



The impact of digitalization on environment and maritime safety within the shipping industry

Master's thesis in Maritime Management

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DEPARTMENT OF MECHANICS AND MARITIME
SCIENCE

MASTER'S THESIS IN MARITIME MANAGEMENT

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

As the maritime industry is experiencing a shift towards digitalization to enhance efficiency, safety, and operational effectiveness, maritime professionals are increasingly required to interact with complex digital systems. While the technologies offer significant advantages, they also introduce challenges related to system reliability, workload, usability, and maritime professionals' well-being. This study investigates the impact of digitalization on maritime professionals' work environment and maritime safety through a quantitative research approach. A structured questionnaire was distributed to maritime professionals across deck and engine departments, shipping companies, port authorities, navy personnel, and other maritime-related roles. Findings reveal that frequent system errors, poor user-centred design, and insufficient technical support contribute to increased workload and decreased trust in digital tools. Over 90% of participants reported experiencing technostress, with many mentioning frustration, pressure to adapt quickly, and fear of making mistakes due to system complexity. The study concludes that while digitalization is a necessary evolution in maritime operations, its implementation must be carefully managed to ensure it supports rather than hinders the maritime professionals' performance training. Improved training, standardized system design, and stronger support structures are critical to maximizing the benefits of digital technologies used on maritime working environment.

Key words: digitalization, ICT, maritime safety, user-centred design, technostress, trust in automation, situational awareness

Digitaliseringens inverkan på miljö och sjösäkerhet inom sjöfartsnäringen

Examensarbete inom Svenskt namn på Maritima studier

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Sammanfattning

När sjöfartsnäringen upplever en förändring mot digitalisering för att öka effektiviteten, säkerheten och operativ effektivitet, måste sjöfolk i allt högre grad interagera med komplexa digitala system. Även om dessa teknologier erbjuder betydande fördelar, introducerar de också utmaningar relaterade till systemens tillförlitlighet, arbetsbelastningen, användbarhet och sjöfolks välbefinnande. Denna studie undersöker hur digitaliseringen påverkar arbetsmiljö och säkerheten i den maritima näringen genom en kvantitativ forskningsansats. Ett strukturerat frågeformulär distribuerades till sjöfartspersonal över däck- och maskinavdelningar, rederier, hamnmyndigheter, marinens personal och andra sjöfartsrelaterade roller. Resultaten visar att frekventa systemfel, dålig användarcentrerad design och otillräcklig teknisk support bidrar till ökad arbetsbelastning och minskat förtroende för digitala verktyg. Över 90 % av deltagarna rapporterade att de upplevde teknostress, där många nämnde frustration och att de upplevde sig pressade att anpassa sig snabbt samt rädsla för att göra misstag på grund av systemets komplexitet. Studien drar slutsatsen att även om digitalisering är en nödvändig utveckling inom sjöfartsområdet, måste den digitala utvecklingen noggrant hanteras för att säkerställa att den stöder snarare än hindrar fartygets framförande och driften ombord. Förbättrad utbildning, standardiserad systemdesign och starkare stödstrukturer är avgörande för att maximera fördelarna med digital teknik ombord.

Nyckelord: digitalisering, ICT, sjösäkerhet, användarcentrerad design, teknostress, förtroende för automation, situationsmedvetenhet

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Preface

This master's thesis was conducted from January 2025 till May 2025 as part of the Maritime Management Master's Degree programme within the Department of Mechanics and Maritime Sciences at Chalmers University of Technology, Sweden. This thesis serves as the final academic for the completion of the programme.

I would like to express my deepest gratitude to my supervisor and examiner, Monica Lundh, from the Department of Mechanics and Maritime Sciences at Chalmers University of Technology. Her encouragement, thoughtful guidance, and extensive knowledge have been invaluable throughout this journey. Her expertise, along with her connections within the maritime industry, greatly supported the data collection process and enriched the overall quality of the research.

I would also like to extend my sincere thanks to all the respondents who generously took the time to participate in the survey, despite their demanding schedules. Your insights, experiences, and perspectives on digitalization in maritime operations were essential in shaping the findings of this study.

Finally, I am incredibly grateful to my family and friends for their unwavering support and encouragement throughout this challenging yet rewarding process.

