thorough examination of the underwater environment by combining high-resolution, sophisticated multi-beam echo sounder data with geographic information system tools. The region has revealed shipwrecks, submerged structures and other features that indicate the existence of port city, ultimately claimed by the sea, consistent with accounts recorded in historical documents and ancient Tamil literature.

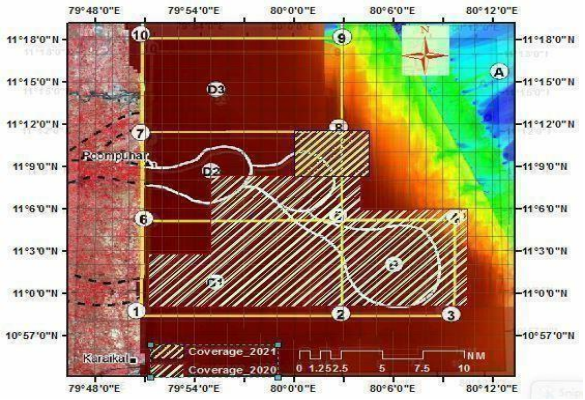


Figure 2. Poompuhar's submerged land area

3. Methodology

This study uses an interdisciplinary approach that combines data processing, archaeological analysis, and marine geospatial technologies to digitally recreate the ancient Poompuhar's submerged landscape. The strategy is broken down into multiple crucial stages such as Data Acquisition, Pre Processing Bathymetric Data, 3D Reconstruction and Geo spatial Analysis, Inverse Distance Weighting depicted in figure 3. Framework of the research.



Figure 3. Framework of the approach

3.1 Data Acquisition

The National Institute of Ocean Technology (NIOT) research vessel Sagar Tara was used to gather Multi-Beam Echo Sounder (MBES) data. The offshore region close to modern-day Poompuhar, Tamil Nadu, was mapped with an emphasis on areas thought to contain submerged archaeological features. To guarantee the spatial accuracy of seabed features, precise georeferencing was accomplished using the Differential Global Positioning System (DGPS). The collected bathymetric data provided detailed information on seabed topography, revealing elevations and potential man-made structures indicative of the ancient port and its maritime infrastructure.

3.2 Preprocessing of Bathymetric Data

For noise filtering, the raw MBES data was processed to remove distortions, noise, and artifacts caused by variations in the water column, tides, and vessel motion. Standard algorithms such as Statistical Outlier Removal (SOR), Moving Average Filtering, and Despiking Techniques were applied to clean the data and enhance signal quality. Sound speed corrections were applied using water column profiling to ensure accurate depth readings.

3.3. 3D Reconstruction and Geospatial Analysis

GIS Integration for spatial analysis, cleaned bathymetric data was loaded into Geographic information system (GIS) programs like QGIS. For viewing, analyzing spatial data, QGIS is a free and open source geographic information system program. It enables to create, edit, visualize, analysis and publication of geographical data including maps analyzes and also helps with managing and organizing geographic data. Digital Terrain modeling to see and examine underwater features, high- resolution 3D seabed models were created. Slope, aspect, and contour analyses were used to find possible archaeological features like linear alignments, depressions, and anomalies.

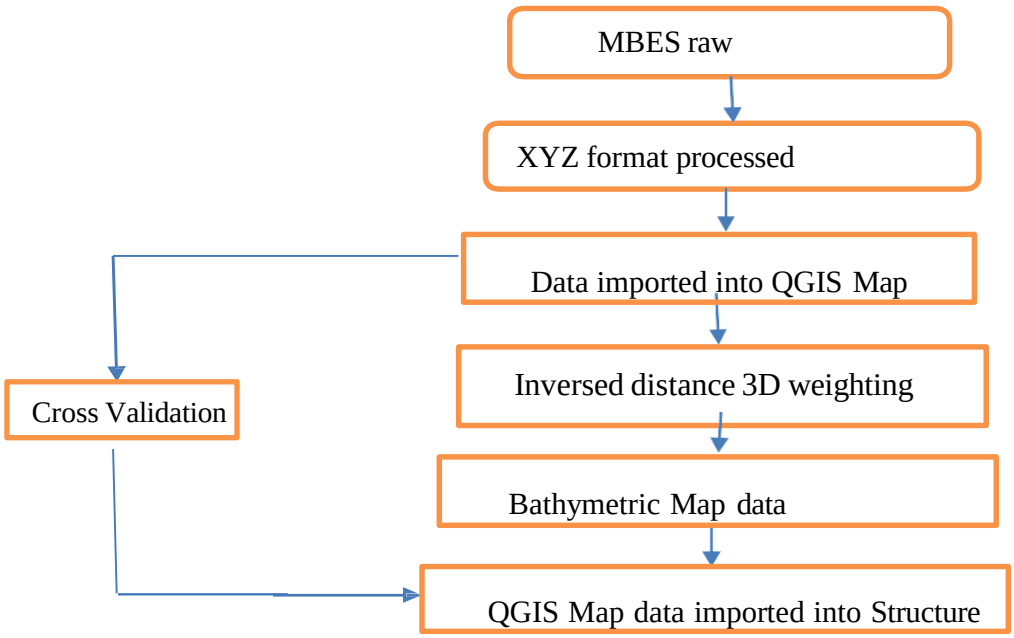


Figure 4. Geo-Spatial Visualization of Multi Beam Echo Sounder Data

3.4 Inversed Distance Weighting

The IDW approach, is based on the idea of distance weighting, is used in this research to interpolate geographical data. Using the known observed depths, this technique can be used to estimate unknown depth data. The IDW gridding technique can be applied with either a smoothing or an exact interpolator. During IDW interpolation, the data are weighted to point from the grid node, the less impact is on another point. For every interpolation technique, reasonable settings were first determined because inadequate parameters, especially when using IDW, can cause noticeable artifacts in the interpolated surface. A range of

interpolation parameter combinations were assessed using brute force. Every analysis that followed was predicated on the

each interpolation's parameters method that yielded the study area's lowest median percent deviation. IDW's parameters were a variable search radius of 8 points and a power of 2. The IDW interpolation technique is widely used to process a variety of spatial data, including digital elevation models, estimations of soil moisture distribution and surface water volume. Point values are assigned in QGIS software using the IDW method, which analyzes data of submerge region.

4. Interpolation in QGIS

The QGIS functions include interpolation. The processing toolbox contains QGIS interpolation tools that make it easy to convert discrete points into a continuous surface. QGIS creates a raster surface that encompasses an entire region by estimating values at unknown locations using vector points with known values.

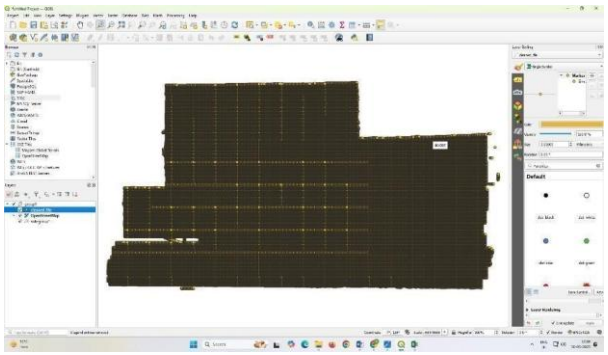


Figure 5. XYZ Processed data in QGIS

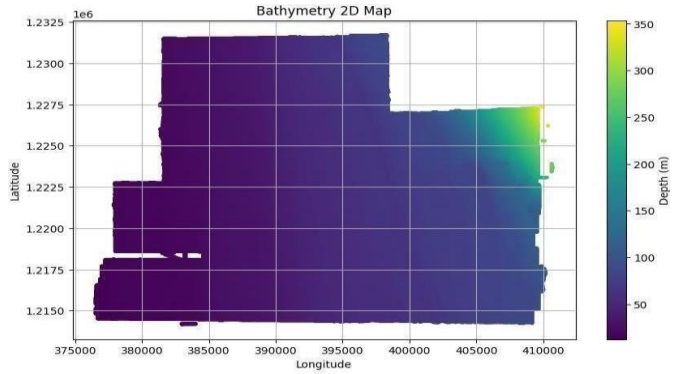


Figure 6. Bathymetry 2D Map

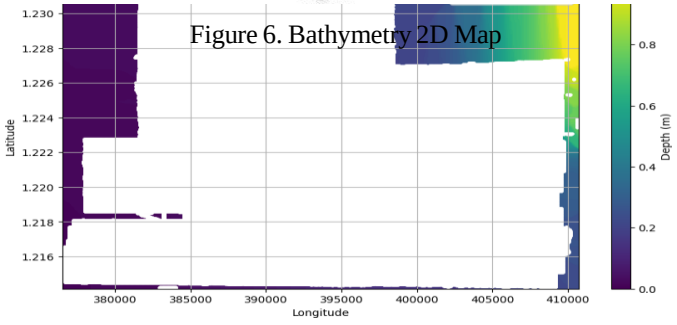


Figure 7. Geo Spatial Visualization Technique

5. Analysis and Interpretation

For viewing, analyzing spatial data, QGIS enables to create, edit, visualize, analysis and publication of geographical data including maps analyses, and also helps with managing and organizing geographic data.

After converting all the raw MBES data into the XYZ format, the interpolation technique is used to create the bathymetric surface. Various adding strategies were used, with Inversed Distance Weighting (IDW) being the most accurate reasonable method in GIS programming. Fig.4, indicates the possible presence of certain objects within that specific area. The features observed could represent remnants of a destroyed port structure or artificially constructed sea walls. Figures 5 and 6 present the bathymetric 2D map and geospatial visualization generated using QGIS software, illustrating the submerged port structures in a 3D visual format. This image displays a dense distribution of depth points, forming a detailed and high-resolution map of the surveyed region. Scatter points are used in the plot to show changes in spatial depth. While the bathymetric data show a gradient from shallow areas on the western side to deeper regions on the eastern side. The X and Y axes represent spatial coordinates. The color coding generated from the mapped data, corresponds to different elevation levels in the DEM produced using the QGIS software. The Tool Box contains a Inversed Distance Weighting (IDW), which is used to create the mapped bathymetric data. To represent the sea floor, from the color-coded DEM map, it can be inferred that the region surrounding Poompuhar lies submerged beneath the sea. This research helps to interpret the variations in the seafloor's various levels and comprehend the range of surfaces from the generated map. From the smooth surface to the lowest depth of sea level, the color-coded map changes.

6. Conclusion

This research highlights the effective integration of modern hydroacoustic techniques, such as Multibeam Echo Sounder (MBES) data and high-resolution imagery from Remotely Operated Vehicles. Various structures in the submerged port city of Poompuhar has been identified and exposing its former trade routes and marine infrastructure. During the Chola dynasty, the city played a crucial role in maritime trade. In order to document submerged archaeological features, cultural heritage and underwater archaeology explorations studies, this research emphasizes the value of integrating technological tools with literary sources. This research contributes a substantial historical geography and maritime history of southern India by charting the ancient shoreline and illustrating submerged structures. The findings not only enhance the understanding of maritime activities and trade networks in the port city during the Chola dynasty but also contribute significantly to preserving cultural heritage and supporting future archaeological research.

Acknowledgement

The first author Dr. T. Sasilatha Professor and Dean, AMET University sincerely acknowledges the financial assistance received for the Project titled, "Underwater Structural Data Acquisition: A case study on Poompuhar Heritage Underwater site" from the Department of Science and Technology, Govt of India under the Programme 'Science and Heritage Research Initiative'.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Advancing MET through technology: ROV education and training for seafarers

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Abstract: As technological innovations continue to transform the maritime industry, Maritime Education and Training (MET) must evolve to adequately prepare seafarers for modern operational demands. Although current MET programs comply with STCW requirements, they are often insufficient in training seafarers to gain skills required for emerging practices such as in-water hull inspections using inspection-class Remotely Operated Vehicles (ROVs). These operations are used to assess damage, corrosion and fouling, thus supporting efficient maintenance planning and classification surveys. This paper, supported by the research project for Young Academic Staff in FY2024, titled "ROV education and training for seafarers," investigates current practices, gaps and training needs in ROV-assisted hull inspections. Based on literature reviews, interviews with ROV manufacturers, shipping companies and seafarers, as well as pilot inspections by the authors, the study identifies core competencies required for safe and effective ROV use. The findings culminate in a proposed training syllabus tailored to seafarers, integrating underwater robotics and digital skills into MET. By encouraging international collaboration, particularly through the IAMU network, this initiative aims to raise educational standards and promote maritime careers among younger generations, aligning MET to evolving technological and industry needs.

Keywords: Maritime education and training (MET); Remotely Operated Vehicle (ROV); Ship's hull inspection

1. Introduction and literature review

The maritime industry is undergoing a significant transformation, driven by technological advances, evolving safety standards and environmental requirements. While the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) provides a framework for minimum required competencies for seafarers, these requirements often lag behind the constant developments in maritime technology and operations. As a result, seafarers are increasingly encouraged to expand their professional competencies and go beyond regulatory minimums in order to remain competitive in the industry. This is especially true for those at the beginning of their careers.

Structural failure is one of the main causes of serious maritime accidents (Dong et al, 2022) and is often caused by factors such as overloading, design faults, material imperfections, poor welding, coating breakdown, and corrosion (Lin et al, 2023). To mitigate these risks, ships are built to strict safety standards and regularly inspected during construction and throughout their service life (Nair et al, 2017).

Groundings, collisions and even minor "touch and go" incidents can compromise the integrity of the hull, potentially causing localized deformation, premature coating degradation and long-term corrosion if not promptly addressed. Regular hull inspections are therefore critical to maintaining structural health, controlling biofouling and maintaining the efficiency of the vessel, as even minor microfouling can increase fuel consumption by up to 16% and pose an environmental risk through the transfer of invasive species (IMO, 2023; Callow et al, 2011).

Hull inspections are governed by the regulations of the classification society and usually takes place during the survey in dry dock. In most cases, however, inspections can also be carried out as an In-water Survey (IWS) during annual surveys while the ship is afloat. As per International Association of Classification Societies (IACS), Remote Inspection Technique (RIT) is a survey method that allows the examination of any part of the structure without direct physical access by the surveyor, using various means,

including divers and ROVs (IACS, 2022; IACS, 2019; IACS, 2016).

While diver-based inspections provide detailed visual assessments, they come with significant safety risks, high operational costs, logistical challenges and complex procedures. Studies show that 15% of commercial diving fatalities occur in the shipping sector, often due to drowning (27%) or unexpected start of the propeller (18%) (Hermans, 2016). An increasingly feasible alternative is the use of remotely operated vehicles (ROVs), particularly compact inspection-class models.

Once limited to the military and offshore industries due to their cost and complexity, modern ROVs are now becoming more affordable and accessible to commercial shipping, being hand-launched, capable of operating reliably with minimal maintenance requirements (Christ et al, 2013). These devices eliminate human risk, offer longer operating time and can be equipped with advanced tools such as ultrasonic thickness gauges, laser measurement systems and manipulators. Case studies, such as the ROV-based Underwater Inspection in Lieu of Dry-Docking (UWILD inspection) by Jacob et al. (2019), demonstrate how ROVs can identify structural issues on the ship's hull and reduce the need for dry-docking.

The growing interest of shipowners in the use of ROVs shows the potential for cost-efficient, timely inspections without having to rely on external diving services. However, this transition entails targeted training of the personnel involved in this task. Currently, ROV operations are often assigned to existing crew members without adequate preparation or development of specific competencies. This leads to suboptimal results, including poor inspection quality, misuse of equipment, followed by equipment damage and extra costs.

The integration of ROV operational training into maritime education, especially for future deck and technical officers, is essential to meet industry demands. The project behind this paper aims to identify the gaps and develop a training syllabus that combines theory and practice, enhancing the safety and efficiency of underwater inspections. The acquired competencies are also transferable to other water-related industries and support career mobility within the wider blue economy.

The following section of the paper describes the methodology used in the research, i.e. the interviews and the pilot in-water survey conducted by the authors. In addition, a shortened version of the syllabus is presented at the end.

2. Methodology

To explore the use of ROVs for the ship's hull inspection, the study is divided into two parts: targeted interviews with key stakeholders and underwater inspections under real conditions. The main objective of the interviews was to gather first-hand insights from key stakeholders actively involved in ROV operations on ships and to incorporate their feedback into the design of the course framework. These stakeholders included ROV manufacturers, seafarers and shipping company representatives.

To ensure relevance and depth, a separate set of questions was compiled for each target group, reflecting their specific roles, responsibilities and expertise. Thus, there were 11, 14 and 9 main questions for ROV manufacturers, seafarers and shipping companies, respectively. The interview was designed as unstructured, containing open-ended questions that allowed respondents more freedom and flexibility in their responses. Originally, the same number of questions were set for each participant in the same group. However, during the interview, new sub-questions were asked based on the direction and content of the previous answers.

Data collection was conducted through a combination of in-person and online interviews. However, two seafarers who were at sea at the time of the interview answered the questionnaire in writing, as this was a more practical and convenient option under the circumstances. Each interview lasted between 20 and 30 minutes on average. The research results were processed qualitatively and the most important conclusions are presented in the following subsection.

A total of 15 respondents took part in the interview and questionnaire phase of this research, with the most prominent group being seafarers (11 respondents). This group included 7 senior officers (Masters and Chief Officers) and 4 junior officers (2nd and 3rd Officers). These individuals were mainly employed on bulk carriers and passenger ships, offering a valuable maritime experience.

In addition to the seafarers, three representatives from internationally recognized inspection class ROV manufacturers (Blueye, Deep Trekker and QYSEA) shared important information on technological advances,

ROV design challenges and current market trends in the shipping industry. Their input was essential to

understand the broader context in which ROVs are being developed and deployed. One respondent, a former Master who now holds a management position at a shipping company operating a fleet of bulk carriers, also contributed with valuable industry perspectives to enhance the research.

The participants' feedback directly influenced the identification of key topics and skills that should be emphasized in the training syllabus for ROV-based inspections. Their experiences, especially valuable mistakes and adaptations, were seen as critical to designing realistic and effective educational content.

The primary objective of this research was to conduct in-depth interviews, which was only possible with seafarers actively using ROVs on board. Although the initial research plan was to include a larger number of respondents, the research revealed that most companies have not yet adopted hull inspections using ROVs, indicating that this concept is still relatively new and evolving. Therefore, the inclusion of respondents with no practical experience of ROV inspection was considered counterproductive to the aims of the study and would not have contributed to the quality of the results.

Pilot in-water hull surveys were organized and conducted by the authors on several ships in the ports of Rijeka and Kraljevica (Figure 2). These ships were passenger ships and ro-ro passenger ships up to 100 meters in length. The inspections provided a broader perspective on the operation reality and the challenges seafarers face during underwater hull inspections. These surveys also served to validate the interview results and confirmed many of the insights gathered from various respondents. They also highlighted additional practical considerations that had not previously been emphasized and that will be important for the preparation of the course syllabus.



Figure 1. Pilot in-water hull inspection (propeller, bilge keel with corrosion protection)

3. Results

3.1 Findings from the seafarers

Finding No.1: ROVs are primarly used to minimize the need for divers, to verify divers' work, to inspect the hull for fouling after extended periods at anchor (thereby improving fuel efficiency), to assess potential damage after contact with the seabed and to identify entanglements such as ropes around propellers and rudder.

Finding No.2: Typically, Chief Officers are responsible for ROV operations. However, in many cases, junior officers often act as ROV operators under the supervision of the Chief Officer. These tasks are also valuable learning opportunities for cadets and junior officers in the area of ship maintenance, especially given the trend towards shorter contracts and less frequent dry docks.

Finding No.3: Technical and operational challenges of ROV operations include the limited tether (cable) length relative to ship size, which limits operational range, especially on larger ships. In addition, the low thruster power becomes particularly problematic in strong sea currents, which impairs the inspection quality. The risk of cable entanglement is also of great importance, especially around sensitive areas such as the stern, where propellers and rudders are located. To reduce these risks, operators on some ships are taking additional safety measures, such as using heaving lines to "hold" the ROV during inspections, especially in strong currents when the vessel is at anchor.

