ACADEMY Publishing Center

E-ISSN: 2812-5622

MRT Journal

MARITIME RESEARCH & TECHNOLOGY

Volume 4
Issue 2
December 2025

Academy Publishing Center

MRT Maritime Research and Technology **1st** edition 2022

ACADEMY Publishing Center

Arab Academy for Science, Technology, and Maritime Transport, AASTMT
Abu Kir Campus, Alexandria, Egypt
P.O. Box: Miami 1029
Tel: (+203) 5622366/88 – EXT 1069 and (+203) 5611818
Fax: (+203) 5611818
Web Site: http://apc.aast.edu
Email: apc@aast.edu

MRT Journal
Volume 4, Issue 2 (December 2025)
eISSN: 2812-5622
pISSN: 2812-5614

MRT Maritime Research and Technology

Maritime Research and Technology (MRT) journal is a biannual international peer-reviewed journal which presents a global forum for dissemination of research articles, case studies and reviews focusing on all aspects of the maritime sector and its role in sustainable development.

MRT publishes original research papers in English analysing the international, national, regional or local maritime industry. MRT includes both theoretical and empirical approaches to topics of current interest in line with the editorial aims and scope of the journal. The objective of MRT is to contribute to the progress, development and diffusion of research in the maritime industry.

The manuscripts presented must be unpublished works, which have not been approved for publication in other journals. They must also fulfil all the requirements indicated in the 'Technical Specifications' section. The quality of the papers is guaranteed by means of a process of blind review by two scientific referees and one linguistic reviewer. Although the journal is published in print format, the processes of submission and reception of manuscripts, as well as revision and correction of proofs, are all done electronically.

The journal is open-access with a liberal Creative Commons Attribution, Non-Commercial 4.0 International License which preserves the copyrights of published materials to the authors and protects it from unauthorized commercial use.

The MRT journal does not collect Article Processing Charges (APCs) or submission fees, and is free of charge for authors and readers, and operates an online submission with the peer review system allowing authors to submit articles online and track their progress via its web interface.

The journal is financially supported by the Arab Academy for Science, Technology and Maritime Transport (AASTMT) in order to maintain a quality open-access source of research papers on Maritime Research and Technology.

MRT has an outstanding editorial and advisory board of eminent scientists, researchers and engineers who contribute and enrich the journal with their vast experience in different fields of interest to the journal.

EDITORIAL TEAM

NATIONAL ADVISORY BOARD

ADMINISTRATIVE BOARD

MRT
ISSN 2812-5622
Vol. 4, Iss. 2 | December 2025

TABLE OF CONTENTS

Critical Considerations for Port Selection in Hydrogen Export Projects

Hossam Eldin Bakr AbdElsalam [1]

[1] Arab Academy for Science, Technology & Maritime Transport (AASTMT), College of Maritime Transport and Technology, Alexandria, Egypt.

Email: hossambakr@aast.edu

Received: 21 April 2025 Accepted: 01 June 2025 Published: 09 September 2025

Abstract

As the world moves towards a greener energy system, the hydrogen industry is seen as a promising one for the future. Transport infrastructure investments are complicated due to the many factors and changing project environment. The terminal's ideal location must maximize economic benefits while avoiding negative consequences. Developing nations find it difficult to choose a port for a hydrogen export terminal. Thus, this study addresses the key elements to consider while selecting a port for a new hydrogen export terminal.

The research uses a descriptive mixed methods approach, combining quantitative and qualitative data to evaluate the importance of factors affecting the selection of a port for a hydrogen export terminal. Primary data was collected through a poll with industry specialists, while secondary data was gathered from academic journals and industry reports. The study employed Likert-scale ratings and open-ended responses to gather qualitative data. Descriptive statistics were used to summarize the survey results. Thematic analysis was used to identify themes and patterns.

The research contributes to a better understanding of and measurement of the importance of the factors that should be taken into consideration in the port industry when choosing a port to construct a hydrogen export terminal. The research presented fourteen factors that were classified under three types of considerations: regulatory and standard considerations, port capabilities considerations, and economic and financial considerations.

Keywords:
Port, Port industry, Hydrogen industry, Hydrogen export terminal.

1. Introduction

Human-induced greenhouse gas (GHG) emissions have resulted in significant alterations to global ecosystems, including an increase in the global average temperature, modified precipitation patterns, intensified storms, diminished biodiversity, and rising sea levels (Calvin et al., 2023). Increasingly, nations are declaring the transition to more sustainable energy sources. In the transition to a more sustainable energy system, hydrogen is regarded as essential for achieving decarbonization goals (Spatolisano et al., 2023). Green hydrogen denotes hydrogen generated from renewable energy sources, devoid of greenhouse gas emissions. Color-band terminology categorizes hydrogen varieties based on production methods facilitated by contemporary technology: gray hydrogen from coal gasification, blue hydrogen from steam methane reforming, and green hydrogen from water electrolysis (Noussan et al., 2020). Although hydrogen is predominantly produced by technologies that generate substantial carbon emissions, the utilization of renewably powered electrolysis is anticipated to decrease costs and assume a more prominent role in the future (Alverà, 2021).

The prospect of maritime hydrogen transport at a levelized cost far below the 2 USD/kg benchmark presents a chance for nations with inexpensive renewable energy sources to emerge as exporters of hydrogen to the global market, thereby enhancing their primary macroeconomic indicators. Consequently, it is essential for policymakers to provide a framework that enables stakeholder intervention in the industry (D'Amore-Domenech et al., 2023).

Ports play a key role in the maritime industry (Paulauskas et al., 2023), as they serve as essential hubs in worldwide transportation networks, enabling trade and guaranteeing seamless, sustainable, and resilient operations (Edgerton, 2021; Ashrafi et al., 2020). Furthermore, the significance of ports in fostering economic growth within coastal nations is widely recognized (Puig & Darbra, 2018). Consequently, ports will be pivotal in the maritime export of green hydrogen and other hydrogen variants, particularly for developing nations.

Selecting a port for the construction of a hydrogen export terminal is a complex issue, particularly for developing nations. Consequently, this research examines the significant factors that must be considered when choosing a port for the establishment of a new hydrogen export terminal.

2. Background

GHG causes changes to ecosystems globally (Change, 2023). The rapid exhaustion of fossil fuels presents significant hurdles in meeting a substantial share of the world's increasing energy demands. The utilization of these conventional energy sources presents certain disadvantages. The primary concern is CO2 emissions and climate change (Obaidat et al., 2018). Energy demand is increasing substantially due to ongoing population increase and economic advancement. Industrialization is essential for the prosperity of every nation (Alkhalidi et al., 2019). This has prompted nations to concur on significantly decreasing GHG emissions and to sign the Paris Agreement.

In the transition to a more sustainable energy system, hydrogen is regarded as essential for achieving decarburization targets; the increasing interest in utilizing hydrogen as a clean energy source is attributed to two primary factors:

1. *Hydrogen can be utilized without direct GHG emissions,*

2. *It can be generated from various low-carbon energy sources (Spatolisano et al., 2023).*

Green hydrogen is a type of hydrogen generated from renewable energy sources that are devoid of GHG emissions. Although hydrogen is predominantly produced by technologies that generate considerable carbon emissions, it is anticipated that renewably powered electrolysis will decrease costs and assume a more substantial role in the future (Alverà, 2021). When it comes to national energy strategy, sixteen of the top twenty nations that create GHG have made hydrogen a priority (Chen et al., 2023).

Color-band terminology categorizes hydrogen varieties based on production methods facilitated by contemporary technology (Noussan et al., 2020). According to the World Energy Council report, green, pink, and yellow hydrogen are produced via electricity, while blue, turquoise, grey, brown, and black hydrogen are produced via fossil fuel. Table 1 presents Color-band terminology categorizing hydrogen types with the method of technology used in production, the source of power used for production/raw material, and the carbon footprint.

Table 1: A spectrum of hydrogen colors.

No.	Terminology	Technology	Electricity source/Feedstock	Carbon footprint
1	Green Hydrogen	Electrolysis	Wind / Solar / Tidal / Geothermal	Minimal
2	Pink Hydrogen		Nuclear	
3	Yellow Hydrogen		Mixed-origin grid energy	Medium
4	Blue Hydrogen	Natural gas reforming + Carbon capture, utilization, and storage (CCUS) gasification + CCUS	Natural gas, coal	Low
5	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon
6	Grey Hydrogen	Natural gas reforming		Medium
7	Brown Hydrogen	Gasification	Brown coal	High
8	Black Hydrogen		Black coal	

Source of data World Energy Council report September 2021

Numerous studies, such as Kamiya et al. (2015), Al-Breiki and Bicer (2020), and Ishimoto et al. (2020), have endeavored to quantify the costs associated with hydrogen production and delivery to facilitate comparisons of various transportation methods. Certain research posited that the expenses associated with hydrogen infrastructure are either equivalent to those of natural gas infrastructure or marginally elevated, particularly with pipelines, as multiple studies indicated comparable to 10% increased capital expenditures (Al-Breiki & Bicer, 2020). Nonetheless, hydrogen and natural gas possess distinct qualities that necessitate varying material specifications (Wang et al., 2021). Prolonged exposure of steel to hydrogen results in embrittlement, necessitating specialized coatings and costly layers for pipelines to transport hydrogen effectively. Furthermore, current compressors utilized in natural gas pipeline networks are inadequate for hydrogen due to their low molecular weight, which may potentially result in leakage (Wang et al., 2021).

Consequently, repurposing existing natural gas pipelines is feasible; however, the associated expenditures would be substantial, ranging from 10 to 50% of the expense of constructing a new pipeline (Wang et al., 2021; Wang et al., 2020). Likewise, several studies presume that the capital costs of Liquefied Hydrogen (LH2) vessels are nearly identical to those for transporting Liquefied Natural Gas (LNG) (Al-Breiki & Bicer, 2020) despite the substantial temperature disparities at which these two gases are transported, with LH2 maintained at −253 °C and LNG at −162 °C. Estimates suggest that LH2 vessels may incur expenditures up to four times greater than those of LNG vessels (Amos, 1999). Notwithstanding the constraints identified in those studies, the expenses associated with hydrogen transportation were determined to be greater than those for natural gas, around 0.88 €/MWhH2/1000 km in contrast to 0.20 €/MWhLNG/1000 km for LNG shipping (Al-Breiki & Bicer, 2020), and 2.17–23.3 €/MWhH2/1000 km in contrast to 0.41–2.36 €/MWhNG/1000 km for the pipeline transport of natural gas (Saadi et al., 2018).

Hydrogen is regarded as a multifaceted and potent energy carrier in the decarbonization of the global economy, aimed at substituting fossil fuel consumption with renewable and sustainable technology (Judkins & O'Brien, 2019). Transporting liquid hydrogen is only viable for extensive distances when the costs of liquefaction can be distributed over that distance (Amos, 1999). An exemplary international hydrogen supply chain comprises production, conversion, storage, transportation, distribution, reconversion, and usage (James & Menzies, 2023). Figure 1 illustrates a conventional green hydrogen supply chain. Ports and shipping are essential components of the supply chain. In exporting nations, hydrogen is generated using water electrolysis utilizing renewable energy sources. The low density of gaseous hydrogen requires its transformation into alternate forms, like compressed hydrogen, LH2, or chemical carriers such as ammonia (NH3), methanol, or liquid organic hydrogen carriers, to enhance its storage and transportation efficiency. Upon its arrival at the export port, hydrogen is transported to the import port. Subsequently, it enters a distribution phase and, when necessary, undergoes reconversion operations to meet the demands of end-users, encompassing transportation (Jayakumar et al., 2022), high-temperature industrial applications, and residential usage (Xu et al., 2024; Elkhatib et al., 2024; Superchi et al., 2023). Energy conversion at the point of consumption can be accomplished by fuel cells, internal combustion engines, steam turbines, gas turbines, and burners.

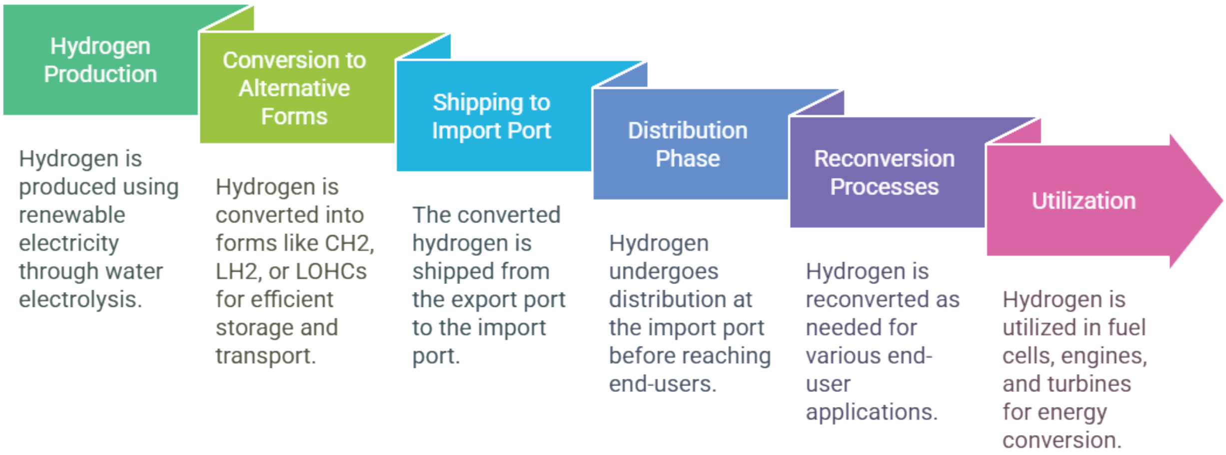

Figure 1: Conventional green hydrogen supply chain.
Source: Author (using Napkin)

The long-distance transport of hydrogen and its international export is regarded as a crucial strategy for mitigating GHG emissions and represents a substantial economic potential, leveraging enormous renewable energy supplies (Walsh et al., 2021). At the end of the year 2021, a liquid hydrogen carrier set sail from Kobe, Japan, to Australia. It arrived back in Kobe at the end of February, carrying the first cargo of its kind. At a temperature of -253 degrees Celsius, this vessel is capable of holding a volume of 1250 cubic meters of liquid hydrogen (Pekic, 2022).

The outcomes of this test shipment will undergo additional analysis and development; nonetheless, the concept is not slated to go to a commercial-stage until the mid to late 2020s. Kawasaki Heavy Industries has announced the development of a large LH2 carrier with a capacity of 160,000 m^3, anticipated to commence operations in the mid-2020s (Kawasaki Heavy Industries, 2022; Raab et al., 2021).

As hydrogen demand escalates, enhanced capacity connecting additional regions will be required for its transportation. The capital expenditures for pipelines are substantial, and it is probable that cryogenic vessels onboard ships for the transport of liquid hydrogen, together with the liquefaction process, will continue to be costly, particularly in the initial phases (Aghakhani et al., 2023). However, scientists and researchers are working on cost reduction as well as any other technologies that provide the chance for production on a large scale, especially for the developing countries that possess a wealth of land and renewable energy resources that facilitate the production of green hydrogen. As a result, the necessitating establishment of export terminals in ports.

Investments in transport infrastructure are inherently complex due to the multitude of influencing aspects and the evolving environment in which projects are executed. Establishing the terminal's best location is crucial to maximize economic benefits while minimizing adverse effects. The establishment of gas terminals is a substantial economic endeavor. It harnesses spatial and economic potentials in accordance with the intended use of the premises, environmental and security regulations, as well as the availability of infrastructure and other essential components for the terminal's operation without substantially adversely affecting individuals and the environment (Krpan et al., 2023).

3. Methodology

The methodology in this research assigned a descriptive mixed methods approach that combines quantitative and qualitative data collection to evaluate and compare the significance of diverse criteria affecting the choice of a port for the establishment of a hydrogen export terminal. A poll was performed with industry specialists from the maritime industry and hydrogen industry to collect primary data using purposive sampling. Engaging with these professionals seeks to acquire useful insights into the current burgeoning hydrogen industry as an energy source.

The questionnaire was piloted with a group of six maritime PhD holders, three of whom are research reviewers. The questionnaire was tested to enhance its quality and check validity and reliability. To furnish a questionnaire with eight questions pertaining to participant data and 27 questions relevant to the research issue. The questionnaire was revised and retested for the same group based on the input received.

Alongside primary data collecting, secondary data is obtained from academic journals, industry reports, and pertinent publications. This secondary data will offer a solid basis of existing information, research outcomes, and theoretical frameworks pertinent to the hydrogen and maritime industries. By synthesizing both primary and secondary data, we can provide a thorough overview of the subject.

Quantitative using Likert-scale ratings that comprise a declaration or inquiry by a sequence of five response sentences. Participants select the choice that most accurately reflects their sentiments toward the statement or inquiry. Qualitative using open-ended responses that Facilitate a thorough and comprehensive examination of the examined issues since open-ended comments enable respondents to offer a broader range of ideas and perspectives. This method entails the methodical organization and categorization of data to discern major themes and patterns, facilitating the derivation of significant conclusions. Descriptive statistics were employed to present a quantitative summary of the participants' viewpoints based on the survey results.

Thematic analysis is a form of qualitative analysis employed to examine categories and highlight themes (patterns) pertinent to the data. Thematic analysis denotes a method of pattern recognition that entails identifying fundamental themes (specifically, 'theories' or 'approaches') by meticulous reading and re-reading of the material (Javadi & Zarea, 2016). Therefore, the method assigned as a qualitative analysis method for questionnaire designing and the analyses of open-ended questions through 5 steps:

1. **Familiarization:** obtain a comprehensive understanding of all the obtained data prior to commencing the analysis of individual items.

2. **Coding:** involves identifying segments of text, typically phrases or sentences, and assigning concise "codes" to encapsulate their meaning.

3. **Generating themes:** Examine the labels or codes developed, discern patterns within them, and begin formulating themes. Themes typically encompass a greater scope than decarbonization codes.

4. **Evaluate themes:** ensure that themes provide meaningful and precise representations of the data.

5. **Naming and defining themes.**

Throughout the research procedure, the author adheres to ethical principles by obtaining informed consent from participants and assuring the maintenance of their privacy and confidentiality. Recognize the constraints of the research, including possible participant availability and the subjective analysis of qualitative data. Nevertheless, the Author is dedicated to meticulously undertaking this study to enhance the current body of information regarding hydrogen and the port industry.

