

# Digital competence, artificial intelligence utilization, and innovation capability: Basis for a maritime technology adoption framework for Filipino seafarers

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## Abstract

This study assessed the digital competence, artificial intelligence utilization, and innovation capability of Filipino seafarers and proposed a Maritime Technology Adoption Framework. The study employed a quantitative descriptive-correlational research design, and 384 Filipino seafarers were selected using purposive sampling. Data were gathered through a structured questionnaire adapted from the DigComp Framework, contemporary maritime artificial intelligence utilization models, and innovation capability frameworks. The results revealed that Filipino seafarers demonstrated a high level of digital competence ( $CM = 3.55$ ), with Information Literacy obtaining the highest assessment. Likewise, respondents exhibited a high extent of artificial intelligence utilization ( $CM = 3.79$ ), with the Human Element dimension receiving the highest rating, highlighting the continued importance of human judgment in AI-assisted operations. Furthermore, Filipino seafarers showed a high level of innovation capability ( $CM = 3.68$ ), with Performance emerging as the highest-rated dimension. Correlation analysis indicated significant relationships between selected dimensions of digital competence and artificial intelligence utilization, as well as between selected dimensions of artificial intelligence utilization and innovation capability. However, no significant relationship was found between digital competence and innovation capability. A framework for Maritime Technology Adoption for Filipino Seafarers was developed based on the findings of the study. The framework identifies Digital Competence as the foundation, Artificial Intelligence Utilization as the enabling mechanism, and Innovation Capability as the outcome, highlighting both the direct and indirect pathways through which digital competence strengthens innovation capability. The framework provides a structured guide for workforce readiness and maritime digital transformation.

**Keywords:** digital competence, artificial intelligence utilization, innovation capability, maritime technology adoption, Filipino seafarers, maritime digital transformation

## **Digital competence, artificial intelligence utilization, and innovation capability: Basis for a maritime technology adoption framework for Filipino seafarers**

### **1. Introduction**

In an era of rapid digital transformation, digital competence, artificial intelligence (AI) utilization, and innovation capability have become key drivers of sustainable development and global competitiveness. These capabilities are particularly vital in advancing the blue economy through the sustainable use of ocean and aquatic resources. Digital competence enables effective engagement with digital technologies, while AI enhances decision-making and operational efficiency. Together, they foster innovation, adaptability, and continuous improvement, helping individuals and organizations address complex challenges and create sustainable opportunities in marine and coastal sectors.

Building upon this foundation, digital competence is defined as a multidimensional construct that integrates the knowledge and application of specific proficiencies essential for navigating modern professional landscapes (Cabaron, 2023). For seafarers facing the complexities of maritime digital transformation, this competence is fundamentally structured around four key dimensions: Information Literacy, Communication and Collaboration, Problem-Solving, and Safety Awareness (Cabaron, 2023; Li & Wang, 2025). Information Literacy serves as the baseline, encompassing the ability to identify, locate, and critically evaluate data necessary for operational decision-making and smart shipping operations (Aşıcı & Temel, 2023; Li et al., 2024). Communication and Collaboration focuses on the proficiency to interact effectively through digital platforms while remaining cognizant of cultural diversity and managing one's digital presence (Aşıcı & Temel, 2023; Li & Wang, 2025). Problem-Solving represents the capacity to utilize digital tools to address technical challenges, adapt to new environments, and innovate processes to meet evolving organizational needs (Aşıcı & Temel, 2023, 2024). Finally, Safety Awareness is critical for safeguarding personal data, ensuring privacy, and maintaining physical and psychological well-being within digital environments (Aşıcı & Temel, 2023; Li et al., 2024). Together, these dimensions form a comprehensive framework that enables seafarers to adapt to the increasing integration of automation and digital control systems on board (Li & Wang, 2025).

Complementing digital competence is the strategic utilization of Artificial Intelligence, which involves the integration of machine learning and data-driven systems to enhance operational intelligence across four essential dimensions: Navigation, Ship/Engine Management, Safety Operations, and the Human Element. Within the dimension of Navigation, AI technologies such as computer vision and predictive algorithms are employed to optimize shipping routes, detect obstacles, and manage autonomous vessel movements (Durlík et al., 2024; Kumar, 2025). Ship/Engine Management utilizes AI for predictive maintenance and fault diagnosis, allowing for the real-time monitoring of marine propulsion systems and the early detection of operational anomalies (Chin & Zhang, 2020; Durlík et al., 2024). In Safety Operations, AI-driven risk analysis and decision support systems play a pivotal role in identifying hazards and managing crew resources to prevent maritime accidents (Durlík et al., 2024; Namazi & Perera, 2023). Lastly, the Human Element dimension focuses on the synergy between seafarers and automated systems, aiming to reduce human error stemming from fatigue or high workloads through improved human-machine interaction (Dominguez & Vuddaraju, 2020; Namazi & Perera, 2023). Together, these dimensions represent a comprehensive approach to AI adoption that ensures both technical efficiency and operational safety in the modern maritime industry (Kumar, 2025).

In addition to digital competence and artificial intelligence utilization, innovation capability represents the vital capacity to translate technological tools into measurable organizational success and industry advancement (Li et al., 2024). This capability is analyzed through four core dimensions: Learning Orientation, Creativity, Collaboration and Support, and Performance. Learning Orientation provides the necessary foundation by fostering a proactive commitment to acquiring new knowledge and adapting to the maritime sector's ongoing digital shifts

(Lambrou, 2016; Li et al., 2024). This openness to new information enables Creativity, which involves the generation of original ideas and the application of divergent thinking to address non-routine operational challenges (Chang et al., 2026; Lambrou, 2016). These creative efforts are further strengthened by Collaboration and Support, which emphasize the importance of building technological partnerships and creating an environment where knowledge is shared across diverse maritime networks (Chang et al., 2026; Li et al., 2024). Ultimately, these factors culminate in Performance, where the successful orchestration of resources and skills leads to enhanced efficiency, operational safety, and a sustained competitive advantage in the global shipping market (Lambrou, 2016; Li et al., 2024). Together, these dimensions ensure that the adoption of maritime technology translates into long-term resilience and professional growth for the workforce (Li et al., 2024).