Göteborg, 2025

ANISA AYU SOPHIA DEWI

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List of Abbreviations

AI	Artificial Intelligence
COLREGs	International Regulations for Preventing Collisions at Sea
ECDIS	Electronic Chart Display and Information Systems
GPS	Global Positioning System
HCD	Human-Centred Design
HMI	Human-Machine Interfaces
ICT	Information and Communication Technology
IMO	International Maritime Organization
ISO	International Organization for Standardization
KR	Korean Register of Shipping
MASS	The Maritime Autonomous Surface Ships
ML	Machine Learning
RPA	Robotic Process Automation
S2SREX	Ship to Ship Route Exchange
SA	Situational Awareness
SIP	Strategy Implementation Plan
SOLAS	Safety of Life at Sea
STM	Sea Traffic Management
UCD	User-Centred Design
VTS	Vessel Traffic Services
WAD	Work as Done
WAI	Work as Imagine

1 Introduction

The maritime industry, as many other industries and particularly all other transport industries, is undergoing a state of digital transformation and information and communication technologies (ICT) (HSBA, 2018). According to Berg-Beckhoff (2017), ICT is a diverse set of technological tools and resources used to manage information for the consumer to work with. In the shipping industry, digitalization has driven technical and organizational changes that have profoundly influenced crew performance and how Work is Done (WAI) (Lundh and Rydstedt, 2016; Hollnagel, 2017; Aylward, 2022).

Digitalization in the maritime sector has introduced significant advantages, such as enhanced decision support, streamlined administrative processes, and advanced communication tools (Ding et al, 2014; World Maritime University, 2023). These innovations have also improved navigational safety, operational efficiency, and overall maritime professional well-being (Jovic et al., 2022; World Maritime University, 2023). Moreover, the rapid pace of digitalization and automation is transforming the industry faster than ever before and the exploitation of the technologies emerging within the maritime industry can change shipping as we know it (DNV GL, 2014; Brooks and Faust, 2018; UNCTAD, 2019).

However, this shift has also presented challenges, including reduced crew sizes and increased workloads, which arise from adapting to rapidly evolving technologies (Brillhart, 2004; La Torre et al., 2018). The increasing reliance on digital systems has also contributed to technostress, a condition characterized by anxiety, fatigue, and reduced productivity due to difficulties in coping with new technologies and their constant updates (La Torre et al., 2018). This can lead to difficulty in meeting the high standards expected by companies and reduced job satisfaction. Additionally, more time may be spent learning how to use new devices, diverting time away from other critical tasks (Ragu-Nathan et al., 2008; Amanuel, 2023). World Maritime University (2023) added that, with the pace that which technology is being integrated into shipping, maritime professionals are increasingly experiencing pressure to rapidly acquire new skills and competences, leading to serious consequences for their mental health and wellbeing.

According to Lützhöft (2004), while this is not necessarily the most urgent problem the maritime industry faces, it is a growing problem that will increase with the continued adoption of more advanced technology and more automated systems. If today's challenges remain unaddressed, we risk creating an unstable foundation for the integration of more advanced automation, which weaken the safety and efficiency gains automation promises to bring (Strauch, 2018).

Recognizing these challenges, the Swedish Shipowners' Association requested research to explore complaints related to digitalization raised by its members. Lundh's et. al (2023) provided insights, identifying recurring issues such as system complexity, frequent software updates, and alarm fatigue. These challenges contribute to cognitive overload and operational stress for crew members, highlighting the gap between how work is imagined (WAI) through system design and how it is actually performed (WAD) onboard (Hollnagel, 2017).

While this research focused on identifying and describing these challenges, the magnitude of these identified issues was however not investigated. Thus, this thesis takes the next step by quantifying their magnitude and frequency. By assessing the

impact of these issues on maritime professional safety and operational efficiency, the study aims to provide actionable insights that can inform better system design and support strategies, ultimately fostering a safer and more effective digital work environment in the maritime industry.

1.1 Objectives

The purpose of this research is to quantify the magnitude and frequency of previously identified issues and assess their impact on maritime professionals workload, safety, and efficiency. By translating the qualitative findings into measurable data, this study aims to provide a clearer understanding of the scope and severity of these challenges.