4. Sampling and papulation

The research assigned purposive sampling to obtain representative samples. where participants are chosen based on their active participation and experience in maritime, port and hydrogen industrial sectors, table 2 present targeted stakeholders and their role in the industry and the rationale behind the choice.

The data were collected through a questionnaire that distrebuted online giving the participent from 2 to 4 weeks to resond, ferthermore, respondes were anonymized for the purpose of confidentiality ensure. The questionnaire was distributed to 67 targeted stakeholders. The final total number of responses for the sample is 28 responses.

Table 2: Targeted Stakeholders.

No.	Stakeholders	Stakeholders role	Rationale
1	Port Authorities and Managers	Decision-making is overseeing port operations, development, and infrastructure (Saieva, 2013; De Martino, 2014).	Comprehend the port's current infrastructure, operational difficulties, capacity, and prospects for expansion (Saieva, 2013; De Martino, 2014).
2	Engineers and Technical Experts	Engaged in the design, construction, and maintenance of hydrogen infrastructure, including storage, pipelines, and liquefaction/ compression facilities (Hao et al., 2024).	Can offer insights into technical feasibility, safety, and the compatibility of existing port infrastructure with hydrogen specifications (Hao et al., 2024).
3	Renewable Energy Producers	Engaged in renewable energy production (solar, wind, hydro) that could provide power for hydrogen generation (Benghanem et al., 2023).	Their contributions are critical for evaluating the availability and dependability of renewable energy required for green hydrogen production through electrolysis (Benghanem et al., 2023).
4	Hydrogen Industry Specialists	Specialists in hydrogen generation, storage, and transportation technologies, especially those from firms focused on green hydrogen development (Hao et al., 2024).	They possess extensive expertise in the specific needs for the safe and effective handling and exportation of hydrogen (Hao et al., 2024).

5	Environmental Experts and Regulators	Environmental scientists, sustainability specialists, and officials from regulatory agencies dedicated to environmental protection and climate change mitigation (Islam et al., 2024; Sharma et al., 2024).	They offer insights into the environmental implications of hydrogen production and export, encompassing legislation, environmental hazards, and sustainability considerations (Islam et al., 2024; Sharma et al., 2024).
6	Economists and Financial Analysts	Economists, financial analysts, and project finance specialists concentrate on substantial infrastructure initiatives.	Their proficiency is essential for evaluating the financial feasibility, long-term return on investment (ROI), and economic implications of the hydrogen export terminal (Ives, 2016).
7	Policy Makers and Government Officials	Government officials engaged in energy policy, infrastructure development, and environmental regulation (Islam et al., 2024).	They can provide insights into national energy strategies, regulatory frameworks, and governmental incentives that may impact the establishment of green hydrogen terminals (Islam et al., 2024).
8	Shipping and Logistics Companies	Representatives from maritime shipping businesses and logistics enterprises responsible for the transportation of products, particularly hazardous items, by sea.	Their experience is essential for assessing the port's capability to manage hydrogen exports and incorporate them into international shipping routes.
9	Safety and Risk Management Experts	Safety officers and specialists in risk management, particularly concerning flammable and dangerous substances such as hydrogen.	They are capable of evaluating safety protocols, emergency response plans, and risk management strategies necessary for the storage, transportation, and exportation of hydrogen (Froufe et al., 2014).
10	Industrial Hydrogen Consumers	Representatives from sectors that may potentially utilize green hydrogen, such as steel manufacturing, chemical industries, and transportation.	Their insights regarding supply chain reliability and hydrogen demand are crucial for ensuring the terminal meets market requirements.
11	Community Stakeholders	Representatives from local communities, environmental non-governmental organizations, and other NGOs focused on sustainability and community effects.	Community feedback is essential for comprehending public sentiment, assessing potential social ramifications, and ensuring the project is congruent with local sustainability objectives.
12	Academia and Research Institutions	Researchers and academics specializing in researching renewable energy, hydrogen technology, environmental science, or port logistics.	Their insights on long-term sustainability, technological advancements, and scholarly research can guide strategic decisions and innovations for the project (Diaconu & Salaj, 2024).
13	International Energy and Trade Organizations	Delegates from entities such as the International Energy Agency (IEA) or the International Maritime Organization (IMO).	Provide insights into global energy trends, forecasts for hydrogen demand, and international rules concerning energy transition and hydrogen commerce.
14	Investors and Private Sector Stakeholders	Institutional investors, venture capitalists, or private enterprises seeking to invest in renewable energy or hydrogen infrastructure.	Their involvement is essential for comprehending financial viability and obtaining funding for sustained development.
15	Legal and Compliance Experts	Legal consultants with expertise in energy law, maritime law, and environmental legislation.	Their contributions guarantee compliance with all legal and regulatory requirements throughout the planning and implementation stages (Islam et al., 2024; Sharma et al., 2024).
16	Labor Unions and Workforce Representatives	Advocates for laborers at the port or associated sectors.	Crucial for tackling personnel preparedness, training requirements, and labor regulations concerning hydrogen exports.

Source: Author

Samples were collected from targeted stakeholders from several nations, including China, Egypt, Japan, Jordan, Nigeria, Saudi Arabia, Sweden, Tunisia, and Uganda. Simultaneously, the sample, as shown in Figure 2 as a percentage, includes 28 responses from the targeted stockholders presented in Table 2, except labor unions and workforce representatives, who did not respond.

Figure 2: Percentage of stakeholder participation in the survey.
Source: Author (using Microsoft Excel)

5. Analysis, Results, and Discussion

5.1. Data analysis methods

Regarding Quantitative Analysis using "Likert Scale Responses," This phase of the study will focus on the number of responses for each element, utilizing the Likert scale (1–5) from the questionnaire. First, the author computed the mean score for each question by summing up the respondents' ratings and dividing them by the total number of responses using the following formula. $Mean\ Score = \frac{\Sigma(All\ Ratings)}{Number\ of\ Respondents}$ This will assist in comprehending the perceived weight of each element. Secondly, the author delineated the high and low-priority variables, with high-priority components exhibiting mean scores near 5, whereas low-priority factors displayed mean scores approaching 1 or 2, indicating lesser significance. Thirdly, the author calculated the Standard Deviation for each question for the purpose of measuring the variability of each question using the formula $SD = \frac{\sqrt[2]{\Sigma(Rating-Mean\ Score)2}}{Number\ of\ Respondents}$ where A low standard deviation indicates consensus among respondents on the component's relevance, while a high standard deviation reflects divergent viewpoints.

Regarding Qualitative analysis of open-ended responses, the respondents' comments and explanations can provide a more comprehensive knowledge of the factors influencing the high or low ratings of specific aspects. The initial phase uses thematic analysis by Highlighting significant themes that emerge in the comments. Consolidate similar responses to identify prevalent issues or suggestions. Followed by Theme Frequency through enumerating the occurrences of each theme after categorizing the comments accordingly. This can facilitate the ranking of difficulties or options that responders most frequently cited, followed by evaluating the comments, whether they express positive, neutral, or negative opinions toward a specific element.

5.2. Results

In accordance with the methodology employed in this research, as shown in Figure 3, the survey results from the questionnaire revealed that the mean scores of the criteria ranged from 4.16 to 3.69 out of 5, indicating that these factors are of high priority. The standard deviation ranges from 1.12 to 1.28, which is seen as low, indicating a consensus among respondents about the factors. The factors are listed below in descending order of importance based on the survey analysis completed.

1. **Operational and Safety Challenges:** indicated as the highest important factor where the importance of chosen port's safety infrastructure and protocols combined with the availability of qualified personals and experts to manage operations related to hydrogen specifically.

2. **Environmental Impact & Regulations:** indicated as the second highest important factor where the importance of the chosen port's ability to comply with environmental regulations for hydrogen production and export, conversely with the capability of the port to handle environmental risks as hydrogen leak and marine impacts.

3. **Logistics & Connectivity:** appeared as the third factor in respect of importance where the importance of the chosen port's connectivity with inland transport systems as rail, road, and pipelines for supplying hydrogen, furthermore, the ability to develop bunkering infrastructure for hydrogen and other renewable fuels.

4. **Risk Management & Safety Protocols:** where the importance of the chosen port's ability to respond to emergencies or accidents involving hydrogen, handle and manage hydrogen-specific risks as leaks and explosions through established safety protocols.

5. **Energy Supply & Integration:** where the importance of the chosen port's crucial factor is the proximity of renewable energy sources to the port, such as offshore wind farms or solar plants, to facilitate electrolysis—the production of hydrogen.

6. **Port accessibility & geographical location:** where the chosen port should be close to the main shipping leans accessing the hydrogen market, moreover, the port should be close to the hydrogen production facilities.

7. **Technological Innovation in Hydrogen Handling:** where the chosen port supported with the availability of advanced technologies regarding hydrogen storage, transport, and safety in addition to the presence of potential for the adoption of automated/digitalized operations for hydrogen export management.

8. **Costs & Financial Viability:** where the chosen port must possess the capacity to secure the requisite initial investments for hydrogen-specific infrastructure through self-funding, governmental help, private investors, or a combination thereof, considering the long-term return on investment (ROI).

9. **Hydrogen Supply Chain Economics:** where the selected port must optimize costs along the hydrogen supply chain, from manufacturing to export.

10. **Hydrogen Handling Infrastructure:** the chosen port must equilibrium between available infrastructure, such as pipelines and storage tanks and, the adoption or expiation for the infrastructure to export hydrogen efficiently and safely.

11. **Energy Transition & Policy Support:** the chosen port's ability to apply the needed alignment with the national and international energy transition policies regarding the port's hydrogen terminal and utilizing government incentives or subsidies for hydrogen industry development.

12. **Market Demand & Supply Chain:** where the importance of the port's ability to integrate with global alliances for hydrogen supply and logistical networks with the proximity to major hydrogen markets in Europe and, Asia.

13. **Stakeholder Collaboration:** The importance of the port's capability to facilitate hydrogen export through collaboration with key stakeholders, including governmental entities, renewable energy providers, and logistics firms.

14. **Port Throughput & Capacity:** The importance of the port's capability to handle substantial hydrogen exports, encompassing storage and loading facilities, together with prospective developments to accommodate the increasing demand for hydrogen exports.

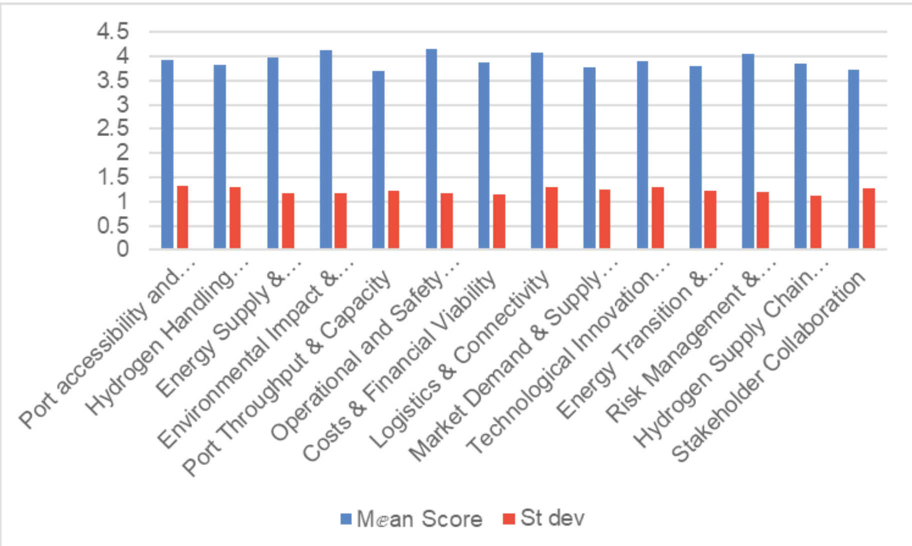

Figure 3: Mean Score and Standard Deviation for the Questionnaire Output.
Source: Author (using Microsoft Excel)

In addition to the above-mentioned factors, shipping and logistics companies' stakeholders, as well as safety and risk management experts, indicated that clarification on the enforcement of safety regulations pertaining to the handling of liquid or compressed hydrogen is required. Port tariffs, docking fees, and operational expenses must remain competitive to provide economical hydrogen transportation. The terminal's operating efficiency, encompassing loading and unloading speed, will influence shipping schedules and expenses. Hydrogen loading infrastructure must reduce delays and synchronize with stringent shipping schedules.

Port Authorities, Managers, experts, and stakeholders indicated that the port must provide deep-water access and sufficient berth capacity to accommodate specialized hydrogen vessels. An evaluation of the current port infrastructure is required to ascertain the feasibility of improvements for hydrogen storage and loading facilities.

Economists and financial analysts indicated that analyzing the trials of industry comparators and monitoring the industry's pressure points may conserve time and lives. In other words, it commences from the conclusions of others.

Academia and Research Institutions, Investors, and Private Sector Stakeholders indicated that The port must possess comprehensive hydrogen storage facilities, infrastructure for effective hydrogen liquefaction or conversion, and a dependable pipeline or trucking system for transferring hydrogen from producing sites to the port. An uninterrupted supply chain with few impediments will diminish operational delays and expenses. The port must possess the capacity for expansion to accommodate the increasing worldwide demand for hydrogen and have a flexible infrastructure capable of incorporating novel hydrogen carriers and technologies.

While Industrial Hydrogen Consumers said, *"We are giving more attention to the green hydrogen."*

5.3. Discussion

Hydrogen serves as an exceptional energy carrier due to its elevated energy density (Gretz et al., 1994). LH2, in contrast to NH3 and liquid organic hydrogen carriers (LOHC), does not necessitate supplementary energy for dehydrogenation or cracking upon importation and exhibits a greater mass density (70 kg/m3) than compressed gaseous hydrogen (Ratnakar et al., 2021). Thus, LH2 is among the most appropriate options for intercontinental renewable energy transfer (Notardonato et al., 2017).

Maritime shipping primarily facilitates large-scale transportation. Maritime shipping is vital, particularly for transcontinental or long-distance transport. The maritime supply chain includes renewable energy generation, hydrogen production, hydrogen liquefaction, export terminals, tankers, import ports, and utilization. Ports serve as a critical node and connections within the supply chain and can function as a central hub for the hydrogen sector from production to consumption (Kim et al., 2024; Hong et al., 2021; Roos, 2021). Ports are advantageous sites for hydrogen production if they are proximate to renewable energy sources, enhance hydrogen transport logistics for both export and import, and utilize hydrogen as an energy source for the ports' assets, including vehicles, machines, and vessels (Fan et al., 2024; Guan et al., 2023; Chang et al., 2019). Fages et al. forecasted that green hydrogen will decarbonize ports and adjacent businesses, resulting in the development of new port infrastructure for hydrogen production and refueling in the forthcoming years (Fages et al., 2023).

Deloitte's extensive analysis forecasts possible demand for as much as 42% (22 million tons) of the EU's hydrogen consumption in 2050 in European ports and coastal regions (Deloitte, 2023). Conversely, Japan revised its hydrogen policy to prioritize the development of hydrogen demand across all economic sectors and the importation of hydrogen from overseas (REI, 2022). The ports' preparedness for worldwide hydrogen trade is nascent. Infrastructure construction or refurbishment, risk management strategies, the formulation of rules and standards, and education and training necessitate increased resources (Chen et al., 2023).

The research results can be divided into three main findings, which are: regulatory and standard considerations, port capabilities considerations and, economic and financial considerations, and these findings are discussed below.

Regulatory and standard considerations:

Regulatory and standard considerations include factors 1, 2, 4, and 11, where the research findings indicate that terminal safety protocols and operational safety challenges are critical due to hydrogen's flammability. Consequently, qualified personnel and experts, in addition to education and training, necessitate increased resources to implement the appropriate protocols and navigate the operational safety challenges effectively. The management of risks associated with the capacity to respond to emergencies or accidents involving hydrogen, as well as the handling and mitigation of hydrogen-specific hazards such as leaks and explosions, emerged as the fourth component, while both factors exhibit a strong correlation concerning adaptation. Both factors were discussed by Chen et al. (2024), Peace et al. (2023), and Lanphen (2019) in their studies.

The compliment with environmental regulations for hydrogen production and export, conversely with the capability of the port to handle environmental risks to comply with as hydrogen leak and marine impacts came as the second import factor which was were discussed by Chen et al. (2024), Peace et al. (2023) and Lanphen, (2019) in their studies. The 11th factor addressed the port's capacity to connect with national and international energy transition strategies concerning its hydrogen terminal and to leverage government incentives or subsidies for the advancement of the hydrogen industry.

Port capabilities considerations:

Port capabilities include factors 3, 5, 6, 7, 10, and 14, where the chosen port should be distinguished by logistical connectivity with inland transportation systems such as rail, road, and pipelines for hydrogen delivery, as well as the capacity to provide bunkering infrastructure for hydrogen and other renewable fuels. Along with energy supply integration, where the port should be close to the hydrogen production facilities, and the closeness of renewable energy sources, such as offshore wind farms or solar plants, to the port is intended to enable electrolysis, the process of green hydrogen production. Furthermore, the importance of port accessibility and geographical location where the closeness to main shipping leans accessing the hydrogen market, as indicated by Chen et al. (2024), Semchukova et al. (2024), Peace et al. (2023) and Lanphen (2019) in their researches.

Complying with Semchukova et al. (2024, Brauer et al. (2022), and Lanphen (2019), the chosen port should be distinguished by sophisticated technology for hydrogen storage, transportation, and safety, as well as the capability for implementing automated and digitalized processes for hydrogen export management, in addition to hydrogen handling infrastructure that is essential for balancing existing facilities, such as pipelines and storage tanks, with the development or expansion of infrastructure necessary for the efficient and safe export of hydrogen and, port efficiency presented in port throughput and capacity.

Economic and financial considerations:

Economic and financial considerations include factors 8, 9, 12, and 13, where the chosen port should be distinguished by the capability to obtain the necessary initial investments for hydrogen-specific infrastructure through self-financing, government assistance, private investors, or a mix of these while taking into account the long-term return on investment (ROI).

The economics of the hydrogen supply chain need the chosen port to optimize expenses across the entire process, from production to exportation. Market demand and supply chain emphasize the significance of the port's capacity to integrate with global hydrogen supply alliances and logistical networks, given its closeness to major hydrogen markets in Europe and Asia. In addition, Collaboration among stakeholders emphasizes the port's capacity to enable hydrogen export through partnerships with essential organizations, including governmental bodies, renewable energy suppliers, and logistics companies.

Finally, for the purpose of validation regarding the results and findings, table 3 is showing the factors consistent and agreement with the literature.