Within the local setting of the Philippines, the adoption of digital competence frameworks is currently serving as a primary driver for educational innovation, as maritime faculty and students increasingly transition to virtual and online learning environments (Cabaron, 2023). Despite these advancements, a significant problem persists in the form of a widening skill gap among seafarers, who are now required to master complex AI tools and decision support systems to remain sustainable within the evolving maritime industry (Bhosale & Bhagwat, 2025). This issue is further exacerbated by a prominent research gap in current literature, which has historically prioritized the technical effects of automation and digitalization while neglecting the critical human factors and specific training needs of the workforce (Narayanan et al., 2023). Furthermore, there is a distinct lack of formalized education and standardized modules to address these knowledge gaps, leaving a void in the systematic preparation of maritime professionals for a technology-rich future (Karahalios, 2025).

The rationale for this study is grounded in the growing need to understand how digital competence, artificial intelligence (AI) utilization, and innovation capability can support the successful digital transformation of the maritime sector. Rather than addressing skill deficiencies, the study highlights the existing competencies of the Filipino maritime workforce and explores how these strengths can be leveraged to maximize the benefits of emerging technologies. For maritime educators, the findings provide a basis for enhancing curricula and instructional practices aligned with evolving industry demands and international standards. For Filipino seafarers, the study offers insights into how digital and AI-related competencies can further support professional growth, operational efficiency, and long-term employability in a technology-driven industry. Personally, this research seeks to contribute to a deeper understanding of the interaction between human expertise and intelligent systems, emphasizing the importance of responsible and effective technology use.

Within maritime education, the study advocates for the continuous integration of digital and AI-oriented learning experiences to sustain educational relevance and excellence. For the maritime industry, the findings serve as a strategic resource for fostering innovation, competitiveness, and resilience through the effective alignment of human capabilities and technological advancements. Finally, for future researchers, this work provides a valuable empirical foundation for examining the evolving relationship among digital competence, AI utilization, innovation capability, and human-centered maritime digitalization.

**Objectives of the study** - The goal of this study is to examine the digital competence, artificial intelligence utilization, and innovation capability of Filipino seafarers as a basis for formulating a Maritime Technology Adoption Framework. Specifically, this study aims to determine the level of digital competence of Filipino seafarers in terms of information literacy, communication, problem-solving, and safety awareness; assess the extent of artificial intelligence utilization in navigation, ship management, safety operations and human element; evaluate the innovation capability of Filipino seafarers in the context of learning and development, creativity, collaboration and support and performance; analyze the interrelationship among digital competence, artificial intelligence utilization, and innovation capability; and propose a Maritime Technology Adoption Framework for Filipino seafarers based on the findings of the study.

## 2. Methods

This study employed a quantitative methodology with a descriptive-correlational research design to examine the technological landscape of Filipino seafarers (Cabaron, 2023). Quantitative research served as the foundation for providing objective measurements and statistical analysis of data collected through structured instruments, such as questionnaires, to identify patterns and trends within a specific population (Li et al., 2024; Sharma & Nazir, 2021). The descriptive component of this design allowed for a detailed characterization of the levels of digital competence and AI utilization among the workforce without direct intervention, accurately reflecting existing conditions in the maritime industry (Cabaron, 2023; Li & Wang, 2025). Simultaneously, the correlational aspect was utilized to analyze the strength and direction of the relationships between the seafarers' digital competence, their strategic utilization of artificial intelligence, and their resulting innovation capability (Lambrou, 2016; Li et al., 2024). This approach was particularly suitable for establishing a maritime technology adoption framework, as it provided the empirical evidence needed to understand how individual proficiencies and technological tools collectively influenced broader organizational and operational performance (Cabaron, 2023; Yuen et al., 2022).

The population for this study comprised Filipino seafarers actively deployed on international commercial vessels, a demographic that represented a cornerstone of the global maritime workforce. According to recent data from the Maritime Industry Authority, the Philippines contributes over 400,000 seafarers annually to the international shipping sector, underscoring the vital need for a technology adoption framework tailored to this group (Bhosale & Bhagwat, 2025). To ensure a representative and statistically robust sample from this extensive population, the study targeted a minimum of 384 respondents (Toygar & Yıldırım, 2023). This sample size was determined using Cochran's formula, which is an established method for determining an appropriate sample size for large or unknown populations at a specified confidence level and margin of error (Mitra, 2024). A purposive sampling technique was employed to select participants who were most relevant to the research objectives, specifically focusing on officers and ratings from the Deck, Engine, and Electro-Technical departments. The inclusion criteria for this study were strictly defined to maintain data integrity and relevance: participants were required to be of Filipino nationality; be currently or recently employed on international commercial vessels; hold a valid Certificate of Competency in the Deck, Engine, or Electro-Technical departments; and have direct, practical experience with digitalized shipboard systems or AI-driven operational tools.

The research instrument used in this study was a structured, adapted questionnaire designed to measure the interplay between individual proficiency and technological application in the maritime sector (Cabaron, 2023). The instrument was divided into three primary sections, each corresponding to the study's core variables: Digital Competence, Artificial Intelligence Utilization, and Innovation Capability. Each variable comprised four dimensions, with five items allocated to each dimension, resulting in a total of 60 statements.

