Tersedia online di: http://ejournal.undip.ac.id/index.php/teknik

TEKNIK, 46 (3), 2025, App. 1-5

Enhancing Maritime Education and Operations through IT, IoT, and Computer-Based Learning

Panderaja Soritua Sijabat *, Larsen Barasa, Natanael Suranta, Marudut Bernadtua Simanjuntak

Maritime Institute, Sekolah Tinggi Ilmu Pelayaran (STIP) Jakarta
Jl. Marunda Makmur, Cilincing, North Jakarta, DKI Jakarta, Indonesia, 14150

Submitted: May 25th, 2025; Revised: July 20th, 2025; Accepted: July 29th, 2025; Available online: July 31st, 2025
DOI: 10.14710/teknik.v46i3.77258

Abstract

This research explores the integration of emerging technologies, specifically IT, IoT, and computer-based learning, in maritime engineering and education. The study examines how these technologies enhance operational efficiency, sustainability, and the learning experience for maritime professionals and students. By gathering insights from maritime professionals and educators, the research identifies the challenges and opportunities associated with the adoption of these technologies. Findings indicate a strong understanding and partial implementation of IT and IoT in maritime operations, with positive impacts on vessel management, predictive maintenance, and operational efficiency. However, challenges remain in infrastructure, cost, and regulatory integration. In maritime education, computer-based learning tools such as virtual simulations and e-learning platforms have improved learning outcomes, yet limitations in resources, instructor training, and technology resistance hinder full implementation. The research emphasizes the importance of collaboration between the maritime industry and educational institutions to ensure effective integration of these technologies in both operational and educational contexts. The study provides valuable insights into enhancing maritime education and operations through technology, offering recommendations for overcoming current challenges and advancing the industry towards sustainability and efficiency.
Keywords*: Maritime engineering, Emerging technologies, IT and IoT, Computer-based learning, Maritime education*

1. Introduction

The maritime industry, one of the key pillars of global trade and transportation, is undergoing a profound transformation. This transformation is driven by the integration of advanced technologies and the adoption of sustainable practices that aim to enhance operational efficiency, reduce environmental impacts, and ensure long-term viability. As the industry faces growing challenges such as environmental sustainability, regulatory compliance, and technological advancements, there is a critical need to leverage innovative solutions that can address these issues while also improving the overall management of maritime operations. The integration of Information Technology (IT), the Internet of Things (IoT), and computer-based learning technologies represents a significant opportunity to meet these challenges and to reshape both maritime engineering practices and maritime education (Dyagileva et al., 2020; Manuel, 2017).

The maritime sector has traditionally relied on manual systems, paper-based operations, and conventional mechanical technologies. However, the rapid development of digital technologies has created new avenues for enhancing the efficiency, safety, and sustainability of maritime operations. From the management of vessels and cargo to port operations and environmental monitoring, IT and IoT have revolutionized the way maritime operations are conducted. IT systems, such as integrated maritime management platforms, allow for the seamless management of operations, including supply chain coordination, scheduling, and real-time communication between ships, ports, and maritime authorities. Similarly, IoT-enabled sensors and devices provide a continuous flow of real-time data on vessel performance, fuel consumption, and environmental conditions, enabling predictive maintenance and optimized operational performance. These advancements, particularly in the

*) Coresponding Author:
E-mail: pande.sijabat@gmail.com

areas of autonomous vessels, smart ports, and green shipping technologies, offer substantial improvements in operational efficiency and sustainability.

Despite the potential benefits of these technological advancements, the maritime industry faces several barriers to their widespread adoption (Jimenez et al., 2022; Tahir et al., n.d.; Wahl & Kongsvik, 2018). One of the primary challenges lies in the integration of these technologies into existing infrastructure. Many ports, vessels, and maritime operations still rely on outdated systems that are not fully compatible with emerging technologies, making the transition to more advanced, digitally-driven practices a complex and costly process. Additionally, regulatory frameworks are often slow to adapt to the rapid pace of technological change, creating uncertainty around the legal and operational implications of adopting new technologies. Furthermore, while maritime professionals and companies recognize the importance of adopting these technologies, there is a significant gap in the necessary knowledge and skills to operate and maintain these advanced systems.

This research, therefore, aims to explore the integration of IT, IoT, and computer-based learning technologies into maritime education and engineering practices. It seeks to examine how these technologies can enhance maritime management, improve operational efficiency, and contribute to sustainability goals within the industry. By exploring the experiences and perspectives of maritime professionals—such as entrepreneurs in the port and shipping industries, officers, and managers of maritime companies, as well as maritime educators—this study investigates the current state of technology adoption in the maritime sector and the barriers that prevent full-scale implementation.

In particular, this research focuses on the role of computer-based learning in maritime education and how emerging technologies can be integrated into curricula to prepare future maritime professionals for the challenges of the evolving industry. Maritime education, particularly in vocational and engineering training programs, plays a crucial role in equipping students with the necessary skills to operate in an increasingly digital and technologically complex environment. However, current training methods are often outpaced by the rapid developments in maritime technology, leaving students inadequately prepared to manage and operate new systems. Computer-based learning tools, including virtual simulations, augmented reality (AR), and learning management systems (LMS), are emerging as powerful tools to bridge this gap (Shao et al., 2022; Slama et al., 2015). These tools offer opportunities for immersive, hands-on learning experiences that allow students to interact with advanced technologies in a safe and controlled environment.

The increasing complexity of modern maritime operations, coupled with the need for sustainability, requires a new approach to maritime education. As the industry embraces green technologies and energy-efficient practices, the educational system must evolve to reflect these changes. This includes the incorporation of sustainable engineering practices, such as the design of low-emission vessels, the integration of renewable energy sources, and the adoption of energy-efficient propulsion systems, into the training programs. The research also explores how these technologies are not only reshaping the operational side of maritime activities but also influencing the curricula of maritime educational institutions, which must provide students with the skills needed to design, operate, and maintain these advanced systems.

One of the key areas of focus for this research is how IoT and smart technologies are being integrated into maritime operations and how they are being taught within vocational programs. The adoption of smart ships and smart ports powered by IoT sensors allows for real-time tracking of vessels, monitoring of fuel consumption, and optimization of logistics operations. These advancements contribute to improved safety, reduced operational costs, and enhanced environmental performance. In addition, the use of IoT for predictive maintenance and asset management enables maritime companies to monitor the health of their vessels and equipment continuously, thus preventing costly breakdowns and improving operational efficiency. The application of these technologies in educational contexts is essential to prepare students for the modern demands of the maritime industry, ensuring that they are equipped to work with these systems upon graduation.

