

Human-Centered Maritime Operations Strategies for Addressing Automation and Artificial Intelligence in the Maritime Industry

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ABSTRACT

The application of automation and artificial intelligence (AI) in the maritime industry drives operational efficiency, but increases risks related to seafarer competence, decision-making, safety, and human-machine interaction. This research aims to identify relevant human-centered maritime operations strategies to support the safe and effective use of automation and AI. The research method used a systematic literature review based on PRISMA 2020 against 2020–2025 publications on Scopus, Web of Science, and ScienceDirect. Of the 214 recordings identified, 25 articles met the inclusion criteria and were analyzed through thematic synthesis. The results show that digital competency training, human-in-the-loop design, system transparency, human supervision, and risk management are strategies. These findings underscore the importance of a human-centered approach to improving the safety, operational reliability, and readiness of the maritime workforce for digital transformation.

INTRODUCTION

The shipping industry is a strategic part of the world's trade system and supply chain as more than 80% of international trade volume of goods is transported by sea. Global maritime trade grew by around 2.2% in 2024, although growth is expected to slow to 0.5% in 2025 due to increasing trade uncertainty and global supply chain disruptions (Trade & (UNCTAD), 2025). At the same time, the maritime sector is undergoing transformation through automation, artificial intelligence (AI), data analytics, intelligent navigation systems, and Maritime Autonomous Surface Ships (Bak, 2025). These changes provide opportunities for increased efficiency and safety, but also change the division of duties, responsibilities, and competencies of the maritime workforce. Song et al. (2025) show that the development of MASS affects the work of seafarers, the content of tasks, competency needs, and the pattern of human interaction with technology, so digital transformation needs to be placed in a framework of operations that remains human-oriented.

The human-centered maritime operations approach views humans and technology as interdependent components in a sociotechnical system. Therefore, increasing automation does not necessarily mean eliminating humans from the operating process, but changing its role from direct executors to supervisors, decision-makers, and controllers when the system encounters abnormal conditions. Sharma & Kim (2022) found that autonomous vessel operations require a combination of technical and nontechnical competencies, including understanding of automated systems, situational awareness, decision-making, communication, and cognitive abilities. This is even more important because Cheng et al. (2024) show that operator performance in human-autonomy collaboration is influenced by factors such as available time, task complexity, and early warning when humans should take control. Thus, system safety depends not only on the sophistication of the algorithm, but also on how the technology is designed to support human ability to supervise and make decisions.

This context is also relevant for Indonesia as an archipelagic country that relies heavily on sea transportation. Digital transformation has been applied to various port and shipping activities through the integration of digital-based services and operational systems. Safuan & Syafira (2024) shows that the development of digital technology in Indonesian ports has included aspects of sea, land, and customer service and has the potential to improve the integration of operational processes. Margaretha et al. (2024) further emphasized that AI, Internet of Things, big data analytics, and automation offer increased efficiency, safety, and competitiveness in Indonesia's maritime sector, but their implementation still faces limitations in digital infrastructure, workforce expertise, and regulatory readiness. More specifically, Bachtar (2025) found that the adoption of AI in Indonesia's maritime industry, including the Port of Tanjung Priok, is still in its early stages and faces problems of system integration and human resource competence. This condition shows that the success of national maritime digitalization needs to be followed by strengthening the human dimension, not just technology investment.

Although attention to human factors in maritime automation is increasing, previous studies still show research gaps. Sharma & Kim (2022) focus on changes in navigator competencies, while Cheng et al. (2024) more specifically analyze human error in the process of taking control in autonomous ship operations. B  k (2025) have developed a human-centered perspective, but the main focus is on the impact of MASS on seafarers. Meanwhile, Xiong et al. (2022) emphasized the human-machine aspects of risk and cooperation, while Belabyad et al. (2025) focused on the identification and prioritization of workforce competencies for autonomous ships. In the Indonesian context, Safuan & Syafira (2024), Margaretha et al. (2024), and Bachtiar (2025) discussed more technology implementation, port digitalization, and AI adoption readiness. Thus, there are still limited studies that integrate digital competencies, human-in-the-loop, human supervision, system transparency, and risk management into human-centered maritime operations strategies in the face of the development of automation and AI.