The first section, which focused on Digital Competence, was adapted from the DigComp 2.2 Framework to evaluate the fundamental skills required in a technology-rich maritime environment (Cabaron, 2023; Li & Wang, 2025). This section assessed four essential dimensions: Information Literacy, Communication and Collaboration, Problem-Solving, and Safety Awareness. With five items for each dimension, this section measured the seafarers' ability to critically manage digital information, interact effectively in digital professional environments, address technology-related maritime problems, and maintain digital safety and cybersecurity practices on board (Cabaron, 2023; Moen et al., 2024). The second section evaluated Artificial Intelligence Utilization and measured the extent to which Filipino seafarers utilized AI-driven tools in their professional activities (Durlík et al., 2024; Kumar, 2025). This variable was operationalized through four dimensions: Navigation, Ship/Engine Management, Safety Operations, and the Human Element (Durlík et al., 2024; Namazi & Perera, 2023). Each dimension consisted of five items that measured the extent of AI utilization in various shipboard functions, including AI-supported navigation, automated engine and machinery monitoring, safety-related operations, and human interaction with increasingly automated systems (Dominguez & Vuddaraju, 2020; Kumar, 2025).

The third section focused on Innovation Capability and assessed the respondents' capacity to apply digital and

AI-related resources toward improved professional and operational practices (Lambrou, 2016; Li et al., 2024). Aligned with the work of Crossan and Apaydin, this section utilized five items for each of its four dimensions: Learning Orientation, Creativity, Collaboration and Support, and Performance. This structure provided a balanced measurement of how seafarers acquired new knowledge, developed solutions to work-related problems, collaborated with others and utilized organizational support, and contributed to improvements in maritime safety and operational efficiency (Li et al., 2024; Narayanan et al., 2023). To ensure data precision and minimize central tendency bias, each of the 60 items was rated using a four-point Likert scale ranging from 4 to 1. This forced-choice format required respondents to indicate a specific level of agreement or frequency, depending on the construct being measured, and provided data appropriate for subsequent statistical analysis. The instrument was administered digitally through Google Forms to accommodate the geographically dispersed nature of Filipino seafarers working aboard international commercial vessels. Prior to full-scale administration, the instrument underwent a validation process involving a panel of maritime educators, industry practitioners, and professional statisticians to establish its content validity and contextual relevance to the maritime industry. Furthermore, a pilot test involving 30 Filipino seafarers was conducted to assess the instrument's internal consistency and reliability. These procedures helped ensure that the instrument provided an appropriate and reliable means of measuring Digital Competence, Artificial Intelligence Utilization, and Innovation Capability among the respondents

### 3. Results and discussion

**Table 1**

*Summary Table of the Level of Digital Competence of Filipino Seafarers*

| Indicators                      | WM          | VI                    | Rank |
|---------------------------------|-------------|-----------------------|------|
| Information Literacy            | 3.74        | Strongly Agree        | 1    |
| Communication and Collaboration | 3.69        | Strongly Agree        | 2    |
| Problem-Solving                 | 3.21        | Agree                 | 4    |
| Safety Awareness                | 3.57        | Strongly Agree        | 3    |
| <b>Composite Mean</b>           | <b>3.55</b> | <b>Strongly Agree</b> |      |

*Legend: 3.50 – 4.00 = Strongly Agree; 2.50 – 3.49 = Agree; 1.50 – 2.49 = Disagree; 1.00 - 1.49 = Strongly Disagree*

Table 1 presents the summary of the level of digital competence of Filipino seafarers across four dimensions: Information Literacy, Communication and Collaboration, Problem-Solving, and Safety Awareness. The overall composite mean of 3.55 indicates that the respondents strongly agree that they possess the digital competencies necessary to perform their duties effectively in a technology-driven maritime environment. This implies that Filipino seafarers generally demonstrate a high level of digital competence, enabling them to utilize digital technologies efficiently for information management, communication, collaboration, operational safety, and decision-making.

Among the dimensions assessed, Information Literacy ranked first with a weighted mean of 3.74 and a verbal interpretation of Strongly Agree. This implies that Filipino seafarers possess strong competencies in locating, evaluating, organizing, and utilizing digital information relevant to maritime operations. The finding indicates that respondents are particularly capable of distinguishing credible information sources from unreliable ones and applying information effectively in operational decision-making. In today's maritime industry, access to accurate and reliable information is crucial for ensuring safe navigation and operational efficiency. Martínez-Bravo, Sádaba-Chalezquer, and Serrano-Puche (2022) emphasized that information literacy is a critical component of digital competence that supports informed decision-making and responsible use of digital information.

Communication and Collaboration ranked second with a weighted mean of 3.69 and a verbal interpretation of Strongly Agree, followed by Safety Awareness, which ranked third with a weighted mean of 3.57 and a verbal interpretation of Strongly Agree. These results indicate that Filipino seafarers are highly competent in utilizing digital platforms for communication, teamwork, information sharing, and maintaining cybersecurity practices onboard ships. The findings suggest that respondents can effectively collaborate with multicultural crews and

shore-based personnel while adhering to digital safety protocols and protecting sensitive information. According to the European Commission (2024), communication and collaboration competencies involve the effective use of digital technologies to interact with, share information, and work with others toward common objectives.

Meanwhile, Problem-Solving ranked fourth with a weighted mean of 3.21 and a verbal interpretation of Agree. This implies that although Filipino seafarers possess adequate problem-solving competencies, this area represents the least developed aspect of their digital competence compared to the other dimensions. The result suggests that respondents are capable of applying critical thinking, analyzing data trends, and adapting to new technologies; however, they may require further enhancement in technical troubleshooting and the use of AI-assisted diagnostic tools. As digital transformation continues to reshape maritime operations, advanced problem-solving skills become increasingly important for addressing complex technological challenges.