The integration of these technologies in maritime management also has significant implications for sustainability. As the maritime industry is a major contributor to global carbon emissions, there is an urgent need to adopt green technologies to mitigate environmental impacts (de la Peña Zarzuelo et al., 2020; Nguyen et al., 2023). Smart port technologies, for example, allow for the optimization of port operations, reducing congestion and fuel consumption while improving cargo handling and safety. Additionally, technologies like LNG propulsion systems and hybrid-electric power solutions are increasingly being adopted to reduce emissions and improve energy efficiency in maritime operations (de la Peña Zarzuelo et al., 2020; Pu & Lam, 2021). This research aims to assess the impact of these technologies on the sustainability of the maritime sector and how they can be incorporated into the training programs for future maritime engineers and operators.

Moreover, this research explores the collaboration between industry and education that is necessary to ensure that maritime students are trained in the latest

doi: 10.14710/teknik.v46i3.75496

technological developments. Industry partnerships with educational institutions can provide students with access to real-world technologies, allowing them to gain practical experience with systems that are already in use within the maritime sector. Through internships, mentorship programs, and collaborative research projects, students can engage with professionals in the industry and learn firsthand about the challenges and opportunities of working with emerging maritime technologies (Cohn & Dennis, 2013). Such collaborations can also provide valuable feedback on the effectiveness of educational programs and help to ensure that curricula are aligned with industry needs.

As the maritime sector continues to evolve, the demand for digital literacy and technological proficiency among maritime professionals will only increase. This research underscores the need for continuous professional development in the maritime industry, particularly for educators, to ensure that they are capable of teaching emerging technologies effectively. It also emphasizes the importance of integrating innovative teaching methods that incorporate computer-based learning, simulation, and practical training into maritime education. By doing so, educational institutions can produce graduates who are not only technically proficient but also adaptable to the fast-changing technological landscape of the maritime industry.

This research aims to provide a comprehensive exploration of the ways in which IT, IoT, and computer-based learning technologies are transforming maritime engineering practices and education. By analyzing the perspectives of industry professionals and educators, this study will identify the key challenges and opportunities for integrating these technologies into maritime management and training programs. The findings of this research will contribute to the development of more effective educational strategies that align with the latest technological advancements, ultimately fostering a more sustainable, efficient, and technologically advanced maritime industry. This research will also provide insights into how the maritime sector can better prepare its workforce to manage the challenges of the future, ensuring that the industry remains competitive, innovative, and environmentally responsible in the years to come.

Research Novelty and Contribution

This research makes three distinct contributions that advance beyond existing maritime technology literature, directly addressing gaps in both operational and educational domains.

What is New Beyond Prior Work:

1. **First**, while previous studies examine IT/IoT adoption in maritime operations (de la Peña Zarzuelo et al., 2020) or maritime education separately (Manuel, 2017), this research provides the first **integrated framework** linking technological implementation in industry with educational preparedness. We bridge the theory-practice gap by simultaneously analyzing how technologies perform in operational contexts and how education systems prepare students for these same technologies. This dual investigation reveals critical disconnects between what the maritime industry needs from its workforce and what educational institutions currently deliver, offering a holistic understanding of the technology integration challenge that single-perspective studies cannot provide.
2. **Second**, existing literature primarily focuses on technology adoption from an engineering or operational efficiency perspective (Jimenez et al., 2022; Pu & Lam, 2021). This research uniquely captures **dual stakeholder perspectives**—both maritime professionals implementing these technologies and educators preparing the workforce—revealing critical misalignments between industry needs and educational delivery. By gathering experiential data from 24 participants across both domains, we expose implementation barriers that remain invisible to single-perspective studies. For instance, our findings demonstrate that high technology awareness does not translate to operational effectiveness when educational systems fail to produce graduates capable of data analytics and system integration nuance that purely operational or purely educational studies miss.
3. **Third**, prior research treats computer-based learning as a general pedagogical tool applicable across disciplines. Our study specifically examines how virtual simulations, AR, and e-learning platforms can be **calibrated to maritime-specific competencies**—vessel management, predictive maintenance protocols, emergency response procedures, and IoT data interpretation—providing granular insights into which learning technologies effectively translate to operational competence in maritime contexts. We identify that simulation-based learning for navigation and cargo handling significantly enhances student preparedness, while generic e-learning platforms show limited effectiveness without maritime-specific contextualization.

For Whom This Matters:

This research has direct implications for three stakeholders, each facing distinct challenges in technology integration:

1. **For Maritime Operations Managers and Company Leaders**: The findings reveal that high technology understanding does not automatically

doi: 10.14710/teknik.v46i3.75496

translate to operational effectiveness. The gap between implementation scores (high) and effectiveness scores (moderate) in our study indicates that companies need not only to adopt IoT/IT systems but also invest in analytics capabilities and unified data management strategies. Our identification of specific barriers—infrastructure incompatibility, lack of standardization across maritime systems, and high initial costs without clear ROI timelines—provides actionable priorities for operational decision-making. Rather than wholesale technology adoption, maritime companies should prioritize data utilization infrastructure alongside IoT deployment, as installing sensors without analytics capability creates limited operational value.

2. **For Maritime Education Institutions and Trainers**: The research demonstrates that current computer-based learning adoption is inconsistent and resource-constrained, creating disparities in graduate preparedness across institutions. We identify specific gaps—instructor training deficits, resistance to technology integration, content currency issues, and limited access to simulation hardware—that prevent educational institutions from producing industry-ready graduates. The findings advocate for standardized integration of simulation-based learning and industry-aligned curricula updates, providing evidence-based guidelines for curriculum developers to prioritize virtual simulations and AR for hands-on skill development over traditional lecture-based instruction. Our data shows that students with simulation-based training demonstrate significantly higher confidence and competence in operating IoT-enabled systems.
3. **For Maritime Policy Makers and Regulatory Bodies**: The slow pace of technology adoption despite strong awareness suggests regulatory frameworks are not facilitating innovation. Our findings indicate that policy interventions are needed to: (1) standardize IoT/IT protocols across ports and vessels to enable interoperability, (2) provide financial incentives or subsidies for infrastructure modernization, particularly for smaller maritime companies, and (3) mandate industry-education partnerships through regulatory requirements for workforce development. The sustainability implications documented in this research—reduced emissions through smart port optimization, fuel-efficient routing systems, and predictive maintenance reducing waste—further underscore the policy urgency for accelerating technology adoption as part of maritime decarbonization strategies.