Finding No.4: Senior officers advise young officers to acquire skills beyond the STCW minimum requirements, where ROV operation becomes a valuable asset. Junior officers believe that previous experience in ROV handling would have a positive impact on their performance appraisal (evaluation of their work on board at the end of their contract) and improve their employability.

Finding No.5: An introductory training course of 3–5 days (or approx. 10 hours of practical piloting) would be sufficient to ensure safe and effective basic ROV operation for hull inspection purposes. Basic knowledge of ship construction is necessary to better interpret the observed conditions.

Finding No.6: Although ROVs are increasingly accepted, there is still some reluctance and hesitation among some users. The concerns are often due to fear of responsibility, risk of equipment damage or a general feeling of uncertainty. Such reactions are common when new technologies are introduced, in particular when additional tasks are not accompanied by extra compensation.

Findings No.7: The majority of seafarers recognize the value and potential of ROVs. They expect ROV inspections to become standard practice in the future, especially as operational requirements increase and technological familiarity improves.

3.2 Findings from the inspection-class ROV manufacturers

Finding No.1: The sales trend of inspection-class ROV for use in the shipping industry is increasing. One ROV manufacturer reports that from 2010 they have sold 5,000 - 6,000 units across all markets, with about 12% of sales going to shipping companies. Over the last 10 years, the capabilities of the inspection-class ROVs have significantly improved, approaching those of larger "professional" units. Another manufacturer has sold 1,300 ROVs in 70 countries since 2018 to all customers, while shipping companies account for about 20% of their sales. While the number of sold units has not dramatically increased over the years, the price per unit has gone up due to advanced sensors enhancing the capabilities of the robots. A third ROV manufacturer, which launched its first compact ROV model in 2016 for simple inspections, has seen steady growth, especially in North America, Europe and Japan, where shipping companies are key customers. Sales trends in the shipping industry shows a steady annual growth of approximately 5-10%.

Finding No.2: In most cases, shipping companies begin by purchasing a single ROV unit to test its quality and capability, eventually equipping each vessel with a dedicated ROV for basic inspections. There are cases where shipping companies buy one ROV for each vessel in their fleet to have something on board for simple (basic) inspections rather than arranging divers. Sensors and probes that are most wanted by the ship owners include thickness measurement gauges and cathodic protection probes. Laser scalers are often used for real- time measurements and various software solutions are being developed for post-processing. Also, new companies have emerged in the market, purchasing ROVs to offer ship hull inspection services to ship owners.

Finding No.3: Manufacturers often provide online training materials (videos, presentations) which can be accessed through their websites or upon request. These resources include safety videos to minimize the risk of damage, learning from past mistakes. Video calls are often used to explain the use of specific ROV accessories (e.g. sonar). However, respondents of this group highlight that advanced skills in ROV operations cannot be adequately developed through virtual instructions alone and require hands-on experience. Sometimes manufacturers arrange on-site meetings for training, which have proved to be the most effective method. During these sessions, the focus is on robot techniques, rather than inspection methodology.

Finding No.4: Recommended training includes a 2–3 day program with 70% theory and 30% practical work, where the practical part should contain all the ROV features and functions, allowing time for additional questions and clarifications that arise during independent inspections.

Finding No.5: Piloting an ROV is easy to learn thanks to their user-friendliness, but operators must also learn task planning, taking into account all external factors affecting the operation. In most cases high-ranking officers on board are guiding younger and less experienced officers (ROV operators) during ship inspections. The most common operational issue remains the entangled tether, which often leads to costly equipment damage.

3.3. Pilot IWS results

One of the most significant findings from the pilot IWS was the importance of comprehensive pre-inspection planning. It became evident that thorough preparation is a fundamental prerequisite for a successful and efficient hull survey, particularly when using ROVs in changing maritime environments. The complexity of underwater inspections demands a structured approach.

Key preparatory actions identified through the pilot inspections include:

- Gathering of all available technical and environmental data related to both the vessel and the inspection location, such as underwater hull plans/sketches and precise under-keel clearance (UKC),
- Obtaining formal permission for ROV deployment from the relevant authorities (e.g. port

authority, harbor master's office) as well as obtaining consent from the ship's Master,

- Reviewing meteorological and oceanographic data, emphasizing on both forecasted and real-time conditions at the site. This will anticipate potential disruptions and reduce the risk of hazardous inspection periods,
- Ensuring operational readiness of all devices necessary for the inspection, including the full charging of the ROV set and associated mobile phone or tablet,
- Consulting a check-list of required equipment before leaving the "base" to avoid omissions and streamline the operational workflow,
- Coordinating with the vessel to announce the commencement of the inspection, ensuring that the ship's crew is aware of the underwater operations.

Once all preparatory work is complete and ROV is deployed, the focus should shift to the inspection itself while ensuring equipment safety, particularly avoiding tether entanglement, which represents a frequent operational risk in confined underwater areas. All personnel involved in the operation (ROV Operator, ROV Supervisor and Cable manager) must be familiar with an inspection plan, including contingency procedures i.e. potential deviations (plan B) in case of unexpected developments of the situation. Continuous and clear communication among the ROV team proved to be an essential success factor during the ROV operations.

Environmental variables such as sea current strength and underwater visibility are the most critical external factors influencing the inspection quality. These factors are found to be highly dynamic, requiring continuous monitoring during the inspection. Any changes in current strength and/or direction, or sudden drop in visibility should be promptly addressed within the ROV team, resulting in adjustments "on the go" or temporary pauses. The efficiency and safety of the inspection are directly influenced by the ability to rapidly assess and react to such changes in the external factors.

3.4. Proposed training syllabus

After thorough research of the literature, completed targeted interviews and pilot IWS on real ships and different environments, it is concluded that the proposed training syllabus needs to cover the topics given in Table 1:

This training program could be delivered over 24-30 hours across 3 to 4 days. It is recommended to combine classroom sessions with field practice in alternating blocks. It is expected that upon completion of the course, participants will be able to perform a full hull inspection under moderate external conditions and generate a basic report using the collected data. At the end of the training session, participants' feedback should be gathered to identify challenges, limitations and suggestions for future improvement.

Table 1. Theoretical lectures and practical exercises for the proposed ROV training

Theoretical lectures	Practical exercises
Structure of the ship's underwater hull (including ship plans)	ROV components of a specific ROV model (familiarization). Launching and recovery in calm water conditions
Underwater ship inspection – Purpose and methods	Surface maneuvering and cable handling
Inspection-class ROVs – parts and functions	Inspection of a simple underwater structure (e.g. the pier) using auto-features (auto-heading, auto-depth)
Understanding external conditions on ROV operation (focus on sea current and visibility)	Piloting through underwater polygon – untangling
Safe practices and basic procedures (launch and recovery, cable management)	Using search patterns for finding hidden objects – use of the compass and the speed of the ROV
Basic underwater orientation and navigation (including ROV navigation features)	Operation in challenging conditions (vc>1kt, Hs>0.5 m, vis.<1 m)
The importance of a thorough plan of the inspection (using the ship's plan)	Small boat hull inspection (with plan/drawing and proper planning of the operation) - taking photos and video materials
Additional features/probes for specific inspection	
Maintenance/troubleshooting of the ROV	
Use of inspection materials (photos, videos) – transfer of data and issuing a report	Ship's hull inspection (using the ship's plan) – data collection and reporting (making an adequate form)

4. Conclusion

This paper highlights the growing importance of the use of inspection class ROVs for underwater hull inspections in the maritime industry. Although ROVs have only been used by shipping companies for a relatively short time, they are already showing significant operational, economic and safety benefits compared to traditional diver-based methods. Extensive stakeholder interviews and pilot in-water surveys have identified the practical needs, challenges and skills required for effective ROV usage on ships. Key findings reveal that seafarers have a strong interest in acquiring ROV operational skills, not only to improve vessel maintenance and inspection outcomes, but also to increase job opportunities in an increasingly competitive labour market.

However, the research also shows a clear gap in the structured training and practical preparedness among current seafarers. The lack of formal education and training in the use of ROV often leads to suboptimal inspection quality and increased risk of equipment damage. In response, a targeted training syllabus has been proposed, developed through a combination of theoretical lectures and practical exercises. The recommended curriculum addresses critical aspects such as equipment handling, inspection planning, environmental awareness and reporting.

By equipping future seafarers (officers) with the skills required for the safe and effective operation of ROVs, the proposed training advances maritime education in line with modern technological trends. It also supports wider goals within the blue economy by promoting sustainable practices, reducing inspection costs and increasing overall safety. The integration of ROV training into standard maritime education will help to establish best practices for underwater inspection tasks at sea.

Acknowledgements

This research was funded by IAMU through the Research project for Young Academic Staff in FY2024, as part of its Capacity Building Project, supported by The Nippon Foundation.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Design of Hybrid Stand-Alone Power Generation System for Marine Applications

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Abstract: In recent, renewable resources gained attention among researchers because of its plenty of advantages such as eco-friendly, cost-effective, lower installation cost, easy to implement, etc. The widely used renewable resources are solar, wind, geo-thermal, hydro and tidal. Among that solar and wind energy resources are considered as adequate to fulfil the needs in future. Both resources have great potential to produce and deliver enormous value of power. This study focuses on developing a renewable resource powered (i.e. solar and wind energy) stand-alone system to deliver required power towards the load without any shortage. Though the selected resources have positive impacts, but considering the negative impacts of the system is crucial. The PV array cannot generate voltage at peak level when climatic condition is not suitable. As like PV array, the wind turbine could fail if there is any variation in speed of wind-blown. To keep in mind of above facts, the proposed system is designed. The Adaptive Neuro Fuzzy Interface System (ANFIS) based MPPT tracking system contributing to this research would support PV array to obtain maximum power and generate huge voltage. To alter the functionality and to boost the performance of wind energy conversion system (WECS), the Doubly Fed Induction Generator (DFIG) is recommended. It can operate at lower and higher speed range which is the main reason the proposed system would perform well. The modified boost converter linked with the solar panel regulates the voltage generation as per the load demand. The switching angle of proposed converter is controlled by PID controller. Any interruption caused in power generation has been compensated by the battery fixed with it. The simulation study of this work is done using MATLAB software and the outputs are evaluated.

Keywords: PV Array; Wind Turbine; DFIG; DC Microgrid; MATLAB Software

1. Introduction

The abundant usage of electric appliances in home and industries causing increase in usage of power consumption will result in power shortage in future. As well as, the depletion of fossil fuels also raised the establishment of several other sources to fulfil the load requirement. In this modern era, renewable energy resources becoming more popular and it could be the alternative of conventional mode of power generation. The advantages of renewable resource namely availability and eco-friendly nature makes this resource more reliable and effective in recent times. There are plenty of renewable resources available in usage and they are solar, tidal, wind, hydro, geo-thermal and so on. Among that solar and wind energy resources usage is quite increasing due to absence of CO2 and greenhouse gas emission risks (Mittal et al. 2020). Globally, 407-446 gigawatts DC power generated from PV array in the year of 2023. Furthermore, wind power generation in 2023 reached 1021 gigawatts which are comparatively 12.5% higher than the year of 2022. Particularly the onshore wind mills contributing majority in power generation. In developing countries like India, power demand is the major aspect for the economic growth of the nation as many of the industrial sectors performs trading all over the globe to enrich the wealth of the nation. The government of India increased a total of 1,94,394 MW generation capacity in the past 9 years. Now the installed capacity of power generation is almost 4,26,132 MW. Between 2023- 2024 power generated is around 9,943 MW. Among that, renewable resources contributing very much and it is encountered to be 5,531 MW from solar, 1,931 MW from wind, 34 MW from Biomass, 42 MW from small hydro and large hydro generation provided 30 MW (Year End Review of Ministry of Power 2023). Now, availability of power in rural areas are 20.6 hours and in metropolis accounting 23.8 hours. The energy demand in India reaches 11,02,887 MU which is 8.6% higher than the past year. Also, the power generation raised to 11,02,887 MU and it showing there is an increase of 8.6% than last year. Report shows that the renewable power generation is 1176.130 BU and it is increases upto 7.7% than the renewable power generation in the year of 2022-2023.

In practical, solar and wind turbine contributing a major role in renewable resource powered power generation system. The combination of both resources will shorten the gap among supply and load requirement in peak hours. This feasible stand-alone power generation system can supply power in remote areas even when the

conventional method of power distribution is chanceless. This study proposes a PV-wind combined stand-alone power generation system to supply power to the remote areas (Malla et al. 2022). This hybrid system is more effective and trustworthy in contradiction with individual functioning of those two resources. Because, one of the resources fails to produce power, another will be in action and balance the load demand. In addition with this, battery energy storage system present in this study takes part and performs discharging its energy when load demand at peak (Jegadeeswari et al. 2024). The PV array is sensitive to the problems namely shading, climatic change and faulty connection. Even though, the power generation of the solar panel is regulated and maintained at peak through the use of MPPT tracker (Ezhilarasi et al. 2018). The purpose of MPPT tracker is the tracking of peak power and produce large volume of power from PV array. Several research studies proposed multiple MPPT algorithms, but some of them fail to perform well as they face one of the major drawbacks such as oscillation around the operating point. To overcome this problem, Mostafa et al. proposed a sliding mode control (SMC) technique (Mostafa et al. 2020). The architecture of SMC contains a sliding surface, which fix the operating point. Another study, the dynamic response of the model is improved by the differential step Newton-Raphson algorithm that depends upon the improved Perturb and Observe method (IP&O) (Hosseini et al. 2013). Following this, Revathy et al. proposed ANFIS based MPPT algorithm to overcome nonlinearity in PV array concerning climatic change (Revathy et al. 2022).

There are plenty of wind power generators available in usage but choosing a generator that can modify its functionality as per the variable wind velocity and produce power is not an easy task. Muyeen at al. performed a comparative analysis on selection of variable speed wind turbine by choosing DFIG, WFSG, and PMSG (Muyeen et al. 2011). This analysis covered transient stability and low voltage ride through (LVRT) characteristics. Additionally, the dynamic characteristics are reviewed with the real-time wind velocity data collected from Hokkaido Island, Japan. Gaillard et al. recommended DFIG to perform power generation and harmonic current mitigation in the transmission system (Gaillard et al. 2009). To improvise the steadiness and standard of the conventional power system, Jadhav et al. proposed DFIG wind turbine and it has an advantage of operating under variable speed.

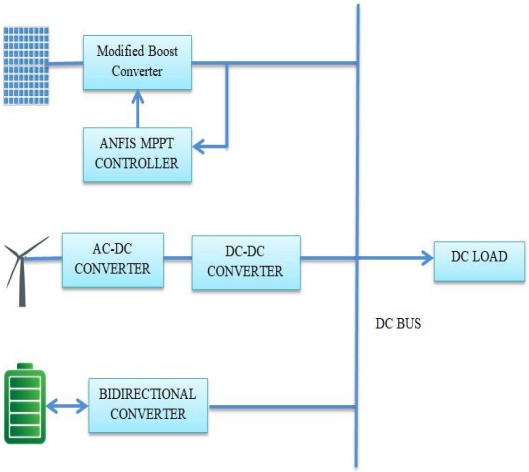


Figure 1. Proposed Block Diagram.

In this proposed study, a hybrid solar and WECS based stand-alone system is proposed. The PV array performance is boosted with the usage of ANFIS MPPT controller and for wind turbine, DFIG is recommended. The purpose of ANFIS controller is to attenuate the common problems faced by the traditional MPPT tracking algorithm. The DFIG Generator can operate at variable speed and produce desired amount of power without any interruptions. The proposed PID controller entirely controls the firing angle of DC-DC converter switches. In case any environmental factors affecting the power generation from those two resources is well managed with the battery bank kept within this transmission system. It stores the energy and the rest of it is transmitted to the load. By this way, the power flow is kept constant.

2. Related Works

Al-Quraan et al. (2021) proposed a stand-alone microgrid system made of solar panel and PMSG based WECS. The power generation of PV array is completely controlled by a Fuzzy logic based MPPT controlled boost converter. It extracts the available power on the solar panel. The rest of the energy after supplying the load is stored in a battery for future. Whenever the battery fails to fulfil the load requirement, the battery will drain its charge completely. Furthermore, the control logic circuit protects the battery when it undergoing operations namely normal, overcharging, and over discharging. Under normal operating condition, the controller acts as usual without considering the batteries state of charge (SOC). Once the SOC attains 80% it could cut-off both

resources and it will be connected only after the SOC is reached to 75%. Further, the SOC tends to be less than 20%, the inverter has to shut down and disconnect the load. Once the battery is charged, the inverter is switched on. Ayas Shaqour et al. (2020) mounted a hybrid standalone system in the roof top of Kasuga city, Japan. This technique implements P&O MPPT algorithm to control power generation of PV array and the PI controller employed in this study controls switching cycle of battery charger and inverter. When no load is connected, the battery charging mode is categorised into two stages to make the battery entirely charged. The experimental analysis showing that this study using an efficient battery charging control system regardless of specific battery converter, maximising voltage gain with Total Harmonic Distortion (THD) less than 1% in steady state and kept output voltage and frequency under charging system dynamics. Follow this, the research done by Ali et al. (2021) implemented P&O based MPPT algorithm and PMSG based wind turbine to produce higher output voltage without interruptions. The Sinusoidal pulse width modulation (SPWM) controls the firing angle of the inverter. This analysis maintained THD value at 0.94%.

Farhad Khosrojerdi et al. introduced ANFIS based MPPT controlled stand-alone PV system in conjunction with the Z source converter (2016). By comparing it with traditional approaches, this system reduces the complications and expenses of the control technique by the absence of PID controller. Instead of ANFIS controller, Shashank Pareek et al. (2021) proposed adaptive PID controller based on ANFIS MPPT to obtain peak voltage from the solar panel. The DC pump connected at load terminal's functions at maximum speed with difference irradiance conditions. Recently, the research conducted by Astitva Kumar et al. (2021) recommended that ANFIS MPPT controller as an alternative solution for PI Controller. It is compared with Incremental conductance method under climatic changes. The results showing that the percentage error, rise time, and voltage fluctuation has been enhanced. Other than PV array and MPPT algorithm, the voltage gain of the stand- alone PV system depends upon the DC converter incorporated with it and the control logic technique. For better outcome and satisfies the load demand, Fatema A. Mohammed et al. (2022) recommended an optimised PID controller. With this control scheme, the proposed Incremental Conductance (IC) MPPT can provide a promising result undoubtedly. In another study, Lata Gidwani (2015) compared performance of a pair of grid connected wind generators namely DFIG and PMSG. Those two resources are attached to the grid via traditional back-to-back converter and Unconventional power electronic interface (UPEI) in various conditions. This research addressed control system of the WECS with respect to pitch angle control, AC and DC voltage regulation, VAR regulation and current regulation of the converter. The perspective of this study is to reduce THD at different fault locations and buses. Later, Mohamed Metwally Mahmoud et al. (2022) compared DFIG with PMSG in terms of fault ride- through (FRT) capability and control of the DC link voltage.

3. Modelling of Renewable Resources

3.1 PV system

The VI characteristics of solar panel is written as

$$I_{pv} = I_{ph} - I_s \mathrm{e}^{\left(\frac{q\left(V_{pv}+R_s I_{pv}\right)}{nKT}-1\right)} - \frac{\left(V_{pv}+R_s I_{pv}\right)}{R_{sh}} \quad (1)$$

Whereas Iph denotes photocurrent, IS diode saturation current, q denotes electron charge, T denotes temperature in Kelvin, n denotes PN junction ideality factor, Rs and Rsh denotes intrinsic series and shunt resistance of the solar cell. The equivalent circuit of a solar cell is visualized in figure 2.

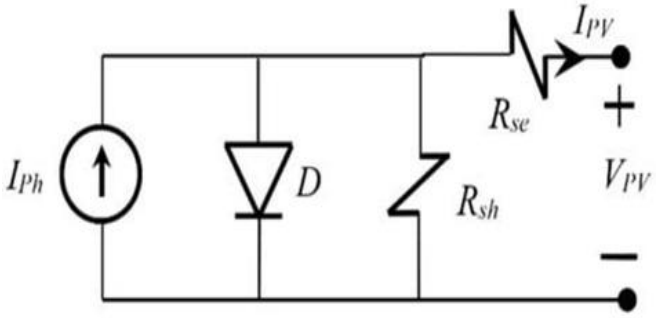


Figure 2. Schematic circuit of a PV cell.