1.2 Research Questions

This study will address the following research questions:

1. What is the magnitude of the problems associated with digitalization?
2. How do digitalization issues affect workload and efficiency?
3. How do the challenges within digitalization impact maritime safety?
4. How do maritime professionals experience technostress?

1.3 Limitations

This survey in this study was distributed solely via LinkedIn, Facebook, and personal networks and relying on voluntary participation. Additionally, the scope of the study is limited to digital tools used in administrative and operational systems. It does not cover aspects related to hardware maintenance or technical infrastructure. Additionally, the respondents targeted are maritime professionals who work with Nordic-flagged vessels.

2 Theoretical Background

This chapter provides a theoretical foundation for understanding how digitalization has influenced the maritime industry, particularly in relation to maritime professionals' working environments and maritime safety. It describes the historical development of maritime operations, the progression of digital technologies, associated challenges such as technostress, and the role of automation and human-centred design. These frameworks help contextualize the findings of the study and support the interpretation of the questionnaire results.

2.1 Maritime operations before digitalization

Before the widespread adoption of digital technologies, maritime operations were largely manual and paper-based. Ships relied on traditional navigation tools, including paper charts, compasses, and celestial navigation methods (Bradarić et al., 2007). Communication was primarily conducted through radio and other non-digital means. Navigation relied on physical charts and the skills of experienced navigators to guide vessel safety across the sea (Bradarić et al., 2007; Kapidani, 2020).

2.2 Evaluation and impact of maritime digitalization

The Third Industrial Revolution, which began in the 1960s with advancements in semiconductors, laid the foundation for modern digitalization by enabling the use of computers and electronic navigation tools such as alarm systems with text displays, anti-collision radars, and docking logs (Nowacki, 2010; Schwab, 2016). As early adopters of advanced information technologies, shipbuilding and shipping have leveraged digital tools to optimize decision-making, administrative tasks, and communication processes (Ding et al., 2014; World Maritime University, 2023). Over time, Information and Communication Technology (ICT) has rapidly transformed the maritime sector, reshaping navigation, improving operational efficiency, and driving automation in ship operations (Hopcraft, 2021). A notable example is the historical evolution of navigational aids used on the bridge (Figure 1).