**Table 2**

*Summary Table on the Extent of Artificial Intelligence Utilization*

| Indicators             | WM          | VI                    | Rank |
|------------------------|-------------|-----------------------|------|
| Navigation             | 3.78        | Strongly Agree        | 3    |
| Ship/Engine Management | 3.67        | Strongly Agree        | 4    |
| Safety Operations      | 3.79        | Strongly Agree        | 2    |
| Human Element          | 3.91        | Strongly Agree        | 1    |
| <b>Composite Mean</b>  | <b>3.79</b> | <b>Strongly Agree</b> |      |

*Legend: 3.50 – 4.00 = Strongly Agree; 2.50 – 3.49 = Agree; 1.50 – 2.49 = Disagree; 1.00 – 1.49 = Strongly Disagree*

Table 2 presents the summary of the respondents' assessment on the extent of Artificial Intelligence Utilization in four key areas of maritime operations: Navigation, Ship/Engine Management, Safety Operations, and Human Element. The overall composite mean of 3.79 indicates that the respondents strongly agree that artificial intelligence is extensively utilized in their maritime duties. This implies that Filipino seafarers recognize the growing significance of AI technologies in improving operational efficiency, safety, resource management, and decision-making processes onboard ships. The findings suggest that AI has become an integral component of modern maritime operations, supporting both technical and human-centered aspects of ship management. The increasing adoption of AI reflects the maritime industry's ongoing digital transformation, where intelligent systems are utilized to enhance situational awareness, operational reliability, predictive maintenance, and safety performance. According to Durlík et al. (2024), AI technologies significantly contribute to maritime operations through navigation assistance, risk management, predictive analytics, and decision-support systems that improve efficiency and safety.

Among the dimensions assessed, Human Element ranked first with a weighted mean of 3.91 and a verbal interpretation of Strongly Agree. This implies that respondents highly recognize the importance of maintaining human oversight, professional judgment, ethical responsibility, and accountability in AI-assisted operations. The result indicates that while AI technologies provide valuable recommendations and decision-support functions, seafarers continue to prioritize human control over critical operational decisions. This finding highlights the importance of human-centered automation, where AI complements rather than replaces human expertise. According to the International Maritime Organization (2024), effective digitalization in maritime operations requires maintaining human involvement to ensure safety, accountability, and ethical compliance.

Safety Operations ranked second with a weighted mean of 3.79, followed closely by Navigation with a weighted mean of 3.78, both receiving a verbal interpretation of Strongly Agree. These findings indicate that Filipino seafarers extensively utilize AI technologies to enhance maritime safety, monitor operational risks, support emergency response systems, optimize route planning, and improve navigational decision-making. The results suggest that AI has become a valuable tool in reducing human error, increasing situational awareness, and supporting proactive safety management. According to Durlík et al. (2024), AI-enabled systems improve maritime safety through real-time hazard detection, predictive risk analysis, and intelligent monitoring technologies.

Meanwhile, Ship/Engine Management ranked fourth with a weighted mean of 3.67 and a verbal interpretation of Strongly Agree. Although this dimension received the lowest ranking among the four categories, the result still demonstrates a high level of AI utilization in vessel maintenance, operational monitoring, fuel optimization, and resource management. This implies that respondents recognize the benefits of AI technologies in improving equipment reliability, maintenance planning, and operational efficiency. However, the findings also suggest that AI applications in ship and engine management may still require further exposure and implementation compared to other operational areas. According to Pannell and Muñoz (2024), AI-driven predictive maintenance and performance monitoring systems help reduce operational costs and improve machinery reliability.

**Table 3**

*Summary Table on the Innovation Capacity of Filipino Seafarers*

| Indicators                | WM          | VI                    | Rank |
|---------------------------|-------------|-----------------------|------|
| Learning Orientation      | 3.66        | Strongly Agree        | 3    |
| Creativity                | 3.59        | Strongly Agree        | 4    |
| Collaboration and Support | 3.73        | Strongly Agree        | 2    |
| Performance               | 3.74        | Strongly Agree        | 1    |
| <b>Composite Mean</b>     | <b>3.68</b> | <b>Strongly Agree</b> |      |

*Legend: 3.50 – 4.00 = Strongly Agree; 2.50 – 3.49 = Agree; 1.50 – 2.49 = Disagree; 1.00 - 1.49 = Strongly Disagree*

Table 3 presents the summary of the respondents' evaluation on the Innovation Capacity of Filipino Seafarers in terms of Learning Orientation, Creativity, Collaboration and Support, and Performance. The overall composite mean of 3.68 indicates that the respondents strongly agree that they possess a high level of innovation capacity. This implies that Filipino seafarers demonstrate the knowledge, skills, attitudes, and behaviors necessary to adapt to technological advancements, generate innovative ideas, collaborate effectively with others, and enhance their work performance. The findings suggest that innovation capacity is an important attribute among Filipino seafarers, enabling them to respond effectively to the increasing digitalization and technological transformation of the maritime industry.

Among the dimensions assessed, Performance ranked first with a weighted mean of 3.74 and a verbal interpretation of Strongly Agree. This implies that innovation among Filipino seafarers is most evident in their ability to improve work outcomes, enhance operational efficiency, and contribute positively to vessel performance using digital technologies and innovative practices. The finding suggests that respondents are able to translate innovative ideas and technological competencies into measurable improvements in workplace performance. Innovation-driven performance is particularly important in the maritime sector, where efficiency, safety, and operational excellence are critical. According to Peng and Yu (2022), innovation and digital literacy contribute significantly to workplace productivity, adaptability, and professional effectiveness.

Collaboration and Support ranked second with a weighted mean of 3.73, followed by Learning Orientation with a weighted mean of 3.66, both receiving a verbal interpretation of Strongly Agree. These findings indicate that Filipino seafarers value teamwork, knowledge sharing, continuous learning, and professional development as important components of innovation capacity. The results suggest that respondents actively support one another in adapting to digital technologies and are committed to acquiring new knowledge that contributes to innovation onboard ships. Collaborative environments encourage the exchange of ideas and facilitate the successful implementation of innovative solutions. Martínez-Bravo et al. (2022) noted that learning orientation and collaborative engagement strengthen individuals' capacity to innovate and adapt in rapidly changing work environments.