The number of modules organised in series and parallel is 15 and 50. The relationship among VI and PV of solar panel is depicted in figure 3. It is evident that the peak power of the module is closer to open circuit voltage (VOC) of the module. The open circuit voltage (VOC) and short circuit current (ISC) is 50V and 5.96A.

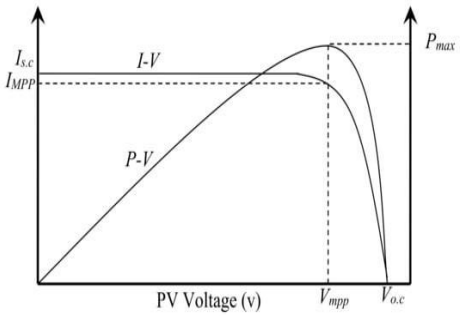


Fig.3.Characteristics of PV module.

3.2 ANFIS MPPT technique

In this study, ANFIS MPPT technique is employed to track the maximum power point (MPP) of the solar system under variable climatic conditions. The input variables are solar voltage, current, and temperature. The output variable is gate pulse that has been used to control the switching angle of modified boost converter to obtain high output voltage. The modelling of traditional fuzzy logic controller depends on the trial and error method which impacts the probability of obtaining optimal performance. Hence, the ANFIS technique is the combination of neural network with fuzzy logic inference. In order to perform this function, the trained data collection could be done initially. Following this, the steps used in this study to get trained data are:

- The model was developed under change in environmental condition and it employing traditional MPPT techniques.
- The collected data were manipulated utilising Matlab code that has been developed to obtain the desired data.
- Then it is shuffled; furthermore, they are filtered one more time to get only the distinctive rows in obtained data. At the end, 60% of the data were utilised for training and rest of the data were split into two equal halves among testing and checking data.

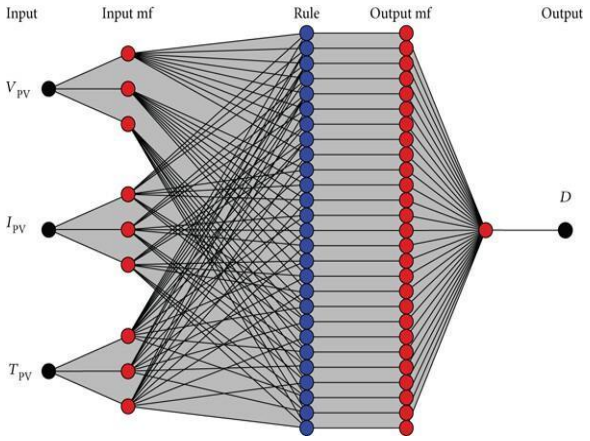
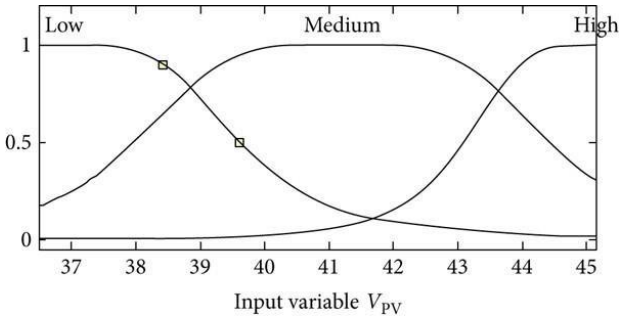
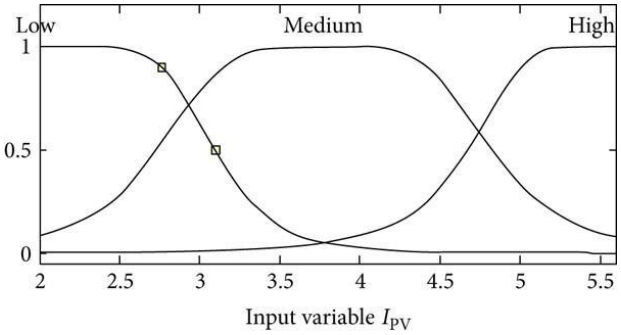


Figure 4. A schematic diagram of ANFIS technique.

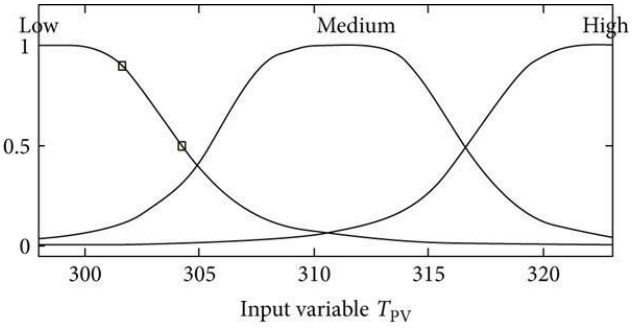
The figure 4 showing that ANFIS technique is designed of 5 layers network. The figure 5(a) shows the membership function of PV voltage produced by ANFIS. The figure 5(b) and 5(c) shows generated membership function of PV current and PV cell temperature. Inputs possess 3 membership functions such as low, medium, and high. The output is duty cycle and in contrast with sawtooth signal to produce gate pulse for the modified boost converter. The PV voltage ranges from 36.48V to 45.13V that is the area of the voltage at maximum power under variable irradiance. Likewise, the PV current ranges from 2A to 5.58A. Moreover, the PV temperature varies from 298K to 323K, respectively. It produces membership function as per the prior knowledge got from trained data; the shape of it differs during training and stage and final shape is obtained once the training has to be done, which is represented in figure 5.



(a) Voltage



(b) Current



(c) Temperature

Figure 5. Membership functions of PV array.

3.3 Modified Boost Converter

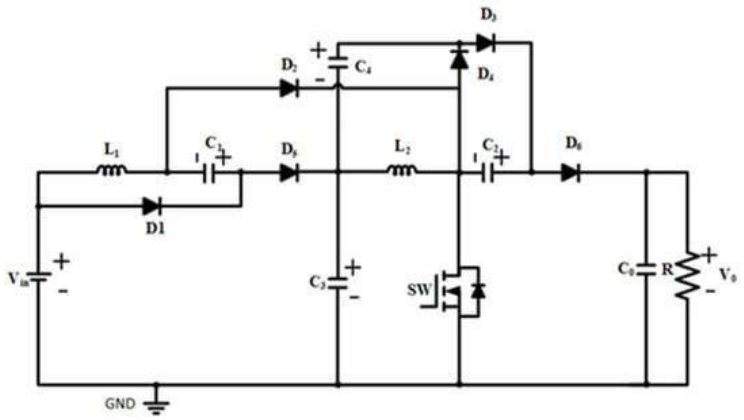


Figure 6. Modified Boost Converter (Jana et al. 2022).

It is designed with a pair of inductors, 5 capacitors, 6 diodes, and a MOSFET switch which is shown in figure 6. The initial voltage boost cell contains 4 components and they are L1, C1, D1, D2; the next integrated voltage boost cell contains 5 components namely L2, C2, C4, D3, and D4. To determine ideal voltage gain of this converter, the passive elements are kept lossless and ideal. While obtaining ideal voltage gain, diode forward voltage drop is not necessary, but in non-ideal voltage gain it is mandatory.

3.4 DFIG based WECS

Wind turbines functions as prime movers of electric generators that are attached to their shaft. As per their rotational directional it is categorised into horizontal axis and vertical axis wind turbine. Following this, based on their modes of operation it is further categorised into fixed and variable speed type. The features of the turbine and the type of WECS employed within it decide the functionality of the wind farm.

Wind turbine characteristics

The power produced from WECS with respect to turbine aerodynamic power coefficient (C_p), as stated below:

$$P = 0.5\rho_a A C_p v^3 \quad (2)$$

The term C_p is impacted by the pitch angle (β) and the tip-speed ratio (λ). A per turbine characteristics, C_p has been written as,

$$C_p = C_1\left(\frac{C_3}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-C_5}{\lambda_i}} + C_6\lambda \quad (3)$$

Whereas, C_1=0.5176, C_2= 116, C_3= 0.4, C_4=5, C_5=21, C_6=0.0068.

$$\lambda = \frac{\omega R}{V_\omega} \quad (4)$$

$$\frac{1}{\lambda_1} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \quad (5)$$

Whereas R denotes turbine radius in (m), V_w denotes wind velocity in (m/s), ω denotes turbine angular speed in (rad/s). The following figure 7 showing power characteristics of WECS with β=0 and difference in rotational speed.

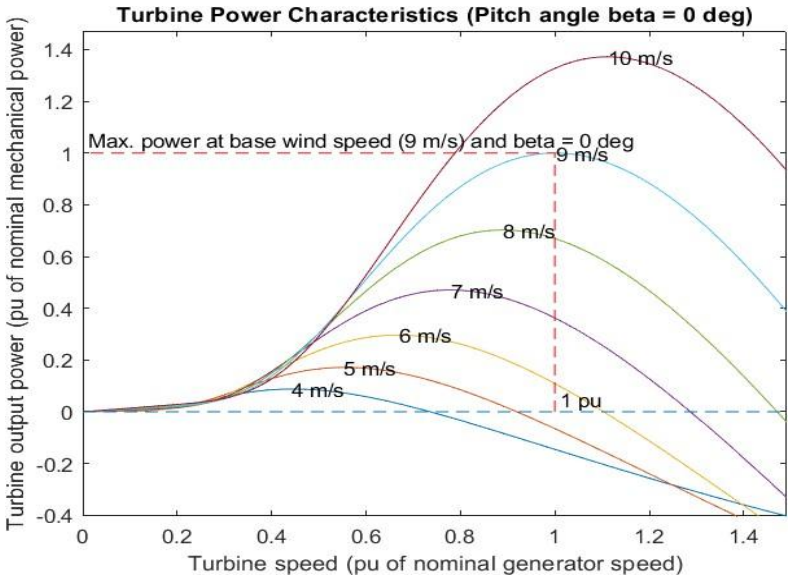


Figure 7. Power characteristics of WECS

The figure 8 represents the difference of C_p Vs λ with various value of β as defined by (2). The below graph showing the value of λ tends to be an appropriate value for variable wind velocity to function WECS with greater C_p value. It is accomplished by difference in wind velocity with selected generator where the motion of rotor is regulated as per the available wind velocity.

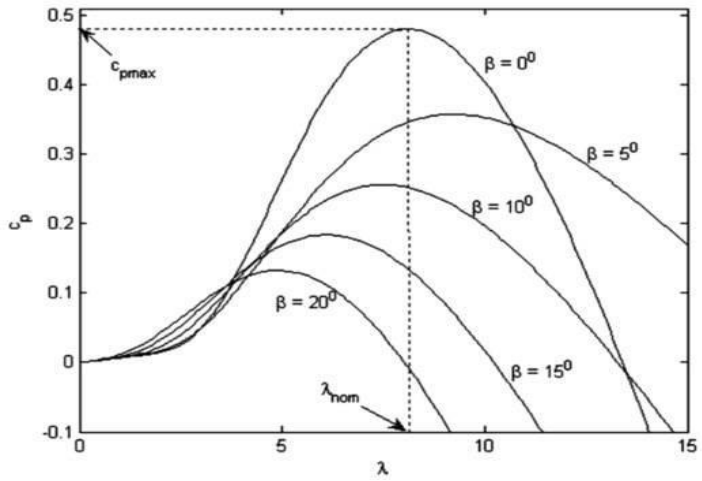


Figure 8. Variation of C_p Vs λ with various value of β.

3.5 Modelling of DFIG Based WECS

The stator winding is attached to the transmission line; a bidirectional converter supplies the rotor windings, permitting variable frequency operation in the rotor currents. This DC converter is designed with dual back-to-back IGBT bridges attached by a DC busbar. The turbine contains a blade pitch angle controller that regulates the rotation of the blades. Figure 9 Shows Schematic diagram of DFIG.

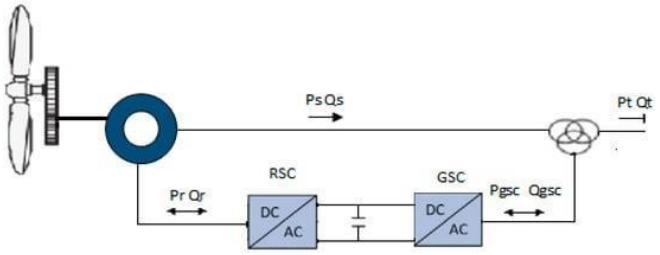


Figure 9. Schematic diagram of DFIG.

It is executed under a 5th order model describe its behaviour. The formulas are mentioned in a direct quadrature for the rotor and stator voltage co-ordinates, that contains the synchronous turning speed in the WECS. It has written as

$$U_{ds} = R_s i_{ds} \pm \frac{d}{dt} \varphi_{qs} - \omega \varphi \quad (6)$$

$$U_{qs} = R_s i_{qs} + \frac{d}{dt} \varphi_{ds} - \omega \varphi \quad (7)$$

$$U_{dr} = R_r i_{dr} \pm \frac{d}{dt} \varphi_{dr} - \omega \varphi_{qr} + \omega_r \varphi_{qr} \quad (8)$$

$$U_{qr} = R_r i_{qr} + \frac{d}{dt} \varphi_{qr} + \omega \varphi_{dr} - \omega_r \varphi_{dr} \quad (9)$$

whereas U denotes voltage, i-denotes current, φ denotes magnetic flux

3.6 WECS Fed DC-DC Converter

Figure 10 shows DC-DC Converter. The WECS fed DC chopper is designed with a pair of switches & inductor, 4 capacitors, and 4 inductors. The output AC voltage of wind turbine is turned into DC and it is improved and regulated using this DC-DC converter structure. The active and passive components were ideal in

their characteristics. Also the components functions with absence of any inherent loss or variation from their desired behaviour makes circuit analysis more tractable. This promises energy conversion and it is more effective, enhancing the performance and reliability of this circuit. At mode 1, both switches were turned ON and the diode D_3 was forward biased. When switch S1 is turned ON, it causes demagnetising of L1 with input voltage and C2 got charged. The capacitor C3 discharged through Diode, D3. Similarly, S2 turned ON and L2 got demagnetised. Correspondingly, the capacitor C4 discharged completely and delivered the voltage to the load terminal. In another mode, the switches are turned OFF and the inductor L1 charged Capacitor C1 through D1. Likewise, the capacitor C3 and C4 got energised by the inductor L1 and L2 through D2 and D4.

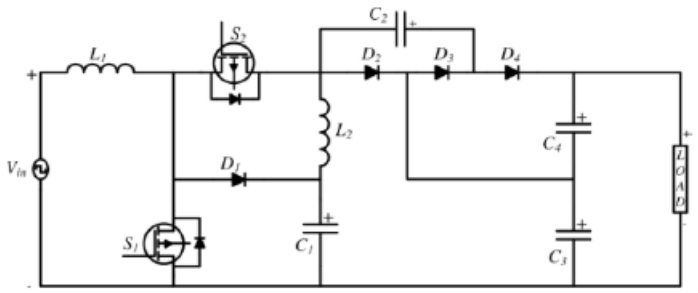


Figure 10. DC-DC Converter (Reddy et al. 2024).

4. Result & Discussion

The experimental analysis of the proposed stand-alone power generation system is developed using MATLAB software, after the designing of entire system parameters and control gains. The solar panel is designed to function at various temperatures. Under this condition, ANFIS MPPT tracker extracts peak power form the solar panel and the voltage gain measured at the end of PV with modified boost converter is said to be 437V which is represented in figure 11.

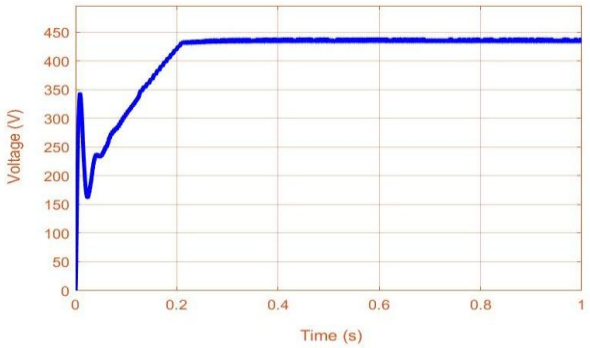


Figure 11. Voltage gain of ANFIS MPPT controlled PV array.

The maximum voltage gain of DFIG based WECS is depicted in figure 12. The generator speed and wind velocity is maintained at 51.02pu and 7.5m/s. At this point, the pitch angle tends to be zero. The rectifier present in it converted the voltage gain of wind turbine into DC and it achieves a DC voltage gain of 296V under variable wind velocity.

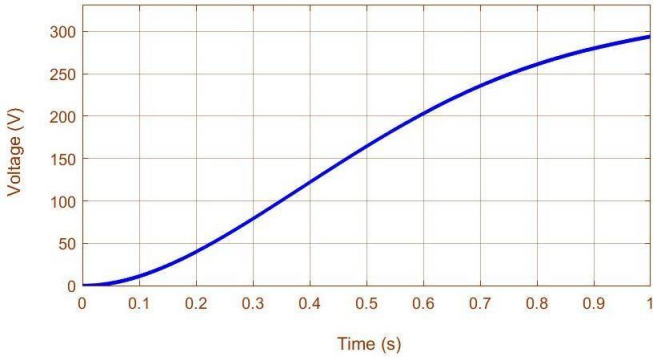


Figure 12. Voltage gain of DFIG based WECS.

From figure 13, it is describing that the SOC of the battery is quite constant when the charging current is positive. We can observe that 60% SOC battery voltage is around 300V, as SOC is kept at nominal value.

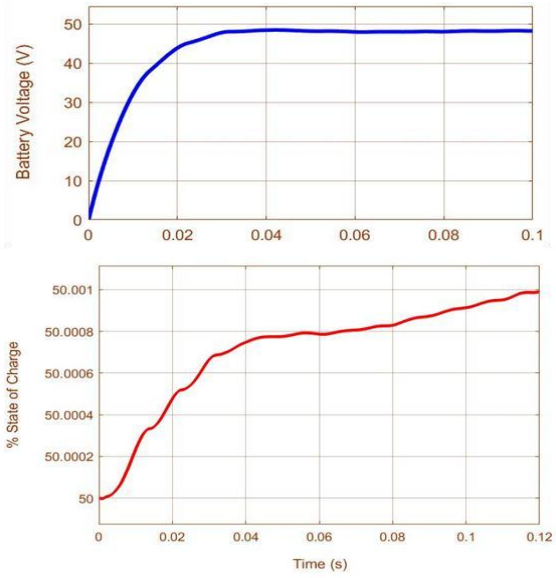


Figure 13. Characteristics of Battery.

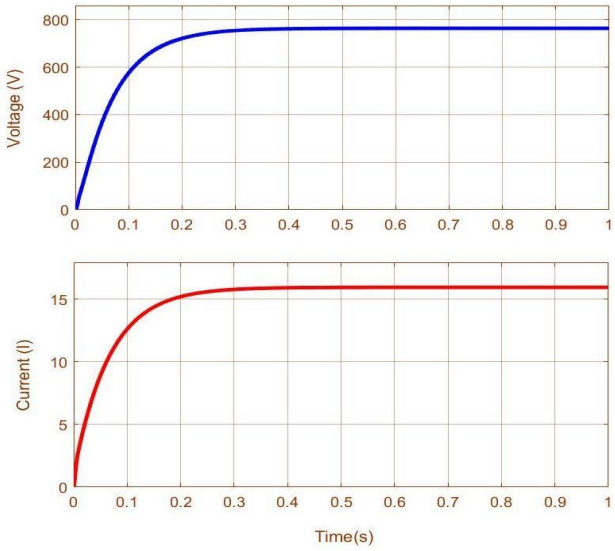


Figure 14. Voltage gain of Modified boost converter.