How This Changes Practice:

This research catalyzes four practical changes in maritime operations and education:

1. **Educational Curriculum Reform**: By documenting the specific computer-based learning tools that enhance maritime competencies—particularly virtual simulations for vessel navigation, AR for equipment maintenance training, and interactive platforms for emergency response scenarios—this study provides evidence-based guidelines for curriculum developers. Educational institutions can now prioritize investments in simulation technologies that demonstrate clear learning outcomes, moving beyond traditional lecture-based instruction. The research establishes that simulation-based learning for navigation and cargo handling significantly improves student readiness, justifying the reallocation of resources toward these technologies.
2. **Industry-Education Partnership Models**: The emphasis on collaboration between maritime companies and educational institutions is not merely aspirational—our findings demonstrate that practical experience with real-world technologies during training significantly improves graduate readiness and reduces onboarding time for employers. This justifies structured internship programs, equipment-sharing agreements where companies provide access to IoT systems for student training, and collaborative curriculum development where industry professionals contribute to course design. The research provides a framework for these partnerships, specifying that they should focus on: technology access, mentorship programs, and feedback loops where industry informs educational content updates.
3. **Technology Implementation Strategy**: Rather than wholesale technology adoption, the research reveals that maritime companies should focus on **data utilization infrastructure** alongside IoT deployment. Our findings show that many companies have installed IoT sensors but lack the analytics capabilities to derive actionable insights from the data streams. This reshapes investment priorities: companies should invest equally in data scientists, analytics platforms, and decision-support systems as they do in sensor hardware. The research also highlights the need for phased implementation strategies that address infrastructure compatibility issues before full-scale deployment.
4. **Professional Development Framework**: The identification of instructor technology resistance and training gaps establishes a clear mandate for continuous professional development programs for maritime educators. The research demonstrates that

doi: 10.14710/teknik.v46i3.75496

educators without hands-on experience with IoT systems struggle to teach these technologies effectively, regardless of pedagogical skill. This justifies investment in instructor training programs, industry sabbaticals for educators, and collaborative teaching models where industry professionals co-teach technology-focused courses. Educational institutions can use our findings to advocate funding dedicated to educators who are upskilled in emerging maritime technologies.

By providing this explicit articulation of novelty, stakeholder impact, and practice changes, this research moves beyond descriptive analysis to offer a transformative framework for maritime technology integration that addresses the full ecosystem—from policy and regulation, through operational implementation, to workforce development and educational delivery.

2. Research Method

This study employs qualitative research design using semi-structured interviews and focus group discussions. The qualitative approach was selected for three methodologically justified reasons:

1. **First**, the research investigates the *experiential dimensions* of technology integration—how maritime professionals and educators perceive, implement, and experience IT, IoT, and computer-based learning in practice. These nuanced perceptions, implementation challenges, contextual factors, and adaptive strategies cannot be adequately captured through quantitative instruments alone. Qualitative methods allow participants to articulate complex experiences in their own terms, revealing barriers and facilitators that predetermined survey items might overlook. For instance, participants' descriptions of "resistance to change" varied significantly—some attributed it to generational differences, others to inadequate training, and still others to legitimate concerns about system reliability. Such nuanced understanding requires open-ended exploration rather than fixed-response measurement.
2. **Second**, the research examines an *emerging and rapidly evolving phenomenon*. IoT and computer-based learning technologies in maritime contexts are relatively recent innovations, with limited standardized measures or validated scales available in the literature. Qualitative inquiry permits exploratory investigation of how these technologies are being adapted to maritime-specific challenges—such as harsh marine environments, regulatory complexity, and the unique skill requirements of seafaring professionals—generating insights that can inform future quantitative instrument development. The exploratory nature of qualitative research is particularly appropriate when investigating contemporary phenomena where theoretical frameworks are still developing.
3. **Third**, the study seeks to capture **dual stakeholder perspectives**—maritime industry professionals and maritime educators—and understand their potentially divergent views on technology effectiveness, implementation priorities, and workforce preparation. Qualitative methods enable comparative thematic analysis across these groups, identifying consensus areas (e.g., both groups acknowledge infrastructure barriers) and divergence points (e.g., industry prioritizes immediate operational efficiency while educators emphasize long-term competency development). This comparative analytical approach informs both operational and educational strategies by revealing where alignment exists and where strategic intervention is needed.

Note on Data Presentation: While the Results section (Section 3) presents participant ratings in visual format to summarize aggregate perspectives across multiple participants, these ratings emerged from qualitative discussions where participants were asked to assess their understanding, implementation experiences, and effectiveness perceptions on a scale of 1-10 during interviews. These are **qualitative assessments converted to visual representation** for interpretive clarity and to facilitate comparison across participant groups, not quantitative measurements derived from standardized instruments. The core analysis remains qualitative and thematic, with these visual representations serving as summary indicators of the range and central tendencies in participant perspectives. All interpretations are grounded in the rich narrative data from interview transcripts and focus group discussions, not in statistical analysis of numerical scores.

Sampling Frame and Participant Selection

Sampling Strategy: Purposive sampling was employed to identify information-rich participants with direct, substantive experience in maritime technology implementation and/or maritime education. This non-probability sampling approach was selected because the research requires participants with specialized knowledge and firsthand experience with the phenomena under investigation—random sampling would likely yield many participants without relevant expertise.

Sampling Frame:

Maritime Professionals:

a) Entrepreneurs in port and shipping industries with decision-making authority over technology investments

doi: 10.14710/teknik.v46i3.75496

b) Port and shipping officers with operational responsibilities involving IT/IoT systems
c) Maritime company managers with foundational knowledge as marine engineers, providing technical understanding of maritime technologies
d) All participants had minimum 5 years of professional experience in maritime operations
e) All had direct involvement with or responsibility for technology implementation projects

Maritime Educators:
a) Maritime vocational trainers delivering hands-on technical training in maritime education institutions
b) University lecturers teaching maritime engineering, navigation, or related technology courses
c) Maritime education researchers investigating pedagogical approaches and curriculum development
d) All participants had minimum 3 years of teaching experience in maritime education
e) All had direct involvement in curriculum development or technology-enhanced teaching

Geographic Scope: Participants were recruited from Jakarta, Indonesia, representing both large commercial ports (container terminals, oil/gas facilities) and diverse maritime educational institutions (polytechnics, maritime universities, vocational training centers).