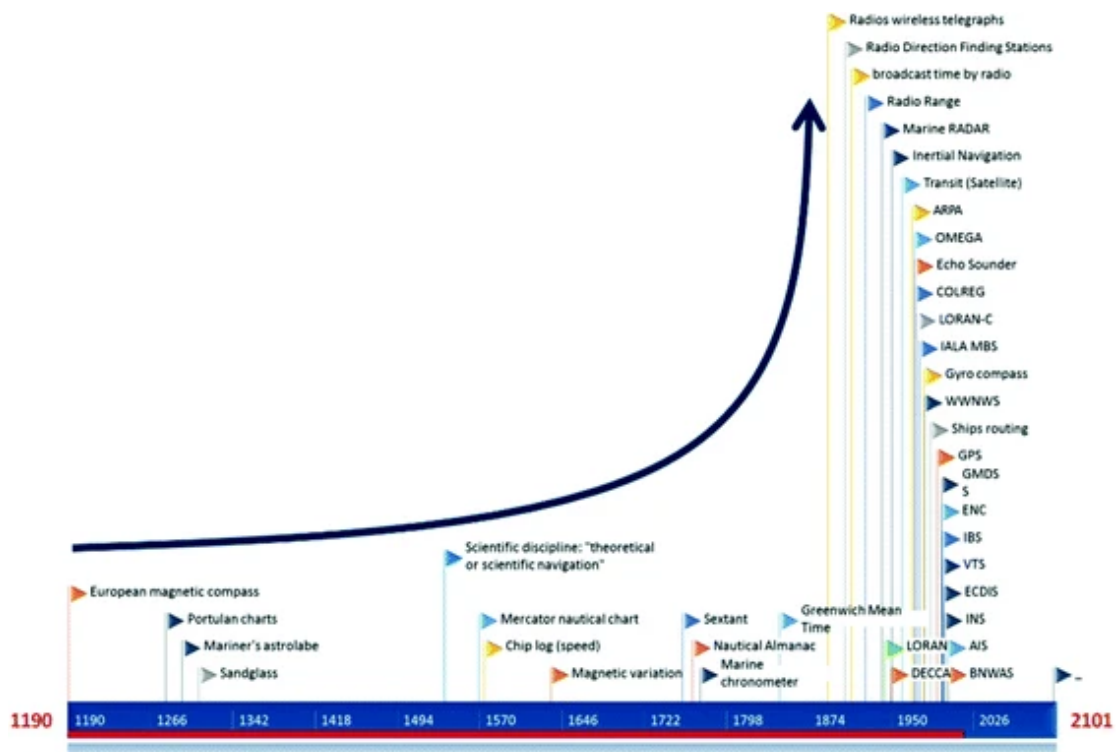


Figure 1. The development of navigational aids (Conceição et al. 2017) (Used with permission from the authors)

The International Maritime Organization (IMO) has also played a critical role in accelerating maritime digitalization, particularly through e-navigation strategies aimed at integrating digital tools into safety and efficiency regulations (IMO, 2011; Baum-Talmor and Kitada, 2022). The concept of e-navigation, driven by international maritime authorities, is a key component of this digital revolution. It involves the digitalization of all maritime operations to ensure efficient and uninterrupted communication between ships and land facilities (Usluer, 2024).

2.3 Accidents associated with digitalization

While digitalization has improved efficiency, it has also led to new types of maritime accidents caused by system failures, automation errors, and human misinterpretation of digital tools. One factor that may lead to behaviour is over-reliance on new technologies (Parasuraman & Manzey, 2010). It is frequently ignored that Mariners are confronted with various industry-related specifics concerning technology assimilation, ranging from a lack of technological know-how, a lack of situational awareness, and appropriate training in the use (Hickethier & Yang, 2023).

For example, the CMA CGM Libra grounding in 2011 demonstrated how over-reliance on digital navigation tools, such as ECDIS, can lead to accidents when not verified through traditional methods (UK P&I Club, 2021). Similarly, the Stellar Daisy case investigation revealed a structural issue. However, KR (Korean Register of Shipping) also stated that the ship's hull stress monitoring system failed to alert the crew in time, and poor data interpretation led to delays in response (Republic of the Marshall Islands, 2017). Recently, the grounding of the MARCO POLO in October 2023 was caused by critical failures in digital navigation. The vessel experienced a GPS data error due to outdated software in one of its GPS receivers, which had not been updated or maintained. This caused the ECDIS and radar systems to reject the GPS input, leading the crew to rely on dead reckoning navigation without cross-verifying the ship's

position using alternative methods. The lack of updated maintenance routines contributed to the crew's unawareness of the GPS limitations. This resulted in multiple groundings and a significant oil spill in Hanö Bay, worsened by delayed situational awareness and ineffective communication between crew members and shore-based support (Statens haverikommission, 2025).

2.4 The role of automation in digitalization

Building on the rapid digitalization of maritime operations, automation technologies such as AI-driven collision avoidance systems and predictive maintenance tools are being widely adopted to enhance operational safety and efficiency (Sanchez-Gonzalez et al., 2019). Sanchez-Gonzales et al (2019) also stated that automation, including autonomous vessels, smart shipping technologies, and predictive maintenance systems, has reduced human error, improved fuel efficiency, and optimized route planning. For example, automation optimizes business processes by using technologies like cloud computing and robotic process automation (RPA), which streamline operations, reduce costs, and improve financial sustainability (Hofmann et al., 2019; Sokolova & Molchanova, 2024).

Furthermore, artificial intelligence (AI) and machine learning (ML) algorithms are now being incorporated into collision avoidance systems, cargo monitoring, and weather forecasting, enhancing safety and operational performance (DNV GL, 2014; Coro, 2024). Predictive maintenance tools, which use sensor data to assess equipment conditions and prevent failures before they occur, have also contributed to reducing operational downtime and improving vessel longevity (UNCTAD, 2019).

2.5 Challenges of digitalization in the maritime industry

Research by Kitada et al. (2023) and World Maritime University (2023) indicates that while digital solutions streamline administrative processes and improve operational control, their rapid implementation without standardized training has led to inconsistencies in system usability. Furthermore, maritime professionals often experience difficulties adapting to digital platforms due to frequent software updates, inconsistent user interfaces across different ship systems, and a lack of interoperability between various maritime software solutions (Kitada & Ölçer, 2015).