The figure 14 represents the DC bus voltage with some oscillations under difference in wind velocity and change in irradiance. The maximum voltage and current recorded at this point is 763.6V and 16A, respectively.

Researchers focused on issues such as energy management, differences observed on usage of various resources, the storage medium, and if the circuit is linked with the grid or not. Ghadimi et al. (2018) developed an energy management system using Artificial Neural Network to satisfy load requirement in future, WECS, and PV panel voltage. Utilising Multi-objective Particle Swarm Optimisation technique, the desired values were used for multi-objective optimisation of expense and release of harmful gas goals. The power flow between battery and the load terminal defined in this analysis resulting in cost saving and limiting harmful gas emission goals.

Talha et al. (2018) designed a PV power generation system to forecast the power crisis and charge the storage system employed flowchart method. This technique adjusts to the change in load requirement. The limited power point mode was utilised to compensate for the excessive power produced by the module because of installation oversizing. It is essential to consider the amount of power driven to the system before sizing the panel. If not, the 85% of storage system's capacity risk the lifetime of battery.

In our proposed study, we studies the power generation employing hybrid source and transmitting it to the load. In this study, battery bank is treated as an alternative source as if both the renewable resource were

failed to supply the load. Both the sources manage the load and supply power without any interruption. This proposed design ensures the life of battery and protecting it from changes in charging/discharging.

5. CONCLUSION

The experimental analysis of solar and DFIG fed WECS stand-alone system is validated in this study. To get high voltage gain from solar system, ANFIS based MPPT was implemented to control switching angle of the modified boost converter. Additionally the WECS generated maximum voltage even under variation in wind velocity. Both resources delivered continuous power to the battery storage system and it is completely controlled with the bidirectional converter. Any one of the resource fails to supply the required power, the battery will discharge its power and fulfil the demand. The controller employed with bidirectional converter prevents the battery from the risk of charging and discharging. The power generated from this system is adequate to supplying electricity to the remote areas where electric grid does not exist.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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A Comprehensive Fuel Management System for Ships Using AI and Web Integration

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Abstract: This study provides a fuel consumption prediction system that make use of deep learning models applied to usage of fuels of main engine in shipping vessels. The system aims to improve sustainability in marine logistics, save operating costs, and increase fuel economy. Real-time ship operating data comprising of shaft torque, rudder angle, engine RPM, speed over land, wind speed, draft conditions, wave height, and direction were utilized to create the dataset for training and evaluation. To predict the fuel usage, deep learning models, such as Convolutional Neural Networks (CNN), Gated Recurrent Units (GRU), Long Short- Term Memory (LSTM) and Artificial Neural Networks (ANN) were used. Based on performance evaluation of ANN model an R^2 score of 0.95 is achieved. This demonstrates high level of precision in fuel usage prediction. With an R^2 value of 0.85, the LSTM model performed admirably well but fell short of the ANN in terms of effectiveness. Similarly, GRU delivered a great performance with an R^2 value of 0.90, whereas CNN was less successful with an R^2 value of 0.80. The study created a web application that in-corporates fuel consumption prediction algorithms.

Keywords: Deep Learning, Fuel Consumption Prediction, Artificial Neural Networks, Maritime Operations, Sustainability, Ship Fuel Management

1. Introduction

Maritime transport handles nearly 90% of global trade, making it vital to the world economy. However, it contributes about 2.5% of global greenhouse gas (GHG) emissions, including CO_2, NO_x, and SO_x, significantly impacting climate change and air quality Deng and Mi (2023). With rising fuel costs and stricter regulations like the IMO 2020 Sulphur cap, enhancing fuel efficiency has become crucial. Traditional fuel monitoring methods are often inaccurate and lack integration of real-time operational and environmental data Mishra SS et. al. (2022). To overcome these limitations, the industry is adopting AI-driven solutions. Deep learning models include ANN, LSTM, GRU, and CNN are increasingly used for fuel consumption prediction, leveraging high-frequency data from onboard sensors for accurate, real-time analysis Wang S et. al (2023). The real-time web interface reduces the generated data into useful framework. (Figure 1) represents the overall workflow of this work.

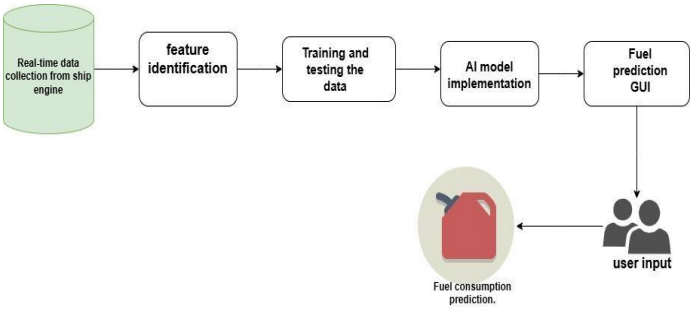


Figure 1. Workflow for an Integrated Fuel Management System

2. Literature review

This section presents a concise review of existing research on ship fuel consumption prediction. Researcher utilized various data obtained from a commercial vessel to estimate fuel consumption using a various machine learning and deep learning modules. The possibility of applying machine learning approaches to

actual operational data, fills up the gap found in earlier research and identifies areas for further investigation using advanced AI models Uyanık T et. al. (2022). For better results of prediction of performance parameters like ship speed and fuel consumption with addition to the ship operator's decision making under the changing environmental condition the data needs to get trained in the deep learning model Tarelko W and Rudzki K (2020). Methods like Back-Propagation Neural Network and Gaussian Process Regression techniques were used to train and predict the fuel consumption of a vessel considering the environmental condition like wind and wave current Hu Z et al. (2019). Implementation of Artificial Neural Networks were used to shows the CO_2 emissions for vessels such as tankers, bulk carriers, and container ships, improving traditional ship propulsion design approaches. and ship speed Cepowski T and Chorab P (2021). Using various machine learning models like Linear Regression (LR), Support Vector Regression (SVR) and Artificial Neural Network (ANN) are used to train the ship fuel consumption data collected using multi source sensors Zhu Y et.al (2021).

Machine learning models such as Multiple Linear Regression, Artificial Neural Networks Back-Propagation Neural Networks, and Gaussian Process Regression are increasingly being used to predict and model ship fuel use. Several limitations are visible, including a lack of usage of multisource and heterogeneous details, insufficient use of environmental elements such as wind, waves, and currents, and a failure to integrate prediction models with operational decision support systems. In addition, existing machine learning models used by researchers frequently lack scalability and flexibility to various vessel types and trip conditions. These shortcomings underscore the need for a comprehensive, flexible, and scalable AI-based system capable of predicting fuel and emission levels in real time across a wide range of operational circumstances. The current work predicts the fuel usage utilising the deep learning methods like Convolutional Neural Networks (CNN), Gated Recurrent Units (GRU), Long Short-Term Memory (LSTM) and Artificial Neural Networks (ANN). The real time ship operations data are used to give a realistic prediction of the fuel usage.

3. Methodology

The architecture in (Figure 2) represents the methodology to design the ship fuel consumption prediction model, which consists of six important phases, starting from data collection to model development. Each phase of model is discussed below

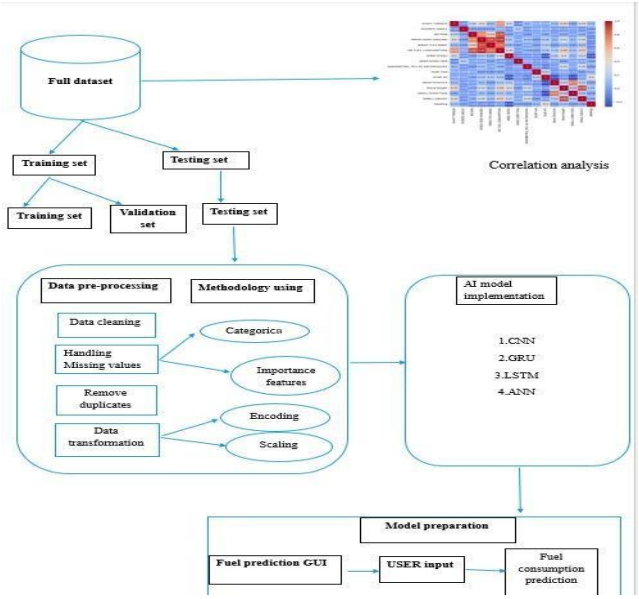


Figure 2. Methodology diagram for Fuel Management System

3.1. Dataset Description

This project uses real-time operational and environmental data collected from a commercial vessel. Key features include shaft torque, main engine RPM (ME RPM), speed, and fuel consumption, representing propulsion and energy usage. Environmental inputs like wind, waves, and swell conditions are also included. Additional parameters such as barometric Pressure, drafts, and heading provide a complete picture of ship dynamics. (Table 1) summarizes the dataset's diverse and multi-dimensional nature.

Table 1. Overview of Dataset

Dataset Name	Features	Instances	Target Variable
Ship Fuel Consumption Dataset	17	17,490	MEFuel Consumption

3.2 Data Preprocessing

Data preprocessing is essential to manage the data process by removing duplicate and unnecessary characteristics so as to reduce noise while improving model accuracy. Outliers were discovered and managed statistically to avoid biased learning. The majority of variables were numerical, therefore only little encoding was required; direction- based data was normalized using trigonometric encoding. These processes assured data integrity and increased the model's capacity to learn precise fuel use patterns.

3.3. Model Selection

The recommended approach utilized techniques such as Artificial Neural Networks, Long Short-Term Memory networks, Gated Recurrent Units, and Convolutional Neural Networks.

3.3.1 Convolutional Neural Networks (CNN)

Convolutional Neural Networks were implemented to autonomously identify geographic trends and extract local features from time-series data. Their use here captures localized interactions among input variables throughout time, boosting prediction accuracy.

3.3.2 Gated Recurrent Units (GRU)

Gated Recurrent Units were used to effectively process serial input. They include temporal relationships in operational and environmental ship data and are operationally simpler than LSTMs, making them suited for real- time forecasting.

3.3.3 *Long Short-Term Memory (LSTM)*

Long Short-Term Memory networks were used for modelling long-term temporal dependencies and nonlinear patterns in ship fuel usage. Their memory cell layout allows the model to retain important prior knowledge, which is critical for detecting time-dependent trends in marine operations.

3.3.4. Artificial Neural Networks (ANN)

ANNs were employed as a baseline model for comparison. They consist of interconnected layers of neurons and are effective for modelling complex relationships in high-dimensional data. ANNs helped establish foundational performance and benchmarked the improvements offered by sequence-based models like LSTM and GRU.

3.4. Training and Validation

An 80/20 dataset split was used, with 80% for training and 20% for testing the fuel consumption prediction models. The models learned relationships between ship operational parameters and fuel usage. Testing on unseen data ensured unbiased evaluation and improved model generalization for real-time maritime deployment.

3.5. Real-Time Monitoring System

A user-friendly web application was developed to deploy the trained fuel consumption models for practical use by ship operators and saving fuel and energy emission Das S et. al(2020). It allows input of parameters like speed, draft, and wind, providing instant fuel consumption estimates. The app visualizes trends, detects anomalies, and supports efficient, IMO-compliant voyage planning.

4. Result and discussion

Here, this project provides a detail of the density distribution of all essential features for model development. This graphical representation in (Figure 3 & Figure 4) and (Table 2) for result analysis sheds light on concentration of variable, providing valuable insights into the dataset's characteristics.

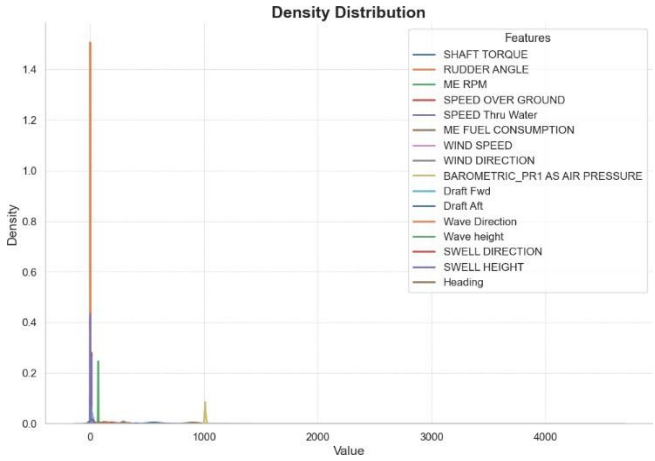


Figure 3. Shows the Density Distribution Plot

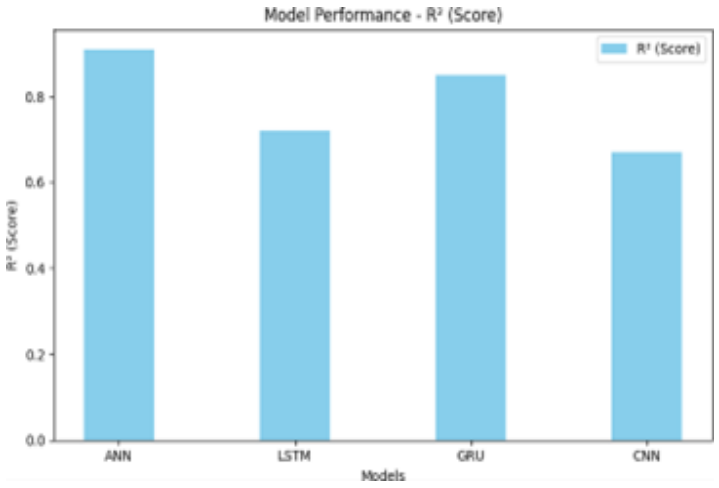
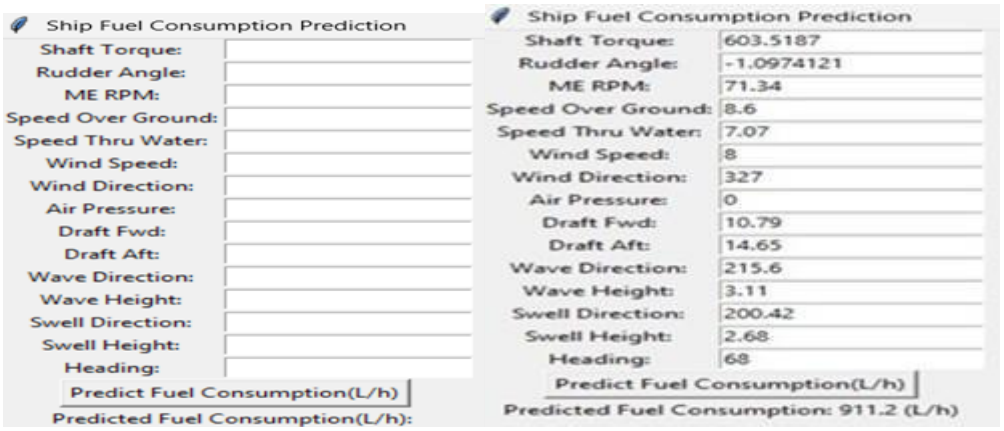


Figure 4. Model Accuracy Comparison Plot

Table 2. Analysis AI Model Evaluation Matrices

AI Model	Precision	Recall	F1 score	Accuracy
CNN	0.89	0.86	0.87	0.80
ANN	**0.91**	**0.89**	**0.90**	**0.95**
LSTM	0.98	0.97	0.97	0.85
GRU	0.94	0.92	0.93	0.90

The outcomes of user interface were examined with the created Graphic User Interface (GUI). (Figure 5(a) and (b)) represent the user interface of the fuel management system.



(a) (b)

Figure5 :-(a) and (b)user interface of the Fuel management

5. Conclusion

This paper successfully demonstrated the application of deep learning techniques ANN, LSTM, GRU, and CNN for predicting fuel usage based on the real time data. Through comprehensive evaluation using metrics such as MAE, MSE, RMSE, and R^2, it was evident that each model exhibited varying strengths in capturing fuel usage trends. Among the tested architectures, delivered the most accurate and stable performance, highlighting its capacity for modelling temporal relationships in time series data. These insights are valuable for energy analysts and stakeholders in anticipating fuel price movements and optimizing resource planning. Future work could integrate external features such as geopolitical data, crude oil trends, or inflation indices to further enhance predictive power.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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AI-powered Approach to Maritime Pirate Attack Detection

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Abstract: The continuous surveillance of maritime vessels across oceanic regions, assisted by technologies such as AIS, satellite-based tracking, and radar systems, has enabled real-time monitoring of vessel movements. However, these traditional systems cannot often immediately detect unusual behaviour or a probable pirate attack. They primarily focus on tracking vessel movements. This paper presents an AI-based pirate attack detection system that uses the YOLOv11 model to improve maritime security. It uses a real-time methodology to detect possible dangers such as unauthorized boats, human behavior, and the presence of weapons. The YOLOv11 model was trained on a carefully selected dataset. This dataset comprises a wide range of environmental conditions, and maritime operations to ensure high model performance cross achieving precision is 95.5%, Confidence 0.04threshold and recall is 92.8% indicating strong reliability in object classification. The trained model has proved to be a dependable real-time vessel identification and threat warning system. To minimize pirate assaults and other maritime hazards, the system conveniently integrates with the existing monitoring infrastructure, boosting situational awareness and allowing for fast response measures. This method sets a new idea for real-time maritime risk recognition by giving a powerful and effective solution for avoiding pirate attacks and protecting vessels

Keywords: Pirate avoidance, Maritime security, Maritime safety, real-time threat identification, Autonomous surveillance systems.

1. Introduction

Maritime piracy has long been a growing and growing danger to worldwide trade and the global economy. Despite significant advances in maritime security, connection marine inspections and the implementation of international rules such as the International Ship and Port Facility Security (ISPS) Code, piracy continues to interrupt commercial shipping operations. With pirate activity resulting in vessel hijacking, crew kidnapping, and the loss of important cargo. These crimes not only risk people's lives but also create huge amounts of money and delays in operations. The open and wide character of the ocean, mixed with the prohibited reach of in control governments, making it challenging to monitor and protect all ships at sea. Traditional maritime surveillance techniques, including the Automatic Identification System radar systems and satellite tracking, are frequently used for vessel tracking and collision avoidance. Teši´j, et al. (2020). While these innovations are useful for navigational safety, they can't evaluate human behaviour or detect situations with significant risks in real-time. Pirates frequently use small, fast-moving boats that may not broadcast AIS signals and might operate surreptitiously thus, there is an increasing demand for innovative systems that go beyond standard tracking to identify and prevent potential risks proactively. Illiashenko O, et al. (2023). The unexpected nature of pirate attacks interests the development of advanced surveillance systems capable of evaluating visual data and detecting suspicious patterns of conduct. The fast development of AI and computer vision technologies, particularly in the field of real-time object identification, has created opportunities to improve marine situational awareness and reaction capabilities, to implement this idea to real time we are using the Models such as YOLO (You Only Look Once) have demonstrated remarkable performance in identifying and classifying objects in various environments with minimal latency. Applying such technology to maritime contexts allows for automated recognition of activities, including unauthorized boat approaches, weapon displays, or panic behaviour among crew members. The real-time system processes AIS data and piracy indicators to provide immediate threat detection and alerts for maritime safety, (Figure 1) shows the workflow diagram for the project.