Inclusion Criteria:
a) Direct professional involvement in maritime operations OR maritime education for minimum specified duration
b) For maritime professionals: demonstrated experience with IT/IoT systems in maritime contexts (e.g., vessel management systems, port automation, IoT sensors for cargo/fleet monitoring)
c) For educators: direct involvement in teaching maritime engineering, maritime technology, or related courses, with exposure to computer-based learning tools
d) Willingness to participate in audio-recorded interviews or focus group discussions
e) Ability to provide informed consent and participate in English
f) Availability for follow-up clarification if needed during analysis phase

Exclusion Criteria:
a) Less than the specified minimum professional/educational experience (5 years for professionals, 3 years for educators).
b) No direct engagement with emerging maritime technologies (e.g., purely administrative roles without operational or technological oversight).
c) Administrative or support roles without operational responsibilities or teaching duties.
d) Inability to communicate effectively in English.
e) Withdrawal of consent at any stage of the research process.

Sample Size and Participant Profiles

Total Sample: N = 24 participants

Maritime Professionals (n = 13):
a) Port/shipping entrepreneurs: 4 participants
   - Roles: Company owners/founders with technology investment decisions
b) Maritime officers (vessel/port operations): 5 participants
   - Roles: Port operations managers, vessel navigation officers, logistics coordinators
c) Maritime company managers (marine engineering background): 4 participants
   - Roles: Technical managers, fleet managers, operations directors
d) Average professional experience: 12.3 years (range: 5-23 years)
e) Gender distribution: 10 male, 3 female
f) Age range: 32-54 years (mean: 41 years)
g) Employment sectors: Container shipping (4), port operations (5), offshore services (2), maritime logistics (2)

Maritime Educators (n = 11):
a) Vocational trainers: 4 participants
   - Institutions: Maritime polytechnics, vocational training centers
b) University lecturers: 5 participants
   - Departments: Maritime engineering, nautical science, marine technology
c) Maritime education researchers: 2 participants
   - Focus areas: Curriculum development, technology-enhanced learning
d) Average teaching experience: 8.7 years (range: 3-18 years)
e) Gender distribution: 7 male, 4 female
f) Age range: 29-51 years (mean: 38 years)
g) Academic qualifications: All held minimum master's degrees; 3 held doctoral degrees
h) Institution types: Maritime universities (6), polytechnics (3), vocational centers (2)

Recruitment Process: Participants were recruited through professional networks, institutional contacts, and snowball sampling where initial participants

doi: 10.14710/teknik.v46i3.75496

recommended colleagues meeting inclusion criteria. All potential participants received participant information sheets describing the research purpose, procedures, time commitment, and ethical protections before agreeing to participate.

Data Collection Procedures

Semi-Structured Interviews:

a) **Number of interviews**: 24 individual interviews (one per participant)
b) **Duration**: 45-75 minutes per interview (average: 58 minutes, median: 55 minutes)
c) **Medium**: 18 interviews conducted face-to-face at participants' workplaces or neutral venues; 6 conducted via video conference platform (Zoom) for participants with geographic or scheduling constraints
d) **Recording**: All interviews audio-recorded using digital recorders with participant consent; video interviews also screen-recorded with audio
e) **Transcription**: Professional transcription service employed for verbatim transcription; all transcripts verified by researchers for accuracy by listening to recordings while reading transcripts
f) **Interview guide structure**: The semi-structured interview guide contained 22 open-ended questions organized into five thematic sections:
    i. Background and experience with maritime technologies (4 questions)
    ii. Current understanding and use of IT/IoT in maritime operations (6 questions)
    iii. Experiences with technology implementation—challenges, successes, barriers (5 questions)
    iv. Perceptions of computer-based learning effectiveness in maritime education (4 questions)
    v. Industry-education collaboration experiences and recommendations (3 questions)
g) **Probing and flexibility**: While the guide provided structure, interviewers used probing questions (e.g., "Can you give me a specific example?" "What do you mean by that?") to elicit deeper insights and allowed participants to raise topics not explicitly in the guide
h) **Assessment ratings**: During interviews, participants were asked to assess their understanding, implementation level, and effectiveness perceptions on a scale of 1-10 to provide a summary indicator; these assessments were accompanied by narrative explanations that formed the primary analytical data
i) **Focus Group Discussions**:
j) **Number of focus groups**: 3 focus group discussions
k) **Composition**:
    i. Focus Group 1: 7 maritime professionals (mixed roles—2 entrepreneurs, 3 officers, 2 managers)
    ii. Focus Group 2: 6 maritime educators (mixed backgrounds—2 vocational trainers, 3 lecturers, 1 researcher)
    iii. Focus Group 3: 5 mixed participants (2 maritime professionals + 3 educators) for cross-stakeholder dialogue
l) **Duration**: 90-120 minutes per focus group (average: 105 minutes)
m) **Medium**: All focus groups conducted face-to-face at neutral, accessible venues (university seminar rooms, conference facilities)
n) **Recording**: Audio and video recorded with all participants' consent; two camera angles used to capture group dynamics
o) **Transcription**: Full verbatim transcripts prepared, including notation of non-verbal communication where relevant (e.g., gestures, expressions of agreement/disagreement)
p) **Focus group protocol**: Each focus group followed a structured protocol including:
    i. Opening: Introductions, ground rules, consent verification (10 minutes)
    ii. Guided discussion: Structured questions on technology integration experiences (40-50 minutes)
    iii. Collaborative activities: Problem-solving exercises about overcoming implementation barriers (20-30 minutes)
    iv. Preliminary findings feedback: Participants' reactions to emerging themes from interviews (20-30 minutes)
    v. Closing: Summary, final comments, appreciation (10 minutes)
q) **Facilitation**: Focus groups facilitated by experienced moderator with assistant moderator taking detailed notes; facilitators used techniques to ensure balanced participation and manage dominant speakers.

Data Collection Timeline: Data collection occurred over 5 months (November 2024 to March 2025). Interviews were conducted first (November 2024 - February 2025) to identify preliminary themes, followed by focus groups (March 2025) to explore these themes in depth and validate initial interpretations through group interaction.

doi: 10.14710/teknik.v46i3.75496

Data Saturation: Data collection continued until thematic saturation was achieved—the point at which no new themes or significant insights emerged from additional interviews. Saturation was assessed through ongoing analysis during data collection, with the research team monitoring for redundancy in participant responses.