Meanwhile, Creativity ranked fourth with a weighted mean of 3.59 and a verbal interpretation of Strongly Agree. Although this dimension received the lowest ranking among the indicators, the result still reflects a high level of creativity among Filipino seafarers. This implies that respondents are capable of generating new ideas, experimenting with digital tools, integrating traditional maritime practices with emerging technologies, and

supporting innovative problem-solving. However, the findings also suggest that there may be opportunities to further strengthen idea generation and creative thinking through targeted innovation programs and technology-driven initiatives. According to Erwin and Mohammed (2022), creativity is enhanced when individuals are provided with opportunities for experimentation, collaborative learning, and digital skills development.

Table 4 shows the relationship between digital competence and artificial intelligence utilization among Filipino seafarers. The results reveal that only a few of the computed rho-values were statistically significant at the 0.05 level, while the majority were found to be not significant. This implies that digital competence does not uniformly influence all dimensions of AI utilization. Instead, specific aspects of digital competence are associated with particular areas of AI application in maritime operations. The findings further indicate that these significant relationships are inverse in nature, suggesting that higher levels of digital competence are associated with lower levels of AI utilization in certain maritime functions. This may imply that seafarers with stronger digital knowledge and skills are more confident in exercising their own professional judgment, analytical abilities, and operational expertise rather than relying extensively on AI-assisted technologies. While digital competence provides the foundational capabilities necessary for understanding and interacting with emerging technologies, the extent of AI utilization may also be influenced by operational requirements, organizational culture, training opportunities, technological accessibility, and individual preferences regarding decision-making.

**Table 4**

*Relationship Between Digital Competence and Artificial Intelligence*

| Information Literacy            | rho-value | p-value | Interpretation  |
|---------------------------------|-----------|---------|-----------------|
| Navigation                      | 0.061     | 0.234   | Not Significant |
| Ship/Engine Management          | 0.027     | 0.594   | Not Significant |
| Safety Operations               | 0.123     | 0.016   | Significant     |
| Human Element                   | 0.008     | 0.874   | Not Significant |
| Communication and Collaboration | rho-value | p-value | Interpretation  |
| Navigation                      | 0.054     | 0.295   | Not Significant |
| Ship/Engine Management          | 0.036     | 0.486   | Not Significant |
| Safety Operations               | 0.030     | 0.554   | Not Significant |
| Human Element                   | 0.052     | 0.311   | Not Significant |
| Problem-Solving                 | rho-value | p-value | Interpretation  |
| Navigation                      | 0.039     | 0.449   | Not Significant |
| Ship/Engine Management          | 0.028     | 0.580   | Not Significant |
| Safety Operations               | 0.004     | 0.931   | Not Significant |
| Human Element                   | - 0.107   | 0.037   | Significant     |
| Safety Awareness                | rho-value | p-value | Interpretation  |
| Navigation                      | 0.129     | 0.012   | Significant     |
| Ship/Engine Management          | 0.096     | 0.060   | Not Significant |
| Safety Operations               | 0.071     | 0.163   | Not Significant |
| Human Element                   | 0.048     | 0.349   | Not Significant |

*Legend: Significant if the p-value is less than 0.05; Not Significant if the p-value is greater than 0.05*

The results indicate that Information Literacy was significantly related only to Safety Operations, while its relationships with Navigation, Ship/Engine Management, and Human Element were not significant. This suggests that respondents who are more capable of locating, evaluating, and interpreting information tend to utilize AI more effectively in safety-related functions. The ability to critically analyze information appears to help seafarers evaluate AI-generated safety warnings, identify hazards, and make informed safety decisions. This finding supports the view that information literacy is particularly valuable in environments where AI systems generate large amounts of operational and safety-related information requiring human interpretation. Martínez-Bravo et al. (2022) noted that information literacy enhances decision-making and critical evaluation of digital outputs.

In contrast, Communication and Collaboration did not show any significant relationship with any of the dimensions of AI utilization. This indicates that although communication and teamwork remain important competencies in maritime operations, they do not significantly influence the extent to which AI technologies are utilized by Filipino seafarers. A possible explanation is that AI utilization is more dependent on technical knowledge, operational familiarity, and decision-making competencies than on interpersonal communication skills.

While collaboration may facilitate the sharing of technological knowledge, the actual use of AI systems appears to be influenced more strongly by individual technological competencies and organizational practices. This observation is consistent with the argument of Peng and Yu (2022), who emphasized that technological adoption in digital environments often requires specialized competencies beyond general communication and collaborative skills.

A more interesting finding emerged with respect to Problem-Solving. While no significant relationships were found, a significant negative relationship was identified between Problem-Solving and the Human Element dimension of AI utilization. This implies that respondents with stronger problem-solving abilities tend to rely less on AI-assisted support when making human-centered operational decisions. The negative correlation suggests that individuals who are confident in their analytical and decision-making skills may place greater trust in their own professional judgment and experience rather than depending heavily on AI-generated recommendations. Although the relationship is weak, it highlights the continuing importance of human expertise in maritime operations. Durlík et al. (2024) emphasized that despite advances in AI-assisted systems, human operators remain critical in evaluating automated recommendations and ensuring safe operational outcomes.

Among all the dimensions examined, Safety Awareness demonstrated the most meaningful relationship with AI utilization. Specifically, Safety Awareness showed a significant positive relationship with Navigation, while its relationships with Ship/Engine Management, Safety Operations, and Human Element were not significant. This finding suggests that seafarers who possess greater awareness of digital safety practices, cybersecurity risks, and responsible technology use are more inclined to utilize AI-assisted navigation systems. The result can be attributed to the fact that navigation systems increasingly integrate AI technologies, predictive analytics, and automated decision-support tools that require users to understand both their benefits and limitations. Safety-conscious individuals are therefore more likely to adopt these technologies responsibly and effectively.