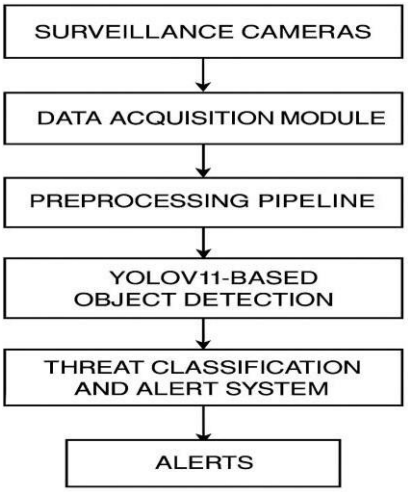


Figure 1. Show the workflow diagram for the project

2. Literature Review

Piracy trend analysis using spatial autocorrelation tools the study utilized data from the National Geospatial Intelligence Agency and employed statistic to identify piracy hotspots in Africa Whitney Akhahenda W et. al.(2024). Analysis of maritime security and risk assessments focusing on AIS-based anomaly detection techniques and collision risk evaluation. The study highlights the effectiveness of AIS data, Marko Perković et. al.(2024) Vessel trajectory data mining techniques were comprehensively reviewed focusing on maritime application ,While the study offers a structured overview of existing methods, it does not explore the integration of advanced AI and machine learning for improved predictive analytics and anomaly detection Troupiotis- Kapeliaris A et. al. (2025) .Priority branches for ship detection in optical remote sensing images utilizing CNNs architecture with a DLA-34 backbone and deformable convolutions. The approach introduced enhanced HRSC2016 dataset, which improved detection accuracy and efficiency were Zhang Y et. al. (2020) .ABO ships, a dataset for inshore and offshore maritime vessel detection datasets. This study created a custom dataset considering diverse conditions like weather ,object detection models (Faster R-CNN, R-FCN, SSD, and Efficient were evaluated, B et. al.(2021) .Machine learning-enhanced maritime security for predicting piracy attacks in high-risk waters was offering a predictive tool for proactive threat mitigation. The study employed supervised machine learning techniques, including Random Forests and LSTM networks, Gradient Boosting machines to predict piracy attacks based on vessel tracking data. Ogboada G et. al. (2024).

The finds of this research are to enhance maritime security and risk assessment by addressing the gaps identified in existing studies. Various studies have highlighted the importance of advanced data analysis techniques for maritime piracy detection and risk evaluation. One study focused on spatial autocorrelation tools for identifying piracy hotspots in Africa but noted the lack of predictive AI models that could improve risk assessment accuracy. Similarly, other research emphasized the effectiveness of AIS-based techniques for trajectory analysis, anomaly detection, and collision risk evaluation but pointed out that AIS spoofing and data gaps undermine the reliability of these techniques. Another study reviewed vessel trajectory data mining, noting that while existing methods like forecasting, clustering, and activity recognition are crucial for real-time vessel tracking, they lack integration with AI and machine learning to enhance predictive analytics and anomaly detection. A different approach introduced an advanced dual-branch CNN architecture for ship detection in optical remote sensing images, achieving high detection accuracy, but lacked exploration of real-time data applications to further enhance the system's robustness. Additionally, the ABO ships dataset was introduced to address the shortage of maritime vessel detection data, but the research highlighted that real-time data integration remains a critical gap in model generalization. Furthermore, another study employed machine learning techniques like Random Forests and LSTM networks for piracy prediction, yet emphasized the need for live video feeds to improve AI model performance in operational environments. The collective findings from these studies point toward a crucial gap in real-time data integration and the use of advanced AI techniques to improve the accuracy, reliability, and generalization of maritime security and piracy prediction

systems. This paper proposes a comprehensive solution to bridge these gaps by incorporating real-time data streams, advanced AI, and machine learning models to enhance predictive capabilities in maritime threat detection and risk assessment.

3. Methodology

The architecture in (Figure 2), represents the methodology to design the model, which consists of the most six important phases, starting from data collection to model representations. Each of the phases of the proposed model is discussed in the listed subsection.

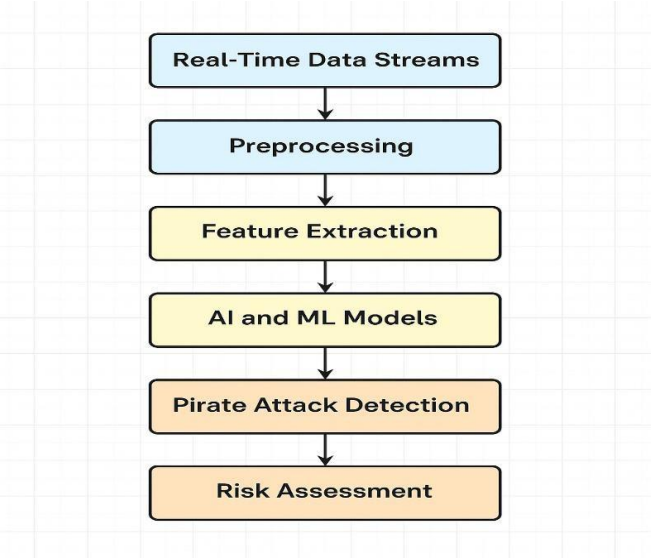


Figure 2. Proposed Architecture for Maritime Pirate Attack Detection

3.1 Data Collection

The data phase for this project collects real-time piracy attack data from Robo flow, which has around 6000 data points. Historical piracy impact data and real-time vessel data are also included in it. The dataset covers significant factors such as piracy boat, aircraft carrier, bulkers, car carrier, container ship, recreational, sailboat, submarine, and tug.

3.2 Data Preprocessing

The data preprocessing and data handling is the takes the most important part of this research provides the quality and usefulness to build the Perfect AI model to predict the piracy attacking , these preparation phases provide the robust and applicable dataset that can be utilized for training models with high accuracy.

3.3 Model Selection

At the points of model selection stage, this study focuses on the YOLOv11 model for piracy detection. YOLOv11 was chosen for its outstanding detection objects identification and fast response time, This AI model ability to develop the structures and detect imperfections with high accuracy helps us to get our goal of real- time pirate detection while also improving the system's reliability in marine security operations.

3.4 Model Training

The YOLOv11 is trained with 80% of the real-time piracy data collected from the Roboflow dataset, and the rest 20% is for validation and testing. After testing, check how well the model is working effectively in some key configurations in the YOLOv11 model, with higher detection accuracy and model efficiency. This shows that training and testing are working effectively. Sahoo S, et al. (2024).

3.5 Deployment and Real-Time Prediction

This framework enables real-time monitoring of pirate detection. When a potential pirate risk is discovered, this technology quickly transmits notifications of the vessel through the system for response and shows the real- time activity happening through the camera, in that camera . Lan D, et al. (2024).

4. Result & discussion

YOLOv11A real-time pirate predictive system for averting potential dangers in marine environments.

The model was trained on 6000 real time piracy data from Robo flow dataset Samonte M J C et al. (2024). The detection results of the system are shown in (Figure 3),which shows that the model effectively detect the suspicious boats which is represented in the precision graph in (Figure 4).



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Figure 3. Show the real time Pirate Attack Detection

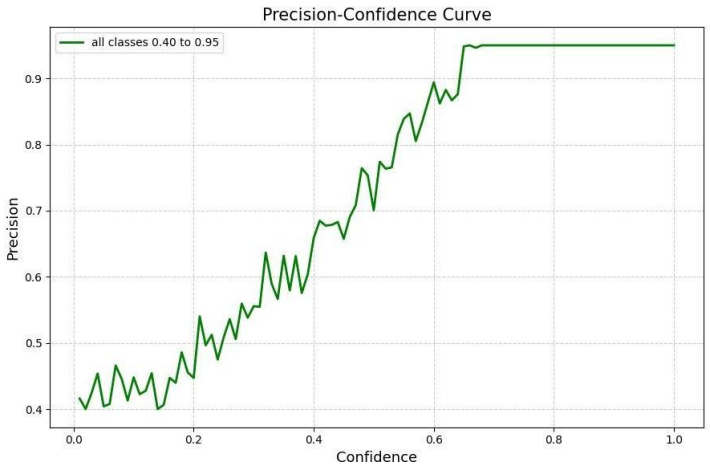


Figure 4. Representation of the precision-confidence curve of the model

The Precision-Confidence Curve in (Figure 4) shows how the model's precision varies with different confidence thresholds. The precision is high around 95% at a greater range of confidence. The graph shows more confidence and better precision. This realistic curve indicates balanced detection validating the model's generalization capability.

5. Conclusion & Future Scope

This paper presents a full pirate prediction system which can take advantage of the real-time vessel information and the advanced AI techniques, particularly the YOLOv11 model, for enhancing security in the maritime environment. A technology which integrates piracy attack data, It is an accurate, real-time approach and scales well for pirate prevention in all vessel types and destinations in the world. this research's future scope includes the addition of new data sources, such as satellite imagery and enhanced environmental sensors, to improve threat detection. Furthermore, the system might benefit from predictive analytics for proactive threat assessment and anomaly identification. To improve accuracy, employ multimodal sensors like radar or infrared. The development of a user-friendly interface for real-time threat monitoring, as well as regular model upgrades with new pirate data, will guarantee that the system remains effective in combating emerging piracy strategies, contributing to long-term marine safety.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
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Social Aspects of Digitalization in the Maritime Industry

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Abstract: The maritime industry, as a critical component of the global trade and logistics, undergoes a profound transformation driven by technological advances, changing social challenges and increasing pressure for sustainability. The technological innovations (blockchain, IoT, AI, automation) transform maritime and logistics operations, making the industry a critical part of the global digital economy. In light of the increasing technological pressure, this publication explores the multifaceted social consequences of the technological innovations in the maritime industry. As a result of in-depth interviews and subsequent factor analyses, contemporary social challenges in the maritime industry are identified: the change of traditional roles, job rotation and, most importantly, the need for systematic, continuous and planned training, qualification and reskilling. The main conclusions from the conducted empirical research highlight the growing social inequalities between developed and emerging markets and ports, as well as the importance of regulatory frameworks for the social and ethical development of the maritime industry. The publication concludes by offering applicable recommendations to support stakeholders towards a sustainable, social maritime future.

Keywords: Digitalization; Maritime industry; Innovation; Sustainability; Workforce ransformation

1. Introduction

The maritime industry undergoes a profound transformation driven by rapid advances in digitalization. Increasing competitiveness and improving energy efficiency are goals that motivate the maritime sector to accelerate its transition to digitalization and automation. Resource management and innovation play a central role in this process. (UNCTAD 2018). The new environmental conditions require adequate restructuring of maritime organizations, assessment of human resource qualifications, analysis and design of tasks and responsibilities, introduction and adaptation to new management methods, strategies and business models (Narlev 2022).

The main function of the maritime sector is the efficient global movement of goods and materials. To streamline these processes, the industry has developed and implemented a number of innovative technologies for port operations and logistics. Autonomous ships and unmanned surface vehicles equipped with algorithms, sensors and remote control systems controlled by artificial intelligence are technological examples with minimal human intervention and high technological input (Conev, Koritarov 2024). The introduction and sustainable operation of these innovations are associated with multifaceted social challenges in the field of employment and professions (Bourhriba 2024).

Digitalization and automation in the maritime sector lead to the transformation of traditional professions, the creation of new ones, job rotation and job polarization (Scientific Foresight Unit 2021). Studies in the sector show that the share of employment in high- and low-skilled maritime professions increases, while that in medium-skilled professions decreases. If they fail to reskill, many medium-skilled human resources in the maritime industry may be forced to take up lower-skilled and lower-paid jobs, while the low-skilled may face the risk of losing their jobs (OECD 2019). This job polarization will deepen in the future in the absence of adequate and effective socio-technological transition policies, including appropriate opportunities for acquiring new knowledge, skills and abilities.

Reskilling and upskilling of human resources in the maritime sector can help in the transition from one profession to another or in the process of adaptation to new work and management requirements in the context of digitalization. The main challenge is the ease of transition from old to new jobs and new functions. As this challenge is closely linked to other current and important trends - globalization, climate change, demographic changes and deepening inequality - if not designed, planned, supported, and effectively managed, digitalization may fail to realize its key role in the development of the maritime sector (International Labour Organization 2021).

Another challenge is the uneven implementation of digital technologies across maritime organisations and countries. Maritime companies that are early adopters and leaders in implementing modern, sophisticated digital technologies are better placed to withstand the pressure of globalisation and competition. The key players in the future maritime business will be those that rely on human resources capable of using existing technologies, adopting new ones and creating new ones (EUROPEAN COMMISSION 2020). Shortages and gaps in the knowledge, skills and capabilities of human resources in the maritime sector are assessed as threats to digitalisation, predetermining to a very high degree the uneven distribution of the benefits and contributions of technologies in the modern maritime world (OECD 2024).

Digitalization of the maritime industry is not only a technological but also a social problem, closely related to human capital. Maritime organizations implement digital technologies to meet the challenges of the fourth industrial revolution (Atanasova 2023). However, the social aspects that facilitate the transition to the new era are often overlooked. In a knowledge-based economy, where value is generated mainly from intangible assets, digital transformation depends and will depend as much on technology as on people (Tabrizi et al. 2019). Having into consideration the indicated arguments and perspectives, the aim of this publication is to explore the multifaceted social challenges and consequences of digitalization in the maritime industry of the Republic of Bulgaria in order to offer recommendations for the development of its sustainable social contribution and support.

2. Methodology of the study

The object of the study are managers of 40 shipping companies in the maritime industry of the Republic of Bulgaria. The pilot study is in the form of in-depth interviews and covers the period 2020 - 2025. The survey items are pre-structured and include multiple research aspects contributing to the research object and subject such as: challenges, opportunities and threats of digitalization; inequality, integration and efficiency of technological processes, as well as their role in human resource management in the maritime business.

The statistical software product XLSTAT 2024 is used to identify and analyze dependencies between the factors of interest. This product has been chosen on the basis of its objective capabilities for appropriate analyses that contribute to a good understanding of the role of digitalization and its relationship with human resources in the modern maritime world.

The main limitations of the empirical study are mostly related to its object. The maritime industry includes a number of counterparties – shipping companies, ports, logistics operators and many others, which design the digital transformation with different rate, management methods and efficiency. Stakeholders also identify various deterrents, risks and opportunities for a successful socio-technological transition. This fact, as well as a more global context of the problem, will be the subject of future research studies on the topic.

3. Results from the study

The impacts of digitalization on maritime organizations have numerous benefits, as well as a number of social challenges and concerns, also related to legal implications and ethical considerations. In just a few decades, the integration and use of new digital technologies have been a significant challenge facing companies in the maritime business of the Republic of Bulgaria. The largest number of managers in the sector (70%) believe that digitalization has already changed the business significantly with its “radical” role, while 20% of respondents report a change, but not its fundamental significance. 10% of the surveyed managers believe that the topic of digitalization in the maritime business is overrated (Figure 1).

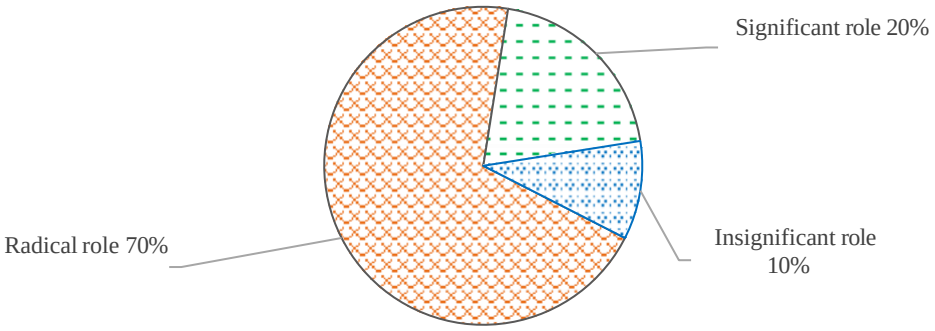


Figure 1. Role of digitalization for the maritime industry

Despite the undeniable role of digitalization in the development of the maritime sector, as found in the study, shipping companies face a number of barriers (Figure 2). The main obstacles to the digital transformation are internal and external organizational factors such as: investment costs (80%), legal and regulatory frameworks (72%), change in traditional roles and responsibilities (40%), ethical and cultural standards (10%), and leadership style (8%).

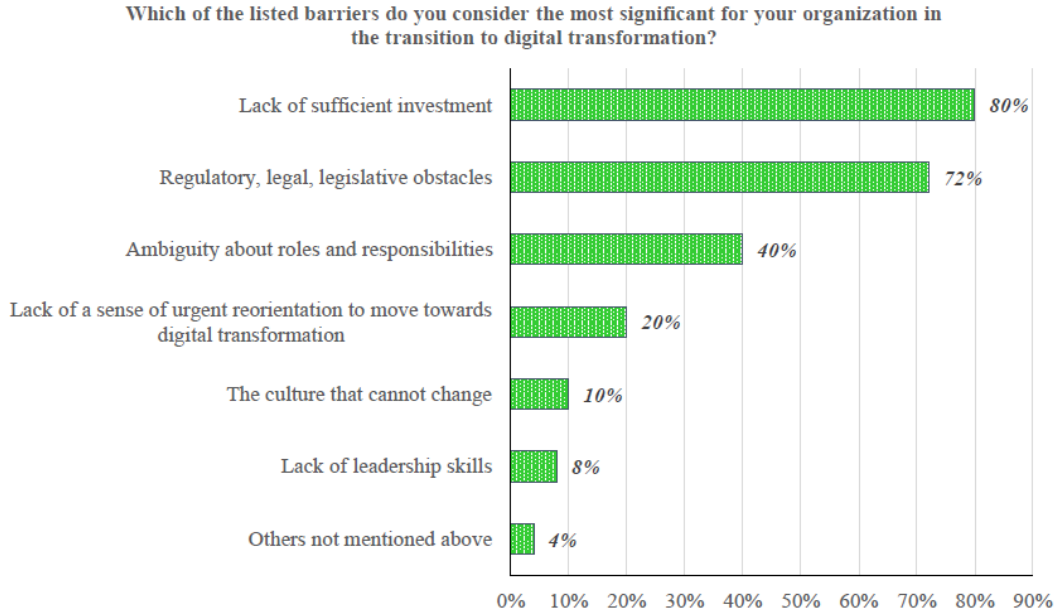


Figure 2. Barriers to digitalization in the maritime industry

A wide range of organizations in the maritime sector are forced to direct financial investments towards the digitalization of processes. During the conducted interviews, it was found that over 60% of the respondents identified the costs of implementing (introducing) digital technologies as the most significant. These high costs are associated with risks to the return on investment for 7% of the managers of the companies surveyed.

The legal aspects are another key issue considered by the maritime sector managers – the rapid development of digitalization outpaces regulatory frameworks. In this regard, a current challenge for 35% of the surveyed managers continues to be the creation of a regulatory framework that protects the rights and ensures a responsible attitude towards human resources. More than half of the respondents believe that the pressure of regulatory requirements on the maritime industry increases over time. It is faced with stricter requirements for achieving a sustainable environment, imposed by the International Maritime Organization (IMO), European Union (EU), United Nations Conference on Trade and Development (UNCTAD), International Labour Organization (ILO), International Association of Ports and Harbors (IAPH), International Council on Clean Transportation (ICCT), World Bank and other organizations. According to 25% of the respondents, further investments, innovative technologies, as well as technical cooperation of the participating organizations are needed to comply with the regulations.

The ethical impacts and considerations of digitalization in maritime companies come next. According to 40% of the managers it is very important to ensure that new digital technologies are built and implemented in a way that respects the privacy rights of people in the organization and maintains transparency and accountability. According to 20% of the surveyed managers, unpredicted consequences, such as deepening prejudice, increasing inequality or creating new ethical issues, need to be carefully considered and addressed proactively.

In relation to the new professions, roles and responsibilities resulting from digitalization, 85% of the respondents demand vital measures and strategies of education and training of human resources with a systematic and continuous nature and expected effect. The lack of training in the sector would lead to subsequent barriers and difficulties, such as:

- skills shortages and difficulties in implementing digitalization processes (20%);
- difficulty in recruiting and selecting human resources against the background of the low and decreasing attractiveness of many positions in the sector (35%);
- technological changes will stimulate employment dynamics, in which traditional maritime jobs will be replaced by higher added value onshore positions (65%);
- there is a risk that changing skills needs will harm employment, leaving some maritime organizations without mentors and trainers (15%).

The survey explores respondents' views on maritime education and training systems (Figure 3). Most managers believe that current systems are able to adapt to the digital transformation of the maritime industry and meet the needs (90%). Furthermore, 80% of the respondents identify the importance of lifelong learning as crucial for maritime jobs to respond to the technological development.