Data Analysis

Thematic Analysis Approach: Following Braun and Clarke's (2006) six-phase framework for rigorous thematic analysis:

Phase 1: Familiarization with Data

a) All researchers read complete interview transcripts and focus group transcripts multiple times
b) Initial observations, reactions, and potential patterns noted in research memos
c) Audio recordings listened to while reading transcripts to capture tone, emphasis, emotion

Phase 2: Initial Coding

a) Systematic line-by-line coding using NVivo 12 qualitative data analysis software
b) 387 initial codes generated across all transcripts
c) Codes captured semantic content (explicit meanings) and latent content (underlying concepts)
d) Examples of initial codes: "IoT sensors for predictive maintenance," "cost barriers to implementation," "simulation effectiveness for navigation training," "instructor resistance to technology"

Phase 3: Searching for Themes

a) Initial codes grouped into candidate themes through iterative team discussions
b) Visual mapping of codes-to-themes relationships using mind maps and clustering techniques
c) Preliminary theme structure developed with main themes and sub-themes
d) Candidate themes: Technology adoption barriers, Learning outcomes enhancement, Industry-education gap, Infrastructure challenges

Phase 4: Reviewing Themes

a) Themes refined by checking them against coded data extracts (internal homogeneity) and entire dataset (external heterogeneity)
b) Some candidate themes collapsed, others split into distinct themes
c) Ensured themes captured coherent patterns with clear boundaries

Phase 5: Defining and Naming Themes

a) Each final theme precisely defined with clear scope and boundaries
b) Theme names crafted to immediately convey essence
c) Detailed thematic analysis documents prepared for each theme, including definition, boundaries, sub-themes, and illustrative quotes

Phase 6: Producing the Report

a) Illustrative quotes selected to represent each theme and sub-theme
b) Analytical narrative constructed linking themes to research questions
c) Findings integrated with existing literature

Inter-Coder Reliability:

a) Two researchers independently coded 25% of randomly selected transcripts (6 interviews, 1 focus group)
b) Inter-coder agreement assessed using Cohen's Kappa coefficient = 0.82, indicating strong agreement beyond chance
c) All coding discrepancies discussed and resolved through consensus before proceeding with full dataset coding
d) Coding framework refined based on these discussions

Final Thematic Structure: Major themes that emerged from the analysis:

1. **Technology Understanding vs. Implementation Gap**: High awareness but moderate operational integration
2. **Infrastructure and Resource Barriers**: Legacy systems, cost constraints, compatibility issues
3. **Computer-Based Learning Effectiveness and Constraints**: Positive outcomes but uneven adoption
4. **Industry-Education Alignment Imperative**: Need for curriculum-practice integration and collaboration

Ethical Considerations

Ethical Approval: This study received ethical approval from Research Board of STIP Jakarta in Research Ethics Committee (Reference Number: 178/2025 - P3M STIP 2025) prior to participant recruitment or data collection. The study protocol was reviewed for adherence to principles of respect for people, beneficence, and justice.

Informed Consent:

a) All participants provided written informed consent before any data collection
b) Participants received detailed Participant Information Sheets explaining:
    i. Research purpose, objectives, and anticipated contributions
    ii. Research procedures (interview/focus group process, duration, recording).

doi: 10.14710/teknik.v46i3.75496

   iii. Voluntary participation and explicit right to withdraw at any time without penalty or need for justification.
   iv. Data confidentiality, anonymization procedures, and secure storage protocols.
   v. Data usage (research purposes only), retention period, and eventual disposal
   vi. Potential risks (minimal—time commitment, slight discomfort discussing workplace challenges) and benefits (contribution to maritime sector advancement).
   vii. Researcher contact information for questions or concerns.
   viii. Ethics committee contact information for complaints or concerns.

c) Consent forms signed before interviews/focus groups commenced.
d) Verbal consent reconfirmed at beginning of each recorded session.
e) Participants explicitly consented to audio/video recording.

Confidentiality and Anonymization:

a) All participant names removed from transcripts and replaced with participant codes.
b) Coding system: Maritime Professionals = MP01-MP13; Maritime Educators = ME01-ME11.
c) All potentially identifying information redacted from transcripts, including:
   i. Specific company names, vessel names, port facility identifiers.
   ii. Colleagues' names or unique position titles.
   iii. Institution names (replaced with generic descriptors: "large maritime university," "polytechnic").
   iv. Any unique incidents or situations that could identify participants.
d) Quotes in publications use participant codes only.
e) Aggregate reporting used where possible to further protect individual identities.
f) Master list linking participant codes to identities stored separately from data in encrypted, password-protected file accessible only to principal investigator.

Data Management and Security:

a) All audio/video recordings stored on password-protected, encrypted devices.
b) Transcripts and analysis files stored on secure, encrypted cloud storage with access limited to research team.
c) Physical documents (consent forms, field notes) stored in locked filing cabinets in researcher's secure office.
d) Data backup procedures implemented to prevent data loss.
e) No identifiable data shared outside research team.
f) Audio/video recordings will be destroyed 5 years post-publication as per institutional policy.
g) Anonymized transcripts retained for potential secondary analysis or research verification purposes.

Participant Rights and Wellbeing:

a) Participants informed of right to decline answering any question without consequence.
b) Participants permitted to take breaks during interviews/focus groups if needed.
c) Participants offered opportunity to review their interview transcripts (member checking).
d) No vulnerable populations involved; all participants were professionals capable of informed consent.
e) Researchers monitored for any signs of participant distress during interviews (none observed).
f) Debriefing provided at end of each interview/focus group, with opportunity to ask questions.

Conflict of Interest:

a) Researchers declared no financial or professional conflicts of interest with participating organizations.
b) No participants were in supervisory or evaluative relationships with researchers that could create coercion.

Trustworthiness and Rigor

To ensure the quality and credibility of this qualitative research, the study implemented multiple strategies aligned with Lincoln and Guba's (1985) criteria for trustworthiness:

Credibility (confidence in the truth of findings):

a) **Prolonged engagement**: Researchers invested significant time understanding maritime context through site visits, industry events, and extensive literature review before data collection.
b) **Persistent observation**: In-depth interviews and extended focus groups allowed deep exploration of participants' experiences.

doi: 10.14710/teknik.v46i3.75496

c) **Triangulation**: Multiple data sources (individual interviews + focus group discussions) and multiple participant groups (professionals + educators) provided convergent evidence.
d) **Member checking**: Preliminary findings presented to 8 participants (4 professionals, 4 educators) for validation; participants confirmed findings accurately reflected their experiences with minor clarifications incorporated.
e) **Peer debriefing**: Research team held regular analytical meetings to challenge assumptions, consider alternative interpretations, and ensure findings grounded in data.