Table 3: Compatibility between results, findings, and sources of literature.

Finding	Factor	Source	Author
Regulatory and standard considerations	Operational and Safety Challenges	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		ADIPEC Conference, Abu Dhabi, United Arab Emirates	(Peace et al., 2023)
		MSc thesis thesis, Delft University of Technology	(Lanphen, 2019)
	Environmental Impact & Regulations	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		ADIPEC Conference, Abu Dhabi, United Arab Emirates	(Peace et al., 2023)
		MSc thesis, Delft University of Technology	(Lanphen, 2019)
	Risk Management & Safety Protocols	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		ADIPEC Conference, Abu Dhabi, United Arab Emirates	(Peace et al., 2023)
		M.Sc. thesis, Delft University of Technology	(Lanphen, 2019)
	Energy Transition & Policy Support	M.Sc. thesis, Delft University of Technology	(Lanphen, 2019)

Port capabilities considerations	Logistics & Connectivity	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		M.Sc. thesis, Delft University of Technology	(Lanphen, 2019)
	Energy Supply & Integration	The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
	Port accessibility and geographical location	The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		M.Sc. thesis, Delft University of Technology	(Lanphen, 2019)
	Technological Innovation in Hydrogen Handling	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		ADIPEC Conference, Abu Dhabi, United Arab Emirates	(Peace et al., 2023)
		18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
	Hydrogen Handling Infrastructure	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
		18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
	Port Throughput & Capacity	18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
Economic and financial considerations	Costs & Financial Viability	The National Renewable Energy Laboratory (NREL)	(Semchukova et al., 2024)
		ADIPEC Conference, Abu Dhabi, United Arab Emirates	(Peace et al., 2023)
		18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
		M.Sc. thesis, Delft University of Technology	(Lanphen, 2019)
	Hydrogen Supply Chain Economics	ADIPEC Conference, Abu Dhabi, United Arab Emirates	(Peace et al., 2023)
		18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)
	Market Demand & Supply Chain	Hydrogen, Volume 5 (2024)	(Chen et al., 2024)
		M.Sc. thesis, Delft University of Technology	(Lanphen, 2019)
	Stakeholder Collaboration	18th International Conference on the European Energy Market (EEM)	(Brauer et al., 2022)

Source: Author

Key stakeholders maintain a strong emphasis on the prioritization of implementing standards and regulations, particularly with safety and environmental issues, as these variables significantly influence the terminal project from the design phase through to operation. The secondary goal for the principal stakeholder in port capabilities is to facilitate the adoption of standards and regulations, as well as to address economic and financial concerns that ensure project funding and guarantee project ROI.

The study employed a limited sample of 28 participants and a small number of variables via a questionnaire, which represents a research limitation, particularly for an emerging sector such as the hydrogen business. Consequently, it is advisable to do additional studies utilizing a larger sample through interviews and questionnaires that incorporate a broader range of variables.

6. Conclusion

The research provided a comprehensive evaluation of 14 critical factors that influence the port selection to develop a hydrogen export terminal. Challenges of operation and safety, regulatory compliance, environmental impact, and port logistics connectivity are highlighted in the findings as the stakeholders' highest priority. These factors underscore the significance of robust safety systems, qualified staff, and stringent compliance with environmental regulations in the management of hydrogen-related processes. Moreover, stakeholders emphasized port capabilities, including port accessibility and geographic location, hydrogen handling technology, access to renewable energy resources, and needed infrastructure. These capabilities support the port effectively from production to export. Furthermore, the research highlights the importance of investment capability and integration with the global market supply chain to ensure economic and financial viability. Key stakeholders confirm a growing general agreement on the essential requirement of port modernization to accommodate a hydrogen export terminal.

References

Aghakhani, A. *et al.* (2024) 'Hydrogen transportation and distribution', in *Towards Hydrogen Infrastructure*. Elsevier, pp. 187–224. Available at: https://doi.org/10.1016/B978-0-323-95553-9.00003-0.

Al-Breiki, M. and Bicer, Y. (2020) 'Comparative cost assessment of sustainable energy carriers produced from natural gas accounting for boil-off gas and social cost of carbon', *Energy Reports*, 6, pp. 1897–1909. Available at: https://doi.org/10.1016/j.egyr.2020.07.013.

Alkhalidi, A., Khawaja, M.K. and Abusubaih, D. (2020) 'Energy efficient cooling and heating of aquaponics facilities based on regional climate', *International Journal of Low-Carbon Technologies*, 15(2), pp. 287–298. Available at: https://doi.org/10.1093/ijlct/ctz053.

Amos, W.A. (1999) *Costs of Storing and Transporting Hydrogen*. Golden, CO (United States). Available at: https://doi.org/10.2172/6574.

Ariful Islam, Md. *et al.* (2025) 'Mitigation of environmental impacts and challenges during hydrogen production', *Bioresource Technology*, 415, p. 131666. Available at: https://doi.org/10.1016/j.biortech.2024.131666.

Ashrafi, M. *et al.* (2020) 'A review of corporate sustainability drivers in maritime ports: a multi-stakeholder perspective', *Maritime Policy & Management*, 47(8), pp. 1027–1044. Available at: https://doi.org/10.1080/03088839.2020.1736354.

Benghanem, M. *et al.* (2023) 'Hydrogen Production Methods Based on Solar and Wind Energy: A Review', *Energies*, 16(2), p. 757. Available at: https://doi.org/10.3390/en16020757.

Brauer, J., Truby, J. and Villavicencio, M. (2022) 'Establishing low-carbon hydrogen trade relations - where to go and who to partner with?', in *2022 18th International Conference on the European Energy Market (EEM)*. IEEE, pp. 1–6. Available at: https://doi.org/10.1109/EEM54602.2022.9921065.

Calvin, K. *et al.* (2023) *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.* Available at: https://doi.org/10.59327/IPCC/AR6-9789291691647.

Chang, C.-C., Huang, P.-C. and Tu, J.-S. (2019) 'Life cycle assessment of yard tractors using hydrogen fuel at the Port of Kaohsiung, Taiwan', *Energy*, 189, p. 116222. Available at: https://doi.org/10.1016/j.energy.2019.116222.

Chen, P.S.-L. *et al.* (2023) 'A review on ports' readiness to facilitate international hydrogen trade', *International Journal of Hydrogen Energy*, 48(46), pp. 17351–17369. Available at: https://doi.org/10.1016/j.ijhydene.2023.01.220.

Chen, P.S.-L. *et al.* (2024) 'Opportunities and Challenges of Hydrogen Ports: An Empirical Study in Australia and Japan', *Hydrogen*, 5(3), pp. 436–458. Available at: https://doi.org/10.3390/hydrogen5030025.

d'Amore-Domenech, R. *et al.* (2023) 'On the bulk transport of green hydrogen at sea: Comparison between submarine pipeline and compressed and liquefied transport by ship', *Energy*, 267, p. 126621. Available at: https://doi.org/10.1016/j.energy.2023.126621.

Deloitte (2023) 'Study on hydrogen in ports and industrial coastal areas – Reports'. Available at: https://www.clean-hydrogen.europa.eu/media/publications/study-hydrogen-ports-and-industrial-coastal-areas-reports_en.

Diaconu, M.G. and Temeljotov Salaj, A. (2024) 'Enhancing Innovation in Higher Education Institutions: Barriers, Actions and Strategic Instruments for Sustainable Innovation', *European Conference on Innovation and Entrepreneurship*, 19(1), pp. 148–157. Available at: https://doi.org/10.34190/ecie.19.1.2619.

Edgerton, M. (2021) 'Port and Maritime Security and Sustainability', in, pp. 155–167. Available at: https://doi.org/10.1007/978-3-030-69325-1_8.

Elkhatib, R., Kaoutari, T. and Louahlia, H. (2024) 'Green hydrogen energy source for a residential fuel cell micro-combined heat and power', *Applied Thermal Engineering*, 248, p. 123194. Available at: https://doi.org/10.1016/j.applthermaleng.2024.123194.

Fages, E. *et al.* (2024) 'Ports and green hydrogen: Match made in heaven?' Roland Berger GmbH. Available at: https://www.rolandberger.com/en/Insights/Publications/Ports-and-green-hydrogen-Match-made-in-heaven.html.

Fan, H. *et al.* (2024) 'Comparative study of LNG, liquid hydrogen, and liquid ammonia post-release evaporation and dispersion during bunkering', *International Journal of Hydrogen Energy*, 65, pp. 526–539. Available at: https://doi.org/10.1016/j.ijhydene.2024.04.039.

GRETZ, J. *et al.* (1994) 'Status of the hydro-hydrogen pilot project (EQHHPP)', *International Journal of Hydrogen Energy*, 19(2), pp. 169–174. Available at: https://doi.org/10.1016/0360-3199(94)90123-6.

Guan, W. *et al.* (2023) 'Safe Design of a Hydrogen-Powered Ship: CFD Simulation on Hydrogen Leakage in the Fuel Cell Room', *Journal of Marine Science and Engineering*, 11(3), p. 651. Available at: https://doi.org/10.3390/jmse11030651.

Hao, G. *et al.* (2024) 'Current Status and Challenges in the Development of Hydrogen Transmission Pipeline Technology', *E3S Web of Conferences*, 598, p. 02008. Available at: https://doi.org/10.1051/e3sconf/202459802008.

Hong, X. *et al.* (2021) 'Techno-enviro-economic analyses of hydrogen supply chains with an ASEAN case study', *International Journal of Hydrogen Energy*, 46(65), pp. 32914–32928. Available at: https://doi.org/10.1016/j.ijhydene.2021.07.138.

Intergovernmental Panel on Climate Change (IPCC), Climate Change 2021 – The Physical Science Basis (2023). Cambridge University Press. Available at: https://doi.org/10.1017/9781009157896.

Ishimoto, Y. *et al.* (2020) 'Large-scale production and transport of hydrogen from Norway to Europe and Japan: Value chain analysis and comparison of liquid hydrogen and ammonia as energy carriers', *International Journal of Hydrogen Energy*, 45(58), pp. 32865–32883. Available at: https://doi.org/10.1016/j.ijhydene.2020.09.017.

Ives, M. (2020) 'Financial Statement Analysis', in *Encyclopedia of Public Administration and Public Policy, Third Edition*. Routledge, pp. 1–7. Available at: https://doi.org/10.1081/E-EPAP3-120043335.

James, N. and Menzies, M. (2023) 'Distributional Trends in the Generation and End-Use Sector of Low-Carbon Hydrogen Plants', *Hydrogen*, 4(1), pp. 174–189. Available at: https://doi.org/10.3390/hydrogen4010012.

Javadi, M. and Zarea, K. (2016) 'Understanding Thematic Analysis and its Pitfall', *Journal of Client Care*, 1(1). Available at: https://doi.org/10.15412/J.JCC.02010107.

Jayakumar, A. *et al.* (2022) 'Can hydrogen be the sustainable fuel for mobility in India in the global context?', *International Journal of Hydrogen Energy*, 47(79), pp. 33571–33596. Available at: https://doi.org/10.1016/j.ijhydene.2022.07.272.

Judkins, M. and O'Brien, J. (2019) 'Australian and Global hydrogen Demand Growth Scenario analysis.', *Deloitte* [Preprint]. Available at: https://www.dcceew.gov.au/sites/default/files/documents/nhs-australian-and-global-hydrogen-demand-growth-scenario-analysis-report-2019.pdf (Accessed: 10 May 2004).

Kamiya, S., Nishimura, M. and Harada, E. (2015) 'Study on Introduction of CO2 Free Energy to Japan with Liquid Hydrogen', *Physics Procedia*, 67, pp. 11–19. Available at: https://doi.org/10.1016/j.phpro.2015.06.004.

Kim, Jungwoog *et al.* (2024) 'Technical feasibility of large-scale transportable liquid hydrogen export terminal', *International Journal of Hydrogen Energy*, 66, pp. 499–511. Available at: https://doi.org/10.1016/j.ijhydene.2024.03.343.

Krpan, L. *et al.* (2023) 'Application of Multicriteria Analysis in the Selection of the LNG Terminal Location', *Naše more*, 70(4), pp. 210–218. Available at: https://doi.org/10.17818/NM/2023/4.3.

Lanphen, S. (2019) 'Hydrogen Import Terminal: Providing insights in the cost of supply chain elements of various hydrogen carriers for the import of hydrogen '. Available at: https://repository.tudelft.nl/islandora/object/uuid%3Ad2429b05-1881-4e42-9bb3-ed604bc15255.

De Martino, M. (2014) 'Sustainable Development Strategies of the Port Authority: The Network Approach', *Advanced Engineering Forum*, 11, pp. 87–95. Available at: https://doi.org/10.4028/www.scientific.net/AEF.11.87.

'News & Events, Kawasaki obtains AIP for large, 160,000m3 liquefied hydrogen carrier' (2022). Available at: https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20220422_3378.

Notardonato, W.U. *et al.* (2017) 'Final test results for the ground operations demonstration unit for liquid hydrogen', *Cryogenics*, 88, pp. 147–155. Available at: https://doi.org/10.1016/j.cryogenics.2017.10.008.

Noussan, M. *et al.* (2020) 'The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective', *Sustainability*, 13(1), p. 298. Available at: https://doi.org/10.3390/su13010298.

Obaidat, M. *et al.* (2018) 'Energy and Exergy Analyses of Different Aluminum Reduction Technologies', *Sustainability*, 10(4), p. 1216. Available at: https://doi.org/10.3390/su10041216.

Paulauskas, Vytautas, Paulauskas, D. and Paulauskas, Vytas (2023) 'Impact of Port Clearance on Ships Safety, Energy Consumption and Emissions', *Applied Sciences*, 13(9), p. 5582. Available at: https://doi.org/10.3390/app13095582.

Peace, C., Campbell, D. and Shen, W. (2023) 'Green Hydrogen Export – Technical Readiness of Jetty-Less Marine Loading Terminals', in *ADIPEC*. SPE. Available at: https://doi.org/10.2118/216910-MS.

Pekic, S. (2022) 'Suiso Frontier brings world's 1st LH2 shipment to Japan'. Available at: https://www.offshore-energy.biz/suiso-frontier-brings-worlds-1st-lh2-shipment-to-japan/.

Puig, M. and Darbra, R.M. (2019) 'The Role of Ports in a Global Economy, Issues of Relevance and Environmental Initiatives', in *World Seas: An Environmental Evaluation*. Elsevier, pp. 593–611. Available at: https://doi.org/10.1016/B978-0-12-805052-1.00034-6.

Raab, M., Maier, S. and Dietrich, R.-U. (2021) 'Comparative techno-economic assessment of a large-scale hydrogen transport via liquid transport media', *International Journal of Hydrogen Energy*, 46(21), pp. 11956–11968. Available at: https://doi.org/10.1016/j.ijhydene.2020.12.213.

Ratnakar, R.R. *et al.* (2021) 'Hydrogen supply chain and challenges in large-scale LH2 storage and transportation', *International Journal of Hydrogen Energy*, 46(47), pp. 24149–24168. Available at: https://doi.org/10.1016/j.ijhydene.2021.05.025.

'Revised Basic Hydrogen Strategy Offers No Clear Path to Carbon Neutrality | Position Paper | Renewable Energy Institute' (2022). Available at: https://www.renewable-ei.org/en/activities/reports/20230720.php.

Roos, T.H. (2021) 'The cost of production and storage of renewable hydrogen in South Africa and transport to Japan and EU up to 2050 under different scenarios', *International Journal of Hydrogen Energy*, 46(72), pp. 35814–35830. Available at: https://doi.org/10.1016/j.ijhydene.2021.08.193.

Saadi, F.H., Lewis, N.S. and McFarland, E.W. (2018) 'Relative costs of transporting electrical and chemical energy', *Energy & Environmental Science*, 11(3), pp. 469–475. Available at: https://doi.org/10.1039/C7EE01987D.

Saieva, G. (2013) *Port Management and Operations*. Informa Law from Routledge. Available at: https://doi.org/10.4324/9780203796689.

Semchukova, V. *et al.* (2024) *Hydrogen Infrastructure Analysis for the Port Applications [Slides]*. Golden, CO (United States). Available at: https://doi.org/10.2172/2459327.

Sharma, M. *et al.* (2024) 'Green Hydrogen and Climatic Change: Current Status and Future Outlook', in, pp. 31–54. Available at: https://doi.org/10.1021/bk-2024-1474.ch002.

Sonia Froufe, Charles–Henri Fredouet and Mame Gningue (2014) 'Expertise modeling and transportation risk management: an application to container transportation security risk management', *Journal of International Logistics and Trade*, 12(1), pp. 75–97. Available at: https://doi.org/10.24006/jilt.2014.12.1.004.

Spatolisano, E. *et al.* (2024) 'Assessing opportunities and weaknesses of green hydrogen transport via LOHC through a detailed techno-economic analysis', *International Journal of Hydrogen Energy*, 52, pp. 703–717. Available at: https://doi.org/10.1016/j.ijhydene.2023.08.040.

Superchi, F. *et al.* (2023) 'Techno-economic analysis of wind-powered green hydrogen production to facilitate the decarbonization of hard-to-abate sectors: A case study on steelmaking', *Applied Energy*, 342, p. 121198. Available at: https://doi.org/10.1016/j.apenergy.2023.121198.

Walsh, S.D.C. *et al.* (2021) 'Evaluating the economic fairways for hydrogen production in Australia', *International Journal of Hydrogen Energy*, 46(73), pp. 35985–35996. Available at: https://doi.org/10.1016/j.ijhydene.2021.08.142.

Wang, A. *et al.* (2020) 'European Hydrogen Backbone: HOW A DEDICATED HYDROGEN INFRASTRUCTURE CAN BE CREATED', *www.h2knowledgecentre.com* [Preprint]. Available at: https://www.h2knowledgecentre.com/content/researchpaper1676.

Wang, A. *et al.* (2021) 'Analysing Future Demand, Supply, and Transport of Hydrogen', *European Hydrogen Backbone* [Preprint], (June).

Xu, S. *et al.* (2024) 'Optimum investment strategy for hydrogen-based steelmaking project coupled with multiple uncertainties', *Journal of Environmental Management*, 356, p. 120484. Available at: https://doi.org/10.1016/j.jenvman.2024.120484.

