

The Role of Management in Developing Seafarers' Digital Skills for Artificial Intelligence-Driven Maritime Transformation: A Systematic Literature Review

Muhaidir Ikram ^{1,✉}, Josafat Gracia Ginting ¹, Muh Nurfadel Hamzah ¹

1. Management/Human Resources Management, Universitas Negeri Makassar, Makassar, IDN

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Abstract

Artificial intelligence (AI)-driven maritime transformation, including Maritime 4.0, smart shipping, and Maritime Autonomous Surface Ships, has reconfigured ship-shore operations and intensified the need for data-driven, automated, and digitally mediated work. As a consequence, competency requirements for seafarers have expanded beyond conventional seamanship toward digital literacy, data and AI literacy, cybersecurity awareness, and the capability to operate within human-automation environments. However, the literature addressing managerial responsibility for building these competencies remains fragmented across technology, safety, education, and workforce studies. This systematic literature review aims to synthesize the literature to identify: (1) the roles of management in developing seafarers' digital competencies, (2) the digital and work competencies most emphasized in the literature, (3) the major challenges and enabling factors encountered by management in competency development, and (4) research gaps and future directions related to management-led competency development. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses-guided systematic literature review was conducted using Scopus and Google Scholar for publications from 2020 to 2025. A total of 2,675 records were retrieved from Scopus and Google Scholar via Publish or Perish. After duplicate removal, title-and-abstract screening, and full-text eligibility assessment, 25 peer-reviewed studies were included in the final synthesis. A structured data-extraction matrix was used to capture study context, competency domains, managerial roles, challenges and enabling factors, and future research directions. The included studies were analyzed using thematic synthesis aligned with four research questions. The review shows that management roles cluster into four main domains: governance of curriculum and competency standards, reskilling and upskilling architecture, organizational change leadership, and operational readiness through safety and cybersecurity governance. The most emphasized competency domains include digital literacy, data and AI literacy, programming-related knowledge, cybersecurity competence, remote operations capability, and cognitive-social skills such as situational awareness, communication, leadership, and decision-making. The main barriers include regulatory and curriculum lag, limited digital infrastructure and onboard connectivity, instructor competency gaps, funding constraints, and uneven empirical evidence on training effectiveness. The review highlights the need for an integrated, management-led competency development framework linking shipping companies, maritime education and training institutions, and regulators in order to support safe, adaptive, and sustainable maritime transformation.

Categories: Strategic Human Resource Management, Digital business, Transportation Management

Keywords: digital competencies, seafarers, artificial intelligence, mass, maritime digital transformation, management-led competency development

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Introduction And Background

The maritime industry constitutes a critical infrastructure for global trade and economic integration. According to the United Nations Conference on Trade and Development (UNCTAD), more than 80% of the volume of international merchandise trade is transported by sea, underscoring the strategic role of shipping in sustaining global supply chains (UNCTAD, 2024). In addition, the International Chamber of Shipping (ICS) estimates that the global seafaring workforce consists of approximately 1,892,720 seafarers serving on internationally trading merchant ships, including 857,540 officers and 1,035,180 ratings (ICS, 2026). Against this background, the acceleration of artificial intelligence (AI), smart shipping, and Maritime Autonomous Surface Ships (MASS) has significant implications not only for maritime technology and operational efficiency, but also for workforce readiness, competency governance, and maritime human resource development.

AI-driven digital transformation has emerged as a major catalyst for structural change in the global maritime industry (Bachtiar, 2025). The deployment of AI in navigation systems, decision support systems, predictive maintenance, autonomous vessels, and smart shipping signifies a paradigm shift from conventional maritime operations toward an increasingly complex and integrated digital maritime ecosystem (Nugraha et al., 2022) (Suprajani et al., 2025). Although maritime AI technologies promise improvements in efficiency, safety, and operational sustainability, this transformation also generates serious implications for maritime human resource readiness, particularly for seafarers, who remain the primary operational actors within these systems (Junus et al., 2023).

From a human resource management perspective, the adoption of maritime AI is not merely a matter of technological uptake; rather, it constitutes a strategic challenge closely associated with competency development, transformational leadership, and change management. Seafarers are increasingly required to possess new skill sets that extend beyond traditional nautical and technical expertise, encompassing digital literacy, an understanding of AI-enabled systems, the capacity to interact with autonomous technologies, and adaptive capabilities in digitally mediated work environments (Belabyad et al., 2026). Insufficient readiness among seafarers may lead to a human-technology mismatch (Pazouki et al., 2018), which can ultimately reduce the effectiveness of AI utilization, increase operational risks, and weaken the competitive advantage of shipping companies (Baum-Talmor and Kitada, 2022) (Chukwuemeka Albert, 2024).

Despite growing scholarly attention to maritime digitalization and maritime AI, the existing literature remains relatively fragmented. Most studies emphasize technical and operational dimensions, such as AI system design, navigational safety, and energy efficiency (Bayrak and Muslu, 2025), while managerial and human resource development dimensions are often treated as secondary concerns (Yuda, 2024). Research addressing seafarers commonly focuses on occupational safety, fatigue, or baseline technical competence (Şenbursa, 2024), without systematically linking these issues to the strategic role of management in cultivating digital skills and AI literacy aligned with the demands of technological transformation (Autsadee et al., 2024).

Furthermore, the role of management in maritime digital transformation is often conceptualized in partial and inconsistent ways. Some studies position management primarily as a provider of technical training, whereas others emphasize leadership or organizational policy, yet few offer an integrative framework that clearly explains the relationships among managerial strategies, seafarer skill development, and successful maritime AI adoption (Wu et al., 2025). In parallel, the notion of seafarers' skills in this context remains heterogeneous and is often restricted to technical aspects, with limited consideration of AI literacy, adaptive capacity, and decision-making competence within increasingly digitalized operational settings (Li et al., 2024).

In addition, prior research remains dominated by specific geographic contexts and maritime sectors characterized by relatively high levels of technological adoption (Zhang et al., 2024). Variations in organizational contexts, vessel types, and shipping company management systems, particularly in developing countries, are rarely examined comprehensively (Raza et al., 2023). The interrelationships among managerial practices, maritime education and training (MET) systems, and the evolving dynamics of maritime AI technologies also remain insufficiently explored in an integrated manner (Emad and Ghosh, 2023) (Sharma and Kim, 2022), resulting in a fragmented understanding of seafarers' readiness for maritime digital transformation.

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In response to these gaps, this study conducts a systematic literature review to critically synthesize peer-reviewed scholarly literature on the role of management in developing seafarers' digital skills in the era of AI-driven maritime digital transformation. Specifically, the study maps the dominant forms of digitalization and AI implementation in the maritime sector, identifies the managerial roles most frequently discussed in the literature, and examines the types of seafarers' digital skills as well as emerging methodological trends in prior studies. Accordingly, this study seeks to provide a more integrated and evidence-based understanding of maritime human resource management in response to AI transformation, while also offering a foundation for the advancement of maritime management theory and practice in the digital era.