Based on these gaps, this study aims to identify and analyze human-centered maritime operations strategies to support the safe and effective application of automation and AI in the maritime industry. The research focuses analysis on how workforce competencies, human-machine collaboration patterns, human oversight mechanisms, technology transparency, and risk management can be combined to maintain operational safety and reliability. This focus is in line with Xiong et al. (2022), who place human-machine cooperation as an important element in maritime transportation safety, and Belabyad et al. (2025), who through the responses of 174 experts found that operational skills, digital skills, and maritime competencies are important skill groups for the operation of ships with an increasing degree of autonomy. To obtain a structured synthesis, the study used a systematic literature review (SLR) with the guidelines of PRISMA 2020 as stipulated in the research design.

Theoretically, this research is expected to strengthen the study of maritime human factors by integrating human-centered perspectives and sociotechnical systems in understanding human relationships, automation, and AI in shipping operations. The main contribution of the research lies in the unification of findings that were previously scattered in competency studies, system design, safety, human supervision, and human-machine cooperation into a more integrated maritime operations strategy framework. In practice, the results of the research are expected to be input for shipping companies, Maritime Education and Training (MET) institutions, technology developers, and regulators in developing digital competency training, maintaining human-in-the-loop mechanisms, improving the clarity of AI systems, and developing risk management that takes into account human and technological limitations. This approach is essential for automation to not only improve efficiency, but also maintain safety, operational reliability, and workforce readiness in the face of the transformation of the maritime industry.

IMPLEMENTATION AND METHODS

Research Design

This research is a secondary research with a qualitative approach using a systematic literature review (SLR) design. This approach is used to identify, evaluate, and synthesize scientific evidence regarding human-centered maritime operations strategies in the face of the development of automation and artificial intelligence (AI) in the maritime industry. The review process follows the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 to improve the transparency, traceability, and repeatability of the literature selection process (Holst et al., 2025). PRISMA 2020 provides a systematic framework for reporting information sources, selection processes, and articles that are finally included in the synthesis.

Data Sources and Search Strategy

Literature search was carried out on publications for the 2020–2025 period through three predetermined databases, namely Scopus, Web of Science, and ScienceDirect. The search strategy is based on the main concepts of the research, including maritime, shipping, automation, artificial intelligence, human-centered, human factors, human-in-the-loop, human-machine interaction, seafarer, and Maritime Autonomous Surface Ships (MASS). Keywords are combined using the Boolean AND and OR operators and are tailored to the characteristics of each database. Documentation of sources and search strategies is carried out systematically so that the search process can be traced, in line with the PRISMA-S principle regarding the transparency of literature search in systematic reviews (Rethlefsen et al., 2021).

Conceptually, the main search combinations can be formulated as follows:

Table1. Search Strategy and Data Sources

Database	Search Strategy	Period
Scopus	("artificial intelligence" OR automation OR "autonomous ship*" OR MASS) AND ("human-centered" OR "human factors" OR "human-in-the-loop" OR "human-machine" OR seafarer*) AND (maritime OR shipping)	2020–2025
Web of Science	Search terms adapted to the database syntax using the same concepts and Boolean operators	2020–2025
ScienceDirect	Search terms adapted to the database syntax using the same concepts and Boolean operators	2020–2025

Population, Sampling, and Eligibility Criteria

The research population is in the form of scientific publications related to automation and AI in the maritime industry and discusses the human dimension in its implementation. Unlike survey or experimental research, this study does not use respondents or informants because scientific articles are the unit of research analysis. Based on the search results on three databases, 214 records were obtained at the identification stage. The selection uses a criterion-based purposive selection technique, where articles are selected based on their suitability for the purpose of the research.

The inclusion criteria include publications in 2020–2025, discussing the maritime or shipping sector, related to automation and/or AI, and containing discussions of human factors, workforce competence, human–machine interaction, human supervision, safety, or operational risks. Publications that are not directly related to the maritime sector, only discuss technical aspects without a human dimension, are duplicates, or do not have substance that is in accordance with the purpose of the research are excluded from the analysis. After all stages of selection were carried out, 25 articles met the inclusion criteria and became the final sample of the research.