Maritime Research and Technology
MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2025.04.2.1346

The Impact of Implementing Digital Transformation Requirements on the Performance of Ports in Accordance with Sustainable Development Requirements

Nabil Abdullah Bin Aifan [1], Mahmoud Al Sayed AlBawab [2], and Alaa Mahmoud Morsi [3]

[1] Deputy General Manager of the Maritime Affairs Authority, Hadhramaut, Yemen.
[2] Arab Academy for Science, Technology & Maritime Transport, Maritime Education and Training, Egypt.
[3] Arab Academy for Science, Technology & Maritime Transport, The Port Training Institute and Research Center, Egypt.

Emails: nnn5582@gmail.com, elbawab@gmail.com, alaamorsy@aast.edu

Received: 13 May 2025 Accepted: 26 June 2025 Published: 11 September 2025

Abstract

The maritime transport industry is vital to global trade, accounting for approximately 90% of cargo movement, with container transport representing 35% of volume and over 60% of cargo value. Seaports play a crucial role in national economic Development by attracting investment, generating foreign exchange, and fostering competitive economic activities. Port development efforts increasingly emphasize the adoption of new technologies, economic diversification, innovation, and alignment with global best practices, in accordance with the Sustainable Development Goals (SDGs).

Digital transformation is becoming prevalent in port development, with many ports undergoing partial or full digitalization. Advanced technologies enhance productivity and operational efficiency, enabling port authorities to function as digital service providers through tailored solutions for strategic planning and real-time monitoring.

This study addresses the research problem of poor performance and low productivity at the Aden container terminal, compounded by inadequate implementation of digital transformation and sustainable development requirements. Employing a descriptive analytical methodology, data were collected and analyzed through an electronic questionnaire. The findings highlight the urgent need to enhance terminal performance by drawing on the experiences of successful regional ports and fully integrating sustainable development principles, particularly digital transformation initiatives.

Keywords:

Sustainable Development, Digital transformation, Aden container terminal.

1. Introduction

The maritime transport sector constitutes the foundation of international commerce, providing the most cost-effective means of conveyance (World Bank, 2023). This industry is responsible for transporting approximately 90% of global trade (IMO.2024), with containerized shipping comprising 35% of total cargo volume and exceeding 60% of its monetary value (World Bank. 2023). Seaports play a crucial role in facilitating national economic growth and serve as essential hubs for fostering competitive business activities (Gurumurthy. 2019).

Port development has experienced significant acceleration over the past three decades, primarily driven by population growth, economic expansion, foreign trade, and containerized transport (Jolly, 2016). Ports have demonstrated resilience, even during severe disruptions. Throughout the COVID-19 pandemic, ports have fulfilled a pivotal role in global transport by ensuring the continuous delivery of medical supplies, food, energy, raw materials, and manufactured goods and components (Alamoush, 2021).

Aden container terminals faces challenges related to reduced operational capacity and urgently require investment packages to maintain their current operational levels (UNDP. 2021). Despite its strategic location near international maritime routes and proximity to the Bab al Mandab Strait, which is only 110 nautical miles away (Qardash. 2021), the port performance remains suboptimal.

This weakness necessitates a thorough study of ports to identify the pathways for their Development, making them key drivers of national economic growth. The implementation of sustainable development requirements as a modern approach enhances the economic performance of ports (Lim, 2019), improving efficiency and contributing to economic prosperity, environmental quality, and social responsibility (ESCAP., 2020). Additionally, integrating digital transformation requirements into port operations, along with investments in sustainable technologies, can improve maritime transport efficiency and help address the challenges associated with port operations (Christodoulou, 2021).

The importance of this research lies in addressing the limitations and deficiencies in the performance and productivity of the Aden container terminal and its limited focus on digital transformation and sustainable Development. This study leverages specialized reports, comparative analyses of successful ports in the region, and survey-based evaluations of Yemeni port specialists and workers. This research aims to assess the current situation, propose actionable solutions, and develop strategies for improvement.

2. Significance and objectives

This study addresses the underperformance and low productivity of the Aden container terminal by exploring sustainable development and digital transformation as a means of enhancing its operations. It also aims to raise awareness of the terminal's strategic importance and contribute to Arabic maritime research.

The research aims to evaluate the current status and challenges of the Aden terminal, assess digital transformation implementation, analyze its impact on performance, and propose recommendations based on regional best practices.

3. Research problem

The Development and continuous improvement of seaports are critical steps toward enhancing their performance, positioning them as drivers of national economic Development, and enabling them to compete with neighboring ports. Achieving this would secure their place among successful ports regionally and globally. However, the research problem lies in the fact that the Aden container terminal suffers from poor performance, low productivity, and limited adoption of mechanisms for container terminal development in alignment with sustainable development requirements. This has led to significant inefficiencies and reduced productivity.

In 2021, the Aden container terminal handled 418,711 containers. This number decreased to 365,470 containers in 2022 and further declined to 282,652 containers in 2023. Similarly, the berth occupancy rate at the terminal also decreased, reaching 42% in 2021, 35% in 2022, and dropping further to 29% in 2023. The yard utilization rate followed the same trend, declining from 62% to 43% during the same period.

These statistics indicate a significant operational deficiency and a clear weakness that poses a substantial future challenge. This underperformance directly affects the future of Yemen's maritime transport sector and national economy as a whole. Furthermore, it raises concerns regarding the ability of the state and its maritime sector to meet the current and future requirements of the global maritime transport industry. Therefore, this situation requires thorough attention and studies to identify and implement appropriate solutions.

4. Literature review

Sustainable development requirements hold significant importance for seaports, as aligning port functions with sustainable development goals is essential (ESCAP., 2020). Progress toward sustainable development goals can be achieved by improving resource efficiency, adopting cleaner and more environmentally friendly industrial technologies and processes, and ensuring countries take action according to their capacities (ESCAP., 2020). According to the World Ports Sustainability Program (WPSP), implementing sustainability focuses on six essential elements, including digitalization applications and capacity building (WPSP, 2020).

Implementing port digitalization contributes to providing better services, generating added value, improving operational efficiency, reducing costs, facilitating trade, increasing transparency, and attracting new business entities (Gurning. 2019); (Mudronja. 2020) Digital transformation in ports is currently the most widely adopted strategy for port development (ESCAP. 2020) The digitalization of ports is also expected to attract global digital operators, such as Amazon and Alibaba, into port operations, while traditional operators, such as Maersk, will incorporate AI-based components into their operations to maintain competitive advantages (Gurumurthy et al. 2019).

Port digitalization is also linked to workforce restructuring (ESCAP., 2020). Contemporary port digitalization requires fewer workers but allows flexibility in performing diverse tasks (Vaggelas, 2020). Therefore, consultations with workers are critical because transitioning from manual labor to skill-based roles requires new capabilities, specific training plans, and certifications, as well as a highly skilled workforce to ensure port efficiency (Vaggelas, 2020). However, port clients have expressed concerns about certain digital port services, citing negative effects such as reduced employment opportunities, risks of power disruptions, unstable Internet connectivity, cybercrimes, difficulties in repairing semi-automated equipment, and increased investments. These concerns necessitate the implementation of digitalization requirements at the highest possible standards (Gurning, 2019).

Explored the effectiveness of digital transformation in port operations and trade by gathering the opinions of 600 port users. The study concludes that digitalization enhances service performance, creates added value, improves efficiency, and provides better operational control. However, port users have raised concerns about employment, costs, and digital transactions.

Similarly, Gurumurthy et al. 2019) emphasized the necessity of automation for Indian ports. The study surveyed 700 users across 14 ports and revealed dissatisfaction due to insufficient digital infrastructure. This study predicts that the sector will witness the involvement of global digital operators and the use of AI-driven services by shipping companies.

5. Methodology

The research adopts a descriptive analytical approach, which focuses on describing the characteristics of the research sample, collecting relevant data, and analyzing the variables and dimensions of the study. This method is employed to achieve the research objectives, provide data and facts regarding the research problem, interpret the findings, answer the research questions, and test the hypothesis.

The study relies on data collected through a questionnaire, which will be analyzed to derive the necessary conclusions. This approach was chosen because it is the most suitable methodology for studying social science research and addressing the complexities of the research problem.

6. The role of Sustainable Development requirements in enhancing port performance

The 2030 Agenda for Sustainable Development, adopted by all United Nations member states in 2015, provides a shared blueprint for peace and prosperity for people and the planet, both now and in the future, through its 17 Sustainable Development Goals (SDGs) (UN, 2023). These goals address a broad range of global challenges, including sustainable economic growth and environmental preservation (UNDP., 2018). Sustainable Development is defined as meeting the needs of the present without compromising the ability of future generations to meet their needs. It has emerged as a guiding principle for global progress, aiming to achieve economic Development, social Development, and environmental protection in a balanced manner (UN, 2023).

In the maritime transport and port industries, sustainable Development refers to business strategies and activities that meet current and future port needs. Sustainable practices in port operations involve strategic and operational approaches. This involves the simultaneous pursuit of economic prosperity, environmental quality, social responsibility, and operational feasibility (Kim, 2014).

Sustainable port development enhances maritime transport efficiency and competitiveness by fostering stakeholder collaboration, aligning operations, and supporting informed decision-making. It improves port performance through cooperative strategies that boost both efficiency and competitive advantage (Christodoulou et al., 2021).

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2025.04.2.1346

6.1. The World Ports Sustainability Program (WPSP)

The World Ports Sustainability Program (WPSP) was established on May 12, 2017, and it is managed by the International Association of Ports and Harbors (IAPH), guided by the United Nations' 17 Sustainable Development Goals (SDGs) (IAPH, 2024). The program enhances and coordinates the future sustainability efforts of ports worldwide, while promoting international cooperation with supply chain partners (IAPH. 2024).

The establishment of the WPSP fulfills multiple roles, including acting as a knowledge hub for consultation among participants in supply chain operations. The program also serves as a research center, where innovative ideas and philosophies surrounding sustainable ports, including the economic factors influencing sustainability, are translated into practical methods for designing, managing, and operating ports effectively.

The WPSP identifies six essential elements for sustainable port development: infrastructure, digitalization, health, safety, security, environmental care, community engagement, and climate and energy. Digitalization is central to improving operational efficiency through innovative applications, stakeholder data sharing, streamlined processes, enhanced communication, and smart-port systems such as port community systems and single maritime windows (WPSP, 2024).

7. Digital transformation requirements in ports

The term "digital transformation" or "Digitalization" refers to the adoption or increased use of digital or computational technologies by an organization, industry, or country as a primary operational trend. Digitalization is a dynamic process that reshapes the factors of production and productivity during the fourth industrial revolution. This is driven by the rapid Development of big data, cloud computing, artificial intelligence, and other next-generation information technologies (Sun., 2021).

The application of digital transformation requirements to port development has become increasingly popular. New port projects will be partially or fully digitalized, and fully digital ports have already become a reality (Gurumurthy et al.2019). The COVID-19 pandemic has accelerated this digitalization trend, enabling ports to continue operations while minimizing physical interaction and contact. It has also spurred the rise of new technologies and online trade, which has changed consumer shopping habits and spending patterns. As a result, investing in digital infrastructure has become crucial for effective information exchange and resource planning, helping to solve many challenges faced by the maritime transport and port industries (UNCTAD, 2021). According to the World Ports Sustainability Program, digital transformation in ports is linked to several Sustainable Development Goals (SDGs), specifically, Goals 17, 11, 9, 8, and 4 (WPSP, 2024).

Several cutting-edge technologies have driven the maritime industry beyond its traditional limits and have created new opportunities to enhance productivity and efficiency. (UNCTAD. 2021).

Several systems play a crucial role in modern ports, including Port Community Systems (PCS), maritime single windows (MSW), Terminal Operating Systems (TOS), Vessel Traffic Services (VTS), and Port Management Information Systems (PMIS) (IMO, 2023). These systems streamline operations and enhance port management efficiency. Figure 1 below illustrates the systems currently in use in maritime ports.

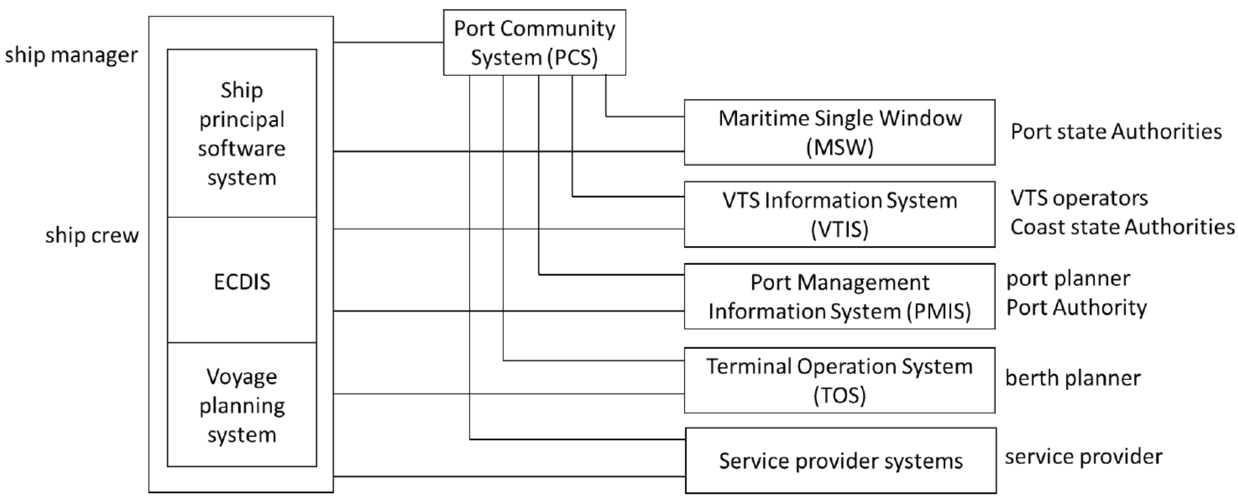

Figure 1: Diagram of Systems in Use in Ships and Seaports.
Source: (IMO 2023)

7.1. Challenges facing ports in implementing digital transformation requirements

Cybersecurity:

Cybersecurity is considered the most critical factor hindering digital transformation operations. Cyber risk management can be defined as the process of identifying, analyzing, evaluating, and communicating internet-related risks, and either avoiding, transferring, or mitigating them to an acceptable level, considering the costs and benefits of the measures taken. This involves necessary steps to protect devices and systems from unauthorized access or attacks. (Aboul Dahab. 2020).

High capital expenditure for digital transformation implementation:

Although ports have adopted technology and digitization more slowly than similar sectors, the pace of adoption has begun to accelerate. Automated ports are safer than traditional ports (Chu et al.2018). However, digitization is not without difficulties, particularly in the early stages of adoption. (Brunila et al. 2021) Initial capital expenditures are exceedingly high (Chu et al.2018), but the impact of digitization on competitiveness is a matter of maturity, especially in the early stages. Economic gains are expected to be significantly higher for early adopters than for latecomers; however, over time, these differences will decrease as technologies mature and become more affordable. Digitization in ports is applied in phases within the context of port operations. (Brunila et al.2021).

Staff capability shortage and fear of job loss:

Advances in port digitization have allowed operations to be conducted with fewer workers possessing skills suitable for digital transformation applications. (Prism. 2019) A report from the World Maritime University (WMU) highlights the impact of technological change on maritime workers' future employment prospects. According to the report, port workers and crane operators will no longer have jobs in their current form by 2040. (Schröder et al.2019) Some ports using digitization applications have shown that workforce reduction can be limited but requires a set of skills different from those of traditional terminals. Lack of capabilities is one of the main barriers hindering successful port automation. (Schröder et al.2019).

Multiple stakeholders involved in port digital transformation:

One of the challenges that some ports still face in using digital systems or find difficult to implement is the large volume of information and the numerous parties involved in port digitization efforts. (Bourish 2017).

8. Developing container terminal performance

The pursuit of performance measurement is critical for ports to organize their operations efficiently and effectively. Performance refers to the execution of port activities in a way that meets the goals and fulfills the expectations of port customers while operating within an economic context and broader port structures. (Notteboom et al.2022) Performance measurement has gained strong ground in contemporary port management, as intense competition and involvement in supply chains have made port performance measurement crucial. It is essential for a port to compare its performance with that of its competitors. (Vaggelas.2019) Performance measurement organizes the use of available resources and planning for their expansion, as well as the interactions between ports and their users, to improve the services provided. Performance measurement results help ports achieve their defined objectives. (Notteboom et al.2022).

Evaluating port performance presents a significant challenge, as it encompasses various dimensions, ranging from service quality and value for money to return on investment and economic efficiency, with a vast array of performance evaluation criteria. (UNCTAD 2023).

Performance evaluation generally involves considering multiple inputs and outputs to assess efficiency. This requires data analysis that aligns well with the strategic goal and the context of each region. This requires ports with a wide range of data to allow for various types of analysis across multiple dimensions. (Nong 2023).

According to the United Nations Conference on Trade and Development (UNCTAD), port performance indicators comprise seven categories: financial, human resources, vessel operations, cargo operations, governance, resilience, and environmental sustainability. The inclusion of sustainability indicators in performance evaluation is vital for their importance. (UNCTAD 2023).

9. Discussion and findings

Yemen Gulf of Aden Ports Corporation (YGAPC) was established under presidential decree No. (61) in 2007, replacing the Yemen Ports Authority in Aden. The corporation includes several key components, such as the Aden container terminal, as well as the quay for ship handling in Ma'alla Port, Small Aden Areas, Khur Makser, Tawahi, and the internal basin of Aden Port (Decree of the Corporation Establishment.2007).

The Aden container terminal (ACT) was officially inaugurated in 1999, and it represents 70% of the port's activity. The Port is located on the northern shore of Aden Port, handling transit cargo and import/export containers for the local market. It has been operated by various global container terminal operators, and since September 20, 2012, it has been managed by Yemen Ports Development Company, a national Yemeni company. (YGAPC 2023)

The terminal is located in a vast area that will be used as backup support for the port's activities. It is also close to international navigation routes, with only four nautical miles away and 110 nautical miles from the Bab al Mandab Strait, which is the southern gateway to the Red Sea. It is a strategic location for all ships passing through Southeast Asia and Europe, via the Middle East. (YGAPC 2023)

Table 1: Aden Container Terminal Statistics (2020 -2022).

Details	2020	2021	2022
Number of Container Ships	123	152	163
Loaded Containers	210,387	213,523	181,182
Unloaded Containers	213,006	205,188	187,316
Total Containers Handled	423,393	418,711	368,498

Source: (YGAPC 2023)

Aden Container Terminal requires an update of the technology used within it by assessing technological needs and replacing outdated equipment and systems with advanced modern technologies. In addition, it is essential to improve information systems, automation, and necessary devices and equipment for container operations (Hafez et al., 2023). There is a significant technological gap between Aden Container Terminal and neighboring competitive ports. The terminal lacks several systems implemented in competing ports, such as remote sensing devices, electronic gates, and renewable energy sources. It also does not apply the ISO energy management requirements.