**Table 5**

*Relationship Between Digital Competence and Innovation Capability*

| Information Literacy            | rho-value | p-value | Interpretation  |
|---------------------------------|-----------|---------|-----------------|
| Learning Orientation            | 0.029     | 0.576   | Not Significant |
| Creativity                      | 0.007     | 0.896   | Not Significant |
| Collaboration and Support       | 0.081     | 0.114   | Not Significant |
| Performance                     | 0.042     | 0.408   | Not Significant |
| Communication and Collaboration | rho-value | p-value | Interpretation  |
| Learning Orientation            | 0.072     | 0.156   | Not Significant |
| Creativity                      | 0.087     | 0.090   | Not Significant |
| Collaboration and Support       | 0.043     | 0.405   | Not Significant |
| Performance                     | 0.012     | 0.820   | Not Significant |
| Problem-Solving                 | rho-value | p-value | Interpretation  |
| Learning Orientation            | 0.065     | 0.206   | Not Significant |
| Creativity                      | 0.047     | 0.315   | Not Significant |
| Collaboration and Support       | 0.085     | 0.098   | Not Significant |
| Performance                     | 0.024     | 0.632   | Not Significant |
| Safety Awareness                | rho-value | p-value | Interpretation  |
| Learning Orientation            | 0.015     | 0.776   | Not Significant |
| Creativity                      | 0.045     | 0.384   | Not Significant |
| Collaboration and Support       | 0.063     | 0.219   | Not Significant |
| Performance                     | 0.064     | 0.213   | Not Significant |

*Legend: Significant if the p-value is less than 0.05; Not Significant if the p-value is greater than 0.05*

Table 5 shows the relationship between digital competence and innovation capability among Filipino seafarers. The results reveal that all computed p-values are greater than the 0.05 level of significance, indicating that there is no significant relationship between the dimensions of digital competence and innovation capability. This implies that possessing higher levels of digital competence does not necessarily result in higher levels of innovation capability among the respondents. Although Filipino seafarers demonstrate strong digital competencies and high innovation capacity, the findings suggest that these two constructs operate independently within the context of maritime operations. The result indicates that innovation capability may be influenced by other factors such as

organizational culture, leadership support, workplace environment, motivation, and opportunities for innovation rather than digital competence alone. Martínez-Bravo et al. (2022) emphasized that digital competence serves as an enabling condition for innovation, but innovative behavior often depends on environmental and organizational influences beyond technological skills.

The results show that Information Literacy is not significantly related to Learning Orientation, Creativity, Collaboration and Support, and Performance. This indicates that although respondents are capable of locating, evaluating, and utilizing digital information effectively, these competencies do not automatically translate into innovative behaviors or outcomes. While information literacy supports informed decision-making and operational effectiveness, innovation requires the ability to transform knowledge into new ideas, practices, and solutions. The findings suggest that the availability of information alone is insufficient to stimulate innovation unless supported by opportunities for experimentation and organizational encouragement. Peng and Yu (2022) noted that digital literacy and innovation may develop independently depending on workplace conditions, learning environments, and organizational support systems.

Similarly, Communication and Collaboration did not demonstrate a significant relationship with any dimension of innovation capability. This implies that effective communication and collaboration skills do not necessarily predict the ability of Filipino seafarers to innovate. While communication facilitates knowledge sharing and teamwork, the findings suggest that innovation requires additional factors beyond collaborative interaction. The result may be attributed to the highly structured and procedural nature of maritime operations, where communication is often focused on operational efficiency and safety compliance rather than innovation generation.

Likewise, Problem-Solving was found to have no significant relationship with Learning Orientation, Creativity, Collaboration and Support, and Performance. This finding indicates that respondents' ability to solve operational and technological problems does not significantly influence their innovation capability. Although problem-solving is often considered a component of innovation, the results suggest that solving routine operational issues may not necessarily lead to the creation of new ideas or innovative practices. The findings imply that the problem-solving skills of seafarers are primarily directed toward maintaining operational continuity and ensuring safety rather than generating innovative solutions. Martínez-Bravo et al. (2022) explained that innovation goes beyond solving existing problems and requires the ability to create new approaches, products, or processes that improve performance and effectiveness.

**Table 6**  
*Relationship Between Artificial Intelligence and Innovation Capability*

| Navigation                | rho-value | p-value | Interpretation  |
|---------------------------|-----------|---------|-----------------|
| Learning Orientation      | 0.016     | 0.705   | Not Significant |
| Creativity                | 0.001     | 0.980   | Not Significant |
| Collaboration and Support | 0.014     | 0.791   | Not Significant |
| Performance               | 0.117     | 0.022   | Significant     |
| Ship/Engine Management    | rho-value | p-value | Interpretation  |
| Learning Orientation      | 0.053     | 0.299   | Not Significant |
| Creativity                | 0.043     | 0.404   | Not Significant |
| Collaboration and Support | 0.053     | 0.305   | Not Significant |
| Performance               | 0.034     | 0.508   | Not Significant |
| Safety Operations         | rho-value | p-value | Interpretation  |
| Learning Orientation      | 0.002     | 0.970   | Not Significant |
| Creativity                | 0.079     | 0.123   | Not Significant |
| Collaboration and Support | 0.005     | 0.927   | Not Significant |
| Performance               | 0.116     | 0.023   | Significant     |
| Human Element             | rho-value | p-value | Interpretation  |
| Learning Orientation      | 0.052     | 0.305   | Not Significant |
| Creativity                | 0.087     | 0.088   | Not Significant |
| Collaboration and Support | 0.008     | 0.883   | Not Significant |
| Performance               | 0.028     | 0.582   | Not Significant |

*Legend: Significant if the p-value is less than 0.05; Not Significant if the p-value is greater than 0.05*

Table 6 shows the relationship between Artificial Intelligence Utilization and Innovation Capability among

Filipino seafarers. The results reveal that only two relationships were found to be statistically significant, while the majority of the computed p-values were greater than the 0.05 level of significance. This implies that the utilization of artificial intelligence does not generally have a significant relationship with the innovation capability of Filipino seafarers.