Study Selection and PRISMA 2020 Procedure

The research procedure was carried out in stages following the flow of PRISMA 2020. The first stage was identification, which was a search on Scopus, Web of Science, and ScienceDirect which yielded 214 records. The next stage includes duplicate checks and screening based on titles and abstracts. Relevant publications are then checked through text reading to ensure suitability with the research criteria. The final stage is inclusion, which results in 25 articles to analyze. This approach is in line with PRISMA 2020 which emphasizes transparent reporting on how recordings are identified, screened, assessed, and assigned as studies included in the review (Holst et al., 2025).

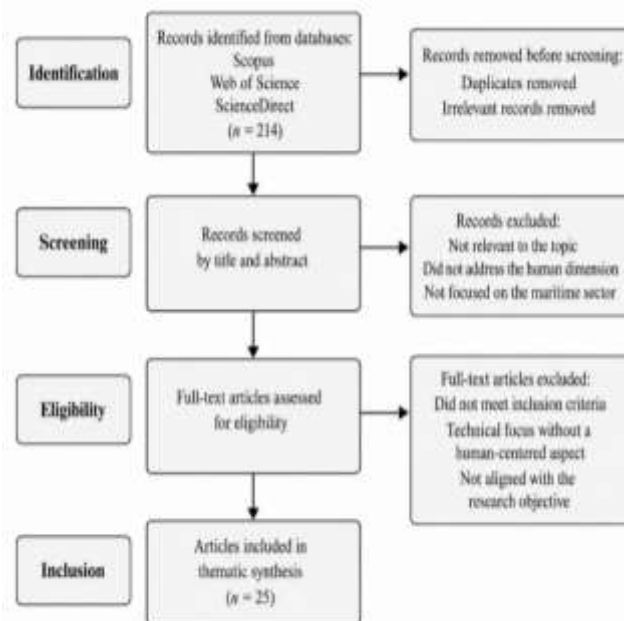


Figure 1. PRISMA 2020

Numbers at the stages between identification and inclusion were not added in this study to remain consistent with the data reported in the abstract. In the presentation of the final article, the flow can be visualized using the PRISMA 2020 flow diagram format. PRISMA 2020 itself is an updated reporting guideline to improve the completeness and transparency of systematic review reporting.

Data Extraction and Methodological Consistency

Data from 25 selected articles were systematically extracted by paying attention to information relevant to the research objectives, especially the context of automation and AI, human roles, labor competencies, human-machine interaction patterns, safety, supervision, system transparency, and risk management. The data is then tabulated to facilitate comparison and identification of patterns between publications. Microsoft Excel is used as a tool to organize, tabulate, and group data during the synthesis process.

Because this study did not use questionnaires or psychometric instruments, validity and reliability tests such as Cronbach's alpha were not applied. Methodological accuracy is maintained through the use of consistent selection criteria, documented search strategies, checking the suitability of articles for research purposes, and structured extraction and coding processes. These principles are in line with the emphasis of PRISMA 2020 and PRISMA-S on traceability and transparency of the systematic review process (Holst et al., 2025; Belabyad et al., 2025).

Data Analysis

A total of 25 articles that met the inclusion criteria were analyzed using thematic synthesis. Analysis is carried out through thorough reading of articles, identification of repetitive concepts, coding of relevant findings, grouping codes into categories, and formation of main themes. The thematic analysis process emphasizes consistency between the research question, the coding process, the development of the theme, and the interpretation of the results, as recommended by (Braun & Clarke, 2023).

The synthesis is directed to identify patterns of human-centered strategies in dealing with automation and AI in the maritime industry. Based on thematic groupings, the analysis is focused on digital competency training, human-in-the-loop design, system transparency, human oversight, and risk management. The five themes were then compared and interpreted to explain how a human-centered approach can support the safety, operational reliability, and readiness of the maritime workforce in the face of digital transformation. The results of the synthesis are then presented narratively and thematically, so that the relationships between findings from various studies can be explained systematically.

RESULTS AND DISCUSSION

Literature Selection Results

Based on the *systematic literature review* (SLR) process, a total of 214 records were identified through Scopus, Web of Science, and ScienceDirect. After the stages of identification, screening, feasibility assessment, and implementation of inclusion and exclusion criteria based on PRISMA 2020, a total of 25 articles were determined as the main source of thematic synthesis. The analysis of the article yielded five interrelated themes, namely (1) digital competence and adaptive training, (2) human-in-the-loop design, (3) system transparency, (4) human oversight, and (5) human-centered risk management. The five themes show that maritime transformation based on automation and AI is not only a matter of improving technological capabilities, but is a change in the sociotechnical system that requires the adjustment of competencies, the division of human-machine authority, interface design, and safety governance.