Review

Search strategy

This study employed a systematic literature review (SLR) to provide a transparent, structured, and comprehensive synthesis of the literature concerning management roles in developing seafarers' digital skills in the context of AI-driven maritime transformation. The SLR method was selected because of its capacity to organize the review process systematically and transparently while enabling a comprehensive and in-depth understanding of the phenomenon under investigation (Tan et al., 2020). The review procedure followed three sequential stages commonly used in systematic reviews in management research: planning, conducting, and reporting (Tranfield et al., 2003).

During the planning stage, the research questions (RQs) were formulated using the PICO (Population, Intervention, Comparison, and Outcome) framework, which facilitates the systematic development of review questions (Tamimi and Sopiah, 2022). In this study, the population was defined as seafarers, the intervention as management roles, and the outcome as the development of seafarers' digital skills to support AI-based maritime transformation. Based on this framework, the review addressed four RQs:

- (1) how management roles contribute to the development of seafarers' digital skills in AI-driven maritime transformation,
- (2) which digital skill competencies are emphasized for seafarers in AI-enabled maritime contexts,
- (3) what challenges and enabling factors are encountered by management in developing seafarers' digital skills, and
- (4) what research gaps and future directions emerge regarding management-led seafarer digital skill development.

Data collection

The data collection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement, which provides updated reporting guidance for systematic reviews, including study identification, screening, eligibility assessment, and inclusion (Page et al., 2021). The literature search was conducted using two electronic databases, Scopus and Google Scholar, to identify studies relevant to management roles in developing seafarers' digital skills within the context of AI-driven maritime transformation. The search covered publications published between January 2020 and December 2025. The year 2020 was selected as the starting point because the period from 2020 onward reflects the acceleration of Maritime 4.0, smart shipping, AI-enabled maritime systems, and Maritime Autonomous Surface Ships (MASS) as prominent themes in maritime workforce and competency research. Earlier studies generally focused on broader maritime digitalization, e-navigation, or automation, whereas the post-2020 literature more directly addresses the implications of AI-driven transformation, remote operations, cybersecurity, and changing seafarer competency requirements. This temporal boundary was therefore used to capture the most recent and contextually relevant evidence for management-led digital skill development. Only peer-reviewed journal articles published in English were considered for inclusion.

Scopus search string (TITLE-ABS-KEY): TITLE-ABS-KEY ((seafarer OR "maritime personnel" OR "maritime worker" OR sailor OR cadet) AND ("digital skill" OR "digital competency" OR "digital literacy" OR "AI literacy") AND (management OR leadership OR "human resource management" OR HRM OR "management role") AND ("artificial intelligence" OR AI OR

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"Maritime 4.0" OR "smart shipping" OR "Maritime Autonomous Surface Ship" OR MASS OR digitalization OR "digital transformation" OR "autonomous shipping"))

For Google Scholar, the search was conducted using Harzing's Publish or Perish software because Google Scholar does not support the same field-specific search structure as Scopus. The original search strategy was therefore translated into simplified keyword combinations reflecting four core concepts: seafarers or maritime workforce, digital skills or digital competencies, management or leadership, and AI-driven maritime transformation. The Google Scholar search produced 1,724 records that were actually retrieved and exported through Publish or Perish. Therefore, the Google Scholar result count reported in this review refers to exported records rather than the estimated number of results displayed by the Google Scholar interface.

The records retrieved from Scopus and Google Scholar were imported into Mendeley Reference Manager for bibliographic management and cross-database duplicate checking. Duplicate records were identified using Mendeley's duplicate detection function and were further verified manually by comparing article titles, author names, publication years, journal titles, and DOI information. Records with incomplete metadata, particularly those retrieved from Google Scholar, were checked manually to prevent erroneous removal. Across the combined Scopus and Google Scholar dataset, 375 duplicate records were identified and removed, leaving 2,300 records for title-and-abstract screening. Additional manual searches were conducted by screening the reference lists of eligible studies to identify potentially relevant articles that were not retrieved through the initial database searches. To ensure transparency and reproducibility in the study selection process, this review used the PRISMA 2020 flow diagram to report the number of records identified, screened, excluded, assessed for eligibility, and included in the final synthesis (Page et al., 2021).

Data extraction

Data extraction was conducted using a standardized data extraction form developed specifically for this SLR. The extraction process was independently performed by the first and second authors to minimize potential bias and improve the reliability of the collected information. Before the full extraction process, both reviewers independently piloted the extraction form using a small sample of eligible studies to ensure consistency in data interpretation and coding. After the independent extraction process, the reviewers compared the extracted information to ensure consistency and accuracy. Any discrepancies were resolved through discussion and consensus. No formal inter-rater reliability statistic, such as Cohen's kappa, was calculated for the data extraction process. Instead, consistency was maintained through independent extraction by two authors, pilot testing of the extraction form, comparison of extracted data, consensus discussion, and final adjudication by the corresponding author when necessary. When disagreements could not be resolved through discussion, the corresponding author reviewed the extracted information and made the final decision based on the predefined eligibility criteria and the original study content. The finalized dataset served as the basis for the thematic synthesis presented in this review.

The extraction form captured the following information: author(s), year of publication, journal, country or region, study design, maritime context, population or sample, technology focus, seafarer competency domains, management-related themes, challenges, enabling factors, key findings, methodological limitations, and implications for future research. These fields were selected to ensure alignment with the four RQs and to support thematic synthesis across heterogeneous study designs.

Inclusion and exclusion criteria

Following the literature search, the retrieved records were screened using predefined inclusion and exclusion criteria to ensure the relevance, quality, and consistency of the evidence base. As shown in Figure 1, the initial search identified a total of 2,675 records from two sources, consisting of 951 records from Scopus and 1,724 records from Google Scholar retrieved through Publish or Perish. Cross-database duplicate checking of the combined Scopus and Google Scholar records identified 375 duplicate records. After duplicate removal, 2,300 records proceeded to the title-and-abstract screening stage.