The terminal uses the Zodiac system, which is outdated compared with the advanced Zodiac programs used in container terminals. This system lacks the features present in other systems, such as electronic customer integration, which allows them to perform transactions, issue invoices, make electronic payments, and more (Amzarbah.2023).

10. Study population and field sample

In light of the main objective of the field study, which aims to identify the impact of implementing sustainable development requirements on the performance of seaports, with application to the Aden container terminal, the study population included officials at the Aden container terminal, employees of the Yemen Ports Authority at the level of section head and above, maritime experts, captains, and marine engineers.

The questionnaire's reliability was measured using Cronbach's alpha, yielding a coefficient of 0.82, which exceeds the acceptable threshold of 0.70, indicating high internal consistency. Reliability analysis of each dimension, through item deletion and Corrected Item-Total Correlation, showed that removing any item reduced reliability, confirming the importance of all items. All item correlations were above 0.30, demonstrating satisfactory consistency.

The questionnaire was electronically distributed to the targeted study population in August 2024, considering the characteristics and variables of the original population. The researcher obtained 219 complete responses. The study sample can be described based on primary characteristics (job rank, years of experience, and qualifications), as presented in Table 1.

Table 2: Description of the Study Sample Based on Primary Data.

Variable	Count	Percentage
Job Rank:		
Employees	57	26.03%
Captain or Marine Engineer	45	20.55%
Section Head	35	15.98%
Department Manager	42	19.18%
General Manager	40	18.26%
Years of Experience:		
Less than 10 years	60	27.40%
10 to 20 years	70	31.96%
More than 20 years	89	40.64%
Educational Qualification:		
High School	13	5.94%
Bachelor's Degree	110	50.23%
Diploma	17	7.76%
Master's Degree	61	27.85%
Doctorate	18	8.22%
Total Study Sample	219	100.00%

10.1. The study sample description, as detailed in Table 1, reveals the following:

- **Job Rank Variable:** The study sample includes 57 employees (26.03%), 45 captains or marine engineers (20.55%), 35 section heads (15.98%), 42 department managers (19.18%), and 40 general managers (18.26%).

- **Years of Experience Variable:** The study sample includes 60 participants with less than 10 years of experience (27.4%), 70 participants with 10–20 years of experience (31.96%), and 89 participants with more than 20 years of experience (40.64%).

- **Educational Qualification Variable:** The study sample includes 13 participants with high school qualifications (5.94%), 110 with a bachelor's degree (50.23%), 17 with a diploma (7.76%), 61 with a master's degree (27.85%), and 18 with a doctorate (8.22%).

10.2. Questionnaire design

The questionnaire was designed electronically using Google Forms, a tool from Google and one of the most popular platforms for creating questionnaires. The questionnaire items were developed using the five-point Likert Scale, a widely used tool for surveys, data collection, and scientific studies.

The Likert Scale was introduced by Rensis Likert in 1935. This scale requires the items to be interrelated and targeted toward measuring the intended attribute (Al Lami, 2021).

10.3. Results related to sustainable development requirements

The degree of fulfillment for sustainable development requirements achieved a "very high" level with a mean score of 4.31. The confidence interval for the mean score at a 95% confidence level ranged between 4.27 and 4.36, confirming that sustainable development requirements fall within the "very high" level.

10.4. Results related to the digital transformation requirements

According to the study sample, the degree of fulfillment for applying the digital transformation requirements achieved a "very high" level, with a mean score of 4.28. The mean scores for the individual items ranged from 3.88 to 4.53, indicating that all items were achieved at a "high" or "very high" level. The items were ranked in descending order by mean scores as follows:

1. The availability of qualified human resources in technology contributes to implementing digital transformation at the terminal, with a mean score of 4.53 and a standard deviation of 0.60.

2. The availability of digital infrastructure at the terminal contributes to service efficiency and performance improvement, with a mean score of 4.45 and a standard deviation of 0.58.

3. Implementing the single window system at the terminal contributes to improving service efficiency and performance, with a mean score of 4.34 and a standard deviation of 0.61.

4. Implementing the Port Community System at the terminal contributed to improving service efficiency and performance, with a mean score of 4.32 and a standard deviation of 0.61.

5. Employee encouragement contributes to implementing digital transformation requirements at the terminal, with a mean score of 4.27 and a standard deviation of 0.56.

6. Encouraging stakeholders—governmental and private institutions—to contribute to implementing digital transformation requirements at the terminal, with a mean score of 4.15 and a standard deviation of 0.61.

7. The terminal has sufficient financial resources to implement digital transformation requirements, with a mean score of 3.88 and a standard deviation of 0.77.

The results regarding the implementation of digital transformation requirements indicate that qualified human resources are ranked first, followed by digital infrastructure. The implementation of the Single Window System and the Port Community System comes next in importance, highlighting the participants' belief in the critical role of these systems for achieving digital transformation in port operations. This emphasizes the need to prioritize human resources and digital infrastructure while ensuring the effective adoption of key systems to enhance operational efficiency and competitiveness.

Employee and stakeholder encouragement ranked fifth and sixth, respectively, in supporting digital transformation requirements. Lastly, financial resources ranked the lowest, which is unexpected because financial support is typically among the most critical factors. However, this result suggests that when qualified personnel and digital infrastructure are in place, the foundational pillars for digital transformation have already been established.

11. Conclusions

1. The Aden container terminal (ACT) has a strategic geographical location, situated only four nautical miles from international maritime shipping lanes connecting East and West and 110 nautical miles from the Bab el Mandeb Strait.

2. The terminal's current management combines private and public sector models. The company is operated by a national company, the Aden Ports Development Company, and functions under private sector principles while being supervised by the Yemeni Gulf of Aden Ports Corporation.

3. Aden container terminals suffer a significant technological gap compared to competing ports in neighboring countries. This requires the urgent modernization of its equipment and systems, replacing outdated technologies with advanced solutions.

4. The terminal operates using the ZODIAC system, which lags behind the advanced ZODIAC systems used in competing container terminals. This system lacks features such as electronic customer connectivity, billing, and online payment capabilities.

5. The terminal does not have key systems such as the Port Management Information System (PMIS), the Terminal Operating System (TOS), the Port Community System (PCS), and the Maritime Single Window (MSW). Existing MSW system requires further Development.

6. Yemen's port sector has been negatively affected by the country's political instability since 2011. The situation further deteriorated following the Yemeni crisis and the conflict that began in 2015.

12. Recommendations

1. Utilize the terminal's geographical location to improve its performance, boost productivity, enhance current services, and offer value-added services.

2. Assess the current technological status of the terminal and conduct a study to strengthen digital transformation efforts, starting with an urgent phase for current operations and scheduling future phases with defined funding mechanisms.

3. Upgrade the existing ZODIAC operating system or replace it with a modern system that aligns with the terminal's current and future operational requirements.

4. This study focuses on the implementation of Port Management Information Systems (PMIS), Terminal Operating Systems (TOS), and Port Community Systems (PCS). The findings were applied to select the most suitable system for terminal operation.

5. Implementation of a maritime single window (MSW) system in accordance with international standards.

6. Explore the establishment of effective partnerships with regular shipping lines and logistics companies or pursue management and operation agreements for the terminal.

7. Benefit from programs aimed at supporting maritime institutions in developing countries, such as those implemented by the International Maritime Organization (IMO), including support for establishing a Single Window System.

8. Utilize artificial intelligence applications to assist with data analysis, forecasting, and decision-making processes.

References

Aboul-Dahab, karim. (2021), "DEMONSTRATING THE CYBER VULNERABILITIES OF SIGNIFICANT MARITIME TECHNOLOGIES TO THE PORT FACILITIES AND ON BOARD OF VESSELS", *SSRN Electronic Journal*, doi: 10.2139/ssrn.3816734.

Alamoush, A.S., Ballini, F. and Ölçer, A.I. (2021), "Revisiting port sustainability as a foundation for the implementation of the United Nations Sustainable Development Goals (UN SDGs)", *Journal of Shipping and Trade*, Vol. 6 No. 1, p. 19, doi: 10.1186/s41072-021-00101-6.

Al-Yazidi, M. (2021), *The Role of Electronic Marketing Tools in Improving Services at Yemeni Ports*, Master's Thesis, Hadhramout University.

Amzarba, M. (2023), *The Impact of Implementing Smart Port Requirements on the Competitive Capabilities of Aden Container Terminal*, Master's Thesis, Arab Academy for Science, Technology and Maritime Transport.

"Areas of Interest - World Port Sustainability Program". (2024), .

Barasti, D., Troscia, M., Lattuca, D., Tardo, A., Barsanti, I. and Pagano, P. (2021), "An ICT Prototyping Framework for the 'Port of the Future'", *Sensors*, Vol. 22, p. 246, doi: 10.3390/s22010246.

Bouriche, H. (2017), "Electronic Management of Maritime Ports: Arab Models. Center for Research and Development of Human Resources (Ramah) and Laboratory for Organizational Development and Human Resource Management, Ali Lounici University of Blida".

Brunila, O.-P., Kunnaala-Hyrkki, V. and Inkinen, T. (2021), "Hindrances in port digitalization? Identifying problems in adoption and implementation", *European Transport Research Review*, Vol. 13 No. 1, p. 62, doi: 10.1186/s12544-021-00523-0.

Christodoulou, A., Dalaklis, D., Ölcer, A. and Ballini, F. (2021), "Linking Digitalization to Sustainable Development: the Case of the Port of Gothenburg In Proceedings of the International Maritime Transport and Logistics Conference, Arab Academy for Science, Technology and Maritime Transport", July, doi: 10.13140/RG.2.2.33917.08168.

ESCAP. (2020), "SUSTAINABLE PORT DEVELOPMENT AND IMPROVING PORT PRODUCTIVITY IN ESCAP MEMBER COUNTRIES".

Sen Gupta, M. (2020), "What is Digitization, Digitalization, and Digital Transformation | ARC Advisory", July.

Gurning, R.O.S. (2019), "Determining The Important Factors of Port Digitalization: The Empirical Cases of Indonesian Ports.", *9th International Conference on Operations and Supply Chain Management, Vietnam, 2019*.

Gurumurthy, A. and Bharthur, D. (2019), "Impact of Digitalisation in the Ports Sector", *SSRN Electronic Journal*, doi: 10.2139/ssrn.3873179.

Hafez, A., Amzarba, M. and Qardash, A. (2023), "The Role of Technological Restructuring in Improving the Operational Performance of Aden container terminal", *Scientific Journal of Commercial and Environmental Studies*.

"IAPH World Ports Sustainability Program". (2024), .

"International Maritime Organization IMO. Guidelines for Harmonized Communication and Electronic Exchange of Operational Data for Port Calls". (2023), .

"International Maritime Organization IMO. Guidelines on Port Community Systems". (2024), .

Jolly, C. (2016), "The ocean economy in 2030", *Workshop on Maritime Cluster and Global Challenges 50th Anniversary of the WP6 (Vol. 1)*.

Kim, S. (2014), "Megaport competitiveness and sustainability practice in container Shipping Logistics in Northeast Asia".

Lim, S., Pettit, S., Abouarghoub, W. and Beresford, A. (2019), "Port sustainability and performance: A systematic literature review", *Transportation Research Part D: Transport and Environment*, Vol. 72, pp. 47–64, doi: 10.1016/j.trd.2019.04.009.

Mudronja, G., Jugović, A. and Škalamera-Alilović, D. (2020), "Seaports and economic growth: Panel data analysis of eu port regions", *Journal of Marine Science and Engineering*, Vol. 8 No. 12, doi: 10.3390/jmse8121017.

Nations, U. (2023), "The 17 Sustainable Development Goals".

Nong, T.N.M. (2023), "Performance efficiency assessment of Vietnamese ports: An application of Delphi with Kamet principles and DEA model", *Asian Journal of Shipping and Logistics*, Vol. 39 No. 1, doi: 10.1016/j.ajsl.2022.10.002.

Notteboom, T., Pallis, A. and Rodrigue, J.-P. (2021), *Port Economics, Management and Policy*, *Port Economics, Management and Policy*, doi: 10.4324/9780429318184.

Oloan, R. and Gurning, S. (2019), "DETERMINING THE IMPORTANT FACTORS OF PORT DIGITALIZATION: THE EMPIRICAL CASES OF INDONESIAN PORTS".

Prism, E. and Analysis. (2019), "Economic Impact Study of Digitization and Automation of Marine Port Terminal Operations in British Columbia".

Qardash, A.Ali. (2021), *Analysis of the Competitive Situation of Aden Container Terminal in Light of Regional Competition*, Master's Thesis, Arab Academy for Science, Technology, and Maritime Transport.

Roh, S., Thai, V. V., Jang, H. and Yeo, G.T. (2023), "The best practices of port sustainable development: a case study in Korea", *Maritime Policy and Management*, Vol. 50 No. 2, doi: 10.1080/03088839.2021.1979266.

Schröder-Hinrichs, J.-U., Song, D.-W., Fonseca, T., Lagdami, K., Shi, X. and Loer, K. (2019), *Transport 2040: Automation, Technology, Employment - The Future of Work*, Malmö, doi: 10.21677/itf.20190104.

Sun, X. (2021), “Digitalization in the port industry from the perspectives of bibliometric analysis”.

Sunitiyoso, Y., Nuraeni, S., Pambudi, N.F., Inayati, T., Nurdayat, I.F., Hadiansyah, F. and Tiara, A.R. (2022), “Port performance factors and their interactions: A systems thinking approach”, *Asian Journal of Shipping and Logistics*, Vol. 38 No. 2, doi: 10.1016/j.ajsl.2022.04.001.

“The World Ports Sustainability Program WPSP. World Ports Sustainability Report 2020, International Association of Ports and Harbours (IAPH). ”. (2020), .

UNCTAD, Parry, I., Kizzier, K., Smith, T. and Heine, D. (2018), “Sustainable freight transport in support of the 2030 Agenda for Sustainable Development”, *United Nations Conference on Trade and Development Commission Sixth Session; 21-23 November*, Vol. 15150 No. September.

“United Nations Conference on Trade and Development UNCTAT. PORT MANAGEMENT2023 Volume 11 Port Performance Indicators.” (2023), .

“United Nations Conference on Trade and Development UNCTAT. Review of maritime transport 2021”. (2021), .

“United Nations Development Programme UNDP. What are the Sustainable Development Goals?. ”. (2018),.

United, N.D.P.U. (2021), “Damage and Capacity Assessment: Port of Aden and Port of Mukalla”.

United, N.U.N. (2024), “World Ports Sustainability Program | Department of Economic and Social Affairs”.

Vaggelas, G.K. and Leotta, C. (2019), “Port labour in the era of automation and digitalization. What’s next?”, *Impresa Progetto-Electronic Journal of Management*, Vol. 3 No. September 2019.

World, B.G. (2023), “The Container Port Performance Index 2023 A Comparable Assessment of Performance Based on Vessel Time in Port”.

“Yemen Gulf Aden Ports Corporation (YGAPC). Establishment”. (2023), .

Reducing Human-Error-Related Maritime Accidents Via Simulation-Based Training: An Empirical Investigation

Dina Mahgoub [(1)], Sameh Farahat [(2)], and Said Abdelkader [(3)]

[(1)] Arab Academy for Science, Technology and Maritime Transport (AASTMT), Integrated Simulators Complex (ISC), Egypt.
[(2)] Arab Academy for Science, Technology and Maritime Transport (AASTMT), Maritime Postgraduate Studies Institute (MPI), Egypt.
[(3)] Arab Academy for Science, Technology and Maritime Transport (AASTMT), College of Maritime Transport and Technology (CMTT), Egypt.

Emails: dinamahgoub@hotmail.com, samehfarahat65@hotmail.com, abdelkader500@hotmail.com

Received: 05 May 2025 Accepted: 24 September 2025 Published: 13 November 2025

Abstract

Newly developed simulators have been designed based on very high and intelligent technology, thus becoming more realistic than ever before. The variety in ship models and the diversity in scenarios and critical situations they encounter have made the simulators a unique training practice. Maritime accidents associated with their severe consequences represent a real threat to the maritime transport industry, thus to maritime safety in general. Human Error Factors (HEFs) are considered to be the main contributors to those accidents, as confirmed through the literature. Therefore, this study empirically investigates how to reduce HEF-based accidents through Simulation-Based Training (SBT), and examines the extent to which this will affect the maritime safety level.

Purpose: *This Paper aims to study and investigate the role of SBT in reducing human error factor-based accidents, thus increasing the maritime safety level.*

Approach/Design/Methodology: *The Paper presents an empirical investigation into the role of SBT in reducing human error factor-based accidents that affect the maritime safety level. The study depends on collecting primary data through specially designed 30 scenario-based experiments, covering three main SBT types: Bridge Resource Management (BRM), Ship Handling (SH), and Dynamic Positioning (DP). The scenarios targeted 120 maritime experts working in the field. 26 HEFs were assessed through the different scenarios. A paired T-test was conducted to identify if there is a significant difference in the participants' performance before and after the debriefing process through SBT. Then, correlation and regression analyses were conducted to examine the relationship between those HEFs and the maritime safety level.*

Findings: *Based on the scenarios' assessment checklists, it is confirmed that there is a significant improvement in the participants' performance through SBT. Correlation and regression analysis findings have partially supported the relationship between the 26 HEFs and maritime safety level.*

Recommendations: *The findings of this Paper could serve as a milestone for further studies to assess more factors that contribute to the occurrence of maritime accidents. The practical contribution of this endeavor is to provide experts and decision makers in the maritime field with a model of the most significant HEFs that have a strong impact on maritime safety.*

Keywords:

Simulation-Based Training (SBT), Human Error Factors (HEFs), Maritime safety, Maritime accidents.

1. Introduction

The maritime transport industry faces significant safety challenges due to complex operations and an unpredictable marine environment (Arslan et al., 2016). According to Maritime NZ (www.maritimenz.govt.nz), a marine accident means an occurrence that involves a ship and in which a person is seriously harmed and/or the ship sustains damage or structural failure, and an incident means any occurrence, other than an accident, that is associated with the operation of a ship and affects or could affect the safety of operation. A variety of human errors impair the performance of maritime operators; these faults are the primary cause of several incidents. The Costa Concordia disaster of 2012 is one of the famous naval disasters that reflects the impact of HEF, where the ship wrecked just off the coast of an Italian island in relatively shallow water. The disaster killed 32 people and seriously injured many others (en.wikipedia.org). Oluseye and Ogunseye (2016) identified nine major human-related factors as major causes of accidents: poor crew interaction, crew fatigue, drug and alcohol use, unsafe vessel speed, commercial pressure from management, complicated work processes, knowledge gaps, faulty crew judgment, and unruly behavior.