Table 2. Data Extraction from 25 Selected Articles

No.	Author (Year)	Focus/Method	Key Findings	Dominant Theme
1	Størkersen (2021)	Safety of remotely operated vessel operations	Changes in safety duties and responsibilities	Risk manageme nt
2	Chang et al. (2021)	MASS operational risk assessment	Technical-human risk interacting with each other	Risk manageme nt
3	Shahbakhs h et al. (2022)	SLR Seafarer Training Needs	The need for new technology competencies	Digital competenci es
4	Sharma & Kim (2022)	Analysis of the competence of autonomous ship navigators	Technical and non- technical competencies required	Digital competenci es
5	Baker & Yildiz (2023)	Cadet survey on the autonomy of sailing	Empowerment- related curriculum gaps	Digital competenci es
6	Kennard et al. (2022)	<i>Transition deck officer</i> to remote operator	New training and competency maintenance	Digital competenci es
7	Chan et al. (2022)	Autonomous navigation experiments/simula tions	Situational awareness supports automation	System transparenc y
8	Veitch & Alsos (2022)	Human-AI interaction SLR on autonomous ships	Humans remain essential to salvation	Human surveillance
9	Hoem et al. (2022)	Human-centered risk assessment for ground control	Control design must be human- centric	Human-in- the-loop

10	Yang et al. (2021)	Overview of human-machine cooperation in MASS navigation	Human-machine division of functions is necessary	Human-in-the-loop
11	Emad & Ghosh (2023)	In-depth interviews with 37 maritime stakeholders	Integration of traditional and digital competencies	Digital competencies
12	Y. Cheng et al. (2023)	System-theoretical approach on two levels of autonomy	Security depends on system interaction	Human-in-the-loop
13	Fan et al. (2023)	Integration of seafarers' psychological factors in safety assessments	Psychological factors affect safety	Risk management
14	Li & Yuen (2024)	<i>Human-centred review terhadap MASS</i>	MASS is changing human roles and competencies	Human-centered operations
15	Moorman et al. (2024)	SLR decision-making on MASS	Transparency and trust influence decisions	System transparency
16	van de Merwe et al. (2024)	Agent transparency on <i>autonomous collision avoidance</i>	Transparency supports human supervision	System transparency
17	Amadi et al. (2025)	Collaborative work study on highly automated navigation	Gaps in design and operational practices	Human-in-the-loop
18	Madsen & Kim (2024)	AI decision transparency review	AI transparency supports human control	System transparency
19	Aalberg & Kongsvik (2026)	Trust in automated systems on board	Trust is influenced by professional standards	Transparency/trust
20	Cheng et al. (2024)	Human-autonomy collaboration experiment in <i>shore control</i>	Time complexity and affect <i>takeover</i>	Human surveillance
21	van de Merwe & Veitch (2026)	Remote and autonomous vessel supervision experiments	Workloads affect supervision performance	Human surveillance
22	Tsekouropoulos et al. (2025)	SLR HRM on the digitalization of shipping	Reskilling and upskilling <i>required</i>	Digital competencies

23	Belabyad et al. (2025)	Competency study; 174 experts and fuzzy TOPSIS	Operational and Digital competencies are priorities	Digital competencies
24	Xiong et al. (2022)	Human-machine cooperation risk analysis	Human-machine risk is interconnected	Risk management
25	Gulen & Arslan (2025)	Risk assessment of seafarers' adaptation to digital transformation	Digital adaptation requires risk management	Risk management

Note: the "Dominant Themes" column indicates the main focus of the article in the synthesis. A single article can contribute to more than one theme.

Digital Competence and Adaptive Training

The first theme shows that automation and AI do not eliminate the need for conventional maritime competencies, but expand the workforce competency profile. Sharma & Kim (2022) emphasize a combination of technical and non-technical skills, while Emad & Ghosh (2023), based on interviews with 37 stakeholders, found that existing shipping skills are still needed and must be complemented by ICT, technology understanding, cognitive skills, leadership, communication, and decision-making. They also found that MET institutions are not yet fully prepared as the development of autonomous ship technology still creates uncertainty over future competencies. This gap is also seen at the level of education. Bogusławski et al. (2022) found that 41.9% of cadets rated the empowerment material as not yet available or not sufficiently covered in the maritime education curriculum. Meanwhile, Theotokas et al. (2024) show that digitalization creates the need for *reskilling*, *upskilling*, and continuous learning, and demands the human resource management function to adapt to changes in maritime work.