The results show that Navigation has no significant relationship with Learning Orientation, Creativity, and Collaboration and Support. However, a significant relationship was found between Navigation and Performance. This indicates that the utilization of AI in navigation is associated with improved performance among Filipino seafarers. The finding suggests that AI-assisted navigation technologies contribute to operational effectiveness by enhancing route planning, situational awareness, decision-making, and navigational accuracy. As a result, seafarers who effectively utilize navigation-related AI systems tend to demonstrate better work outcomes and operational performance. This observation supports the growing role of AI in improving maritime efficiency and productivity. According to Pannell and Muñoz (2024), AI-powered navigation systems improve vessel performance through predictive analytics, route optimization, and real-time operational support.

Similarly, Ship/Engine Management showed no significant relationship with any dimension of innovation capability, including Learning Orientation, Creativity, Collaboration and Support, and Performance. This finding implies that the utilization of AI technologies for maintenance planning, predictive diagnostics, resource allocation, and machinery monitoring does not significantly influence the innovation capability of Filipino seafarers. Although these technologies contribute to operational efficiency and equipment reliability, their use appears to be more technical and task-oriented rather than innovation-driven. The result suggests that AI-based ship and engine management systems may support operational effectiveness but do not necessarily encourage innovative behaviors or workplace creativity.

The findings further reveal that Safety Operations has no significant relationship with Learning Orientation, Creativity, and Collaboration and Support, but demonstrates a significant relationship with Performance. This implies that the utilization of AI technologies in safety-related operations contributes positively to work performance among Filipino seafarers. AI-supported safety systems such as intelligent alarms, hazard detection sensors, predictive monitoring tools, and risk assessment technologies enable more effective safety management and operational decision-making. As a result, seafarers who actively utilize AI in safety operations tend to achieve better performance outcomes. According to Durlik et al. (2024), AI technologies enhance maritime safety through real-time monitoring, hazard detection, and predictive analytics, all of which contribute to improved operational efficiency.

Meanwhile, Human Element was found to have no significant relationship with Learning Orientation, Creativity, Collaboration and Support, and Performance. This suggests that human-centered AI utilization, including maintaining professional oversight, evaluating AI-generated recommendations, and ensuring ethical decision-making, does not significantly influence the innovation capability of respondents. While seafarers recognize the importance of human judgment and accountability in AI-assisted operations, these competencies do not appear to directly affect their capacity for innovation. The finding may be explained by the fact that the human element dimension primarily focuses on responsible technology use and operational control rather than the development of innovative ideas and practices. According to the International Maritime Organization (2024), human oversight remains essential in technology-assisted operations to ensure safety and accountability; however, innovation capability requires additional factors such as creativity, organizational support, and continuous learning.

The proposed Maritime Technology Adoption Framework for Filipino Seafarers is presented in Figure 1, illustrating the relationships among Digital Competence, Artificial Intelligence (AI) Utilization, and Innovation Capability in supporting maritime technology adoption. The framework is grounded in the empirical findings of the study, which revealed high levels of digital competence, AI utilization, and innovation capability among Filipino seafarers. Furthermore, significant relationships were identified between selected dimensions of digital competence and AI utilization, as well as between selected dimensions of AI utilization and innovation capability,

providing empirical support for the linkages reflected in the framework. Specifically, the framework positions Digital Competence as the foundational capability, Artificial Intelligence Utilization as the central enabling mechanism, and Innovation Capability as the desired outcome. It also recognizes the direct contribution of digital competence to innovation capability and the indirect contribution facilitated through AI utilization. Consistent with a human-centered perspective, the framework emphasizes the continued importance of professional judgment, accountability, operational safety, and responsible technology use in maritime practice. The framework therefore serves as a conceptual guide for understanding how Filipino seafarers can effectively adapt to the technological demands of Maritime 4.0 and digital transformation within the shipping industry.