While digitalization enhances efficiency, its rapid implementation without adequate training has led to increasing operational challenges, particularly affecting maritime professionals' adaptability and mental well-being. These challenges not only impact operational efficiency but also contribute to technostress, as maritime professionals are required to learn and adapt to evolving digital infrastructures without sufficient support (Ragu-Nathan et al., 2008; Amanuel, 2023). The shift toward digitalization has also led to crew redundancy, where fewer personnel are required onboard due to automation, increasing pressure on the remaining members to manage complex systems (La Torre et al., 2018). Ichimura et al. (2022) highlight the psychological and operational implications of this shift, noting that while automation enhances efficiency, it also increases the risk of over-reliance on digital tools, which may lead to reduced situational awareness in critical situations.

As the industry continues to integrate digital solutions, there is an urgent need for standardized digital training programs, improved user-centred design in maritime software, and regulatory frameworks that ensure digitalization enhances rather than disrupts maritime safety and workforce stability (Strauch, 2018; Kitada & Ölçer, 2015). Addressing these factors is crucial for ensuring that digital transformation in shipping

aligns with both technological advancements and the human element in maritime operations (Strauch, 2018).

2.6 Trust in automation and human-automation interaction

Trust plays a fundamental role in determining how operators interact with automated systems. According to research on Trust in Automation, effective system design must encourage appropriate reliance, ensuring users neither over-trust (misuse) nor under-trust (disuse) automated tools (Lee & See, 2004).

Lee and Moray (1992) initially identified three key factors influencing trust in automation: performance, process, and purpose. Lee and See (2004) later expanded on this framework, defining performance as the automation's reliability, predictability, and effectiveness based on both past and current operations, essentially describing what the system does. Process relates to the appropriateness of the automation's algorithms in achieving the operator's goals, focusing on how the system functions. This aligns with interpersonal trust, where consistency and adherence to acceptable principles build credibility (Mayer et al., 1995). Lastly, purpose reflects whether the automation is being used as originally intended by its designers, emphasizing why it was developed. This factor corresponds to the perception that the system has a positive orientation toward the user, fostering trust in its intent and application.

When trust is miscalibrated, operators either over-rely on automation (as seen in CMA CGM incidents where crews fail to verify ECDIS inputs) or underutilize valuable digital support tools, reverting to manual operations unnecessarily. Maritime accidents, such as the MARCO POLO case, highlight how system failures, coupled with poor data interpretation, can erode trust in automation and delay corrective actions.

2.7 Technostress and digital workload

The American psychologist Craig Brod was one of the first scholars who suggested that computer technology can be a cause of stress among its users (Brod, 1984). In the maritime industry, rapid digitalization has introduced new complexities in maritime professionals' daily work, leading to technostress, a condition caused by difficulties in adapting to new technologies and managing digital workloads (Ragu-Nathan et al., 2008). As automation and digital tools become more integrated into ship operations, maritime professional members face increasing pressure to learn, operate, and troubleshoot multiple systems, often without standardized training or support (World Maritime University, 2023).

2.7.1 Causes of technostress in maritime operations

The frequent software updates, inconsistent system interfaces, and high dependence on electronic navigation tools require continuous adaptation, which contributes to cognitive overload and work-related stress (Amanuel, 2023). Research by Lundh et al. (2023) highlights that seafarers often struggle with alarm fatigue, where excessive notifications from digital systems lead to delayed reactions, increased stress, and decreased situational awareness. Additionally, the expectation for constant availability and digital monitoring from shore-based management has blurred the boundaries of work responsibilities, further intensifying stress levels (Rohwer et al., 2022; Kitada et al., 2023).

The Denmark case study from the World Maritime University (2023) report also highlights how digitalization has increased maritime professionals' workloads, often

without adequate training or compensation. According to this study, many maritime members struggle with troubleshooting modern shipboard technologies, leading to extended working hours, fatigue, and stress. The transition from manual inspections to system-based monitoring has also made operations more complex and requires constant adaptation. Staff shortages and high turnover rates result in experienced maritime members bearing the responsibility of training new hires. While some appreciate technological advancements, many feel overwhelmed by the need to continuously adapt, and the lack of structured support worsens the challenges of working with ever-evolving digital systems.