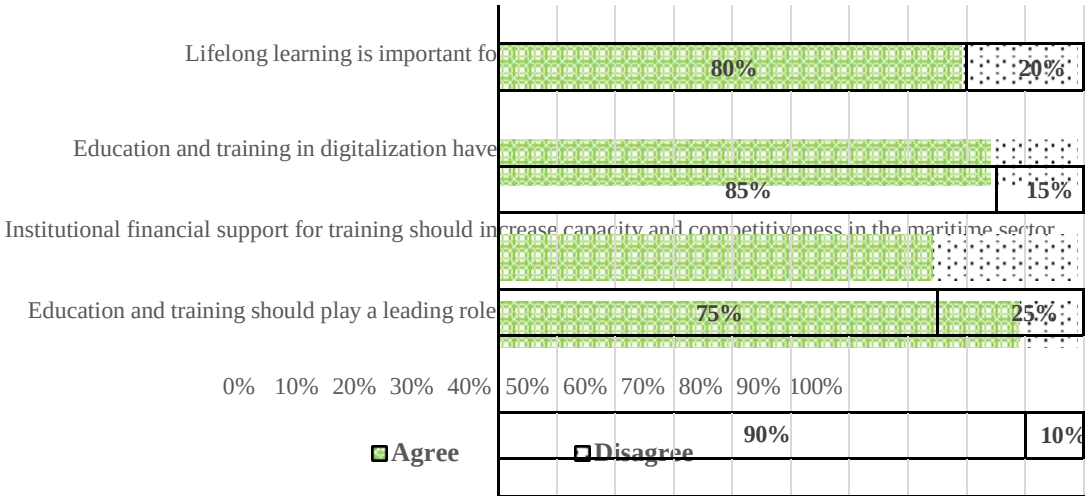


Figure 3. Challenges facing education and digitalization in the maritime industry

In-depth interviews show that resources are an important factor in the decision to provide training and qualification opportunities in the maritime industry. Most often, training in the country is financed by the company itself. Blue sector managers (75%) insist on public support for funding continuous training of human resources, including acquisition of new digital technologies. Such an approach would increase the capacity of maritime companies and enhance their competitiveness.

According to 85% of the managers in the sector, training is the way to overcome the problems related to the uneven implementation of digital technologies across maritime organizations and countries. The lack of adequate training programs, according to half of the managers, will lead to increasing unevenness in the future, a noticeable lack of digital skills and a qualified workforce. These interrelated problems are expected to deepen in the future, as the emergence of new technologies requires even more digital skills and technological knowledge.

Empirical research proves that the future shape of the maritime sector will depend largely on the effectiveness of the applied digital technologies, which are, however, characterized by unevenness. The new maritime industry 4.0 will require a change in the organization and management of maritime companies, as well as in the skills and qualities of human resources. Cooperation between universities and the maritime sector

(through investment in knowledge, new learning and training hubs, creative and educational projects) is important for the successful implementation and development of technologies in the maritime industry.

4. Conclusion

Digitalization is both a social and technological process, closely related to the modern maritime industry. This process requires a high degree of managerial and institutional commitment. In order to develop sustainably and overcome inequalities in the sector, there must be an appropriate legal, regulatory, ethical and political framework at national and supranational levels, comprising all stakeholders. Planned, systematic investments in the development and improvement of human resources for the purposes of digitalization are also required.

The study reveals that managerial interest is focused on training and qualification, the possible loss of traditional jobs and the creation of new ones. As a result of the study, it is concluded that regulatory aspects and norms that protect the rights, as well as the social and ethical attitude towards human resources, should be taken into account when implementing innovative technologies in the maritime sector.

In summary of the theoretical framework derived and the empirical studies conducted, the following are some guidelines for supporting the digitalization process and sustainable future in the maritime sector of the Republic of Bulgaria:

- investments in education, training, qualification and reskilling of human resources, thereby supporting the continuous digital transformation and overcoming gaps in the knowledge, skills and abilities;
- institutional support for improving digital transformation processes in order to overcome discrepancies between organizations, markets and regions;
- encouraging collaboration between industries, thereby facilitating the maximum implementation of digitalization and the principles of sustainability in the maritime sector;
- promotion of standardization, compliance with regulatory and legal frameworks towards a smooth and sustainable transition to digitalization of the maritime industry.

At the stage of our social and technological maritime development, digitalization is a continuous and increasingly rapidly developing organizational and institutional process. The collaboration between human resources and artificial intelligence as a tool for increasing efficiency and safety in the maritime sector will pose new challenges, opportunities and prospects for the development of digitalization in the future.

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The 25th IAMUC

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Proceedings of the
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Faculty and Students' Feedback on the use of Online Platform and Its Impact on the Academic Performance in Collision Regulation

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Abstract: The COVID-19 pandemic resulted in extensive school closures, necessitating a transition to online learning. This change aligned with e-learning theory, which draws from cognitive science and Connectivism, emphasizing technology's role in enhancing education. In response to school closures due to pandemic, JBLFMU adopted JeL (JBLFMU E-Learning), an online platform, to deliver maritime education, including the Collision Regulation course. This study examined faculty and student feedback on JeL during the first semester of 2021–2022, using surveys and a One Group Pretest-Posttest design. Participants included three instructors and 165 first-year BSMT students. Analysis methods included thematic analysis, t-tests, and effect size calculations. Results showed that instructors considered JeL effective, and students found teaching methods appropriate, though some reported occasional technical issues. Most students demonstrated strong retention of the Collision Regulation topics. The study concluded that JeL was effective for online delivery of Collision Regulation, as shown by a significant improvement in posttest scores. It is recommended that JeL should continue to be used, with technical enhancements to improve performance.

Keywords: online learning; academic performance; Collision Regulation; survey; one group pretest-posttest

1. Introduction

The pandemic has caused school closures worldwide. Globally, more than a billion learners are not in school. As a result, education has changed dramatically, with the proliferation of e-learning that takes place remotely on digital platforms and with the essential need for the online method of learning (Li & Lalani, 2020). The E-learning theory is built on cognitive science principles that demonstrate how the design and use of educational technology, including the use of internet facilities, can enhance effective learning (David, 2015). A set of principles derived from Cognitive Load Theory served as the foundation for the theory's development. (Sweller et al., 2019). E-learning theory is a component of the overarching theory of Connectivism, since it highlights the utilization and design of technology and internet resources to generate novel learning opportunities and enhance successful learning. (He et al., 2021). This study was aligned to the previously mentioned theory.

The toll of the COVID- 19 pandemic pushed John B. Lacson Foundation Maritime University (JBLFMU) to use internet facilities and online platforms which will not require students to undergo classes face-to-face for their safety and health. The use of the principles of E-learning became a tool to deliver maritime education via online. JBLFMU further developed its own online platform which became a tool for maritime education known as JBLFMU E-Learning (JeL) and wanted to improve the modalities that are used for the higher education of students in spite of the pandemic.

One of the courses in the Marine Transportation program of John B. Lacson Foundation Maritime University - Arevalo is Collision Regulation. After completing the course, the learners must exhibit in-depth knowledge and comprehension of the purpose, application, and content of the amended 1972 International Regulations for Preventing Collisions at Sea. The university has adapted to the needs of the existing situation where flexible learning is seen as a solution to continuous learning despite the effects of the COVID19 pandemic and continued offering courses like Collision Regulation to students. This study focused on how JeL as a learning platform can greatly help students in the Collision Regulation course. And to determine the results and effects of the

online learning platform in a maritime course such as Collision Regulation, this research was conducted. This study aimed to determine the feedback from instructors and students on the use of JeL and the academic performance in Collision Regulation course, concepts learned, and pretest-posttest mean score performance in the first semester for the school year 2021-2022.

2. Methods

The research designs for this study were One Group Pretest-Posttest and Survey. In quantitative research, Survey Research Design is a process whereby researchers administer a survey to a sample or the entire population in order to characterize the attitudes, beliefs, actions, or characteristics of that population. In this method, using questionnaires or interviews, the researcher gathers quantitative, numerical data, which is then statistically analyzed to identify patterns in the responses to the questions and to evaluate research questions or hypotheses (Tanny, 2018). Survey was used because feedbacks from faculty and students regarding the use of JeL will be determined. Additionally, students' feedback includes the use of JeL, teaching delivery, teaching assessment, and concepts learned.

Meanwhile, a commonly employed quasi-experimental research technique is the One Group Pretest-Posttest design, in which one group of participants takes a pretest, has an independent variable manipulated, and then takes a posttest. If the pretest and posttest scores differ significantly, then the difference may be attributed to the independent variable, but if the research design is not a true experimental design and there is no control group, this inference is uncertain, and the difference may be due to extraneous variables such as order effects or regression towards the mean (Colman, 2015). One Group Pretest–Posttest verified the student's academic performance in Collision Regulation in the university's learning platform, JeL in this time of pandemic. The distribution of respondents and participants is shown in Table 1.

Table 1. Distribution of Respondents and Participants

Category	f	%	N	n
A. Instructors (Teaching Collision Regulation)	3	100	-	-
B. First Year BSMT students (taking Collision Regulation)	-	-	345	236
Section A	22	100	-	-
Section B	24	100	-	-
Section C	18	100	-	-
Section D	21	100	-	-
Section E	31	100	-	-
Section F	10	90	-	-
C. Pilot-testing	41	100	-	-
D. One Section (One Group Pretest-Posttest)	39	98	-	-

Note. f stands for frequency, N for total population while n is the sample size.

3. Instruments

The faculty feedback survey form and the students' feedback survey form were used as instruments in the study. The open-ended questionnaire for students was utilized to gather feedback on the use of JeL, teaching delivery, teaching assessment, and concepts learned in Collision Regulation. The open-ended questionnaire for faculty was used to collect feedback on the use of JeL. These were validated by three faculty who have proficiency in research and grammar.

When content validation was complete, the test in Collision Regulation was issued to 40 students who are officially enrolled in Collision Regulation this first semester, school year 2021-2022 through online for reliability-testing. The students were provided with two hours to accomplish the test. The result was, then, recorded in Excel and was submitted to the statistician for reliability testing. The Kuder-Richardson (KR) 20

reliability index obtained was 0.91. To measure the students' academic performance, this reliability-tested questionnaire was used for the pretest-posttest. It was comprised of a 60-item multiple-choice type of questionnaire.

4. Data Collection

The academic performance of students in Collision Regulation was measured with the use of pretest and posttest. Using the reliability-tested questionnaire, the pretest was administered and retrieved to the student participants taking Collision Regulation at the beginning of the midterm using JeL as the online learning platform. JeL was also used as an intervention for eight weeks. On the fourth week of midterm, a feedback survey was sent to the student respondents via JeL. Their individual feedback was recorded, tallied, and processed using Microsoft Excel. Also, the Collision Regulation instructors' feedback on the use of JeL were gathered on the fourth week of midterm through Google Forms. At the end of the half of final term coverage, a posttest was conducted to measure the academic performance of students. This was done on the eighth week. The pretest and posttest scores were submitted to the statistician for statistical analyses after being tallied in Excel.

5. Data Analysis

Both qualitative and quantitative techniques were used in the conduct of this study. Qualitative analysis technique employed thematic analysis. It was used to synthesize the feedback of the participants. In addition, percentage, rank, and frequency were also applied for the feedback of faculty and students. Percentage measures the number of feedback per hundred while rank was used to organize the highest to lowest frequency. Frequency was used to ascertain the number of times the feedback showed. Meanwhile, mean, t-test of dependent samples set at .05 level of significance, standard deviation, and Cohen's d effect size were utilized as statistical tools for the intervention. Standard deviation calculated the spread of the responses that were obtained in the students' pretest and posttest results. To ascertain whether there was a significant difference between the students' pretest and posttest mean score performances at the.05 level of significance, the dependent samples t-test was employed. The efficacy of JeL learning modality in relation to students' performance in Collision Regulation was assessed using Cohen's d effect size. The students' mean performance scores on the pretest and posttest were calculated using the mean. Table 2 displays the descriptive rating, mean scale, and indications for analyzing the mean scores on the pretest and posttest.

Table 2. Mean Scale, Descriptive Rating, & Indicators for Interpreting the Pretest & Posttest Mean Scores

Mean Scale	Descriptive Rating	Indicators
48.04 – 60.0	Excellent	Students have mastered all the competencies
36.03 – 48.03	Very Good	Students have mastered most of the competencies
24.02 – 36.02	Good	Students have mastered at the average competencies
12.01 – 24.01	Fair	Students have mastered few competencies
1.0 – 12.0	Poor	Students have mastered very few competencies

6. Results and Discussion

Feedback submission is optional and respects participants' privacy by using the Informed Consent Form (ICF) and Privacy Notice Form (PNF). The number of participants in the final sample who participated in the one group pretest/posttest was 39 out of 40 first year BSMT students of JBLFMU-Arevalo during the first semester of school year 2021-2022. All three instructors teaching Collision Regulation submitted feedback on the use of JEL and 126 students gave feedback on their experience with JEL as the new university online learning platform.

6.1 Feedback of Faculty on the Use of JeL Good online platform

The university's online learning platform served as a medium to cater the educational needs of both teachers and students. Instructor 1 said that JeL has many features and options which is an advantage. According to Instructor 2, Accessibility in any gadgets is an advantage. Having many options is also good for teachers. Instructor 3 commended JeL and said it is helpful in remotely delivering lessons in this time of Pandemic.

6.2 Feedback of Students on the Use of JeL

Table 3 shows the summary of feedback from students on the use of Jel.

Table 3. Summary of Feedback from Students on the Use of JeL

Feedback (in themes)	f	%	Rank
1. Server/System Problem	67	30	1
2. Good Online platform	51	24	2
3. Technical Feature Issues	50	23	3
4. Unorganized	40	18	4
5. Internet Connectivity Problems	12	5	5

6.3 Feedback of Students on Teaching Delivery

Table 4 shows summary of feedback from students on teaching delivery.

Table 4. Summary of Feedback from Students on Teaching Delivery

Feedback (in themes)	f	%	Rank
1. Good Class Delivery	90	48	1
2. Effective	35	19	2
3. Below Satisfactory	21	11	3
4. Engaging	18	10	4
5. Organized	16	9	5
6. Internet Connection Disturbances	7	3	6

6.4 Feedback of Students on the Teaching Assessment

Table 5 shows the summary of feedback from students on teaching assessment.

Table 5. Summary of Feedback from Students on the Teaching Assessment

Feedback (in themes)	f	%	Rank
1. Appropriate	80	64	1
2. Technical Problems	13	11	2
3. Below Satisfactory	12	10	3
4. Related to the Course	8	7	4
5. Unorganized	6	5	5
6. Internet Problems	4	3	6

6.5 Concepts Learned by Students in Collision Regulation

Table 6 shows the summary of concepts learned by the students in Collision Regulation.

Table 6. Summary of Concepts Learned by Students in Collision Regulation

Concepts Learned (by Lesson)	f	%	Rank
1. All COLREG Rules Discussed	34	40	1
2. Part C-Lights and Shapes (Rules 20-31)	26	30	2
3. Part B-Steering and Sailing Rules Section 11-Conduct of Vessels in Sight of One Another (Rules 11-18)	14	16	3
4. Part B-Steering and Sailing Rules Section III - Conduct of Vessels in Restricted Visibility (Rule 19)	12	14	4

6.6 Academic Performance of Students in Collision Regulation

Table 7 shows the pretest and posttest mean score performances of students in Collision Regulation.

Table 7. Pretest and Posttest Mean Score Performances of the First Year BSMT Students taking Collision Regulation

Test	n	Mean	Descriptive Rating	SD
Pretest	39	29.74	Good	10.88
Posttest	39	55.05	Excellent	4.23

7. Conclusions

The university's latest online learning platform, JeL, was considered a good platform by the three instructors

teaching the said course. On the other hand, despite considering JeL as a good online learning platform, the students also cited that they occasionally experience server or system problems with the said platform. In terms of teaching delivery, the students find their instructor's teaching methods generally good and effective. The teaching assessments for Collision Regulation using JeL were considered appropriate based on the feedback of the students. Majority of the students had remembered topics about all the Collision Regulation rules that have been discussed during the coverage of the whole midterm and half of the finals period (Rules 11-31). From the results and discussion, this study concludes that after using Jel as an online learning platform, the students' performance was "Excellent" based on the difference of the pretest posttest mean score performances. JeL has proven to be effective in managing lessons in Collision Regulation. However, there is no comparison or control group, several factors that could have an impact on the students' academic performance were not considered.

Recommendations

Based on the outcomes of this study, the following recommendations were made:

1. Since some students still have problems regarding internet connection, the university may consider other choices in delivering distance learning.
2. Due to occasional server or system errors with JeL, the university may exert more effort, time and budget to fix these errors that interrupt the platform usage of the students.
3. The technical features of JeL may also be improved so that teachers can have individual and separate controls over their course, quizzes, and activities that may help organize the set-up of the courses in the platform. Upgrading the storage capacity of the platform may also improve the user experience of the students and it would ease the hassle they encounter when submitting output online.
4. The institution may carry out refresher training to instructors to improve and enhance their teaching methods, specifically when delivering online classes.
5. Conduct a follow-up study with a comparison or control group when face to face classes resume after the pandemic.
6. Additionally, a follow-up study may be carried out to authenticate the results of this research.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Arctic Navigation- Digital Voyage Planning & Management

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Abstract: Driven by the effects of climate change and declining sea ice, the Arctic is witnessing a significant rise in maritime traffic which creates risks to Arctic coastal communities and ecosystems. International scientific bodies identify Indigenous Knowledge (IK) as a good approach to ecological diversity and management that demands sustainable practices.

Given the navigational complexities of high latitude navigation in conducting Arctic ship traffic routing; ecosystem-based management (EBM) in close collaboration with IK and digital route planning may lead to enhanced decision-making capability for mariners and stakeholders.

The exponential rise in maritime traffic due to industrialization across the Arctic region needs to be sustainably managed and regulated because maritime transport bears a positive correlation to economic activities in a region. Integrating co-produced knowledge and coastal community perspectives into the future digital route optimization model (D-ROM) for the Bering Strait region will facilitate the development of a framework that balances environmental, societal, economic, and cultural aspects, thereby fostering sustainable ecosystems and resilient coastal communities. The ice navigator needs the waypoints when confronted with sea ice and all the challenges of high latitude navigation in a remote location with little infrastructure and communication. The D-ROM output is a set of waypoints depicting the 'least cost' path for the vessel to traverse (Pandey, 2016). The waypoints are a set of geographical coordinates plotted instantly either on the ECDIS or the nautical paper charts for voyage planning purposes while the vessel is underway. While the mariner on board may be the biggest beneficiary of the integrated EBM, other stakeholders such as ship operators, port authorities, insurance companies, ice breakers, search, and rescue (SAR) organizations may benefit from the information provided (Pandey, 2016). The D-ROM is a good first step towards risk mitigation and decision making in ice. It is, however, not intended to replace the judgment of the shipmaster and may function as an enhanced decision-making tool for risk management in a desolate region fraught with dangers (Pandey, 2016)

Keywords: Arctic, navigation, sustainability, ecosystem-based management, digital

1. Introduction

The continued decline in Arctic sea-ice exacerbated by anthropogenic activities in the region is enhancing accessibility for industrial operations and related transportation needs (NASA, 2025). Oil & gas exploration, mining of minerals, commercial fishing and leisure activities such as tourism impact the Arctic marine ecology and the natural surroundings of marine species. Marine life depends on and thrives in their natural surroundings for survival and is inextricably linked with the rich cultural heritage of the Indigenous people who revere nature that provides a source of sustenance in a tundra region covered with permafrost. The transforming Arctic region presents both an opportunity and a challenge for maritime transport in a region that remained frozen for millennia. Sea-ice retreat, thinning down of the summer and winter ice cover is opening navigable shipping corridors in several regions of the vast yet confined Arctic Ocean.