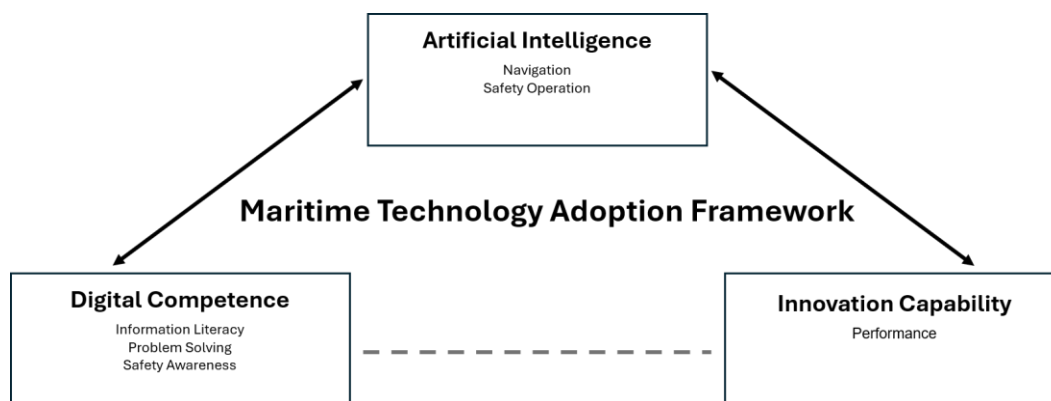


Figure 1. Proposed Maritime Technology Adoption Framework for Filipino Seafarers

Digital Competence serves as the foundation of the framework because it represents the essential skills and knowledge required for seafarers to effectively engage with digital technologies. As presented in the framework, Digital Competence consists of Information Literacy, Problem-Solving, and Safety Awareness. The results of the study revealed that Information Literacy obtained the highest assessment, indicating that Filipino seafarers possess strong capabilities in accessing, evaluating, and utilizing digital information for operational and professional purposes. The framework further illustrates a direct relationship between Digital Competence and Innovation Capability. This relationship suggests that seafarers with stronger digital competencies are more capable of enhancing workplace performance through the effective application of digital knowledge and skills. The direct linkage recognizes that innovation does not depend solely on technological tools but can also emerge from an individual's capacity to analyze information, solve problems, and maintain safe and effective operational practices. This finding aligns with Li et al. (2024), who argued that innovation capability transforms knowledge and technological resources into organizational competitiveness, and Karahalios (2025), who emphasized the importance of continuous learning and digital sustainability in fostering innovation within the maritime sector.

Innovation Capability is positioned as the outcome of the framework and is represented by the dimension of Performance. The study revealed that Performance received a very high assessment, indicating that innovation among Filipino seafarers is reflected primarily through improved workplace effectiveness, productivity, and operational outcomes. Within the framework, innovation capability represents the ability of seafarers to apply technological knowledge, adapt to changing operational environments, and contribute to organizational improvement. As seafarers strengthen their digital competence and effectively utilize AI technologies, their capacity to achieve higher levels of performance likewise increases.

Artificial Intelligence Utilization occupies the central position within the framework, reflecting its role as the primary enabling mechanism linking Digital Competence and Innovation Capability. The construct consists of Human Element, Navigation, and Safety Operation. The findings revealed that the Human Element obtained the highest assessment, indicating that Filipino seafarers recognize the benefits of AI technologies while maintaining responsibility for operational decision-making. The framework suggests that digitally competent seafarers are more capable of effectively utilizing AI technologies, and that such utilization enhances innovation capability by

improving operational efficiency, decision-making quality, and overall workplace performance.

The linkages between Artificial Intelligence Utilization and both Digital Competence and Innovation Capability highlight the interconnected nature of maritime technology adoption. Digital competence provides the knowledge and skills necessary for the effective use of AI systems, while AI utilization creates opportunities for improved performance and innovation. Through AI-enabled technologies, seafarers gain access to enhanced decision-support systems, automated processes, and advanced operational insights that contribute to more efficient and innovative practices. At the same time, innovative and high-performing seafarers are more likely to maximize the benefits of AI technologies, creating a mutually reinforcing relationship between technological utilization and performance outcomes.

Embedded throughout the framework is a human-centered perspective that underscores the importance of safety, ethics, professional judgment, and accountability in technology-enabled maritime operations. Although AI technologies play an increasingly significant role in navigation, safety management, and operational decision-making, the findings indicate that Filipino seafarers continue to value human involvement as an essential component of maritime operations. Respondents strongly agreed that human operators should remain responsible for final decisions in AI-assisted environments, reinforcing the principle that technology should enhance rather than replace human expertise.

For implementation, the framework may serve as a guide for the Maritime Industry Authority (MARINA), maritime higher education institutions, training centers, and shipping companies in developing policies, competency standards, training programs, and professional development initiatives that strengthen digital competence, AI readiness, and innovation capability among Filipino seafarers. Through MARINA's leadership and regulatory functions, the framework can support the integration of emerging digital and AI-related competencies into maritime education, training, certification, and workforce development programs aligned with the demands of Maritime 4.0.

#### 4. Conclusion

- Filipino seafarers demonstrate a high level of digital competence in terms of information literacy, communication and collaboration, problem-solving, and safety awareness.
- Artificial intelligence is highly utilized by Filipino seafarers in navigation, ship/engine management, safety operations, and human element functions.
- Filipino seafarers exhibit a high level of innovation capability in terms of learning orientation, creativity, collaboration and support, and performance.
- There are limited significant relationships among digital competence, artificial intelligence utilization, and innovation capability. Significant relationships were found only between selected dimensions of digital competence and AI utilization, and between selected dimensions of AI utilization and innovation capability, while no significant relationship was found between digital competence and innovation capability.
- A Maritime Technology Adoption Framework was developed based on the findings of the study.
- Recommendations
- Maritime institutions, training centers, and shipping companies may strengthen digital competence development programs, particularly in advanced problem-solving, digital diagnostics, cybersecurity awareness, and information management, to further enhance Filipino seafarers' readiness for increasingly digitalized maritime operations.
- Shipping companies and maritime organizations may expand the integration of artificial intelligence

technologies in navigation, ship and engine management, and safety operations through hands-on training, simulations, and continuous AI competency development programs to ensure the effective and responsible utilization of emerging maritime technologies.

- Maritime stakeholders may promote innovation-enhancing initiatives by encouraging continuous learning, creativity, collaborative problem-solving, knowledge sharing, and performance improvement programs that will enable seafarers to translate technological knowledge into innovative operational practices.
- Maritime education and industry sectors may review and implement institutionalize the proposed Maritime Technology Adoption Framework as a guide for curriculum enhancement, workforce development programs, technology adoption strategies, and policy formulation to ensure the effective integration of digital competence, artificial intelligence utilization, innovation capability, and human-centered decision-making in maritime operations.
- Future researchers may expand this study by examining additional variables such as technology acceptance, organizational support, digital resilience, innovation climate, leadership support, learning agility, and workforce readiness. Future studies may also utilize advanced statistical techniques such as Structural Equation Modeling (SEM), path analysis, or mediation analysis to explore the causal relationships among digital competence, artificial intelligence utilization, innovation capability, and maritime technology adoption.

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