Hontvedt (2015) has highlighted some important human elements, including exhaustion, lack of situational awareness, lack of collaboration, and poor decision-making, that are frequently linked to shipping accidents. Even while the significance of human variables in accidents is acknowledged, it is unclear how effective training to combat these elements might be.

It is argued that the primary cause of marine incidents is a lack of acceptable working attitudes, sense of responsibility, mutual cooperation, and appropriate Bridge Resource Management (BRM) on the part of seafarers. On the one hand, in some accident scenarios, the crew lacks even the most basic professional ethics. On the other hand, some individuals believe that if the shipping company's crew is well-versed in operating rules and regulations, the ship's safety and operational benefits will be secured. In that circumstance, future soft skill development is required (Zhang, 2017).

Based on their activities, human mistakes may be divided into two categories: intentional and unintentional. Mistakes that happen accidentally and often in routine tasks that are carried out so frequently that they become automatic are known as unintentional action mistakes. These mistakes are separated into memory impairment and slips. On the other hand, there are two types of intended action errors: mistakes and violations. Errors happen when, in spite of a sincere effort to stick to protocols, a decision-making error leads to the application of an improper rule. Therefore, by enhancing supervision, training, and the quality of procedural documentation, roles and knowledge-based mistakes may be minimized from this category (Al-Shammari and Oh, 2018).

According to the European Maritime Safety Agency report, human factors were the main reason behind most of the maritime accidents that occurred from 2014 until 2020 (EMSA, 2021). Furthermore, the navigation accidents assessment conducted by EMSA in 2022 revealed that nearly 78% of the navigation incidents that have been investigated had some sort of "human factor" component. By focusing on the intricacy of human mistakes, it was demonstrated that marine casualty is not explained by the variability of the major actors' performance. On the other hand, human activity results from complex, non-linear, and dynamic socio-technical interactions between individuals onboard, organizations onshore, policies, procedures, and machinery (EMSA, 2022).

The distribution of contributing factors for the period from 2014 to 2022 determines the percentage of contributing factors and is organized by contributing factor types and accident event types, as shown in Figure 1 (EMSA, 2023). Shipboard operation is the most important contributing factor type, with 69.9% of all the contributing factors, while shore management with 23.2%, and external environment with 6.9%. The figure also emphasizes that 'Human action' is the main accident event type, with 67.6% of all the contributing factors, followed by 'System/equipment failure' with 19.7% of all the contributing factors.

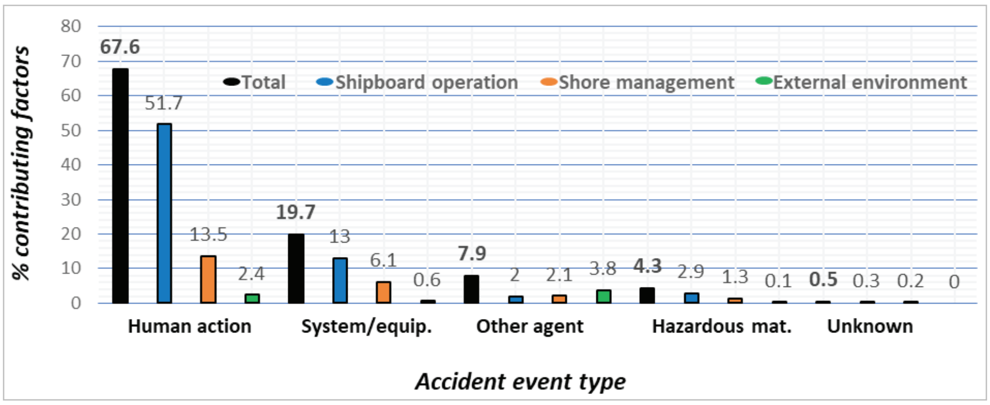

Figure 1: Percentage of contributing factors for the period 2014-2022 (EMSA, 2023).

Through a systematic examination of these Human Error Factors (HEFs) through Simulation-Based Training (SBT) technique, this paper endeavors to clarify the complicated interplay between human actions and maritime safety level. This study aims to provide valuable insights for industry stakeholders, regulatory bodies, and maritime professionals regarding how SBT could have an effective impact on those HEFs by reducing their potential in the future while enhancing the participants' performance. Therefore, understanding human error factors is essential for enhancing maritime safety by reducing the rate of maritime accidents.

While significant strides have been made in understanding the complicated relationship between human error and maritime safety, there still exists a noticeable research gap regarding the comprehensive examination of specific human error factor groups and their collective impact on maritime safety level, especially through an empirical methodology. The existing body of literature often addresses isolated aspects of human error in maritime contexts, but this study is investigating five different HEF groups and their impact on maritime safety level through an empirical investigation, "Scenario-Based Experiment" via Simulation-Based Training (SBT).

Simulators are useful teaching and training tools for the maritime industry. Simulators can support the development of knowledge, abilities, and proficiency across a range of levels of accountability, from standard shipboard operations to challenging performances, responsibilities, and tasks. Simulator training can help trainees apply their knowledge from the training to real-world circumstances (Maung, 2019). Simulation technology enables officers and masters to practice navigational skills and see how ships behave and react in a risk-free environment. The ability to replay task performance provides extensive feedback and conversations, as well as gives educators the chance to modify the training material and track and evaluate the participants' progress. Additionally, the usage of simulators could make it easier for trainees to practice non-technical abilities (Kim et al., 2021).

The integrated transportation system, meanwhile, depends on sea transit. Additionally, a variety of mishaps, such as ship collisions and groundings, regularly cause significant environmental damage, monetary losses, and deaths. As a result, one of the most important study topics for water transportation is maritime safety (Xue et al., 2021). Therefore, the urgency of this Paper lies in its potential to identify more accurately the human error factors that have a significant impact on marine accidents; thus, on the maritime safety level, in order to study the suitable preventive actions to reduce them in the future. From this Paper's perspective, SBT could help to reduce the potential of those HEFs through effective training programs, also to guide participants regarding how to behave in a professional manner during emergencies and critical situations, and how they can gain more knowledge and experience through accredited experienced instructors, in order to avoid such risks in real life. The findings of this study have the potential to significantly contribute to the overall safety and elasticity of maritime operations, ensuring the well-being of maritime personnel, the protection of valuable cargo, and the sustainability of global trade.

2. Methodology

This study is based on an empirical approach, where 30 scenario-based experiments concerning three types of simulation training: Bridge Resource Management (BRM), Ship Handling (SH), and Dynamic Positioning (DP), will be conducted on 120 maritime trainees (officers, masters, and pilots) working in the industry. The trainees will be assigned 30 different challenging scenarios with variant emergency situations, to examine and assess their performance regarding 26 human error factors that have been embedded in the scenarios' design in order to assess their performance before and after the debriefing process through the SBT technique. Based on the scenarios' result analysis, a paired T-test will be conducted for the 26 human error factors with the aim of comparing means. Also, it will be conducted for the five human error factor groups with the aim of comparing overall means for the groups. Finally, correlation and regression analysis will be conducted on the HEFs in order to test the study hypotheses and to investigate the relationship between those HEFs and the maritime safety level.

2.1. Selection of factor groups

After reviewing the diversity in HEFs' types and classifications through literature, five main HEF groups were considered, with a total of 26 factors as follows:

- **Competency Factors (CFs) group,** which includes (Technical Knowledge, Training, Skills, Attitude, Response, Experience, and Perception).
- **Team Factors (TFs) group,** which includes (Communication (EXT), Communication (INT), Team Management, Watch keeping, and Safety Awareness).
- **Psychological Factors (PSFs) group,** which includes (Risk Tolerance, Stress Resistance, Panic Resistance, and Complacency).
- **Voyage Management Factors (VMFs) group,** which includes (Passage/ Voyage Plan, Decision Making, Procedures and Checklists, Look Out, and Situation Awareness).

- **Application Factors (AFs) group,** which includes (Position Fixing, Usage of Bridge Equipment, Maneuvering, Interpretation Adequacy, and Ship Speed).

It is important to mention here that the selection of factors and groups has been discussed in detail in a previous study (Mahgoub et al., 2024). The study hypotheses assume that there is a strong correlation between each of the independent variables (5 HEF groups) and the dependent variable (Maritime Safety Level), i.e., the more one can control and reduce those human factors leading to errors and narrow the gap of its potential causes, thus decreasing marine accidents rate, the higher maritime safety level could be achieved. This will be done through the effective adoption of SBT.

2.2. Integrated Simulators Complex (ISC) at the AASTMT

Integrated Simulators Complex (ISC) in the Arab Academy for Science, Technology and Maritime Transport (AASTMT) is a prominent specialized entity in the field of Maritime training and consultation by using the top-of-the-line simulators since 1996. The ISC will provide its latest technology in the Full Mission Ship handling Simulator (FMSS) class (A) by Wärtsilä (TRANSAS) with 360° of visualization, as well as the DP2 Full Mission Offshore Vessel Simulator class (A) by ARI, with 360°, to use their capabilities and training facilities in order to conduct this empirical study.

2.3. Scenario-Based Experiment via SBT

Thirty different scenarios/maneuvers (scenario-based experiments) with various difficulty levels of unfamiliar and emergency situations are designed to test and assess the trainees' performance before and after the debriefing process via SBT. Effective SBT should be accompanied by an adequate debrief given by senior instructors to demonstrate the participant's mistakes that led to such accidents and to ensure the optimum performance for each scenario after debriefing. In so doing, human error factors related to marine accidents are identified and measured more accurately.

Three types of SBT are targeted in this study, which are: BRM, SH, and DP. Each type includes 10 different scenarios with a total of 30 scenarios. Every single scenario has been assessed twice, the first one is done before the debriefing process provided by the accredited experienced instructor/assessor, and the second one is done after debriefing and the effective training through SBT.

Table 1 represents the 30 specially designed scenario-based experiments regarding BRM, SH, and DP through the SBT technique.

Table 1: Scenario-based experiments regarding BRM, SH, and DP.

a	b	c	d	e	f
BRM Code	**Scenario Description**	**SH Code**	**Scenario Description**	**DP Code**	**Scenario Description**
BRM 1	Singapore Port Unberthing from Singapore Tanker Terminal and proceeding to Malaysia	**SH 1**	Aden Port Berthing Tanker on jetty #3 at Tanker Terminal	**DP 1**	Diving Operation Emergency Failure: Position Reference Failure (PRF)
BRM 2	Port Said Port Berthing Bulk carrier at Bulk Terminal inside Port Said Harbor, passing through Old Suez Channel	**SH 2**	Aden Port Berthing on jetty #2 (AZIMUTH propeller)	**DP 2**	Remote Operating Vehicle (ROV) Emergency Failure: Power Failure
BRM 3	Port Said Port Berthing Bulk carrier at Bulk Terminal	**SH 3**	Aden Port Unberthing from jetty #1 from Container Terminal	**DP 3**	Diving Operation Emergency Failure: Position Ref. Failure "Fan Beam"
BRM 4	El Sukhna Port Unberthing the Cargo ship	**SH 4**	Damietta Port Berthing a Huge Container on jetty #6 at Container Terminal	**DP 4**	ROV Follow Operation Emergency Failure: Switch Board / Power Failure
BRM 5	Damietta Port Berthing LNG on jetty #2 at Gas Terminal	**SH 5**	Aden Port Berthing on jetty #2 at Container Terminal	**DP 5**	Diving Operation Emergency Failure: Failure in Sensors in addition to PRF
BRM 6	Alexandria Port Berthing a Huge Container at Container Terminal	**SH 6**	El Sukhna Port Berthing vessel on dock (Bow in)	**DP 6**	ROV Follow Operation Emergency Failure: Thruster Failure in addition to Power Failure

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2025.04.2.1333

BRM 7	El Sukhna Port Berthing vessel on the dock, St/rd alongside	**SH 7**	Damietta Port Unberthing the Cargo ship	**DP 7**	Diving Operation Emergency Failure: Failure in the sensors "GYRO"
BRM 8	Singapore Port Unberthing from Singapore Tanker Terminal	**SH 8**	Alexandria Port Berthing Tanker at Petroleum Terminal	**DP 8**	ROV Follow Operation Emergency Failure: Failure in the thrusters
BRM 9	Aden Port Berthing on the jetty at Container Terminal	**SH 9**	Port Said Port Berthing Bulk carrier at Bulk Terminal	**DP 9**	Diving Operation Emergency Failure: Failure in sensors in addition to the PRF "Artemis 1"
BRM 10	Alexandria Port Unberthing the Bulk carrier from Bulk Terminal	**SH 10**	Alexandria Port Berthing Tanker at Petroleum Terminal	**DP 10**	ROV Follow Operation Emergency Failure: Thruster Failure in addition to Power Failure

3. Results

3.1. Pair T-test analysis

Table 2 shows a paired T-test analysis that has been conducted on the 5 HEF groups and the 26 HEFs based on the trainees' empirical assessment results through the 30 simulation training scenarios, before and after the debriefing process. It shows that the mean value for each HEF group and also for each individual factor is obviously increased after debriefing, which means that there is an obvious improvement in trainees' performance after the debriefing process, as the corresponding P-values are less than 0.05. Also in Table 2, HEF groups and factors are ranked based on their improvement %.

Table 2: Pair T-test analysis for the: (a) 5 HEF groups and (b) 26 HEFs, ranked upon their improvement %.

a	b	c	d	e	f	g
Pair #	**(a) Human Error Factor Group**	**Status**	**No. of scenarios**	**Mean value**	**P-Value**	**Improvement %**
Pair 1	Competency Factors Group	Before	30	0.233	0.000	**66.2**
		After	30	0.895		
Pair 2	Voyage Management Factors Group	Before	30	0.250	0.000	**63.7**
		After	30	0.887		
Pair 3	Team Factors Group	Before	30	0.266	0.000	**63.0**
		After	30	0.896		
Pair 4	Application Factors Group	Before	30	0.305	0.000	**51.6**
		After	30	0.821		
Pair 5	Psychological Factors Group	Before	30	0.370	0.000	**37.0**
		After	30	0.740		
Pair #	**(b) Human Error Factor (HEF)**	**Status**	**No. of scenarios**	**Mean value**	**P-Value**	**Improvement %**
Pair 1	Training	Before	30	0.153	0.000	**81.4**
		After	30	0.967		
Pair 2	Experience	Before	30	0.163	0.000	**80.4**
		After	30	0.967		
Pair 3	Response	Before	30	0.155	0.000	**78.8**
		After	30	0.943		
Pair 4	Decision Making	Before	30	0.143	0.000	**78.7**
		After	30	0.930		
Pair 5	Stress Resistance	Before	30	0.163	0.000	**75.4**
		After	30	0.917		

Pair 6	Situation Awareness	Before	30	0.177	0.000	**72.0**
		After	30	0.897		
Pair 7	Safety Awareness	Before	30	0.175	0.000	**71.4**
		After	30	0.889		
Pair 8	Team Management	Before	30	0.257	0.000	**67.6**
		After	30	0.933		
Pair 9	Panic Resistance	Before	30	0.190	0.000	**66.7**
		After	30	0.857		
Pair 10	Passage/ Voyage Plan	Before	30	0.290	0.000	**65.7**
		After	30	0.947		
Pair 11	Communication (EXT)	Before	30	0.285	0.000	**64.7**
		After	30	0.932		
Pair 12	Technical Knowledge	Before	30	0.267	0.000	**62.5**
		After	30	0.892		
Pair 13	Watchkeeping	Before	30	0.253	0.000	**57.7**
		After	30	0.830		
Pair 14	Usage of Bridge Equipment	Before	30	0.313	0.000	**57.4**
		After	30	0.887		
Pair 15	Procedures and Checklists	Before	30	0.270	0.000	**57.3**
		After	30	0.843		
Pair 16	Perception	Before	30	0.265	0.000	**56.5**
		After	30	0.830		
Pair 17	Maneuvering	Before	30	0.223	0.000	**56.0**
		After	30	0.783		
Pair 18	Skills	Before	30	0.276	0.000	**55.4**
		After	30	0.830		
Pair 19	Risk Tolerance	Before	30	0.267	0.000	**55.0**
		After	30	0.817		
Pair 20	Communication (INT)	Before	30	0.360	0.000	**53.7**
		After	30	0.897		
Pair 21	Ship Speed	Before	30	0.267	0.000	**52.3**
		After	30	0.790		
Pair 22	Position Fixing	Before	30	0.357	0.000	**52.0**
		After	30	0.877		
Pair 23	Complacency	Before	30	0.862	0.000	**49.0**
		After	30	0.372		
Pair 24	Attitude	Before	30	0.353	0.000	**47.7**
		After	30	0.830		
Pair 25	Look Out	Before	30	0.370	0.000	**44.7**
		After	30	0.817		
Pair 26	Interpretation Adequacy	Before	30	0.367	0.000	**40.3**
		After	30	0.770		

3.2. Correlation and regression testing

In this section, the hypotheses under study are tested using correlation and regression analysis. The Pearson correlation is used as the data under study are shown to be normally distributed. Correlation matrices for the relationship between the 5 HEF groups and maritime safety level have been established. Table 3 is an example that shows the Correlation matrix for the CF group and maritime safety level.

To investigate the impact of the 5 HEF groups on maritime safety level, multiple regression analysis has been done for each group. For the impact of the Competency Factors (CFs) group on the maritime safety level. It could be observed that there is a significant positive impact of response, training, and skills on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.634, 0.505, and 0.201, respectively. On the contrary, it could be observed that there is an insignificant impact of technical knowledge, experience, perception, and attitude on maritime safety level, since the P-value was still more than 0.05. Moreover, the maritime safety level could be described by 0.990 using training, skills, and response, as the R2 is 99%, as shown in Table 4.

For the impact of the Psychological Factors (PSFs) group on the maritime safety level. It could be observed that there is a significant positive impact of risk tolerance, complacency, and stress resistance on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.332, -0.239, and 0.756, respectively. On the contrary, it could be observed that there is an insignificant impact of panic resistance on maritime safety level, since the P-value was still more than 0.05. Moreover, the maritime safety level could be described by 0.970 using risk tolerance, complacency, and stress resistance, as the R2 is 97%.