The exponential rise in maritime traffic volumes witnessed on the Northern Sea Route (NSR) in general and the Bering Strait in particular is testament to the close correlation between industrial activity and maritime transport which is demand driven. Research conducted by intergovernmental bodies such as the Arctic Council show that such activities can impact the quality of marine habitats and the fitness of species that depend on those habitats for survival, as well as the rich cultural heritage of the Arctic region (PAME1, 2024). The Arctic Council comprises of the eight Arctic states and six permanent

participants who represent Indigenous peoples. Consensus among the member states is how decisions within the Council are taken by, rather than by majority rule or binding resolutions (Arctic Council, 2025).

The threat from climate change and rising human activities (such as industrialization and transportation) necessitates ecosystem-based management and spatial planning of ocean areas to safeguard human subsistence, marine biodiversity, and conservation efforts in the Arctic (EPA, 2025)

Route planning for ships to avoid marine protected areas (ecologically & biologically sensitive) is thus essential in the ice infested Bering Strait, a narrow stretch of water connecting the Pacific and the Arctic Ocean and thus of immense significance to ship navigation and trans-Arctic maritime trade. Besides reducing intercontinental sailing distances (by 35%-40%) compared to sub-Arctic routes (PNAS, 2023), the Arctic is rich in minerals and energy reserves which require intra Arctic as well as destinational (primarily involves shipping goods to and from Arctic coastal nations) maritime traffic. Sea-ice that used to act as a barrier to economic development and maritime transport in the past is receding with longer navigation season and an exponential increase in maritime trade and traffic (USCMTS, 2019). Arctic waters will pose an existential threat to shipping even in 'open water' regimes (<10% ice coverage as defined under the Polar Code) due to risk of contact damage by isolated ice pieces (bergy bits) that may be difficult to forecast accurately coupled with mariner complacency and fatigue imposed by rigors of high latitude navigation.

An integrated ecosystem-based management approach necessitates that development activities, including transportation, be coordinated to minimize their environmental impact (both oceanic and atmospheric) and incorporate considerations across environmental, socioeconomic, political, and sectoral domains (NOAA- EBM,2024).Maritime transport activities that are essential to support industrial development elsewhere in the vast Arctic region introduce an element of risk to the pristine Arctic ecology through ocean & atmospheric pollution. Ship sourced oil (cargo or bunker) pollution, sewage or garbage discharges and even untreated water ballast may induce invasive species detrimental to marine ecology that require regulatory mechanism and oversight. Black carbon (soot) emitted by fossil fuel driven ships adds another dimension to accelerated ice melt due to the ice-albedo effect besides greenhouse gases (mainly carbon and methane) in the region that is warming up much faster (thrice or four times) as much as the sub-arctic (IPCC2, AR63, 2023)

The management of anthropogenic activities in the transforming Arctic needs to focus on realistic, practical steps directed towards reducing environmental damage, protecting biodiversity, and promoting the health and prosperity of Indigenous coastal communities, the permanent residents of the region.

Recognizing that resilience for this region requires local knowledge of the longtime inhabitants, the Indigenous peoples Knowledge (IK) in planning and policy as climate change continues to transform the ice infested Bering Strait into a high-density ship traffic zone. It will put coastal communities in Alaska and the Northern Bering Strait Area at greater risk as they rely on the ecosystem for food security and protective cultural practices. Indigenous Knowledge Systems (IKS) refer to the comprehensive set of knowledge, practices, and beliefs that Indigenous peoples have cultivated through their interactions with the natural world over centuries. "Traditional knowledge" is not what is understood but also includes ongoing development and adaptation of knowledge within Indigenous communities (Kawerak, 2024).

2. Related works

Coastal communities in Alaska have voiced their worries about how environmental changes are affecting their livelihoods and overall well-being (Kawerak, 2024). In one study on climate change impacts, public hearings held across Alaska showed that rural communities had concerns about erosion, flooding, loss of permafrost, and subsistence (impacts on fish and game) (Alaska Climate Impact Assessment Commission 2008). Changes in the timing of the ice season impacts the frequency and timing of hunting activities, with implications for food security and nutritional health among communities that rely significantly on subsistence (Furgal and Seguin 2006).

"The complex, interconnected and trans-boundary nature of these drivers of change and pressures on the Arctic marine environment, including its peoples, requires collaborative international response" (MPA, 2015). ("Framework for a Pan-Arctic Network of Marine Protected Areas")

"Of particular concern from a marine biodiversity perspective are the climate-related trends of diminishing sea ice resulting in habitat loss; melting permafrost and glaciers and reduced snow cover resulting in changes in ocean chemistry; releases of methane; increasing sea surface temperatures; and increased coastal erosion of some shorelines" (MPA, 2015).

The distribution of many species of flora and fauna is shifting or expanding northwards as the Arctic continues to warm (CAFF 2013). The introduction of non-native species, often transported in untreated ballast water, is becoming more likely with the rise in Arctic shipping activity and could significantly disrupt the region's natural environment.

In addition, the increasing concentration of atmospheric carbon dioxide and absorption by the ocean is leading to acidification of ocean waters and may impact many groups of organisms such as plankton, shellfish, deep sea corals, fish (including larval stages of fish), and marine mammals, therefore altering the composition of the Arctic ecosystem (Yamamoto-Kawai et al 2009).

"Areas of heightened ecological and cultural significance" have also been identified by Arctic States within their EEZs [4] (AMAP/CAFF/SDWG, 2013). Regions recognized for their increased ecological and cultural importance based on the International Maritime Organization (IMO) criteria for Particularly Sensitive Sea Areas (PSSA). The criteria for designating PSSA's include ecological, socio-cultural, economic, scientific, and educational (IMO-PSSA, 2025). There are 17 IMO designated PSSA's (NOAA-PSSA, 2025) but none in the Arctic.

The term stems from Recommendation IIC of the Arctic Council's 2009 Arctic Marine Shipping Assessment (AMSA): "That the Arctic states should identify areas of heightened ecological and cultural significance in light of changing climate conditions and increasing multiple marine use and, where appropriate, should encourage implementation of measures to protect these areas from the impacts of Arctic marine shipping, in coordination with all stakeholders and consistent with international law." ("ARCTIS | Arctic Marine Shipping Assessment (AMSA)") (PAME 2009).

IMO's MARPOL (International Convention for the Prevention of Pollution) Convention categorizes the Antarctic region (south of 60°S parallel) as a Special area thereby meaning stricter discharge criteria for pollutants such as Oil (Annex I), Noxious liquid substances (Annex II) and ship-sourced garbage (Annex V).

The restrictions imposed by IMO's pollution convention in the ecologically sensitive Arctic Ocean, which is more populated and economically active (due to industrial and maritime activities) compared to the Antarctic, are less stringent, particularly regarding the use of heavy fuel oil by ships. Equitable application of the Polar Code, UNCLOS[5], SOLAS[6] & MARPOL among other IMO conventions in both Polar regions may rectify these aberrations as far as ship transport is concerned.

Like Antarctic waters, Canada, as an Arctic Council member and a littoral state provides examples of approaches to protection measures in the Canadian Arctic. The Arctic Council has considered a Framework for a pan-Arctic Network of Marine Protected Areas since 2015 to protect and restore marine biodiversity, ecosystem function, and preserve cultural heritage and subsistence resources (PAME.IS). IMO approved routing measures (2018) and the park like initiative program shared by Russia and the U.S. (1991) in the Bering Strait are examples of IMO initiated and regional regulatory mechanisms that complement vessel traffic safety and environmental protection.

The ease of access by ships in a fragile ecological geographical region with limited maritime assets and infrastructure (modern hydrography, charting, buoyage systems, repair yards, ports et al) must be managed to protect the local communities, and the commercial shipping industry. Optimized voyage planning and strategic navigation can be conducted through spatial and temporal planning (integrated EBM) to avoid areas of conflict on the ocean as mentioned in the methodology section of this paper. Digital ship route planning with sea ice thickness data and MPA avoidance techniques may unleash the power of technology to enhance decision making and conduct sustainable shipping in the Bering Strait.

Spatial Analysis and maritime route network modelling in GIS require the selection of proper GIS software suite among a host of commercial and open-source software available in the market. (Pandey,2016)

The US National Ice Centre moved towards a GIS production (GRASS software) environment for ice charts in 1996 and subsequently opted for ESRI's 'ArcInfo' suite in the late 1990's (Fequet et al., 2009). The Canadian Ice Service adopted the ArcGIS suite for ice analysis in 2006 (Pandey, 2016). The SIGRID-3 files used by CIS have coastline features derived from the DCW7 data sets originally created by ESRI in 1993 (Fequet et al., 2009). The US National Snow and Ice Data Centre make use of various GIS software suites including ESRI's ArcGIS in their product offerings. ESRI's ArcGIS software is the most popular among researchers and national ice centres in North America and elsewhere. Having reviewed the available literature and the elements needed for route modelling; the study finds ESRI's ArcGIS commercial software to be the platform most convenient to try the model (Pandey, 2016).

3. Methodology

The author has conceptualized a method of conducting integrated EBM using Geographical Information Systems (GIS) by creating digital layers of MPA's that ships may avoid or sail at a safe distance while in navigable waters that suits their draft, disposition and ice classification. It involves creating a Safe Navigation Zone (SNZ) layer in GIS that takes care of several attributes including but not limited to the following: depth in relation to ship's draft, marine protected areas in the region, charted navigational dangers, ship's ice classification, ship type and size. The GIS output is a digital SNZ (route safety module in *exhibit 1*) that will be integrated with the proposed Route Economy Module. The economy module attributes include sea ice data available from US National Ice center

(USNIC), Alaska sea ice program (ASIP) among others in a digital format. A least cost path analysis (multiple iterations) is carried out using ice impedance and ship advance calculations in various ice regimes based upon the data input for the area.

The model developed is explicitly spatial and temporal in nature to ease its use in voyage planning and route optimization analysis that include sea ice data in a digital format (SIGRID[8] 3). Atmospheric weather data may also be added to create distinct layers in GIS in addition to MPA's. The model has used the latest concepts in the calculation of ice regime from the AIRSS [9] method as well as the POLARIS [10] concept wherever applicable. The proposed model is digital in scope and application and relies on a digital database of historical sea-ice, current data and electronic navigational charts (ENC) of the ocean area (Pandey, 2016).

An MPA[11] refers broadly to distinct types of designated conservation zones within the Arctic marine eco- system and defined as "A clearly defined geographical space recognized, resolute, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values." (IUCN/[12]WCPA 2024). The draft Polar Code as adopted on 21 November 2014 (IMO- Draft Polar Code, 2014) stipulates additional guidance (Part I-B) in the form of limitations for operating in ice. Shipping companies and other maritime stakeholders have long felt the need to have a link between the ice classification of the vessel and the various ice regimes it may be working during the year (Pandey, 2016). An IMO constituted technical group led by the IACS has proposed a Risk Indexing System (POLARIS, 2014) with a goal to develop a decision-making system that can be used for voyage planning or in 'real-time' navigation from the ship's bridge. The risk assessment philosophy for 'real-time' navigation implies actual ice conditions by visual observation, ice class, and operational mode (independent operation or icebreaker escort). The basis of POLARIS is an evaluation of the risks posed to the ship by ice conditions using ice descriptions consistent with WMO nomenclature and the ship's assigned ice class consistent with the ice classes referenced in the draft Code (Pandey, 2016).

The Route Safety Module (RsM)and the Route Economy Module (ReM) are combined in a GIS software environment to produce the Digital Route optimization model (D-ROM).

The digital route optimization model (D-ROM) is structured around the Least Cost Pathway concept as depicted in figure 1.

Goal: Evaluating a set of optimized shipping routes in Bering Sea/Bering Strait

Objectives: a) Route Safety and b) Route economy

The above involves two input modules namely, a) Route safety b) The Route economy. Both modules get inputs from the multi-criteria analysis & least cost path analysis sub-modules. The final output is the D-ROM (digital route optimization model) that will generate waypoints in GIS.

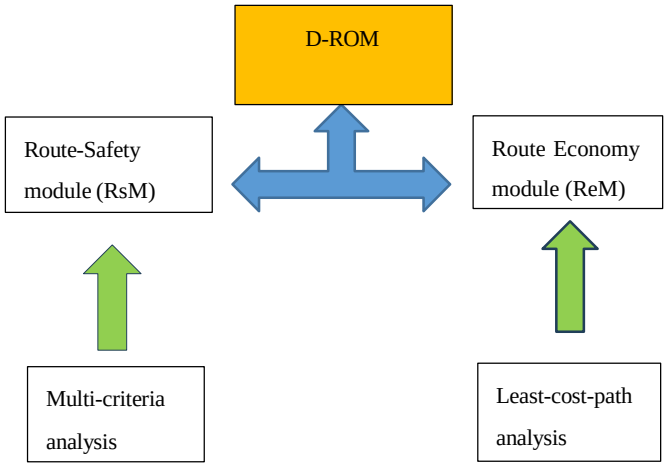


Figure 1: Digital Route Optimization Model (source: author)

Benefits of DROM in sea-ice include:

- Decision making in ice -timely and correct.
- Voyage planning –gives an optimized route among several alternative routes including the speed of advance.
- A tactical route optimization tool 'on-the-fly' will immensely aid in better decision making on the safest route to follow in ice.
- Aids in ship scheduling and planning for shipping companies.

- Precise voyage time and cost estimation –ice bound transits including Bering Strait.

4. Conclusion

Integrated ecosystem-based management in coastal Alaska and the Bering Strait region is necessary to conduct sustainable shipping and build resilient communities adversely impacted by climate change. It could be achieved by adhering to the two basic principles of voyage planning: a) route safety and b) route economy in ice infested waters (Pandey, 2016).

To reduce the adverse impact of maritime transport in the Arctic, it is critical to map designated MPA's and thereby ensure Arctic's marine ecology and biodiversity. High latitude navigation and the operational complexities it brings have several challenges to contend with including lack of maritime infrastructure and the presence of detached sea-ice drifting in the shipping lanes that may be difficult to predict and detect on radar.

The receding sea-ice remains an existential threat to ship navigation (Pandey, 2016) and may get more risk prone to mariners in the coming years. The paper demonstrated that the proposed model should be able to contribute to decision making (Pandey, 2016) and managing risks by charting a safe passage to avoid user conflicts and ensure sustainability in the Arctic ship transport.

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[1] PAME: Protection of Arctic Marine Environment

[2] IPCC: Intergovernmental Panel on Climate Change

[3] AR6: Sixth assessment report (2022-23)

[4] EEZ: Exclusive Economic Zone

[5] UNCLOS: United Nations convention on Laws of the sea

[6] SOLAS: Safety of life at sea convention

[7] DCW: Digital Charts of the World

[8] SIGRID 3- Sea ice data grid

[9] AIRSS: Arctic Ice Regime Shipping System

[10] POLARIS: Polar Operational Limit Assessment Risk Indexing System

[11] MPA: Marine Protected Area

[12] IUCN/WCPA: International union for conservation of nature- World commission on protected areas

The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Enhancing Maritime English Proficiency among Cadets in Georgia: An Action Research Approach to Developing a Tailored E-Learning Course

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Abstract: This study addresses the gap in Maritime English proficiency among Georgian cadets by developing and evaluating a context-specific, asynchronous e-learning course. Using an action research methodology, two iterative cycles were conducted: the first engaged stakeholders—crewing agents, maritime educators, and cadets—to identify challenges and inform the course design; the second involved extended use by cadets who used the platform as a way to enhance their skills by incorporating it into their learning schedule . The platform itself incorporated behaviourist, cognitivist, and connectivist educational principles and focused on technical terminology, communication skills, and interview preparedness. Feedback, from both stakeholders and cadets who actually used the platform, demonstrated that the course improved cadets' confidence, retention, and engagement with Maritime English. Asynchronous access and mobile compatibility proved especially effective for cadets balancing studies with external responsibilities. The findings suggest that tailored digital solutions can enhance language training in non-English speaking MET environments and offer a scalable model for similar maritime nations.

Keywords: Maritime English; e-learning; action research; MET; language proficiency

1. Introduction

The maritime industry remains the backbone of global trade, handling over 80% of global cargo volume (UNCTAD, 2023). For this sector to operate efficiently and safely, effective communication is essential—especially in English, which is the working language at sea. However, for countries such as Georgia, who produce non-native English-speaking seafarers, this presents a significant challenge.

Despite Georgia's strategic positioning between Europe and Asia and its growing Maritime Education and Training (MET) capacity, cadets often struggle to meet international and private company standards for Maritime English proficiency. In contrast to countries like the Philippines or India, where English proficiency is more widespread, Georgian cadets often enter the maritime workforce with insufficient English skills—particularly in technical terminology and interpersonal communication. This skills gap limits their employability and performance in a competitive global maritime labor market.

Previous studies have explored the role of e-learning in improving language proficiency in MET institutions globally (Bauk et al., 2013; Hafita et al., 2024). However, in Georgian case, no tailored solution has been designed, where cadets face additional challenges, such as limited practice opportunities and external responsibilities like part-time employment. These constraints often make traditional classroom-based or synchronous learning formats less effective.

To address this gap, this study develops and implements a prototype of an asynchronous e-learning course designed specifically to enhance Maritime English proficiency among Georgian cadets. The research

follows an action research methodology, involving three iterative phases: needs analysis, course development, and evaluation. By incorporating stakeholder feedback and relevant educational theories—including behaviourism, cognitivism, and connectivism—the study presents a context-sensitive, scalable approach to language training in MET. The aim is to contribute to the ongoing conversation in maritime education about leveraging technology to improve language skills, with a focus on practical application and learner adaptability. The objective is not just to contextualize Georgia but to serve as a model for similar non-English-speaking maritime nations seeking to improve language courses within MET frameworks.

2. Related Work

Maritime English has long been recognized as one of the main competency for safe and effective operations at sea. The International Maritime Organization (IMO) formalized its importance through the adoption of the Standard Marine Communication Phrases (SMCP), aimed at creating a standardized and simplified framework for shipboard communication (IMO, 2001). Maritime English proficiency, in this case, includes both general language skills and specific specialized technical terminology that is essential for operational safety.

Trenkner (1998) defines Maritime English as "the entirety of all those means of the English language which… contribute to the safety of navigation and facilitation of the seaborne business," highlighting the driving force behind the evolution of the field. In the Global Maritime Professional (GMP) framework developed by the International Association of Maritime Universities (IAMU), English proficiency is categorized as a part of cognitive as well as affective learning domain, further reinforcing its importance in maritime competency (IAMU, 2019).

Studies have been conducted where E-learning solutions have been explored as a tool for improving Maritime English, especially in countries where English is not the native language. For example, Bauk et al. (2013) and Hafita et al. (2024) studied implementations in Montenegro and Indonesia, respectively, highlighting the value of asynchronous learning for students who face external challenges. The OceanTG.com platform and Farwater initiative both demonstrated that tailored, modular language content can support cadets' proficiency without replacing basic courses offered worldwide.

From a theoretical background perspective, theories such as behaviourism, cognitivism, and connectivism offer useful principles that could be incorporated into digital language learning. Skinner's operant conditioning (1957) supports repetition and instant feedback, while Piaget and Bruner's cognitive theories show that structured, scaffolded learning makes best of the learners' capabilities. Siemens' connectivist model (2005) show how collaborative, networked learning environments are key elements in modern digital education.

While these frameworks have informed general MET e-learning strategies, there are not much studies that explored how such approaches can be contextually adapted, for example to nations like Georgia with contextualized factors, such as cadets balancing studies with jobs or limited English exposure, require custom solutions. This research tries to build upon the global works within the field of Maritime English and e-learning practices, nad then apply it specifically to the Georgian MET environment.

3. Methodology

This study implements an action research methodology at its core in order to design, implement, and then consecutively refine a tailored e-learning course aimed at improving Maritime English proficiency among Georgian cadets. Action research has proven to be effective for education-based interventions, offering a cyclical and collaborative framework for developing practical solutions in real-world contexts (Reason & Bradbury, 2008).

The research was structured around the Cooperative Method Development (CMD) model (Dittrich et al., 2008 as adapted by Bolmsten et. al for education technology development), which emphasizes three core phases:

(1) understanding the problem, (2) implementing change, and (3) evaluating improvements. This study involved two full action research cycles.