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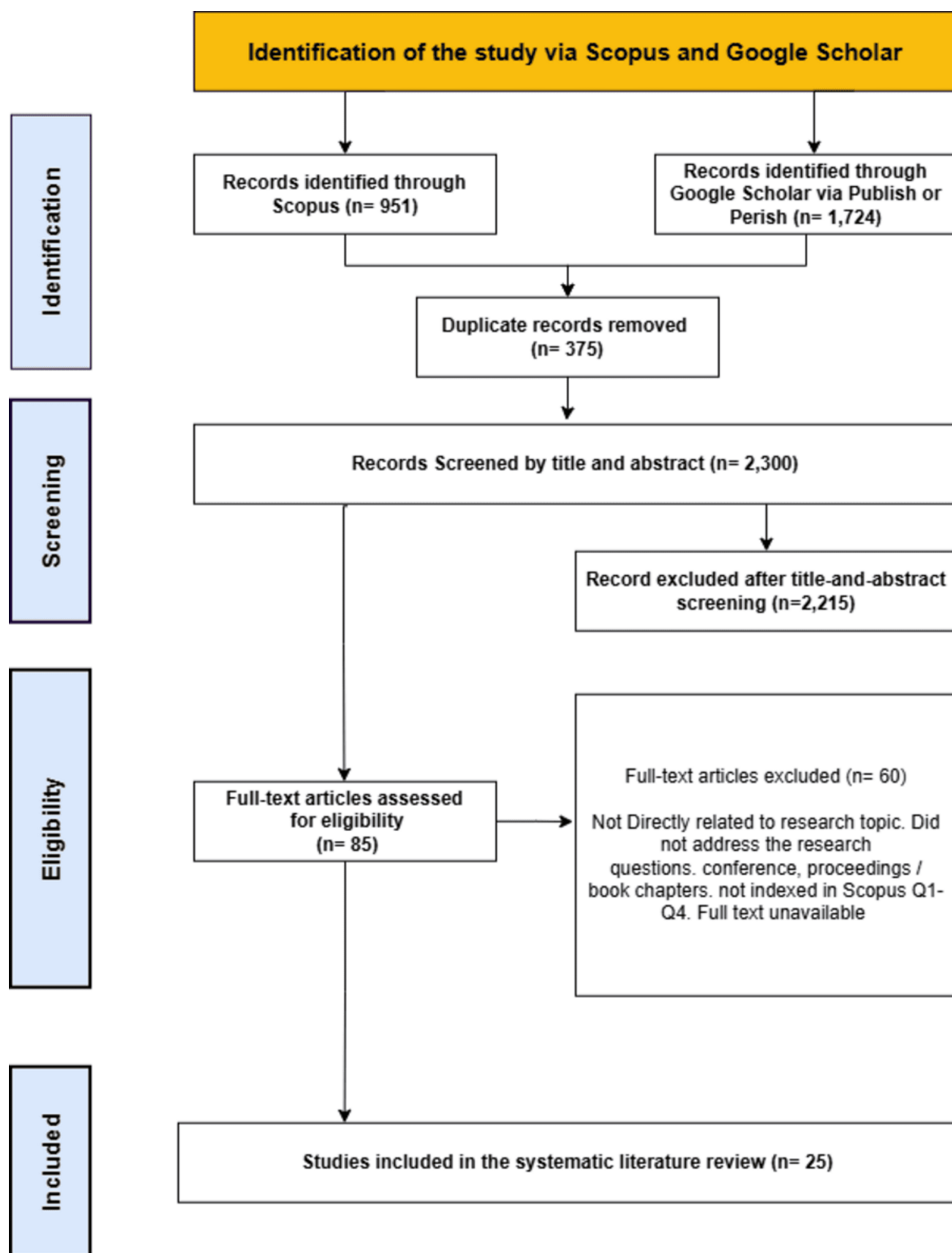
At the screening stage, titles and abstracts were assessed to determine their relevance to the topic of management roles in developing seafarers' digital skills within AI-driven maritime transformation. A total of 2,215 records were excluded at this stage because their titles and abstracts were considered irrelevant to the objectives of the review. As a result, 85 articles were retained for full-text assessment at the eligibility stage.

Studies were included if they met the following criteria: (1) they were relevant to the topic of management roles in developing seafarers' digital skills within AI-driven maritime transformation; (2) they were published in reputable journals; (3) they were accessible in full text; (4) they were published between 2020 and 2025; (5) they explicitly addressed one or more of the study's RQs; (6) they were indexed in Scopus within the Q1-Q4 categories; and (7) they were peer-reviewed journal articles, including empirical, conceptual, theoretical, review-based, policy-oriented, or document-analysis studies, while conference proceedings, book chapters, dissertations, technical reports, and grey literature were excluded.

Studies were excluded if they were published in predatory journals, unavailable in full text, published prior to 2020, not directly related to the study's RQs, not written in English, or classified as non-journal sources such as dissertations, book chapters, conference proceedings, technical reports, or grey literature. Based on these criteria, 60 articles were excluded during the full-text eligibility assessment. Ultimately, 25 articles met all inclusion criteria and were retained as the final evidence base for this SLR. Non-journal sources, where cited in the manuscript, are used only as contextual background references and not as included studies or as part of the thematic synthesis. These studies were then used for the thematic synthesis and discussion presented in the subsequent sections.

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FIGURE 1: PRISMA 2020 Flow Diagram of the Study Selection Process.

Source: Author's creation based on PRISMA 2020 guidelines

PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Thematic synthesis was conducted to integrate findings from the included studies and to answer the four RQs. The synthesis process consisted of three stages. First, the extracted data from each included study were read repeatedly and coded to identify recurring concepts related to management roles, seafarers' digital competency domains, managerial challenges, enabling factors, research gaps, and future research directions. Second, similar codes were grouped into descriptive categories, including curriculum and competency-standard governance, reskilling and upskilling architecture, digital leadership and change management, cybersecurity governance, digital literacy, data and AI literacy, and human-automation competence. Third, these descriptive categories were synthesized into broader analytical themes aligned with the four RQs. To enhance consistency, the first and second authors independently reviewed the initial coding structure and compared the emerging categories. Differences in interpretation were discussed until consensus was reached. The corresponding author then reviewed the final theme structure to ensure that each theme was supported by the extracted evidence and remained aligned with the review objectives. An audit trail was maintained through a synthesis matrix linking each analytical theme to the supporting studies.

The methodological quality and potential risk of bias of the included studies were assessed using a design-sensitive appraisal approach. For empirical qualitative, quantitative, and mixed-methods studies, the appraisal was guided by the Mixed Methods Appraisal Tool (MMAT) 2018 (Hong et al., 2018). For conceptual, theoretical, review-based, policy-oriented, and document-analysis studies, the appraisal focused on clarity of purpose, transparency of evidence sources, coherence of argumentation, relevance to the review questions, and acknowledgement of methodological limitations. The appraisal was not used to exclude studies based on numerical scoring; rather, it was used to assess the relative strength and limitations of the evidence and to guide cautious interpretation during thematic synthesis. Table 1 represents the methodological appraisal and risk-of-bias considerations for the included studies.