For the impact of the Team Factors (TFs) group on the maritime safety level. It could be observed that there is a significant positive impact of safety awareness, watchkeeping, and team management on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.689, 0.261, and 0.243, respectively. On the contrary, it could be observed that there is an insignificant impact of communication (EXT) and communication (INT) on the maritime safety level, since the P-value was still more than 0.05. Moreover, maritime safety level could be described by 0.981 using safety awareness, watchkeeping, and team management, as the R2 is 98.1%.

For the impact of the Application Factors (AFs) group on the maritime safety level. It could be observed that there is a significant positive impact of position fixing and usage of bridge equipment on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.785 and 0.677, respectively. On the contrary, it could be observed that there is an insignificant impact of ship speed, interpretation adequacy, and maneuvering on maritime safety level, since the P-value was still more than 0.05. Moreover, the maritime safety level could be described by 0.925 using position fixing and usage of bridge equipment, as the R2 is 92.5%. And finally, for the impact of the Voyage Management Factors (VMFs) group on the Safety Level. It could be observed that there is a significant positive impact of passage plan, situation awareness, decision making, and procedures/ checklists on maritime safety level, since the P-value was less than 0.05 and the estimate stayed 0.222, 0.731, 0.207, and 0.164, respectively. On the contrary, it could be observed that there is an insignificant impact of lookouts on the maritime safety level, since the P-value was still more than 0.05. Moreover, maritime safety level could be described by 0.975 using passage plan, situation awareness, decision making, and procedures/ checklists, as the R2 is 97.5%.

Table 3: Correlation matrix for the CFs group and maritime safety level.

Competency Factors group		Technical Knowledge	Experience	Training	Skills	Response	Perception	Attitude	Maritime Safety Level
Technical Knowledge	Pearson C.	1							
	Sig. (2-tailed)								
	N	60							
Experience	Pearson C.	.961	1						
	Sig. (2-tailed)	.000							
	N	60	60						
Training	Pearson C.	.961	.996	1					
	Sig. (2-tailed)	.000	.000						
	N	60	60	60					
Skills	Pearson C.	.939	.937	.935	1				
	Sig. (2-tailed)	.000	.000	.000					
	N	59	59	59	59				
Response	Pearson C.	.964	.974	.975	.945	1			
	Sig. (2-tailed)	.000	.000	.000	.000				
	N	60	60	60	59	60			
Perception	Pearson C.	.944	.963	.965	.922	.972	1		
	Sig. (2-tailed)	.000	.000	.000	.000	.000			
	N	60	60	60	59	60	60		
Attitude	Pearson C.	.895	.914	.914	.875	.926	.941	1	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		
	N	60	60	60	59	60	60	60	
Maritime Safety Level	Pearson C.	.971	.977	.980	.954	.991	.974	.922	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	
	N	60	60	60	59	60	60	60	60

Table 4: Multiple regression of the impact of the CFs group on maritime safety level.

Model	Unstandardized Coefficients		Standardized Coefficients	Sig. P-value	R^2
	B	Std. Error	Beta		
(Constant)	-.265	.029		.000	0.990= 99%
Technical Knowledge	.178	.089	.115	.051	
Experience	-.310	.183	-.256	.097	
Training	.505	.184	.422	.008	
Skills	.201	.076	.118	.011	
Response	.634	.102	.506	.000	
Perception	.212	.117	.123	.077	
Attitude	-.038	.079	-.020	.630	
Dependent variable: maritime safety level					

4. Discussion

Based on the empirical study results, it could be observed that the trainees' performance regarding dealing with emergency situations has been improved, as demonstrated through the Pair T-test results. Also, the scenarios have been fulfilled safely through the repetition of the scenario for the second time. During the first time scenario running, trainees have made some critical errors that led to fatal accidents like ship collision and grounding. On the other side, while running the same scenario for the second time, after the debriefing had been demonstrated by senior instructors, those types of errors by trainees were obviously decreased, and no accidents occurred. Based on these assessments, a paired T-test analysis was conducted to investigate the trainees' performance to determine if there is a difference in means or if it is the same before and after the debriefing process. Results show that there is a significant difference between means for all 5 HEF groups and the 26 HEFs before and after the effective debriefing through SBT, as the corresponding P-values are less than 0.05.

In order to determine the extent of the impact of human error factors on maritime safety level, correlation and regression tests were conducted on the five groups with their 26 pertinent factors. The results firstly showed that regarding the effect of competency factors group on maritime safety level, there is a significant positive impact of Training, Skills, and Response on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Technical Knowledge, Experience, Perception, and Attitude on maritime safety level, since the P-value was still more than 0.05. Which means that the effect of the competency factors group on maritime safety level is partially acceptable.

Secondly, regarding the effect of psychological factors on maritime safety level, there is a significant positive impact of Risk Tolerance, Complacency, and Stress Resistance on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Panic Resistance on maritime safety level, since the P-value was still more than 0.05. Which means that the influence of the psychological factors group on the maritime safety level is partially acceptable.

Thirdly, the results showed that the impact of team factors group on maritime safety level is significant, with a positive impact of Safety Awareness, Watchkeeping, and Team Management on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Communication (EXT) and Communication (INT) on the maritime safety level, since the P-value was still more than 0.05. Which means that the impact of the team factors group on maritime safety level is partially acceptable.

Fourth, the results showed concerning the effect of application factors group on maritime safety level, that there is a significant positive impact of Position Fixing and Usage of Bridge equipment on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Ship Speed, Interpretation Adequacy, and Maneuvering on maritime safety level, since the P-value was still more than 0.05. Which means that the effect of the application factors group on maritime safety level is partially acceptable.

Fifth, the results showed that regarding the impact of voyage management factors group on maritime safety level, there is a significant positive impact of Passage Plan, Decision Making, Procedures and checklists, and Situation Awareness on maritime safety level, since the P-value was less than 0.05. While it is also observed that there is an insignificant impact of Look Out on the maritime safety level, since the P-value was still more than 0.05. This means that the effect of the voyage management factors group on maritime safety level is partially acceptable.

5. Conclusion

The empirical study results have emphasized the role of SBT in reducing the occurrence of maritime accidents through enhancing the performance and skills of trainees. This was confirmed through the 30 scenarios that have been executed after debrief. Furthermore, the pair T-test analysis' results have confirmed the improvement rate of participants' performance before and after the SBT effective debriefing provided by senior instructors; correlation and regression analysis' results have emphasized the same findings, and, moreover, the most significant HEFs that have a strong impact on maritime safety level have been identified as follows: position fixing, stress resistance, situation awareness, safety awareness, usage of bridge equipment, response, training, risk tolerance, watchkeeping, team management, complacency, passage plan, decision making, skills, and procedures/checklists.

It is also verified through Pair T-test analysis that the competency factors group is the group that has been improved the most after debrief, followed by the voyage management factors group, then the team factors group, the application factors group, and finally the psychological factors group, as shown in Figure 2.

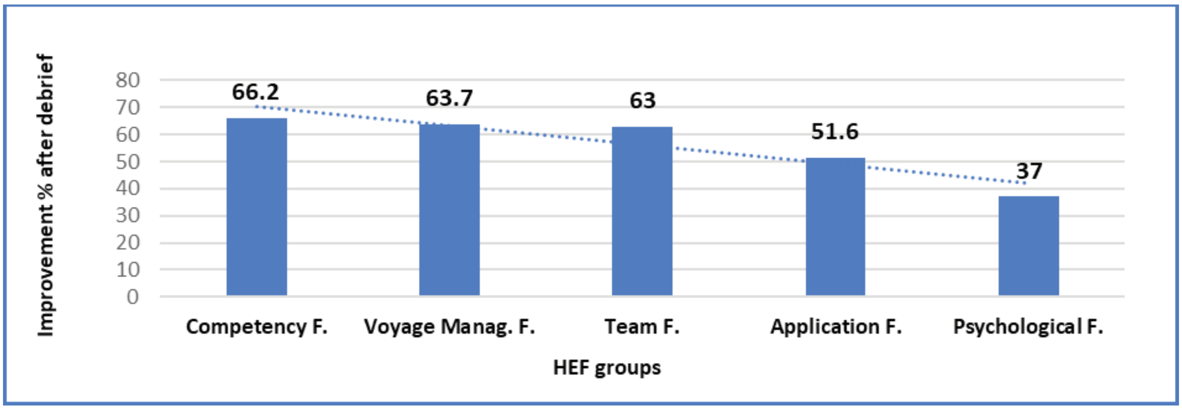

Figure 2: Percentage HEF groups' improvement after debriefing.

Regarding the HEFs, the study has concluded that the lack of training, inadequate experience, late response and decision making, mismanagement during panic and stress, lack of situation and safety awareness, inefficient team management, lack of communication skills and technical knowledge, and the misperception of emergency situations are the most important human error factors that have a significant impact on maritime accidents. Therefore, Maritime Education and Training (MET) should focus more effectively on the improvement of seafarers' technical and non-technical skills as mentioned.

The study results could help the decision makers to adopt the most suitable solutions to neutralize those factors and to subsequently enhance the skills and performance of seafarers towards achieving higher safety levels. However, the results reported herein cannot be generalized without taking the limitations encountered during conducting this study into consideration.

Three such limitations were dictated; firstly, this research took place at the Arab Academy for Science, Technology, and Maritime Transport in Egypt. Therefore, it is suggested to conduct similar studies in other universities in developed countries, on a larger scale of participants, in order to provide a comparative study between the results of developing and developed countries. Secondly, the empirical study has covered only three types of SBT scenarios (BRM, SH, and DP), so it is recommended to investigate more factors, such as mechanical failures, environmental and weather conditions, through other SBT types, such as natural gas and petrochemicals handling simulation, environment protection, and crisis management simulation. Thirdly, this research has covered only specific types of maritime accidents, which are: vessel collision and grounding regarding BRM and SH, loss of DP capability regarding two main DP operations, i.e., diving and ROV operations. Therefore, it is strongly suggested to conduct more scenarios to cover further areas related to maritime accidents.

Lastly, the current study was compared with similar studies of other investigators as follows: Ziaul et al. (2023) identified through the intensive review of literature some factors that have been mostly assessed through the simulation scenarios/exercises; as per this study did (Situation awareness, usage of bridge equipment "Radar and ECDIS", watchkeeping, maneuvering, dynamic positioning, and decision making), but it is important to mention here that this study has assessed 26 factors regarding five different groups, which made the results of this study more accurate after assessment. Also, data collection approaches were almost the same, including simulator data, video recording, voice recordings, and monitoring through specialized cameras. The comparison also assured that the mean comparison tests, like the Pair T-test analysis, which is used in this study, were the most common analysis methods used in similar studies. Moreover, this study has used more than one analytical tool, as it used Pair T-test analysis, correlation, and regression analysis, which support this endeavor's findings and results.

References

Arslan, V., Kurt, R.E., Turan, O. and De Wolff, L. (2016), "Safety Culture Assessment and Implementation Framework to Enhance Maritime Safety", *Transportation Research Procedia*, Vol. 14, pp. 3895–3904, doi: 10.1016/j.trpro.2016.05.477.

Chan, S.R., Hamid, N.A. and Mokhtar, K. (2016), "A Theoretical Review of Human Error in Maritime Accidents", *Advanced Science Letters*, Vol. 22 No. 9, pp. 2109–2112, doi: 10.1166/asl.2016.7058.

Dominguez-Péry, C., Vuddaraju, L.N.R., Corbett-Etchevers, I. and Tassabehji, R. (2021), "Reducing maritime accidents in ships by tackling human error: a bibliometric review and research agenda", *Journal of Shipping and Trade*, Vol. 6 No. 1, p. 20, doi: 10.1186/s41072-021-00098-y.

European Maritime Safety Agency (EMSA). (2021), "Marine Casualties and Incidents: Preliminary Annual Overview of Marine Casualties and Incidents 2014-2020", November.

European Maritime Safety Agency (EMSA). (2022), "Safety Analysis of EMCIP Data: Analysis of Navigation Accendents – Summery Report", November.

European Maritime Safety Agency (EMSA). (2023), "Annual Overview of Marine Casualties and Incidents."

Fan, S. (2020), *Human Factors in Maritime Transportation and Mental Workload Analyses for Seafarers in Bridge Simulation*, Liverpool John Moores University , United Kingdom.

FSH Al-Shammari, N. and Oh, J.-S. (2018), "Effects Of Human Error On Marine Safety: Case Study", *Journal of Engineering Research and Application Www.Ijera.Com*, Vol. 8.

Hontvedt, M. (2015), "Professional vision in simulated environments — Examining professional maritime pilots' performance of work tasks in a full-mission ship simulator", *Learning, Culture and Social Interaction*, Vol. 7, pp. 71–84, doi: 10.1016/j.lcsi.2015.07.003.

Ismila Che Ishak, Mohamad Fitri Azlan, Shaiful Bakri Ismail and Norhayati Mohd Zainee. (2019), "A STUDY OF HUMAN ERROR FACTORS ON MARITIME ACCIDENT RATES IN MARITIME INDUSTRY", *Asian Academy of Management Journal*, Vol. 24 No. Supp. 2, pp. 17–32, doi: 10.21315/aamj2019.24.s2.2.

Kim, T., Sharma, A., Bustgaard, M., Gyldensten, W.C., Nymoen, O.K., Tusher, H.M. and Nazir, S. (2021), "The continuum of simulator-based maritime training and education", *WMU Journal of Maritime Affairs*, Vol. 20 No. 2, pp. 135–150, doi: 10.1007/s13437-021-00242-2.

Kretschmann, L. (2020), "Leading indicators and maritime safety: predicting future risk with a machine learning approach", *Journal of Shipping and Trade*, Vol. 5 No. 1, doi: 10.1186/s41072-020-00071-1.

Liu, Y., Hou, X., Sourina, O., Konovessis, D. and Krishnan, G. (2016), "Human factor study for maritime simulator-based assessment of cadets", *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, Vol. 3, doi: 10.1115/OMAE2016-54772.

Mahgoub, D.F., Farahat, S. and Abdelkader, S. (2024), "Identification and prioritization of human error factors related to maritime accidents", *Maritime Research and Technology*, Vol. 3 No. 2, p. 77, doi: 10.21622/MRT.2024.03.2.913.

Maung, C.T. (2019), *Simulation Training and Assessment in Maritime Education and Training.* , Masters' Thesis, World Maritime University, Malmö. Sweden.

Munim, Z.H., Krabbel, H., Haavardtun, P., Kim, T.E., Bustgaard, M. and Thorvaldsen, H. (2023), "Scenario Design, Data Measurement, and Analysis Approaches in Maritime Simulator Training: A Systematic Review", *Lecture Notes in Networks and Systems*, Vol. 769 LNNS, doi: 10.1007/978-3-031-42134-1_4.

Oluseye, O. and Ogunseye, O. (2016), "Human Factors as Determinants of Marine Accidents in Maritime Companies in Nigeria", *British Journal of Education, Society & Behavioural Science*, Vol. 18 No. 4, doi: 10.9734/bjesbs/2016/29548.

Reza Emad, G. and Kataria, A. (2022), "Challenges of simulation training for future engineering seafarers - A qualitative case study", doi: 10.54941/ahfe1002501.

Uğurlu, Ö., Köse, E., Yıldırım, U. and Yüksekyıldız, E. (2015), "Marine accident analysis for collision and grounding in oil tanker using FTA method", *Maritime Policy and Management*, Vol. 42 No. 2, doi: 10.1080/03088839.2013.856524.

Xue, J., Papadimitriou, E., Reniers, G., Wu, C., Jiang, D. and van Gelder, P.H.A.J.M. (2021), "A comprehensive statistical investigation framework for characteristics and causes analysis of ship accidents: A case study in the fluctuating backwater area of Three Gorges Reservoir region", *Ocean Engineering*, Vol. 229, p. 108981, doi: 10.1016/j.oceaneng.2021.108981.

Zhang, W. (2017), "Assessing the competency of seafarers using simulators in bridge resource management (BRM) training", *World Maritime University Dissertations*.

An Innovative Digital Self-Learning Model for Training and Education in the Philippines: Basis for a Proposed Policy in Accrediting Electronic Training Record Book (E-TRB)

Enrico O. Santos [(1)], and Sylvino V. Tupas [(2)]

[(1)] Maritime Industry Authority (MARINA), Philippines.
[(2)] John B. Lacson Foundation Maritime University, Iloilo, Philippines.
[(2)] John B. Lacson Colleges Foundation-Bacolod, Bacolod City, Negros Occidental, Philippines.

Emails: ericsantos0207@gmail.com, sylvino.tupas@jblfmu.edu.ph

Received: 09 July 2025 Accepted: 01 August 2025 Published: 17 November 2025

Abstract

Purpose: *This study aims to explore the readiness and utilization of e-learning platforms among maritime students in the Philippines.*

Approach/Design/Methodology: *Employs a descriptive-correlational research method utilizing a quantitative approach. A researcher-made instrument, duly validated, was used to survey 383 maritime students across the three major regions of the country. Discussion among colleagues in the maritime industry, heads of MHEIs, and CHED generates comprehensive information that provides a basis for recommendations. The analysis utilized means and standard deviations for descriptive data and Pearson r for inferential data, with an alpha level set at .05.*

Findings: *It was found that students have a high level of readiness and acceptance of digital learning tools. A user-friendly and intuitive learner interface compatible with different devices is the main feature of the students' desired e-TRB. Furthermore, it emphasizes the vital role of institutional support and strategic implementation in enhancing e-learning effectiveness in maritime education, which is essential for policymakers and educators aiming to advance the digital learning infrastructure in the maritime sector, supporting current trends in education.*

Research Implications: *This study contributes to the growing body of literature on digital learning in maritime education by demonstrating that Filipino maritime students exhibit a high level of readiness and acceptance of e-learning platforms. This suggests that future researchers can delve deeper by examining its long-term impact on student performance and competency development in optimizing digital learning tools, such as the e-Training Record Book (e-TRB). Additionally, to explore the role of institutional support mechanisms in sustaining engagement and addressing potential challenges in e-learning adoption within the maritime industry.*

Practical Implications: *Institutions should focus on enhancing and increasing familiarity and utilization of various digital self-learning platforms, as well as leveraging high acceptance and readiness. Policies can further integrate diverse e-learning tools into the curriculum, capitalizing on these high levels of acceptance and readiness. Lastly, promoting the effectiveness of e-TRB by highlighting its high perceived effectiveness can further enhance its use and acceptance among students.*

Keywords:

Maritime Education in the Philippines, e-TRB, Digital Readiness, Self-learning Platform.