More recent findings from Belabyad et al. (2025) reinforce this pattern. The study of 174 experts shows the importance of a combination of operational, digital, and maritime competence skills. As such, AI training is inappropriate when separated from *seamanship*, navigation, risk assessment, communication, and problem-solving. This has important consequences for the MET: curriculum transformation is not enough to be done through the addition of technology courses, but requires the integration of the use of AI, digital information interpretation, automation supervision, *troubleshooting*, and abnormal condition training into maritime learning. These findings also clarify the difference between the view that automation will replace the ability of sailors and evidence that suggests a transformation of roles. The higher the automation, the fewer some routine tasks are performed manually, but the human competence to understand the context, diagnose failures, and take charge of the system becomes increasingly critical. Therefore, the first strategy resulting from this synthesis is workforce readiness through continuous digital and maritime competency development.

Human-in-the-Loop as an Operational Safety Strategy

The second theme shows that the presence of humans in automated systems must be understood as meaningful human control, not just the existence of operators as backups. Veitch & Alsos (2022) found that humans still have a number of safety functions in autonomous ship systems. (Li & Yuen, 2024) also emphasized the need for a proper division of functions between humans and machines so that the advantages of automation can be harnessed without eliminating the ability of humans to understand situations and make decisions.

(Hoem et al., 2022) suggest that a human-centered approach needs to be applied from the risk assessment and design stages of the ground control center. Aspects such as alarms, procedures, interfaces, transfer of control, and emergency situations cannot be considered as additional elements after the technology has been developed. Similarly, (T. Cheng et al., 2024) show that safety at various levels of autonomy should be analyzed as an interaction between humans and systems, not simply as the reliability of technological devices.

An interesting finding was obtained by (Veitch & Alsos, 2022). From a design perspective, navigators are often portrayed as staying *in-the-loop*, but in a highly automated operational experience, navigators can feel placed as backups that are only expected to come in when technology encounters problems. The difference has important implications: the human-in-the-loop must be accompanied by authority, information, time, and the ability to act. Humans who are still formally listed in the control structure but do not understand the AI process or do not have enough time to intervene in practice do not have meaningful control. These results support a sociotechnical approach that views safety as the result of human interaction, technology, tasks, procedures, and organizations. The second strategy that can be formulated is meaningful human control, with an explicit division of functions regarding the conditions under which the system works automatically, when the operator should be warned, who has the authority to take over, and how the *handover/takeover* process is carried out.

System Transparency, Trust, and Situational Awareness

The third theme confirms that an accurate but incomprehensible AI by operators does not necessarily result in safe operations. (Lynch et al., 2024) identified transparency, *trust*, *situation awareness*, *decision support system*, division of tasks, accountability, and teamwork as factors influencing decision-making in MASS. These results are in line with, (Chan et al., 2022) who place understanding automation and situational awareness as important issues in autonomous maritime operations.

(Madsen & Kim, 2024) specifically point out the importance of AI decision transparency. The navigator's shift from direct control to AI-based *collision avoidance* system supervision can reduce human control if the reasons behind the system's decisions cannot be understood. Therefore, AI recommendations or actions should be presented in a form that allows operators to understand the logic, evaluate risks, as well as choose alternative actions when necessary.

(Van de Merwe & Veitch, 2026) strengthened the findings through the concept of *agent transparency* to support human supervision in autonomous collision avoidance systems. Transparency does not mean showing the entire computing process to the operator. All that is needed is information relevant to the decision: the state of the system, the purpose of the action, the limitations, as well as the possible operational consequences. The trust aspect should also not be understood as an aim to make operators "more trust" in AI. (Aalberg, 2024) show that mariners' trust in automated systems has to do with their professional identities and standards. Thus, a more appropriate design goal is calibrated trust: operators are confident enough when the system is reliable, but still maintain vigilance and readiness to intervene when the system reaches its limits. Consequently, the third strategy is transparent and interpretable maritime automation. Interface design needs to avoid two extremes, namely lack of information that results in *automation surprise* and information overload that increases cognitive load. AI information needs to be presented as needed by the task, especially to help operators maintain *situational awareness*.