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No.	Study	Study Design	Appraisal Category	Main Quality Concern	Overall Appraisal
1	(Jo et al., 2020)	Empirical study on maritime cadets' perceptions	Quantitative descriptive	Reliance on self-reported perceptions and cadet-based sample may limit generalizability to active seafarers	Included with moderate concern
2	(Raza et al., 2023)	Literature-based/strategic trend analysis	Qualitative/document-based appraisal	Findings are based on sectoral trends and strategic interpretation rather than direct seafarer-level evidence	Included with moderate concern
3	(Kechagias et al., 2022)	Cybersecurity systemic approach	Review-based/conceptual appraisal	Strong conceptual relevance, but limited primary empirical validation of the proposed systemic approach	Included with moderate concern
4	(Gulen and Arslan, 2025)	Risk assessment study	Quantitative/model-based appraisal	Findings depend on risk-model assumptions and expert judgment; external validation may be limited	Included with low-to-moderate concern
5	(Karahalios, 2025)	Maritime education and digital sustainability study	Review-based/conceptual appraisal	Useful for curriculum discussion, but limited evidence on actual training outcomes	Included with moderate concern

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6	(Malmquist and Munim, 2025)	Exploratory study on barriers to autonomous shipping	Qualitative/exploratory appraisal	Barrier identification may be context-dependent and influenced by expert or stakeholder perspectives	Included with moderate concern
7	(Ozdemir et al., 2023)	Educational project/case-based study	Qualitative case appraisal	Evidence is project-specific, which may limit transferability to other maritime education and training contexts	Included with moderate concern
8	(de Klerk et al., 2021)	Comparative scenario planning study	Qualitative comparative appraisal	Scenario-based findings depend on assumptions about future autonomous shipping development	Included with moderate concern
9	(Li et al., 2024)	Empirical study on seafarers' digital literacy	Quantitative descriptive	Self-reported digital literacy and country-specific sample may limit cross-context generalization	Included with low-to-moderate concern
10	(Li and Wang, 2025)	Empirical assessment of seafarers' digital literacy	Quantitative descriptive	Digital literacy measurement may be influenced by self-assessment bias and contextual factors	Included with low-to-moderate concern
11	(Shi et al., 2024)	Data-driven competency analysis using Bayesian networks	Quantitative model-based appraisal	Model assumptions and restricted operational context may limit broader applicability	Included with low-to-moderate concern
12	(Yu et al., 2025)	DACUM-integrated competency framework study	Mixed/expert-based appraisal	Competency framework depends on expert input and may require further	Included with moderate concern

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				empirical testing across contexts	
13	(Theotokas et al., 2024)	Empirical study on e-HRM practices in shipping companies	Quantitative non-randomized	Cross-sectional and country-specific design may limit causal interpretation and generalizability	Included with low-to-moderate concern
14	(Shahbakhsh et al., 2022)	Conceptual/transitional analysis of seafarers' roles	Qualitative/literature-based appraisal	Strong theoretical relevance, but limited direct empirical testing of proposed role transitions	Included with moderate concern
15	(Ichimura et al., 2022)	Mapping study of strategic plans of maritime actors	Qualitative document analysis	Reliance on organizational strategic documents may not fully capture implementation realities	Included with moderate concern
16	(Kim and Mallam, 2020)	Delphi-AHP study on STCW leadership competence	Mixed/expert-based appraisal	Expert selection and consensus process may influence competency prioritization	Included with low-to-moderate concern
17	(Jo and D'Agostini, 2020)	Policy and workforce transition analysis	Qualitative/secondary-data appraisal	Korea-specific context and future-oriented projections may limit international generalizability	Included with moderate concern
18	(Sharma and Kim, 2022)	Competency study for autonomous shipping	Mixed/expert-based appraisal	Competency identification is influenced by assumptions about future autonomous navigation roles	Included with low-to-moderate concern
19	(Emad and Ghosh, 2023)	Qualitative study on future operators of autonomous ships	Qualitative appraisal	Transferability may be limited by participant selection and the emerging nature of	Included with low-to-moderate concern

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				autonomous ship operations	
20	(Bogusławski et al., 2022)	Empirical study on cadets' perspectives	Quantitative descriptive	Cadet perceptions may not fully represent experienced seafarers or operational shipping realities	Included with low-to-moderate concern
21	(Li and Yuen, 2024)	Human-centred review of MASS	Review-based appraisal	Findings depend on literature coverage and synthesis decisions rather than primary empirical data	Included with moderate concern
22	(Narayanan et al., 2023)	Theoretical/activity theory-based study	Qualitative/conceptual appraisal	Strong theoretical contribution, but findings may require further empirical validation in diverse maritime workplaces	Included with moderate concern
23	(Chan et al., 2025)	Empirical training-impact study	Quantitative non-randomized/experimental appraisal	Training effects may be influenced by simulation setting, sample characteristics, and short-term measurement	Included with low-to-moderate concern
24	(Kim, 2024)	Competency study for MASS remote operators	Quantitative/exploratory competency appraisal	Remote-operator roles remain emerging, so competency priorities may change as MASS implementation develops	Included with moderate concern

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25	(Kennard et al., 2022)	Training transition study for autonomous and remote-controlled vessels	Qualitative/exploratory appraisal	Future-oriented transition analysis may be affected by uncertainty in technology adoption and regulation	Included with moderate concern
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TABLE 1: Methodological Appraisal and Risk-of-Bias Considerations for Included Studies.

Source: Authors’ appraisal using MMAT 2018 for empirical studies and design-sensitive appraisal criteria for non-empirical studies
MASS, Maritime Autonomous Surface Ships; MMAT, Mixed Methods Appraisal Tool; STCW, Standards of Training, Certification and Watchkeeping for Seafarers

Synthesis of results

Following the identification, screening, eligibility assessment, and methodological appraisal stages, 25 peer-reviewed journal articles were retained as the final evidence base for this SLR. Table 2 presents the characteristics of the included studies, including author and year, country or region, study design, sample or data source, maritime context, and main focus. This table provides an overview of the evidence base used to examine seafarers’ digital skills, autonomous shipping, MET, cybersecurity, and management-related competency development.

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Author (Year)	Country/Region	Study Design	Sample/Participants	Maritime Context	Main Focus
(Kim and Mallam, 2020)	International	Delphi-AHP	Maritime experts	Autonomous operations	STCW leadership competencies
(Jo and D'Agostini, 2020)	South Korea	Quantitative	Maritime cadets	MASS	Workforce transformation
(Jo et al., 2020)	South Korea	Survey	Maritime cadets	Industry 4.0	Cadet perceptions
(de Klerk et al., 2021)	International	Comparative analysis	National policy documents	Autonomous shipping	National preparedness
(Bogusławski et al., 2022)	Poland	Survey	Maritime cadets	MET	Education implications
(Ichimura et al., 2022)	International	Strategic review	Maritime organizations	Digitalization	Strategic plans
(Kechagias et al., 2022)	International	Conceptual	Maritime systems	Cybersecurity	Systemic approach
(Kennard et al., 2022)	International	Policy analysis	Deck officers	Remote vessels	Career transition
(Shahbakhsh et al., 2022)	International	Conceptual	Maritime workforce	Autonomous shipping	Role transition
(Sharma and Kim, 2022)	International	Competency analysis	Navigators	Autonomous shipping	Technical and non-technical skills
(Karahalios, 2025)	International	Systematic literature review	Literature on maritime students and maritime education	Maritime education and digital sustainability	Digital competencies and maritime digital information literacy
(Emad and Ghosh, 2023)	International	Qualitative	Maritime experts	Autonomous ships	Training framework
(Narayanan et al., 2023)	International	Theoretical	Seafarers	Digital workplace	Participation and learning
(Ozdemir et al., 2023)	Europe	Case study	Maritime students	Future education	Closing competency gaps
(Raza et al., 2023)	International	Review	Liner shipping firms	Digital logistics	Digital transformation