1. Introduction

In the dynamic landscape of the 21st century, education and training in the maritime sector have drastically evolved. Propelled by the global COVID-19 pandemic, which heightened the use of blended and fully digital innovations in teaching and learning, the maritime industry must take a step forward in digitalization. As a highly technical profession, it is imperative for the sector to review necessary training documents, such as the Training Record Book (TRB), to align with international standards and modern innovations.

The growing number of Filipino seafarers highlights the nation's strong presence in the global maritime labor market. These seafarers frequently serve on ships with diverse international crews, navigating complex interactions between local labor laws, global maritime operations, and their cultural backgrounds. Many works under European officers aboard vessels registered under flags of convenience, often owned by Western or Japanese entities (Acejo, 2021). To remain competitive, the Philippines must enhance the quality of maritime education and training, ensuring a steady supply of highly skilled seafarers. The involvement of international entities in shaping policies for Filipino seafarers further underscores the country's substantial impact on the global maritime industry (Maido, 2021; Turgo, 2021).

In response to these demands, this research seeks to establish a clear policy framework for the use of digital e-learning methodologies in maritime education and training, particularly concerning shipboard training for cadets. It aims to eliminate ambiguity, inconsistency, and disunity in the integration and implementation of digital learning tools. Specifically, this study proposes a framework for a self-learning electronic Training Record Book (e-TRB) that Filipino seafarers can utilize in the future.

This study is anchored in the theoretical framework of four digital learning spaces: Individual Space, Working Group, Community of Interest, and Open Connections (Dalsgaard & Ryberg, 2023). These frameworks illustrate how digital technologies serve as cognitive partners, collaboration tools, sharing platforms, and network connectors. Technology enhances an individual's cognitive abilities rather than replacing them. It also strengthens collaborative knowledge-building within working groups, facilitates access to collective knowledge, and expands students' interaction with the global community through networked connections.

To support these innovations, regulatory frameworks must adapt accordingly. The Commission on Higher Education (CHED) and the Maritime Industry Authority (MARINA) implemented Memorandum Circular No. 1, series of 2023, emphasizing the significance of proper training records and onboard training (JCMMC 01 s. 2023). With the increasing Adoption of digitized and innovative educational materials, the Philippine maritime sector has begun integrating electronic formats and Information, Communication, and Technologies (ICT) into training. To align with these advancements, policymakers should approve the use of e-TRBs for cadets' Onboard Training (OBT).

The competence of engine officers plays a crucial role in ensuring safety and environmental protection. The updated International Shipping Federation (ISF) Book enables cadets and their companies to systematically monitor and evaluate onboard training in accordance with the new STCW Convention requirements. A training record book is a mandatory tool for trainees aiming to qualify as ship officers, as it provides structured evidence of onboard training (ICS, 2013).

Thus, this study aims to formulate a policy supporting an innovative digital self-learning model for Standards of Training, Certification, and Watchkeeping (STCW) training and education in the Philippines. It seeks to assess: Maritime students' familiarity with and utilization of the self-learning platform, their acceptance of the platform, and their readiness in using e-learning tools, particularly in a) Self-directed learning, b) Motivation for learning, c) Learner control, d) Computer/internet proficiency, and e) Interaction with other learners.

Additionally, this study will determine the preferred features of the e-TRB among maritime students, their perceived effectiveness in using the e-TRB, and the level of readiness among maritime industry stakeholders to adopt technological innovations in education and training. Finally, the study will examine the relationship between students' familiarity, utilization, acceptance, and readiness in using self-learning platforms and their perceived effectiveness in using the e-TRB. Based on these findings, a policy for accrediting the e-TRB will be recommended to MARINA.

2. Methodology

This study employed a descriptive-correlational research design with a quantitative approach, utilizing a survey. The respondents were 383 randomly selected Maritime students enrolled in the year 2022 from MHEIs randomly located in various regions in the Philippines. The researcher used a researcher-made instrument to gather the data needed for this investigation. The items were crafted personally by the researcher with several inputs from the industry partners. The research instrument is divided into five sections that include:

1. Familiarization and Utilization of self-learning platform,
2. Acceptance of self-learning platforms,

3. Readiness in using self-learning platforms,

4. e-Training Record Book (e-TRB) design,

5. Perceived Effectiveness in using the e-Training Record Book,

6. Readiness and Adaptation of Maritime Industry stakeholders (students) to technological innovation in education and training.

Discussions with key maritime industry stakeholders—including the Maritime Industry Authority (MARINA), the Commission on Higher Education (CHED), shipping companies, and MHEI representatives—provided additional insights that served as the basis for policy recommendations regarding the accreditation and Adoption of the e-TRB. Validity and reliability testing were conducted to ensure the instrument was valid and reliable, with a validity index of .871 and an alpha coefficient (Cronbach's alpha) of .988.

As to data gathering, permission was requested from the school administrator or the president concerned to allow the researcher to gather data for this study. Upon approval, the researcher sends a link to the Google form to the focal person, who distributes it among their maritime students. As soon as the target number of respondents was reached, the online survey was closed. The data was sent to the statistician for processing. All data were subjected to statistical treatment and analysis using the Statistical Package for the Social Sciences (SPSS) software, version 21. Privacy and confidentiality were observed in adherence to the Data Privacy Act. The students' names were not disclosed, and they remained anonymous. Access to the data was exclusive only to the researchers and data analysts. The analysis utilized means and standard deviations for descriptive data and Pearson's r correlation for inferential data, with an alpha level set at .05.

3. Results

3.1. Familiarity and utilization of Self-Learning Platform

The data in Table 1 indicate that the familiarity and utilization of LinkedIn Learning, Coursera, Udacity, and SkillShare are moderate, with mean values of 2.93, 2.87, 2.76, and 3.07, respectively. The school's LMS has the highest utilization, with a mean of 3.31 and a standard deviation of 1.14.

Table 1: Level of maritime students' familiarity and utilization of Self-Learning Platform.

Digital Self-Learning Platform	Mean	SD	Interpretation
LinkedIn Learning (formerly "Lynda")	2.93	1.17	Moderate
Coursera	2.87	1.19	Moderate
Udacity	2.76	1.19	Moderate
SkillShare	3.07	1.11	Moderate
School's Learning Management System (LMS)	**3.31**	**1.14**	**Moderate**

3.2. Readiness in using the e-Learning Platform

As shown in Table 2, maritime students across the Philippines exhibit a high level of acceptance for e-learning platforms, with an aggregate mean of 3.73 and a standard deviation of 0.793. The mean scores fall within the high range, indicating strong acceptance and readiness.

Table 2: Maritime students' level of acceptance in using the e-Learning Platform.

Acceptance of using the e-Learning Platform	Mean	SD	Interpretation
As a Whole	3.73	0.793	High

Moreover, Table 3 evaluates various aspects of readiness among maritime students across different regions of the Philippines. Self-directedness showed the highest mean (M = 3.69), followed by Proficiency in using computers and internet proficiency (M=3.67) and motivation (M = 3.55), which indicates a strong intrinsic motivation to engage with e-learning platforms. Lastly, Students' ability to control the pacing of their courses (M = 3.53) and interaction with other learners (M = 3.53). This indicates that student are comfortable managing the speed of their learning and are more engaged in collaborative learning.

In general, maritime students in the Philippines demonstrate a high (M=3.60) level of readiness across various aspects of using e-learning platforms. The standard deviations (SD = .63) are relatively low, indicating consistent responses within each category and region. The overall interpretation for all aspects remains high, suggesting that maritime students are well-prepared and positive about engaging with e-learning platforms.

Table 3: Maritime students' level of readiness in using the e-Learning Platform.

Readiness in using the e-Learning Platform	Mean	SD	Interpretation
Self-directedness	3.69	0.74	High
Motivation	3.55	0.71	High
Proficiency in Computer/Internet	3.67	0.76	High
Control in Pacing the Course	3.53	0.74	High
Interaction with other Leaders	3.53	0.75	High
As a Whole	**3.60**	**0.63**	**High**

3.3. The most preferred features of the proposed e-Training Record Book

Table 4 presents the most preferred features of the proposed e-training record book for maritime students, arranged in descending order. User-friendly and Intuitive Learner Interface is the most popular among students, indicating a high value placed on ease of use and intuitive design, followed by Responsive Design (Compatibility with Different Devices), highlighting the importance of accessibility across different platforms, Variety in Learning Resources and Methods, showing a preference for a rich and varied learning experience. Next are the Automated Learning Journeys, Chat/Messaging, Mobile Compatibility, Free Access, AI learning, Collaboration, and Social Learning Tools (Discussion Boards). E-certification is the least emphasized feature, suggesting that while recognized, it is not as critical to students compared to other features. In general, the data support the notion that maritime students value usability, accessibility, and diverse learning resources in their e-learning platforms. The emphasis on fundamental features over advanced ones suggests a need to strike a balance between innovation and practical functionality to enhance the overall learning experience.

Table 4: Features of the e-Training Record Book.

Features of e-TRB	f	Rank
User-friendly and intuitive learner interface	231	1st
Responsive design (compatibility with different devices)	189	2nd
Variety in learning resources and methods	137	3rd
Automated learning journeys	75	4th
Chat/messaging	66	5th
Mobile	64	6th
Free	58	7th
AI-learning	45	8th
Collaboration and social learning tools (Discussion boards)	42	9th
E-certification	36	10th

3.4. Level of effectiveness in using the e-Training Record Book

The data in Table 5 indicate that maritime students across different regions in the country uniformly perceive the e-Training Record Book as highly effective. The overall mean score of 3.80, interpreted as high, suggests that students generally find the e-TRB to be an effective tool in their training. The low standard deviations across the board reflect consistent responses, reinforcing the high level of perceived effectiveness of the e-TRB among maritime students.

Table 5: Maritime students' perceived level of effectiveness in using the e-Training Record Book.

Effectiveness in using e-TRB	Mean	SD	Interpretation
As a Whole	3.80	0.74	High

Maritime Industry stakeholders have a high level of readiness and adaptation to technological innovation, with a mean of 3.78 and a standard deviation of .74, as shown in Table 6. This implies that students are ready to adopt the use of e-TRB as a form of innovation appropriate for the current trend in education and training.

Table 6: Maritime industry stakeholders' level of readiness and adaptation to technological innovation in education and training.

Level of Readiness and Adaptation to Technological Innovation	Mean	SD	Interpretation
As a Whole	3.78	0.74	High

3.5. Relationships between the students' level of familiarity and utilization, acceptance, and readiness in using the Self-learning Platform, and the perceived effectiveness of using the e-TRB

Table 7 illustrates the strongest correlation (r = 0.763) between students' readiness and perceived effectiveness in using the e-TRB, with readiness accounting for approximately 58.2% of the variance in perceived effectiveness, making it the most influential factor. This highlights the importance of ensuring students are well-prepared to use e-learning platforms. Thus, policies should prioritize building comprehensive readiness through technical support, training, and resources that enhance students' skills and confidence in using these platforms.

Approximately 46.9% of the variance in acceptance is explained by perceived effectiveness, with a strong positive correlation (r = .685) between students' acceptance of self-learning platforms and their perceived effectiveness of the e-TRB. It is essential to strengthen a positive attitude and trust among students.

Lastly, it shows a moderate positive correlation (r = 0.382) between students' familiarity and utilization of self-learning platforms and their perceived effectiveness of the e-TRB, with only about 14.6% of the variance in perceived effectiveness being attributed to familiarity and utilization.

Table 7: Relationships between the students' level of familiarity and utilization, acceptance, and readiness in using the self-learning platform, and the perceived effectiveness of using the e-TRB.

Variable	Mean	r	r^2	p-value	Interpretation
Familiarity and Utilization	3.26	0.382	0.146	0.000	Significant at 0.05 alpha level
Perceived Effectiveness	3.80				
Acceptance	3.73	0.685	0.469	0.000	Significant at the 0.05 alpha level
Perceived Effectiveness	3.80				
Readiness	3.60	0.763	0.582	0.000	Significant at the 0.05 alpha level
Perceived Effectiveness	3.80				

4. Discussion

Maritime students demonstrate a moderate familiarity and utilization of various digital self-learning platforms. The most commonly used and familiar with is the school's Learning Management System (LMS), suggesting an institutional preference or requirement compared to the platforms (e.g., LinkedIn Learning, Coursera, Udacity, and SkillShare) which are slightly utilized.

Students have a high level of readiness for e-learning in terms of acceptance, indicating their preparedness and positive attitude toward engaging with digital learning technologies.

When it comes to platform preferences, most of the maritime students preferred a user-friendly interface and responsive design in the proposed e-Training Record Book (e-TRB). This indicates that they value the importance of accessibility, ease of use, and diverse learning resources, as well as interactive features and communication tools (e.g., chat and messaging) that facilitate engagement and collaboration. Although AI-driven learning and e-certification features rank lower in priority, this suggests that while students are open to innovation, they currently emphasize fundamental usability and accessibility.

Regarding effectiveness, maritime students across different regions uniformly perceive the e-TRB as highly effective in their training. The low standard deviations in responses reflect a strong consensus, reinforcing the platform's reliability and usefulness in maritime education. Popa and Cupsa (2019) highlight the advantages of using e-learning platforms and how distance education can solve many problems, saving time and also increasing efficiency on board for seafarers.

Maritime industry stakeholders, especially the students, demonstrate a high level of readiness for and adaptation to technological innovations. It means that students are prepared to adopt the e-TRB as an innovative tool for learning.

Furthermore, significant positive relationships were observed between familiarity, utilization, acceptance, readiness, and the perceived effectiveness of e-learning platforms. It underscores the importance of ensuring that students are well-equipped to use these tools effectively and enhancing familiarity and utilization through training and curriculum integration to build a comprehensive readiness through technical support and resource development.

4.1. Proposed policies for accreditation of the e-TRB

The proposed policies aim to enhance familiarity, acceptance, and readiness among maritime students in using the e-TRB, as well as improve its perceived effectiveness and overall utilization in maritime education and training. The proposed policies are the following:

1. **The Administration:**

   ✓ Ensure that all maritime students receive adequate training and resources to become familiar with and effectively use the e-TRB.

   ✓ It should promote the acceptance of the e-TRB by communicating its benefits and integrating it seamlessly into the learning and assessment processes.

2. **The Shipping Companies:**

   ✓ Should provide support and encouragement for using the e-TRB among trainees, ensuring it is recognized and valued as a valid training record.

   ✓ Should collaborate with educational institutions to align the use of the e-TRB with industry standards and requirements.

3. **The Commission on Higher Education:**

   ✓ The Commission on Higher Education may endorse and mandate the use of the e-TRB across all maritime education institutions to standardize training records.

   ✓ As well as provide guidelines and support for the implementation and continuous improvement of the e-TRB system.

4. **The Maritime Higher Education Institutions (MHEIs):**

   ✓ MHEIs should incorporate the e-TRB into their curriculum and ensure that faculty are trained to assist students in its use

   ✓ and continuously monitor and evaluate the effectiveness of the e-TRB by making necessary adjustments based on feedback from students and industry partners.

Implications for policy and practice

1. **Enhancing the utilization of e-TRB based on the level of acceptance and Readiness**

   ✓ Policies should leverage the high acceptance and readiness levels to further increase familiarity and utilization of various self-learning platforms beyond the existing LMS.

2. Institutional Integration

✓ Institutions should continue to integrate and promote the use of the LMS while also encouraging the use of other self-learning platforms to diversify and enrich students' learning experiences.

3. Improving Familiarity

✓ Training and support programs can be designed to improve familiarity with platforms like LinkedIn Learning, Coursera, Udacity, and SkillShare, given their moderate current levels of utilization.

4. Leveraging Perceived Effectiveness

✓ The high level of perceived effectiveness of the e-TRB may be emphasized in communications and training sessions to further boost students' engagement and utilization.

5. Conclusion

Maritime students have a high level of utilization of their school's LMS; however, a moderate level of familiarity and utilization of other platforms. This implied that it is necessary to create opportunities for them to be more flexible and technology-driven. Despite moderate engagement on the other platforms, students still exhibit high levels of acceptance and readiness for digital self-learning, especially on the e-TRB. Significant positive relationships exist between familiarity, utilization, acceptance, readiness, and the perceived effectiveness of e-learning platforms, underscoring their importance in enhancing the learning experience.

Given these findings, maritime higher education institutions should implement the following in order to foster a more dynamic and effective digital learning environment for maritime students such as

1. Enhance Training Programs to improve students' Proficiency with various digital self-learning platforms,
2. Diversify E-Learning Tools – to promote a wider range of platforms beyond the LMS to enrich learning experiences,
3. Advocate for e-TRB Adoption – to conduct awareness campaigns highlighting the benefits of e-TRB to encourage its broader use,
4. Establish Feedback Mechanisms – to regularly assess and refine digital learning platforms based on student input to ensure continued effectiveness.

References

Acejo, I. (2021), "The Experience of Being a Filipino Seafarer on a Multinationally Crewed Ship", pp. 99–111, doi: 10.1007/978-3-030-49825-2_9.

Dalsgaard, C. and Ryberg, T. (2023), "A theoretical framework for digital learning spaces: learning in individual spaces, working groups, communities of interest, and open connections", *Research in Learning Technology*, Vol. 31, doi: 10.25304/rlt.v31.3084.

ICS. (2013), "ISF Launches New On Board Training Record Book for Engine Cadets", November.

Maido, M.A. (2022), "The Filipino 'Backer System' in the Maritime Industry: The Privileged Access to Seafaring Jobs", *Sociologija. Mintis Ir Veiksmas*, Vol. 1 No. 48, doi: 10.15388/socmintvei.2021.1.31.

MARINA. (2023), "Joint CHED-MARINA Memorandum Circular No. 1, series of 2023", Official Website of MARINA STCW Administration Office.

Popa, T. and Cupsa, O.S. (2019), "E-LEARNING PLATFORMS – NEW SOLUTION FOR CONTINUOUS TRAINING OF ADULTS", pp. 3140–3145, doi: 10.21125/edulearn.2019.0848.

Turgo, N. (2021), "A Taste of the Sea: Artisanal Fishing Communities in the Philippines", pp. 9–22, doi: 10.1007/978-3-030-49825-2_2.

مركز الأكاديمية للنشر

ACADEMY Publishing Center

MRT Journal

MARITIME RESEARCH & TECHNOLOGY

Volume 4,
Issue 2,
December 2025

E-ISSN: 2812-5622