Human Oversight, Workload, and Takeover Performance

The fourth theme shows that human performance in autonomous systems is greatly influenced by the working conditions shaped by technology. (Y. Cheng et al., 2023) show that the available time, task complexity, and conditions before *takeover* affect the operator's ability to respond to abnormal circumstances. This shows that intervention failures are inappropriate if they are always interpreted as the individual operator's lack of ability. The experimental evidence of (Veitch & Alsos, 2022) provides a more concrete explanation. The study examined the operator's skill factors, the duration of monitoring, the number of vessels supervised, the time available for action, and the presence of DSS. Supervision performance is affected primarily by conditions such as the number of vessels, response time, and decision support. Thus, the increase in the number of vessels supervised by an operator simply because technology allows it to create new risks in the form of *overload*, detection delays, and takeover failures.

These findings are important because they show the limits of training-oriented strategies. Highly trained operators can still fail if they are given only a very short intervention time or have to handle too many systems simultaneously. Therefore, individual competencies and work system design must be developed simultaneously. For *shore control centers*, this means that companies need to establish human supervisory capacity based on evidence, not just efficiency considerations. Operator-to-vessel ratio, alarm design, minimum *takeover* time, automation level, and DSS need to be assessed as safety variables. The fourth strategy produced is workload-aware human supervision, which is automation that takes into account the limitations of human attention, time, and information processing capacity.

Human-Centered Risk Management

The fifth theme shows an important shift from an approach that separates *human error* and *technical failure* towards integrated human-machine risk management. (Chang et al., 2021) show that the risks of MASS operations cannot be separated from a combination of technical and operational factors. (Størkersen, 2021) also shows that the transfer of ship functions towards remote control is changing safety management practices and structures so that conventional safety approaches cannot simply be moved without adaptation. Fan et al., (2023) expand this perspective by including seafarers' psychological factors in safety assessments. This is important because automation can reduce manual activities but at the same time change patterns of cognitive load, monitoring, *situation awareness*, and decision-making. In other words, automation doesn't eliminate the human factor; It changes the mechanism by which human factors contribute to risk.

(Fan et al., 2023) then placed safety as a human-machine cooperation issue, where human and machine risk factors are interconnected in a network of systems. The findings of (Gulen & Arslan, 2025b) regarding seafarers' adaptation to digital transformation also show that human readiness is part of the risk of technological transformation, not a matter of human resources separate from operational safety. Thus, risk management in AI-based maritime operations needs to include at least operator competence, a level of trust in automation, workloads, interface design, division of functions, takeover conditions, sensor or algorithm failures, organizational procedures, and human-machine communication. The fifth strategy is integrated human-machine risk governance, which assesses failures as a result of system interaction and not solely human or machine error separately.

Integration of Findings and Research Contributions

Overall, the five themes form a mutually reinforcing relationship. Digital competence enables humans to understand and use technology; system transparency provides the information necessary to maintain situational awareness; human-in-the-loop determines human position and authority; human supervision ensures the capacity to detect and deal with abnormal conditions; while risk management integrates human and technological factors within the safety framework.

Based on this synthesis, the strategy of human-centered maritime operations can be summarized as follows.

Table 3. Dairy and research contributions

Strategy Dimension	Main Orientation	Operational Implications
Workforce readiness	Maritime + digital competencies	<i>Reskilling, upskilling</i> , AI literacy, ICT, decision-making, and simulation
Meaningful human control	Human-in-the-loop	Intervention authority, <i>handover/takeover</i> procedures, clear division of duties
Transparent automation	Transparency and <i>calibrated trust</i>	Understandable AI, relevant alarms, visible system status and limits
Workload-aware supervision	Human surveillance	System/vessel number limits, adequate intervention time, DSS, workload design
Integrated risk governance	Human-machine risk	Sociotechnical analysis, psychological, technological, organizational, and procedural factors

The contribution of this research lies in integrating aspects that were previously more often discussed separately. Mainly organize the impact of MASS on human occupation, tasks, skills, and risks; (Lynch et al., 2024) emphasize human-machine decision-making; (Veitch & Alsos, 2022) focus on human interaction and supervision; while competency research emphasizes the need for MET. This synthesis connects these perspectives as an operation strategy, so that *human-centered maritime operations* can be understood as a complete human-AI management framework, not just an interface design concept.