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(Malmquist and Munim, 2025)	International	Exploratory study	Autonomous shipping-related evidence and maritime stakeholders	Autonomous shipping	Barriers to autonomous shipping adoption
(Kim, 2024)	South Korea	Conceptual	Remote operators	MASS	Sustainable competencies
(Li et al., 2024)	China	Quantitative	Chinese seafarers	Digital literacy	Influencing factors
(Li and Yuen, 2024)	International	Review	Literature	MASS	Human-centered impacts
(Theotokas et al., 2024)	Greece	Quantitative	Shipping managers	e-HRM	Organizational culture
(Shi et al., 2024)	International/restricted waters	Data-driven modelling study	Maritime accident data and seafarer competency indicators	Restricted waters/bridge resource management	Seafarer competency analysis using Bayesian networks
(Chan et al., 2025)	International	Experimental	Seafarers	Autonomous shipping	Training effectiveness
(Gulen and Arslan, 2025)	Turkey	Risk assessment	Seafarers	Digital transformation	Adaptation risks
(Li and Wang, 2025)	China	Quantitative	Chinese seafarers	Digital literacy	Literacy assessment
(Yu et al., 2025)	South Korea	DACUM study	Marine superintendents	Eco-digital transition	Competency framework

TABLE 2: Characteristics of the Included Studies.

Source: Authors' synthesis based on the reviewed studies

AHP, Analytic Hierarchy Process; DACUM, Developing a Curriculum; e-HRM, Electronic Human Resource Management; MASS, Maritime Autonomous Surface Ships; MET, Maritime Education and Training; STCW, Standards of Training, Certification and Watchkeeping for Seafarers

As shown in Table 2, the included studies demonstrate substantial geographical and methodological diversity. The literature is dominated by international and East Asian contexts, particularly South Korea and China, and employs a variety of research designs, including quantitative surveys, qualitative studies, conceptual analyses, policy reviews, experimental studies, and systematic reviews. The participant groups range from maritime cadets and active seafarers to shipping managers and maritime experts. Collectively, these studies address key issues related to autonomous shipping, digital literacy, cybersecurity, MET, human resource development (HRD), and management-led competency

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development, thereby providing a comprehensive foundation for the thematic synthesis presented in the subsequent sections. However, this diversity also requires cautious interpretation because not all included studies provide direct empirical evidence on management interventions. Table 3 represents the thematic summary of the reviewed literature.

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Focus	Key Findings	Key References
Management roles in competency development	Management is positioned as a capability-governance actor through: (1) curriculum and competency-standard governance (MET/STCW), (2) transformation leadership and change management, (3) reskilling and upskilling HRD architecture, and (4) operational readiness through safety, risk, and cybersecurity governance. Effective implementation also depends on collaboration among industry, MET institutions, regulators, and R&D actors.	(Kim and Mallam, 2020), (Raza et al., 2023), (Bogusławski et al., 2022), (Narayanan et al., 2023), (Emad and Ghosh, 2023), (Li and Yuen, 2024)
Digital competency domains	The most emphasized competencies include: (1) basic digital literacy, (2) data and AI literacy, (3) cybersecurity competence, and (4) human-automation and remote-operations competence. These are complemented by soft skills and human-factor capabilities such as situational awareness, decision-making, communication, teamwork, and leadership.	(Bogusławski et al., 2022), (Jo et al., 2020), (Li and Wang, 2025), (Chan et al., 2025), (Kim, 2024)
Managerial challenges	Major challenges include regulatory lag, misalignment between emerging competencies and existing standards, instructor readiness gaps, limited facilities, cybersecurity vulnerabilities, high internet costs, weak onboard connectivity, workforce resistance, and the lack of mature remote-operator training models.	(Emad and Ghosh, 2023), (Sharma and Kim, 2022), (Shahbakhsh et al., 2022), (Malmquist and Munim, 2025), (Gulen and Arslan, 2025), (Kechagias et al., 2022), (Bogusławski et al., 2022)
Enabling factors	Key enabling factors include improved onboard connectivity, IT training provision, modular and adaptive learning systems, simulation and VR, data-driven training prioritization, segmented training pathways, and stronger collaboration among industry, MET institutions, regulators, and technology partners.	(Li and Wang, 2025), (Ozdemir et al., 2023), (Yu et al., 2025), (Shi et al., 2024), (Li and Yuen, 2024)
Research gaps	The literature remains predominantly technology-oriented and still lacks strong empirical evidence on management intervention, training effectiveness, and implementation outcomes. Major gaps include limited generalizability across	(Narayanan et al., 2023), (Raza et al., 2023), (Li and Wang, 2025), (Yu et al., 2025), (Kechagias et al., 2022), (Theotokas et al., 2024), (Ichimura et al., 2022)

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	contexts, insufficient role-specific analysis, methodological dominance of exploratory approaches, underdeveloped organizational and HRM perspectives, and limited evidence on labor-market transition under MASS adoption.	
Future research directions	Future studies should adopt comparative, longitudinal, and intervention-based designs; clarify role-specific competencies; evaluate training outcomes more rigorously; develop scalable, data-driven, and context-sensitive competency frameworks; and examine ship-shore career transitions and labor-market implications more systematically.	(Gulen and Arslan, 2025), (Kim, 2024), (Kennard et al., 2022), (Ozdemir et al., 2023), (Shahbakhsh et al., 2022), (Shi et al., 2024), (Li and Wang, 2025)

TABLE 3: Thematic Summary of the Reviewed Literature.

Source: Authors’ synthesis based on the reviewed studies
AI, Artificial Intelligence; HRD, Human Resource Development; HRM, Human Resource Management; MASS, Maritime Autonomous Surface Ships; MET, Maritime Education and Training; R&D, Research and Development; STCW, Standards of Training, Certification and Watchkeeping for Seafarers; VR, Virtual Reality

Management roles in developing seafarers’ digital skills

The role of management in developing seafarers’ digital skills within AI-driven maritime transformation, including smart shipping and MASS, is consistently framed in the literature as a form of capability governance rather than merely a training function. This perspective positions management as an actor that (i) steers competency standards and curricula, (ii) leads organizational change and technology adoption, (iii) designs reskilling and upskilling HRD architectures, and (iv) institutionalizes digital competence through integrated risk, safety, and cybersecurity systems (Kim and Mallam, 2020) (Raza et al., 2023).

First, governance of curriculum and competency standards within MET/Standards of Training, Certification and Watchkeeping for Seafarers (STCW) emerges as the most prominent managerial contribution. Digitalization and autonomy are reshaping seafarers’ work into information-centric tasks, including monitoring, diagnosing, and making decisions through digital interfaces, thereby requiring conventional curricula to be restructured in order to remain relevant (Bogusławski et al., 2022) (Narayanan et al., 2023). Several studies argue that the STCW framework needs to be updated to accommodate future competency demands, while competency research is increasingly used as an empirical basis for developing new training frameworks (Kim, 2024) (Sharma and Kim, 2022). Accordingly, managerial contributions at this level are both normative and structural, including the specification of mandatory competencies, the design of certification pathways, and the alignment between global standards and MET implementation.