Transferability (applicability to other contexts):
a) **Thick description**: Detailed documentation of research context, participants, settings, and procedures enables readers to assess applicability to their contexts.
b) **Purposive sampling**: Diverse participant selection (different roles, experience levels, institution types) enhances potential transferability.
c) **Detailed participant profiles**: Comprehensive demographic and professional information allows comparison with other populations.
d) **Contextual information**: Description of maritime sector characteristics, technology types, and educational system features provides context for interpretation.

Dependability (consistency and replicability of processes):
a) **Audit trail**: Comprehensive documentation of all research decisions, analytical steps, and methodological adaptations maintained throughout study.
b) **Clear research protocol**: Detailed interview guides, focus group protocols, and analytical procedures documented and followed systematically.
c) **Transparent data management**: Systematic procedures for data collection, storage, transcription, and analysis documented.
d) **Methodological coherence**: Clear alignment between research questions, methodological approach, data collection methods, and analytical strategies.

Confirmability (objectivity and groundedness in data):
a) **Reflexivity**: Researchers maintained reflexive journals documenting personal assumptions, biases, and reactions to data; acknowledged researcher backgrounds (one researcher with maritime engineering background, one with educational technology expertise).
b) **Multiple analyst verification**: Two researchers independently coded subset of data; all themes reviewed by full research team.
c) **Data-grounded interpretations**: All claims supported by direct participant quotes and explicit linkage to coded data.
d) **Negative case analysis**: Actively searched for data that contradicted emerging themes; divergent perspectives acknowledged and discussed in findings.
e) **External audit**: Experienced qualitative researcher not involved in data collection reviewed analytical process and findings for logical consistency and evidentiary support.

These trustworthiness measures collectively ensure that the findings accurately represent participants' experiences and perspectives, that the analytical process was rigorous and systematic, and that interpretations are firmly grounded in the data rather than researcher preconceptions.

3. Results

Indicator 1: Integration of IT and IoT in Maritime Engineering Practices

The data from the participants reveals a strong understanding of IT and IoT technologies and their applications in maritime engineering. Maritime professionals, such as entrepreneurs, officers, and managers, consistently report high scores in their understanding of how these technologies can enhance operational efficiency, safety, and sustainability. The implementation of IT and IoT systems is rated similarly, demonstrating that maritime companies are increasingly adopting these technologies for real-time vessel monitoring, predictive maintenance, and route optimization.

However, the effectiveness of the integration of these technologies in operational practices shows slightly lower scores than the understanding and implementation ratings. This gap suggests that while the technology is well understood and adopted, its full potential has not been realized due to challenges such as outdated infrastructure, lack of compatibility across different systems, and high initial costs. The challenges identified by the participants—such as the technological gaps in port systems and the need for more specialized curriculum in maritime education—highlight the barriers that must be overcome for more seamless integration and greater operational efficiency. Integration of IT and IoT in Maritime Engineering Practices is shown in Figure 1.

doi: 10.14710/teknik.v46i3.75496

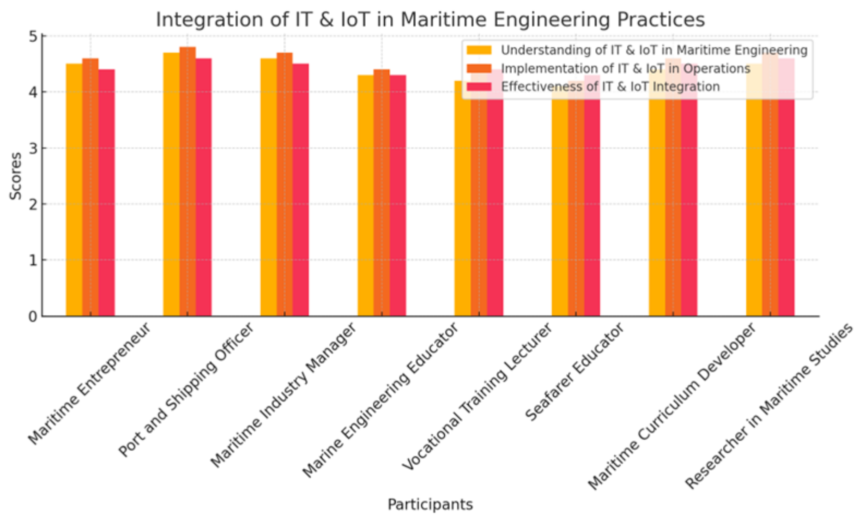

Figure 1. Integration of IT and IoT in Maritime Engineering Practices.

Indicator 2: Effectiveness of Computer-Based Learning in Maritime Education

The second indicator examines the role of computer-based learning in enhancing maritime education, particularly in terms of training students to work with advanced technologies in the maritime sector. The data shows that the adoption of computer-based learning tools, including virtual simulations, online learning platforms, and augmented reality, is growing within maritime education institutions. The effectiveness of these learning tools is highly rated, with significant improvements in learning outcomes and a more engaging, interactive educational experience for students as shown in Figure 2.

Participants, including both educators and industry professionals, acknowledge the positive impact of computer-based learning in preparing students for the technological demands of the maritime industry. The use of simulations and VR technologies, for instance, allows students to interact with complex maritime systems, gaining practical experience without the need for physical access to ships or equipment. However, challenges remain in the implementation of these technologies across all educational institutions. Limited resources, resistance to new technologies, and the need for updated content and instructor training were frequently cited as obstacles to the effective deployment of these learning tools.

Comprehensive Tables and Results Interpretation

The tables presented above reflect the scores given by participants in the study based on their experiences and perceptions of the integration of IT, IoT, and computer-based learning in maritime engineering and education. These scores are divided into three main areas:

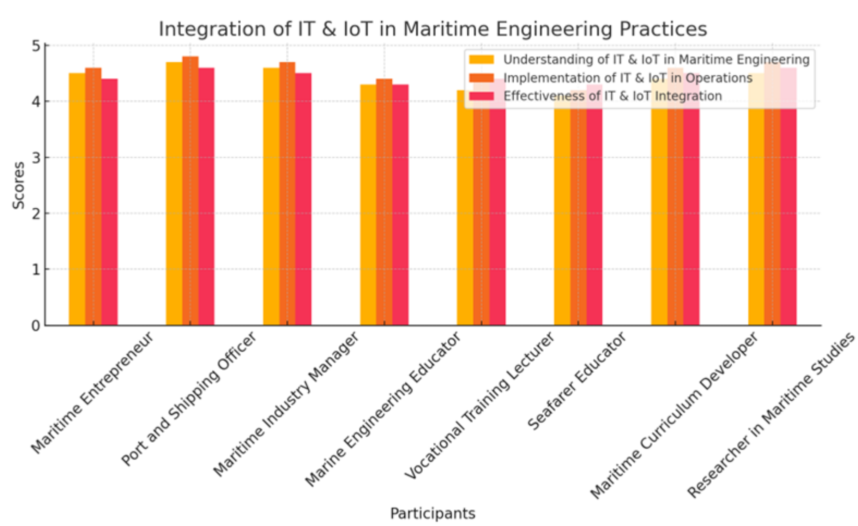

Figure 2. Effectiveness of Computer-based Learning in Maritime Education.

doi: 10.14710/teknik.v46i3.75496

understanding of the technology, its implementation in practice, and its effectiveness in achieving desired outcomes.