Differences in Findings from Previous Studies

One important difference is found in the assumption of diminished human roles. The synthesized evidence does not suggest that simply increasing autonomy renders humans unnecessary. Instead, human functions move from routine execution to monitoring, diagnosis, interpretation, coordination, and intervention of abnormal conditions. (Veitch & Alsos, 2022) show the breadth of human roles in autonomous systems, while (Emad & Ghosh, 2023) found that conventional shipping competencies remain considered relevant by stakeholders.

Another difference arises between the focus on individual competencies and the evidence on the design of the work system. Training is indeed a consistent need in the literature, but (Y. Cheng et al., 2023) intervention performance is also strongly influenced by time, complexity, number of systems to monitor, and decision support. This means that safety cannot be achieved simply by providing more trained seafarers; Technology and organization must be designed so that humans can use their competencies effectively. There are no statistical hypotheses tested in this SLR. Therefore, findings that support or differ from the initial conjecture are understood as the convergence and divergence of

evidence between publications, rather than the acceptance or rejection of a hypothesis based on statistical value.

Practical Implications

For shipping companies, the results show the need to integrate automation with competency development policies, *takeover* procedures, workload control, and human-machine risk management mechanisms. The efficiencies gained through automation should not automatically be used to increase the number of systems supervised by an operator if human capacity has not been evaluated. For Maritime Education and Training (MET) institutions, learning materials need to combine shipping competencies with AI literacy, ICT, remote surveillance, DSS interpretation, *troubleshooting*, digital security, communication, *situational awareness*, and automation failure handling exercises. These needs are consistent with findings regarding curriculum gaps and the readiness of educational institutions.

For technology developers, transparency and human intervention capabilities need to be made design requirements. AI needs to provide enough information for operators to know the status, reasons for decisions, and limits of the system's capabilities. For regulators, future safety standards need to include operator competence, human-machine division of authority, *shore control centers*, transparency requirements, takeover of control, and workload management, in addition to technology reliability requirements.

Research Limitations and Advanced Research Agenda

This research has several limitations. First, search resources are limited to Scopus, Web of Science, and ScienceDirect, as well as publications for the 2020–2025 period, as per the established research design. Second, the diversity of study designs—ranging from SLRs, surveys, interviews, simulator experiments, to risk analysis—causes the findings to be more precisely synthesized thematically rather than combined through *meta-analysis*. Third, the use of the terms MASS and *autonomous ships* in the literature has led to evidence that autonomous ships are relatively dominant, so automation and AI on conventional ships may be underrepresented.

Further research needs to test the framework of *human-centered maritime operations* through field and longitudinal studies on ships and *shore control centers* with different levels of automation. Experimental research is also needed to determine the limit on the number of vessels an operator can supervise, the minimum *takeover time*, the safe information load, and the effectiveness of various forms of AI transparency. In addition, indicators that can measure meaningful human control, calibrated trust, AI transparency, situation awareness, and the quality of human-machine collaboration need to be developed so that *the human-centered* concept can be translated into measurable operational safety standards.

CONCLUSIONS AND RECOMMENDATIONS

Based on a systematic literature review of 25 articles, this study shows that the application of automation and artificial intelligence in the maritime industry needs to be supported by an operation strategy that still places humans as an important element in the system. The five main strategies identified include strengthening digital competencies and adaptive training, implementing human-in-the-loop, increasing system transparency, human supervision, and integrated human-machine risk management. These findings suggest that automation does not completely replace the role of the sailor, but rather transforms human functions towards supervision, decision-making, and intervention when systems encounter abnormal conditions. A human-centered approach is thus essential to maintain the safety, operational reliability, and readiness of the maritime workforce in the face of digital transformation.

Shipping companies are advised to integrate the application of AI and automation with digital competency enhancement, workload management, handover/takeover procedures, and human-machine risk evaluation. Maritime Education and Training institutions need to adapt learning materials to technological developments, especially related to AI, decision support systems, remote supervision, and situational awareness. Technology developers also need to ensure the system is easy to understand and allows for human intervention when needed. Further research is recommended to conduct field tests on ships and shore control centers to evaluate the effectiveness of such strategies at different levels of automation as well as develop indicators that can be used to measure the quality of human-AI interactions in maritime operations.

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