Second, management functions as a transformation leader and change manager by linking technology adoption to workforce readiness. Maritime digital transformation is conceptualized as a strategic organizational change that requires vision, governance structures, and cross-functional coordination, as technology reshapes ship-shore workflows and decision-making patterns (Ichimura et al., 2022) (Raza et al., 2023). The literature further emphasizes the need for implementation roadmaps and managerial strategies to prevent organizational resistance, ambiguity regarding

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emerging roles, and operational unpreparedness within autonomous ecosystems (de Klerk et al., 2021) (Shahbakhsh et al., 2022). From a managerial standpoint, the central contribution lies in aligning technological change with process redesign, work-structure adjustments, and evolving competency requirements.

Third, the HRD reskilling and upskilling architecture constitutes a primary mechanism through which management translates technological demands into structured competency development. Multiple studies indicate that future-oriented training should not rely solely on short-term courses; instead, it should be delivered through planned, modular, and adaptive learning pathways that correspond to different levels of technological maturity (Emad and Ghosh, 2023) (Yu et al., 2025). Empirical evidence also suggests that seafarers' digital competency development is significantly influenced by practical managerial decisions, including the availability of IT training and the provision of digital infrastructure (Li et al., 2024) (Li and Wang, 2025). Thus, managerial contributions in HRD include program design, resource allocation, and the configuration of learning conditions within distributed maritime work settings.

Fourth, digital skill development is strengthened when it is institutionalized through risk management, safety management, and cybersecurity governance. AI and automation introduce distinctive risks, such as automation bias, complacency, and cyber threats; therefore, digital competencies must be embedded in formal systems such as the IMS/PDCA cycle, audits, drills, and continuous improvement processes (Gulen and Arslan, 2025) (Kechagias et al., 2022). Experimental evidence further indicates that managerial decisions regarding training design, particularly training focused on human-automation interaction, can enhance diagnostic performance in responding to system failures (Chan et al., 2025).

Overall, RQ1 indicates that managerial contributions are end-to-end, spanning competency standards and curricula, change leadership, HRD architecture development, and the embedding of digital competencies within safety and security systems. At the same time, multiple studies emphasize that success depends on effective collaboration among industry actors, MET institutions, regulators, and R&D stakeholders.

Digital competency domains required in AI-driven maritime transformation

The synthesis of the 25 reviewed studies indicates that maritime digitalization and the development of autonomous vessels are shifting seafarers' competency requirements from conventional procedural skills toward a hybrid profile that combines digital, technical, cognitive, and social competencies (Jo and D'agostini, 2020) (Shahbakhsh et al., 2022). This transition is reflected in the "e-farers" narrative and in the projected expansion of shore-based work, such as ship control centers (SCCs) and remote operation centers (ROCs), which require capabilities in remote monitoring, interface-based control, and preparedness for heightened cyber risk resulting from increased connectivity (Jo et al., 2020) (Kennard et al., 2022). Overall, the literature suggests that the most frequently emphasized competencies can be grouped into four major clusters: basic digital literacy, data and AI literacy, cybersecurity competence, and human-automation or remote-operations competence, all of which are complemented by soft skills and broader human-factor capabilities (Li et al., 2024) (Yu et al., 2025).

The first cluster concerns basic digital literacy. Frameworks adapted for seafarers highlight information and data literacy, digital communication and collaboration, digital content creation, digital security and ethics, and digital problem-solving as foundational capacities for adaptation to digital maritime work environments (Li and Wang, 2025). A recurring finding is that digital content creation, particularly programming, remains a significant capability gap, thereby indicating the need for practical computational training relevant to maritime tasks (Karahalios, 2025). At the organizational level, the digital transformation of maritime logistics further reinforces the importance of data-driven decision-making, IoT and sensor data, cloud systems, and AI or machine-learning applications. This implies that seafarers increasingly need to understand data pipelines and decision-support logic in order to translate system outputs into operational actions (Ichimura et al., 2022) (Raza et al., 2023).

The second cluster is data and AI literacy. The reviewed studies suggest that seafarers are increasingly required to interpret digital dashboards, process data-rich operational information, and understand the logic underpinning AI-enabled decision-support systems (Ozdemir et al., 2023). AI literacy extends beyond general awareness of AI toward a practical understanding of machine learning, familiarity with emerging tools such as large language models, and the

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ability to critically assess system-generated outputs within human-AI collaboration settings (Li and Wang, 2025). Statistics and programming are often positioned as bridging competencies that support algorithmic understanding, debugging, and participation in future-oriented maritime coding and machine-learning training activities (de Klerk et al., 2021) (Karahalios, 2025).

The third cluster concerns cybersecurity competence. Because human factors are widely regarded as a major source of vulnerability in increasingly connected maritime systems, the literature emphasizes the importance of practical capabilities such as recognizing phishing attempts, reporting cyber incidents, maintaining safe digital behavior, and applying operational cyber hygiene, including USB control, BYOD awareness, and patch management (Kechagias et al., 2022) (Malmquist and Munim, 2025). Cyber risk assessments further identify inadequate digital competence and limited cybersecurity awareness as major barriers to safe digital transformation, thereby reinforcing the need for regular cyber-awareness training and preparedness drills (Gulen and Arslan, 2025).

The fourth cluster is human-automation and remote-operations competence. The literature highlights the growing importance of remote operations center skills, automation and digital navigation literacy, and the ability to diagnose ship conditions remotely through navigational instruments and system-generated data (Kim, 2024). Beyond technical proficiency, the reviewed studies consistently stress the importance of human-factor capabilities such as situational awareness, information processing, fault recognition, diagnostic reasoning, and the mitigation of automation bias and complacency in highly automated environments (Chan et al., 2025) (Kim and Mallam, 2020). Accordingly, MET systems are increasingly expected to combine technical-digital learning with soft skills development, including communication, teamwork, leadership, and self-management, while promoting lifelong learning through simulation and virtual reality environments that strengthen readiness for manual intervention and emergency response when automation fails (Bogusławski et al., 2022) (Jo et al., 2020).

Overall, RQ2 indicates that the competency profile required in AI-driven maritime transformation is multidimensional and extends well beyond traditional seamanship. The reviewed studies suggest that future seafarers must be equipped not only with digital and technical competencies, but also with the cognitive and social capabilities required to work effectively in highly automated, data-intensive, and cyber-sensitive maritime environments.

Managerial challenges and enabling factors

AI-driven maritime transformation, encompassing digitalization, autonomy, and eco-digital shifts, indicates that seafarer competency development constitutes a broad organizational change challenge involving culture, leadership, and work practices, rather than merely a technical curriculum adjustment (Raza et al., 2023) (Theotokas et al., 2024). In this context, management must address human-factor issues such as complacency risks in automated environments and the need for transition strategies that reflect the heterogeneous perceptions of seafarers and cadets (Jo et al., 2020) (Theotokas et al., 2024). At the macro level, organizational readiness is also shaped by policy support and enabling environments established by governments and regulators, which influence the capacity of organizations to sustain long-term competency development (de Klerk et al., 2021) (Ichimura et al., 2022). As work roles increasingly shift from ship-based operations to shore-based monitoring and supervision, management is further required to reconfigure collaboration ecosystems, strengthen reskilling agendas, and support new career transition pathways (Ichimura et al., 2022) (Raza et al., 2023).