For **Indicator 1**, participants consistently rated the understanding and implementation of IT and IoT technologies highly. However, the effectiveness scores suggest that, while there is a solid foundation for the adoption of these technologies, the maritime industry still faces challenges in optimizing their use for maximum efficiency and sustainability. These challenges primarily stem from the high costs, slow infrastructure upgrades, and lack of uniform standards across different sectors of the maritime industry.

For **Indicator 2**, the adoption and effectiveness of computer-based learning tools are rated positively, indicating that these technologies are becoming increasingly integral to maritime education. The significant improvement in learning outcomes demonstrates the potential of these tools to enhance students' understanding and readiness to work with modern maritime systems. Nevertheless, the barriers to full implementation, such as resource limitations and resistance from educators, suggest that more work is needed to standardize the integration of computer-based learning across educational institutions.

The results from both indicators demonstrate a strong trend toward the adoption of IT, IoT, and computer-based learning technologies in the maritime industry and educational sectors. The understanding and implementation of these technologies show considerable promise, yet their full potential is often hindered by infrastructure limitations, resistance to change, and a lack of standardized systems. These findings emphasize the need for further investment in infrastructure, curriculum updates, and professional development to ensure that the maritime sector and educational institutions are equipped to harness the full capabilities of these emerging technologies.

4. Discussion

The results of this research provide important insights into the integration of emerging technologies such as IT, IoT, and computer-based learning in maritime engineering and education. The study reveals that both maritime professionals and educators recognize the potential benefits of these technologies, but challenges remain in fully realizing their effectiveness in both operational practices and educational outcomes. The following discussion examines the key findings from the research, highlights the implications of these results, and explores potential strategies for overcoming the challenges identified.

Integration of IT and IoT in Maritime Engineering Practices

The integration of IT and IoT technologies into maritime engineering practices has shown significant promise, with participants indicating a strong understanding and implementation of these systems in real-world operations. Maritime entrepreneurs, officers, and managers reported high levels of awareness regarding the advantages of these technologies, particularly in the areas of predictive maintenance, real-time monitoring of vessels, and operational efficiency. These technologies have the potential to revolutionize maritime operations, allowing companies to improve decision-making, reduce downtime, optimize fuel consumption, and enhance safety standards.

However, the research also highlights a gap between the understanding of these technologies and their full-scale implementation. While many maritime professionals acknowledge the benefits of IoT and IT in theory, the practical challenges involved in implementing these technologies remain substantial. The industry faces barriers such as the high initial investment costs required for upgrading existing infrastructure, the complexity of integrating new technologies with legacy systems, and the lack of standardization across different sectors of the maritime industry. These barriers hinder the widespread adoption of IT and IoT solutions, particularly in smaller ports or shipping companies that may lack the financial resources or technical expertise to implement such systems.

Additionally, the findings point to a slower-than-expected rollout of smart ports and IoT-enabled vessels. Despite the clear advantages of these technologies, such as improving vessel management, reducing operational costs, and enhancing fuel efficiency, many ports and maritime companies continue to rely on traditional methods and infrastructure. The research suggests that this slow pace of adoption is partly due to regulatory challenges, the reluctance to invest in new technologies without immediate returns, and the lack of a cohesive strategy for implementing IT and IoT solutions at the industry level.

The effectiveness of the integration of these technologies also remains a work in progress. While participants acknowledged that these technologies have improved operational efficiency, they also pointed out that their full potential has not yet been fully realized. For example, although IoT sensors are capable of providing real-time data on vessel performance, many companies are still in the early stages of using this data effectively. The analysis of this data requires sophisticated analytics tools and decision-support systems, which many maritime companies still lack. Furthermore, the integration of data from multiple sources—such as sensors on vessels, at ports, and within supply chains—

doi: 10.14710/teknik.v46i3.75496

remains a challenge, and without a unified data management strategy, the value of these technologies is reduced.

Challenges in Maritime Education

While the research highlights the promising role of computer-based learning technologies in maritime education, it also underscores the barriers to their full implementation within educational institutions. The adoption of computer-based learning tools, such as virtual simulations, augmented reality (AR), and e-learning platforms, has shown a positive impact on student engagement and learning outcomes. These tools provide immersive and interactive experiences that allow students to practice their skills in a simulated environment, offering a safer and more cost-effective alternative to traditional, hands-on training. Students can gain practical experience in ship navigation, cargo handling, and emergency response procedures, all of which are essential skills for future maritime professionals.

However, the research also reveals that the adoption of computer-based learning technologies is not without its challenges. Many maritime educational institutions face resource limitations that hinder the widespread use of these technologies. The initial costs of acquiring the necessary hardware and software, as well as the ongoing expenses for system maintenance and updates, can be prohibitive, particularly for smaller or underfunded institutions. Additionally, some educators resist integrating new technologies into their teaching practices, either due to a lack of familiarity with these tools or concerns about their effectiveness. Without adequate professional development and training opportunities for educators, the full potential of these technologies cannot be realized.

Another challenge identified in the research is the inconsistency in the integration of computer-based learning across different institutions. While some maritime education programs have successfully incorporated advanced technologies into their curricula, others continue to rely on traditional teaching methods. This inconsistency creates disparities in the quality of education, with some students having access to state-of-the-art training tools while others do not. This highlights the need for a more standardized approach to integrating computer-based learning into maritime education, ensuring that all students have access to the same high-quality resources, regardless of the institution they attend.

Enhancing Learning Outcomes Through Computer-Based Learning Tools

The effectiveness of computer-based learning tools in enhancing student learning outcomes is one of the most positive findings of this research. The data suggests that students who engage with these technologies experience a more engaging and interactive learning environment. Virtual simulations and AR tools allow students to explore complex maritime systems in a way that traditional textbooks and classroom lectures cannot. These tools also offer students the opportunity to practice real-world scenarios, such as ship navigation, cargo loading, and crisis management, in a risk-free environment. The ability to simulate emergency situations and practice problem-solving in real-time is particularly valuable for maritime students, who are often required to make quick decisions under pressure.