3.1. Cycle 1: Stakeholder-Led Development

In the first cycle, Phase 1 consisted of semi-structured interviews with key stakeholders—maritime educators, cadets, and crewing agency representatives. Their input showed challenges such as low technical vocabulary, oral communication skills, and insufficient practice opportunities due to external responsibilities like employment and family matters.

Phase 2 involved developing a prototype asynchronous e-learning course, incorporating the educational theories of behaviourism (through repetition and immediate feedback), cognitivism (via structured modules and real-life scenarios), and connectivism (using a peer-based community board).

In Phase 3, the prototype was tested with the original stakeholders. A/B testing was used to compare different design elements. Feedback focused on usability, content relevance, and applicability in the local context.

3.2. Cycle 2: Cadet-Centered Implementation

A second action research cycle started by inputting the stakeholder feedback collected from the first cycle into phase 1 of the second cycle. After adapting to these changes, the prototype was given to the Batumi Navigation Teaching University cadets, who had full access to the platform and were given time to study modules specifically designed for the study. The cadets were given flexibility and instructions on how to leverage the asynchronous nature of the course.

In Phases 2 and 3 of the cycle, data was collected from the cadets during and after the completion of the course. Additional data was also collected based on their regular class work performance. This allowed for a better understanding and contextual involvement in the process. The feedback collected from the cadets was used to contribute to the findings and prepare for the next iterative cycle.

Throughout both iterative cycles, the main focus was to understand the drawbacks as well as strengths of the information collected and analyzed, so it can be used and adapted for the next upcoming cycles.

4. Results and Evaluation

The evaluation process was conducted over two action research cycles, each offering unique insights into the effectiveness of the developed platform for improving Maritime English among Georgian cadets.

4.1 Cycle 1: Stakeholder Feedback

During the first cycle, the stakeholders tested the prototype for a short period of time and then provided feedback regarding content relevance, design, usability and expected learning impact.

- Content Relevance: All stakeholders agreed that the course addressed genuine gaps, particularly in technical Maritime English and oral communication. The modules on SMCP, interview preparation, and emergency phrases were considered highly relevant and were commended.
- Usability: While the interface was generally well-received, cadets noted that some navigation elements were unintuitive. This led to minor interface redesigns in preparation for the second cycle.
- Learning Outcomes: Crewing agency representatives appreciated the interview practice module as a useful pre-screening preparation tool. Cadets considered that the learning outcomes of the course had to be in unison with their regular studies.

A/B testing between two course variants provided to all the stakeholders showed a preference for the version featuring mobile-friendly practice tools and peer-to-peer feedback via a community board, which was created based on the connectivist theories.

4.2. Cycle 2: Cadet-Based Implementation

The second cycle focused on direct cadet engagement over a longer time frame. As one of the drawbacks of the first cycle was a short time frame of the stakeholders being exposed to the platform, a revised version

of the course was integrated into cadets' school work on a trial basis, with voluntary participation. Cadets used the platform over several weeks and then provided structured feedback through a follow-up survey and informal interviews conducted by the researcher.

Key findings included:

- Speaking Confidence: Although the asynchronous format limited real-time speaking feedback, recorded responses and peer interaction features contributed to improved confidence in oral communication.
- Self-Paced Advantage: Several cadets highlighted the platform's flexibility, stating that it allowed them to catch up on missed sessions due to work or family obligations.

Overall, both cycles confirmed that the prototype had a positive impact on Maritime English competency, especially for the cadets leveraging the asynchronous nature that fit well with learners' real-life problems. The results reinforced the need for blended approaches that combine structured language input with practical application tools that respect the cadets' schedules and learning contexts

5. Discussion, Conclusion, and Recommendations

This study set out to address a persistent challenge in Georgia's Maritime Education and Training (MET) sector: the gap in English language proficiency among cadets preparing for international maritime careers. Through the action research approach, the development and evaluation of a tailored, asynchronous e-learning course revealed meaningful opportunities for improving Maritime English instruction in non-native English- speaking contexts.

5.1 Discussion

The findings demonstrate that a well-designed e-learning platform that is grounded in educational theory and then contextualized to cadets' needs could enhance language skills. The integration of behaviourist methods (e.g., repetition and automated feedback) supported vocabulary acquisition and memorization of key maritime terms. Cognitivist strategies, such as scenario-based exercises and structured modules, facilitated deeper understanding of the topics. Finally, connectivist elements, like community boards and peer-reviewed recordings, fostered engagement despite the asynchronous delivery.

Importantly, after the two full cycles, it was highlighted that improvement in language proficiency is not solely dependent on curriculum content but also on delivery format and learner context. Cadets who had access to the course over time, and could slot it into their schedules, showed greater engagement and perceived improvement compared to those who tested it only in a review session. This supports the argument that e- learning in MET should be adaptable to learners' external responsibilities.

5.2 Limitations

While the study provided encouraging results, several limitations must be acknowledged:

- The sample size was relatively small and localized, with all participants based in Batumi and all the cadets being from Batumi Navigation Teaching University.
- The evaluation relied on self-reported improvement rather than standardized language assessments that are recognized worldwide.
- The asynchronous model, while effective for vocabulary and reading comprehension, is less suited for real-time speaking practice, which remains a critical skill at sea.

5.3 Recommendations

Based on the research findings, the following recommendations are proposed for MET institutions, regulators, and course developers:

1. Incorporate modular Maritime English e-courses into cadet training programs as supplementary tools alongside traditional instruction.
2. Design platforms with mobile compatibility and asynchronous access to accommodate cadets with work or family responsibilities.
3. Include speaking-oriented modules with optional recording and peer-review features to develop oral proficiency in low-pressure settings.

4. Expand future studies to include quantitative language testing and larger, more diverse cadet populations across multiple institutions.
5. Encourage collaboration between MET institutions in Georgia to co-develop or license shared e-learning resources and avoid fragmented efforts.

5.4 Conclusion

This research contributes a context-sensitive solution to a well-documented challenge in MET: the need for accessible and effective Maritime English instruction in non-English speaking countries. By combining stakeholder input with pedagogical theory and iterative design, the developed e-learning course offers a scalable, practical pathway for supporting Georgian cadets in achieving internationally relevant communication skills.

As global maritime operations become increasingly reliant on standardized communication, initiatives contextualized in local realities and international standards play an essential role in improving safety, employability, and professionalism at sea.

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The 25th IAMUC

Chennai, 16-17 Oct 2025

Proceedings of the
International Association of Maritime Universities (IAMU)
Conference

Launching the AMET Marine Exploration Data Portal for Maritime Heritage Studies

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Abstract: AMET Marine Exploration Data Portal is designed to serve as a valuable resource for researchers, policy makers and maritime enthusiast by offering an interactive and data driven approach to explore Poompuhar's rich maritime history and ecological significance. The portal serves a platform for the archaeologists, researchers, mariners to utilize the resources, methodology in exploring the underwater maritime ancient heritage sites across the world. The study examines the reconstruction of Poompuhar, a historic port city that flourished on intercontinental trade during Chola Dynasty till 200 CE. The local system and their civilization were mentioned in the Sangam Tamil literatures Silapathikaram and Manimegalai. This research involves underwater surveys and photography by remotely operated vehicles (ROV) and sensor based geodynamic techniques such as Multi beam echo sounder (MBES) to bring out the exhaustive details on the time series evolution and extinction of the port city Poompuhar. The portal's implementation ensures security, availability, and excellent performance while offering a sustainable platform that protects and makes available invaluable underwater archeological data.

Keywords: Maritime data portal; Maritime heritage; Multi beam echo sounder; ROV; under water exploration.

1. Introduction

The Chola Empire was on of the most influential dynasties in South India, as documented in classical Tamil Sangam literature. Founded by Vijayalaya Chola in the 9th century CE following his defeat of the Pallavas, the dynasty governed Tamil Nadu from the 9th to the 13th centuries CE. Poompuhar, also referred to as Cauvery poompatttinam, functioned as both the primary port and capital city of the Chola Dynasty. Covering an area of approximately 76.8 km^2, it is recognized in the Tamil epics Silapathikaram and Manimegalai as an early Chola capital. The ancient city extended Southwards to Thirukadayur, Northward to Kalikamur, Westward to Karuvindanathapuram and Kadarankondan, and Eastward to the Bay of Bengal, and is believed to have shifted several kilometers seaward, with elevations estimated at 8-10 meters above the present sea level during the Sangam period. An essential part of India's maritime history was contributed by the ancient Tamil port of Cauvery Poompattinam, also known as Poompuhar or Puhar. Poompuhar was approximately 76.8 Square Km in size. Poompuhar played a vital role in maritime trade, especially in the export of goods like pearl, spices and textiles. Numerous port cities and coastal areas have vanished or submerged primarily as a result of neotectonic activity, sea level fluctuations, coastal erosion, and other factors including tsunamis. When represented digitally the ancient Poompuhar port details will transfer on the culture and tradition to future generations. Knowledge of the cultural heritage of Poompuhar needs to be mapped and integrated with disparate data sources. Around the Poompuhar region marine archaeological investigations have been done along with observations of the coastal landmarks and other findings. A pair of structures on an ancient Cauvery waterway have been found during excavation near the location of two Wharves. A portion of focusing has been submerged in the sea, according to the findings of offshore investigation conducted at minimum water depth of 8 meters. The ancient shoreline of Poompuhar may be shifted some distance offshore, as it was expected to be between 8 and 10 meters above sea level during the Sangam period. Poompuhar was flourishing port city of Chola. Understanding the history of Poompuhar to know about the ancient Chola kingdom, maritime history, education and cultural development. Poompuhar is not only a site of historical significance, but also a place to where valuable archaeological evidence of submerged structure. To learn about Chola Poompuhar is significant because it tells Chola dynasty maritime excellence, economic importance, and cultural influence. Poompuhar enables the exchange of items

such as pearls, spices and textiles, which helps to the Chola Empire's economic prosperity. The study by explores the historic submerged port city of Poompuhar (Ramasamy et al., 2020), which is off the southern coast of India. It focusses on the complex issues of real-time underwater data collecting, assimilation and management. Underwater data was collected using Multi-Beam Echo sounder (MBES), Single Beam Echo Sounder (SBES) in the Poompuhar site. This AMET Marine Exploration Data Portal, which serves as a valuable resource for network institutions and researchers engaged in marine exploration and underwater archaeological studies.

2. Data Collection

The maritime port is extended up to 8Kms into Bay of Bengal and for around 20 Kms along the shore. Total area for data collection is 936 sq.km. The study area is divided into parts for collecting data. The specific regions of data collection are illustrated in Figure 1.

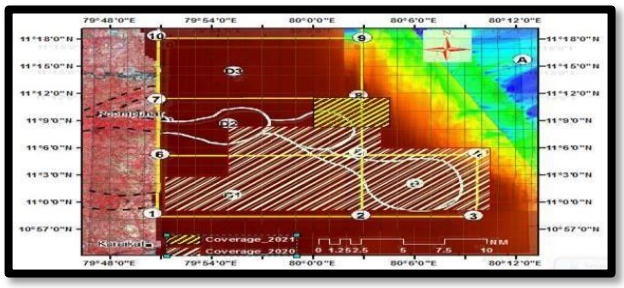


Figure 1. Region of Data Collection

AMET collaborates with the National Institute of Ocean Technology (NIOT), Chennai, to acquire comprehensive underwater data using NIOT research vessels equipped with ROVs, sub-bottom profilers, SBES, and MBES. The bathymetric survey covers depths ranging from 8.5 m to 173 m, with visual interpretation feasible up to approximately 120 m. The collected data are stored and graphically represented to reveal historical sites and underwater features. A Single-Beam Echo Sounder survey was conducted in the shallow 2–10 m depth zone. This survey contributed to the creation of bathymetric charts and Digital Terrain Models (DTMs) for shallow areas, helping to identify probable scattered remains associated with the Poompuhar harbor and enhancing the understanding of its original layout. The Multi-Beam Echo Sounders (MBES) were deployed in the 10–70 m depth range to generate high-resolution bathymetric charts and DTMs. MBES data provide detailed information on scattered underwater features and the geomorphic characteristics of the seafloor. MBES operates by emitting sound waves in a fan-shaped pattern toward the seafloor; these waves reflect back to the receiver, which records the angle and travel time. Using this information, a high-resolution three-dimensional representation of the seafloor is produced. The MBES data are stored in XYZ format, where X and Y represent spatial coordinates and Z represents depth (Figure 2. Sample data availability in data portal).

X	Y	Z
387855.000000000000	1224975.000000000000	31.190000000000
387885.000000000000	1224975.000000000000	31.260000000000
387915.000000000000	1224975.000000000000	31.300000000000
387945.000000000000	1224975.000000000000	31.380000000000
387975.000000000000	1224975.000000000000	31.460000000000
388005.000000000000	1224975.000000000000	31.540000000000
388035.000000000000	1224975.000000000000	31.570000000000
388065.000000000000	1224975.000000000000	31.620000000000
388095.000000000000	1224975.000000000000	31.700000000000
388125.000000000000	1224975.000000000000	31.770000000000
388155.000000000000	1224975.000000000000	31.850000000000
388185.000000000000	1224975.000000000000	31.910000000000
388215.000000000000	1224975.000000000000	32.040000000000
388245.000000000000	1224975.000000000000	32.100000000000
388275.000000000000	1224975.000000000000	32.180000000000
388305.000000000000	1224975.000000000000	32.260000000000
388335.000000000000	1224975.000000000000	32.350000000000
388365.000000000000	1224975.000000000000	32.430000000000
388395.000000000000	1224975.000000000000	32.530000000000
388425.000000000000	1224975.000000000000	32.620000000000
388455.000000000000	1224975.000000000000	32.710000000000
388485.000000000000	1224975.000000000000	32.810000000000
388515.000000000000	1224975.000000000000	32.890000000000
388545.000000000000	1224975.000000000000	33.000000000000
388575.000000000000	1224975.000000000000	33.110000000000

Figure 2. Sample data available in data portal

3. AMET Marine Exploration Data Portal

The data collected from both Multi-Beam Echo Sounders (MBES) and Single-Beam Echo Sounders

(SBES), including processed and unprocessed datasets, are securely stored in the AMET Marine Exploration Data Portal (Figure 3. AMET's on-campus data portal). This portal, hosted at AMET University, maintains a total of 620 GB of data obtained from NIOT surveys conducted at the Poompuhar sites. The repository upholds the highest standards of data reliability and integrity, providing dependable access for researches and institutions focused on marine and underwater archaeological studies (Figure 4. User access to the AMET Maritime Exploration Data Portal).



Figure 3. AMET's on-campus data portal

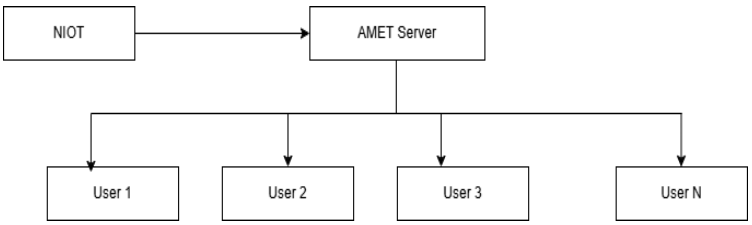


Figure 4. User access to the AMET Maritime Exploration Data Portal

Users must install FileZilla, a free and open-source FTP (File Transfer Protocol) program that can be found online by searching for "FileZilla software", in order to access the raw Poompuhar datasets. FileZilla facilitate secure and efficient transfer of data between a local computer and a remote server. FileZilla client, which enables users to connect to servers and control data transfer and FileZilla Server a windows-based program for hosting and controlling FTP connections are the two main versions of this software. Researchers and organizations can safely access, download and manage the large datasets kept in the AMET Marine Exploration Data Portal by utilizing FileZilla in figure 5. Remote access of underwater exploration datasets.

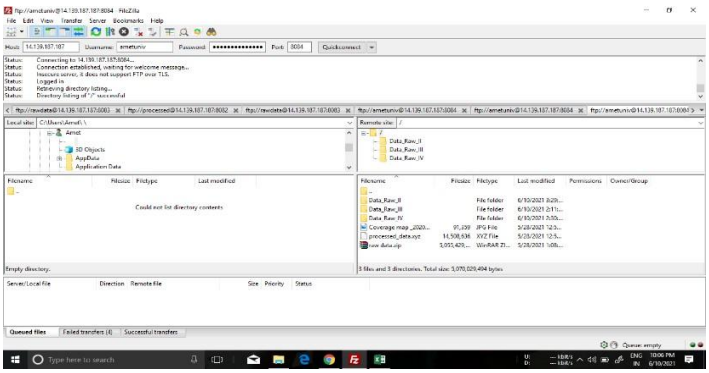


Figure 5. Remote access of AMET Data.

Users must create their own login credentials after installing FileZilla in order to access the raw and processed datasets that are stored in the AMET Marine Exploration Data Portal. There are 2,010 underwater data files totaling about 300 GB in Raw data 2, 1048 files totaling about 130GB in Raw data 3, and 838 files totaling about 100 GB in Raw data 4 within the portal. Coverage_Map_2020 (91,359 bytes), Processed_data.xyz (14,508,636 bytes), and raw_zip, a compressed archive of about 5 GB, are additional resources. Additionally, 552 GB of raw data in XTF (eXtended Triton Format), a specialized format for storing hydrographic survey information, has been contributed by the National Institute of Ocean Technology (NIOT). Using tools like side scan sonar, single beam echo sounders, and multi beam echo sounders, hydrographic surveys gather comprehensive data about the physical attributes of water bodies, such as water depth, submerged and navigation channels.

Table 1. Processed MBES data accessible through the AMET Marine Exploration Data Portal

S. No	Data Type	Data Format	Amount of Data Received
1.	MBES Raw Data	.ALL	614 GB
2.	MBES Processed Data	.ASCII, GEOTIFF	3.64 GB
3.	Sub bottom profiler Raw Data	.SGEY	2.34 GB
4.	Sub bottom profiler Processed Data	.JPG	42 MB
5.	ROV Data	.MP4	415 MB

The data from the study area will be stored in AMET Marine Exploration Data Portal. The type of data and the storage area are indicated in Table1.

4. Discussion

AMET Marine Exploration Data Portal provides access to underwater bathymetric and image dataset of the Poompuhar region. With the aid of these datasets, researches and archeologists can understand and retrieve the hidden knowledge about the Poompuhar region and they also can digitally reconstruct Poompuhar through which future generation can understand and appreciate cultural richness and architectural sophistication of ancient Tamil Civilization. Through this data portal a wide range of stakeholders including marine archeologists, researchers, and policy makers can make use of this data for methodical investigation as well as a systematic exploration and evaluation of Poompuhar's submerged heritage. For remotely accessing the data, security protocols by AMET University have to be followed for secured and controlled data distribution. By leveraging computational modelling, archeological evidence and geospatial data this study highlights the significance of repossessing historically important regions and associated historic data of submerged cultural sites. In addition to this, the datasets from this portal can be made use for creating strategies for preserving heritage sites and to develop additional technologies for field analysis for improved research.

5. Conclusion

The launch of the AMET Maritime Exploration Data Poral has significantly improved the digital preservation and utilization of historical heritage site of the South India, Poompuhar. This platform allows the user to make use of the bathymetric data of the heritage site for digitally reconstruct the submerged port of Poompuhar by integrating literature and epigraphic sources with current research. The portal also helps in the academic research which offers strong security and optimal performance. The preservation of Poompuhar's historical data helps the future generations to attain knowledge about the secreted history and it also proves underwater bathymetric data of historical significance can be preserved in the digital format for future research. This initiative offers a secure and sustainable digital environment which connect the ancient history and technological advancements which helps in the archeological research and improvement of academic explorations.

Acknowledgements

The first author Dr. T. Sasilatha Professor and Dean, AMET University sincerely acknowledges the

financial assistance received for the Project titled, "Underwater Structural Data Acquisition: A case study on Poompuhar Heritage Underwater site" from the Department of Science and Technology, Govt of India under the Programme 'Science and Heritage Research Initiative'.

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