One of the most frequently cited managerial challenges is regulatory lag and the misalignment between emerging competency needs and prevailing standards or regulations. The literature suggests that competency updates often progress more slowly than technological change, thereby complicating managerial efforts to define relevant learning priorities and competency standards (Emad and Ghosh, 2023) (Sharma and Kim, 2022). This challenge is compounded by uncertainty regarding training content, facilities, and instructor preparedness for autonomous shipping and digitally intensive operations, which makes standardization across MET institutions and shipping companies particularly difficult (Shahbakhsh et al., 2022). In addition, operational leadership demands increasingly require STCW-related competencies, such as leadership, situational awareness, and information processing, to be revisited in light of remote operations and data-rich work environments (Kim and Mallam, 2020) (Sharma and Kim, 2022). The lack of certified remote-center

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operators and the continued absence of fully MASS-ready regulatory frameworks further intensify the challenge of designing certification systems and prioritizing capability barriers (Malmquist and Munim, 2025) (Shahbakhsh et al., 2022).

Another key barrier concerns cybersecurity and digital infrastructure. Legacy and operational technology systems are often vulnerable, difficult to patch, and unevenly distributed across fleets and vendors, thereby limiting the feasibility of standardized technical control measures and competency programs (Gulen and Arslan, 2025) (Kechagias et al., 2022). Moreover, the involvement of multiple actors, such as remote-access vendors and external monitoring parties, can blur accountability structures and increase governance complexity, requiring stronger cyber-awareness training and clearer managerial oversight, including at decision-making levels (Karahalios, 2025). At the individual level, high internet costs, weak onboard connectivity, and long voyage durations reduce access to learning resources and may weaken organizational prioritization of upskilling. In contrast, improved onboard connectivity and stronger IT training provision have been empirically associated with higher levels of digital literacy among seafarers (Li et al., 2024).

From a learning and development perspective, the literature highlights the challenge of keeping training content current in response to rapid technological change, while seafarers themselves face time, mobility, and access constraints that reduce the suitability of traditional training formats (Ozdemir et al., 2023) (Yu et al., 2025). Digitalization may also disrupt onboard communities of practice when mentors themselves lack technological mastery or when collective learning practices fail to adapt to digitally mediated work environments (Narayanan et al., 2023). From an evidence-based management standpoint, limitations in STCW-based competency capture and restricted access to operational data also create difficulties in prioritizing training needs, thereby reinforcing the value of data-driven competency modeling for more efficient resource allocation (Shi et al., 2024). At the same time, the literature notes that real-world empirical evidence on human elements in MASS remains limited, suggesting that pedagogical adaptation and regulatory strengthening are necessary to prevent competency strategies from being built primarily on assumptions rather than robust evidence (Li and Yuen, 2024).

Finally, field-level implementation is strongly influenced by workforce acceptance and the behavioral risks associated with human-automation interaction. The literature shows that effective training designs must address not only technical feature mastery but also automation bias, alarm fatigue, complacency, and other behavioral risks that may undermine safe operations (Chan et al., 2025) (Kennard et al., 2022). Major managerial barriers also include curriculum gaps in MET, limited coverage of autonomization topics, concern over job displacement, and insufficient regulatory support, all of which may reduce seafarers' motivation to engage in reskilling processes (Bogusławski et al., 2022). Furthermore, the lack of mature training models for remote operators, together with differences in competency priorities across experience levels, indicates the need for more segmented, continuously updated, and role-sensitive development pathways (Kim, 2024). In response, a pragmatic managerial strategy is to strengthen computational education and formally structure ship-shore career transition pathways in anticipation of future SCC-based work and specialized qualifications (Jo et al., 2020).

Overall, RQ3 indicates that managerial challenges in seafarer competency development are multidimensional, spanning regulation, infrastructure, pedagogy, organizational culture, and workforce acceptance. At the same time, the literature identifies several enabling factors, including improved onboard connectivity, stronger IT training provision, data-driven training prioritization, adaptive learning models, and closer collaboration among industry actors, MET institutions, regulators, and technology partners. These findings suggest that effective competency development requires not only technical preparedness but also institutional alignment, managerial commitment, and a supportive learning ecosystem. The major managerial challenges and enabling factors identified in the reviewed literature are summarized in Table 3.

Research gap and future research direction

The reviewed literature remains predominantly technology-oriented, while the human, learning, and managerial intervention dimensions of competency development are still underdeveloped as an empirical agenda (Narayanan et al., 2023) (Raza et al., 2023). Existing studies are often grounded in specific institutional or national contexts, which limits

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their generalizability across countries, organizations, and categories of maritime personnel (Karahalios, 2025) (Jo et al., 2020). In addition, seafarers are frequently treated as a relatively homogeneous workforce, despite differences in competency needs by role, rank, and surrounding policy or educational systems (Li et al., 2024) (Yu et al., 2025). Methodologically, much of the literature relies on expert judgment, Delphi methods, qualitative inquiry, or exploratory approaches, with limited evidence on implementation and rigorous evaluation of management-led training effectiveness (Emad and Ghosh, 2023) (Gulen and Arslan, 2025) (Chan et al., 2025). The literature also offers limited insight into organizational and HRM dimensions, labor-market transition, and the operationalization of future competencies into scalable training and assessment systems (Kechagias et al., 2022) (Theotokas et al., 2024) (Shahbakhsh et al., 2022) (Shi et al., 2024).

Future studies should adopt more comparative, longitudinal, and intervention-based designs in order to strengthen empirical evidence on management-led competency development (de Klerk et al., 2021) (Malmquist and Munim, 2025). Greater attention is needed to role-specific and rank-specific competencies, broader operational domains beyond navigation, and structured ship-shore career transition pathways under autonomous and remote operations (Kim and Mallam, 2020) (Sharma and Kim, 2022) (Kennard et al., 2022) (Ozdemir et al., 2023). Future research should also examine how organizational culture, e-HRM, digital innovation, and governance arrangements shape workforce readiness and organizational outcomes (Kechagias et al., 2022) (Li and Yuen, 2024). In addition, more work is needed to translate future competency requirements into data-driven curricula, modular training pathways, and robust evaluation instruments that are scalable across contexts (Shahbakhsh et al., 2022) (Shi et al., 2024) (Li and Wang, 2025).

Discussion

This review extends previous maritime competency and digitalization reviews by shifting the analytical focus from the identification of future seafarer skills to the managerial conditions required to develop, govern, and institutionalize those skills. Prior studies have commonly examined digital literacy, autonomous shipping, MET, cybersecurity, or human-automation interaction as separate issues. In contrast, this review integrates these fragmented streams through a management lens and argues that seafarer digital skill development should be understood not merely as a training agenda, but as a broader organizational and institutional capability-building process.