Moreover, computer-based learning tools enable students to progress at their own pace, allowing for personalized learning experiences that cater to individual needs. Students can revisit complex concepts, engage with interactive content, and receive immediate feedback, which enhances their understanding and retention of the material. This approach contrasts with traditional teaching methods, which often rely on one-size-fits-all lectures and assessments.

However, the research also highlights some areas for improvement in the use of these learning tools. Although the tools themselves are effective, their implementation is sometimes hindered by technical issues, such as poor connectivity, lack of technical support, and outdated software. In some cases, students and educators have difficulty using these tools due to a lack of training and familiarity with the technology. To overcome these challenges, it is crucial to invest in both the infrastructure required to support these technologies and the professional development of educators to ensure that they can effectively use and integrate these tools into their teaching practices.

The Role of Collaboration Between Industry and Education

One of the most significant findings of this research is the importance of collaboration between the maritime industry and educational institutions. The integration of emerging technologies in maritime education requires close cooperation between educators and industry professionals to ensure that students are learning the skills needed to succeed in the modern maritime sector. The research shows that maritime companies value practical experience and are increasingly looking for graduates who are familiar with the latest technologies and can apply them effectively in real-world settings.

Industry involvement in the development of curricula, the creation of training programs, and the provision of real-world learning opportunities such as internships and apprenticeships is essential for aligning educational outcomes with industry needs. By working together, industry professionals and educators can ensure that students are well-equipped to handle the technological challenges they will face in their careers. This

doi: 10.14710/teknik.v46i3.75496

collaboration also allows industry professionals to provide valuable insights into the practical applications of emerging technologies, ensuring that students receive relevant, up-to-date training.

Implications for Maritime Education and Engineering

The findings of this research have significant implications for both maritime education and maritime engineering practices. For education, the research highlights the need for a paradigm shift in how maritime training is delivered. Traditional methods, such as lectures and textbooks, must be complemented with modern, technology-driven teaching tools that provide hands-on experience and simulate real-world scenarios. For maritime engineering, the research underscores the importance of integrating emerging technologies, such as IoT and smart systems, into both operational practices and the training of future engineers. This shift will ensure that the maritime industry remains competitive and capable of meeting the challenges of the future.

The research also emphasizes the need for continued investment in both technology and education. The challenges identified in the research, such as infrastructure limitations, resistance to change, and the lack of standardized curricula, must be addressed to fully realize the potential of IT, IoT, and computer-based learning in maritime operations and education. By overcoming these challenges, the maritime industry can pave the way for a more sustainable, efficient, and technologically advanced future.

While the integration of IT, IoT, and computer-based learning technologies into maritime engineering practices and education shows great promise, several challenges remain in fully realizing their potential. The research highlights the need for greater collaboration between industry and educational institutions, continued investment in technology and infrastructure, and the development of standardized curricula that equip students with the skills necessary to thrive in an increasingly digital and technologically advanced maritime industry. Overcoming these challenges will be key to ensuring that the maritime sector remains competitive, sustainable, and capable of addressing the emerging needs of the global economy.

5. Conclusion

This research highlights the transformative role of emerging technologies such as IT, IoT, and computer-based learning in enhancing maritime engineering practices and education. The study reveals that while there is a strong understanding and adoption of these technologies within the maritime sector, challenges such as outdated infrastructure, high implementation costs, and the lack of standardized educational curricula hinder their full integration. The findings underscore the need for continued investment in technological infrastructure and the development of more adaptable, future-oriented training programs that prepare students for the demands of the modern maritime industry. Additionally, the research emphasizes the importance of collaboration between maritime professionals and educational institutions to ensure that curricula reflect the latest industry trends and technological advancements. By fostering closer ties between industry and education, both sectors can work together to enhance operational efficiency, safety, and sustainability through the effective use of emerging technologies. The integration of IoT in vessel management, smart ports, and the adoption of computer-based learning tools are key to enhancing both operational practices and educational experience.

References

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101.

Cohn, A. B., & Dennis, J. M. (2013). 1055 Maritime Archaeology, the Dive Community, and Heritage Tourism. In B. Ford, D. L. Hamilton, & A. Catsambis (Eds.), *The Oxford Handbook of Maritime Archaeology* (p. 0). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199336005.013.0046

de la Peña Zarzuelo, I., Soeane, M. J. F., & Bermúdez, B. L. (2020). Industry 4.0 in the port and maritime industry: A literature review. *Journal of Industrial Information Integration*, *20*, 100173.

Dyagileva, O., Goridko, N., Popova, H., Voloshynov, S., & Yurzhenko, A. (2020). *Ensuring sustainable development of education of future maritime transport professionals by means of network interaction*.

Jimenez, V. J., Kim, H., & Munim, Z. H. (2022). A review of ship energy efficiency research and directions towards emission reduction in the maritime industry. *Journal of Cleaner Production*, *366*, 132888.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

Manuel, M. E. (2017). Vocational and academic approaches to maritime education and training (MET): Trends, challenges and opportunities. *WMU Journal of Maritime Affairs*, *16*, 473-483.

Nguyen, T.-T., My Tran, D. T., Duc, T. T. H., & Thai, V. V. (2023). Managing disruptions in the maritime industry--a systematic literature review. *Maritime Business Review*, *8*(2), 170-190.

Pu, S., & Lam, J. S. L. (2021). Blockchain adoptions in the maritime industry: a conceptual framework.

doi: 10.14710/teknik.v46i3.75496

Maritime Policy & Management, *48*(6), 777-794.

Shao, C., Yang, Y., Juneja, S., & GSeetharam, T. (2022). IoT data visualization for business intelligence in corporate finance. *Information Processing & Management*, *59*(1), 102736.

Slama, D., Puhlmann, F., Morrish, J., & Bhatnagar, R. M. (2015). *Enterprise IoT: Strategies and Best practices for connected products and services*. O'Reilly Media, Inc.

Tahir, M. S. M., Mustapha, R., Hashim, M. E. A. H., Mohd, N., & Razalli, A. K. (n.d.). *Merging the Application of Artificial Intelligence Technology in Maritime Industry: A Systematic Literature Review*.

Wahl, A. M., & Kongsvik, T. (2018). Crew resource management training in the maritime industry: a literature review. *WMU Journal of Maritime Affairs*, *17*(3), 377-396.

doi: 10.14710/teknik.v46i3.75496