The main theoretical contribution of this review is the concept of management as capability governance. In this context, management does not only provide technical training or allocate learning resources. Rather, management coordinates the alignment between competency standards, curriculum reform, HRD, safety management, cybersecurity governance, and ship-shore operational readiness. This interpretation is important because AI-driven maritime transformation creates competency demands that exceed the boundaries of traditional seamanship. Digital literacy, data and AI literacy, cybersecurity competence, remote-operation capability, and human-automation decision-making require coordinated governance across shipping companies, MET institutions, regulators, technology providers, and maritime workforce actors.

At the same time, the evidence base should be interpreted cautiously. Only part of the reviewed literature provides direct empirical evidence on management practices, seafarer training outcomes, or organizational interventions. Several included studies are conceptual, theoretical, review-based, policy-oriented, or future-oriented. Therefore, some managerial implications identified in this review are inferred from broader evidence on digital transformation, maritime education, autonomous shipping, cybersecurity, and workforce transition rather than derived from direct evaluations of management-led competency programs. This distinction is important because the review supports the conceptual relevance of management as a capability-governance actor, but the empirical validation of this role remains limited.

The strength of the evidence lies in its interdisciplinary coverage. The included studies collectively show that AI-driven maritime transformation is not only a technological transition but also a human resource, learning, safety, and governance challenge. However, the limitations of the evidence are also clear. Many studies are exploratory, expert-based, country-specific, or dependent on projections about future autonomous shipping. Few studies evaluate the

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effectiveness of actual management interventions, training programs, or organizational readiness strategies over time. Consequently, while the review provides a coherent conceptual synthesis, it does not yet establish a universally validated model of management-led seafarer digital competency development.

These findings imply that future maritime management research should move beyond identifying required competencies and begin testing how such competencies can be developed, assessed, and sustained in real organizational settings. Comparative, longitudinal, and intervention-based studies are needed to examine whether management-led capability governance improves seafarer readiness, training effectiveness, safety outcomes, cybersecurity behavior, and ship-shore operational performance. This would strengthen the empirical foundation of the capability-governance perspective and provide more actionable guidance for shipping companies, MET institutions, and regulators.

Limitation

Despite following the PRISMA 2020 guidelines and applying a systematic review process, this study has several limitations that should be acknowledged. First, the literature search was limited to Scopus and Google Scholar. Although these sources provide broad coverage of peer-reviewed literature, relevant studies indexed in other databases, such as Web of Science, IEEE Xplore, ScienceDirect, or specialized maritime and engineering databases, may not have been captured. In addition, Google Scholar has limitations in terms of search transparency, reproducibility, and relevance ranking, which may have affected the consistency of record retrieval.

Second, the review was restricted to peer-reviewed journal articles published in English between 2020 and 2025. As a result, relevant studies published in other languages, conference proceedings, book chapters, dissertations, technical reports, policy documents, and other forms of grey literature were excluded. This restriction may have introduced language bias and publication bias, particularly because emerging developments in AI, autonomous shipping, and maritime digitalization are often first reported in conference papers, industry reports, or policy documents before appearing in peer-reviewed journals.

Third, the thematic synthesis involved researcher interpretation during the coding, categorization, and theme development process. Although structured data extraction, independent review, and consensus-based discussion were used to enhance consistency, subjective interpretation cannot be completely eliminated in qualitative evidence synthesis. In addition, no formal reviewer agreement statistic was calculated for the data extraction or coding process. Although independent extraction, pilot testing, consensus discussion, and corresponding-author adjudication were used to strengthen consistency, the absence of a formal reliability metric remains a methodological limitation. Therefore, the themes identified in this review should be understood as an interpretive synthesis of the available literature rather than as definitive empirical conclusions.

Finally, the rapid evolution of AI, MASS, smart shipping, and maritime digitalization means that new evidence is likely to emerge continuously. Consequently, the findings of this review reflect the state of knowledge available within the review period and should be interpreted cautiously, particularly in relation to the generalizability and long-term robustness of management-led competency development strategies. Future reviews may need to include broader databases, multilingual sources, grey literature, and updated search periods to provide a more comprehensive understanding of seafarers' digital skill development in AI-driven maritime transformation.

Conclusions

This review suggests that AI-driven maritime transformation is reshaping not only ship technologies but also the competency requirements of seafarers and the managerial systems needed to support them. The synthesis indicates that management can play an important role in capability governance by aligning curriculum standards, reskilling and upskilling systems, change leadership, safety governance, cybersecurity readiness, and cross-stakeholder coordination. However, because part of the evidence base is conceptual, exploratory, and future-oriented, these conclusions should be interpreted as a theoretically grounded synthesis rather than as definitive empirical proof of management intervention

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effectiveness. The review further shows that management contributes to competency development through four main domains: governance and alignment of curriculum and regulatory standards, the design of reskilling and upskilling architectures, change management and digital leadership, and operational readiness through safety and cybersecurity governance. At the same time, management faces substantial barriers, including regulatory lag, limited infrastructure and connectivity, instructor readiness gaps, workforce resistance, and the still limited empirical evidence on training effectiveness. These findings highlight that successful maritime digital transformation depends on stronger institutional alignment among shipping companies, MET institutions, regulators, and other relevant stakeholders.

In practical terms, this review implies that shipping companies and maritime education providers should develop role-based digital competency roadmaps, strengthen flexible reskilling and upskilling systems, improve onboard connectivity and learning access, and integrate cybersecurity and human-automation issues into routine competency development. In theoretical terms, the review reinforces the need to position management as a central actor in capability governance within AI-driven maritime transformation, rather than merely as a provider of technical training. Future research should move toward more comparative, longitudinal, and intervention-based designs in order to evaluate management-led competency development more rigorously. Further studies are also needed to clarify role-specific competency requirements, examine labor-market transitions under MASS adoption, and translate emerging competency needs into scalable, data-driven, and context-sensitive training frameworks. Overall, a more integrated and evidence-based research agenda is necessary to support safe, adaptive, and sustainable maritime transformation.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Muhaidir Ikram, Josafat Gracia Ginting, Muh Nurfadel Hamzah

Acquisition, analysis, or interpretation of data: Muhaidir Ikram, Josafat Gracia Ginting, Muh Nurfadel Hamzah

Drafting of the manuscript: Muhaidir Ikram, Josafat Gracia Ginting, Muh Nurfadel Hamzah

Critical review of the manuscript for important intellectual content: Muhaidir Ikram, Josafat Gracia Ginting, Muh Nurfadel Hamzah

Supervision: Muhaidir Ikram, Josafat Gracia Ginting, Muh Nurfadel Hamzah

Disclosures

Conflicts of interest: In compliance with [the ICMJE uniform disclosure form](#), all authors declare the following:

- **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work.
- **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.
- **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

No new datasets were generated in this study. The findings of this systematic literature review are based on published studies cited in the reference list. Data supporting the review, including the study selection and extracted information, are available from the corresponding author upon reasonable request.

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