2.7.2 Impact of technostress on maritime professionals' performance

In their research, Dragano and Lunau (2020) emphasize that digitalization has increased administrative burdens, as maritime professionals are now required to handle complex reporting systems, data input tasks, and compliance-related digital documentation. It makes them reduce their ability to focus on primary operational duties. Unlike traditional physical workloads, digital workload often extends beyond regular working hours, as crew members must resolve technical issues or undergo mandatory system training during their limited rest periods (Allen et al., 2008). This can result in job dissatisfaction, lower productivity, heightened risks of errors, and the feeling of being replaceable (French & Caplan, 1972; Cooper et al., 1989; Amanuel, 2023).

The generational divide also plays a role in how maritime professionals experience technostress, while younger members may struggle with information overload, senior officers often find it challenging to adapt to the frequent changes in digital infrastructure (Cooper et al., 1989). Addressing these concerns requires a comprehensive approach, including improved digital literacy training, user-friendly system design, and regulatory measures to limit unnecessary digital interventions that add to maritime professionals' workload (Strauch, 2018; Fleron & Stana, 2024).

2.7.3 Situational awareness in maritime operations

As maritime operations become increasingly digitalized, maintaining situational awareness (SA) is critical for ensuring safe navigation and effective decision-making (Franke & Brynielsson, 2014). Situational awareness refers to an operator's ability to perceive, comprehend, and predict relevant elements in a dynamic environment (Endsley, 1995). Endsley's three-level model of SA provides a framework for analyzing human interaction with automated systems in complex operational settings:

1. Perception (Level 1 SA) - The ability to detect and recognize relevant information in the environment, such as ship traffic, weather conditions, or system alarms. In maritime operations, seafarers rely on electronic chart display and information systems (ECDIS), radar, and other digital tools to perceive key navigational data.
2. Comprehension (Level 2 SA) – The ability to interpret and understand the significance of the information. This involves integrating different sources of data to assess risks and operational status, such as identifying a potential collision based on vessel movement patterns.
3. Projection (Level 3 SA) – The ability to anticipate future events based on current conditions. In maritime automation, this means predicting potential navigation hazards, adjusting course accordingly, and responding proactively to changes in traffic patterns or environmental factors.

While Endsley's model of situational awareness (SA) has been widely applied in complex operational settings, it has also faced criticism. One major concern is the issue of circular reasoning. SA is often concluded from an operator's performance, but poor performance is also attributed to a loss of SA, making it difficult to establish a clear causal relationship (Flach, 1995). Nevertheless, Endsley's SA model remains a dominant framework for understanding human-system interactions, particularly in high-risk environments such as aviation, defense, and maritime operations.

2.8 The role of automation in enhancing safety

Over the past few decades, safety-critical industries have increasingly adopted computerization and automation to enhance safety, efficiency, and productivity while simultaneously reducing operating costs (Hadnett, 2008; Harris, 2011). Automated technologies such as collision avoidance systems, autopilot functions, and predictive maintenance tools have been designed to enhance decision-making, reduce human error, and improve response times in critical situations (Ding et al., 2012; DNV GL, 2014).

The European Union (EU) funded project aimed to address safety concerns within navigation called Sea Traffic Management (STM) (Sea Traffic Management, 2018; Aylward et al., 2020). The STM Validation project and its predecessor MONALISA aimed to improve maritime safety and efficiency through digitalization, particularly by facilitating real-time information exchange align with navigational safety protocols. With that, STM has contributed to reducing navigational risks and improving situational awareness for both crews and shore-based operators. (Sea Traffic Management, 2018).

A crucial framework underpinning maritime navigation is the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), which serve as the "rules of the road" for ships and other vessels to mitigate negative incidents in traffic situations (Aylward, 2022). However, Aylward's research (2020) highlighted some unintended consequences of this digital solution. Her study found that while decision support systems, like the ship-to-ship route exchange (S2SREX), allowed operators to act earlier and maintain greater distances from potential collision targets, it also inadvertently led to an increase in COLREG violations. Operators appeared to rely on projected future states generated by these systems, which sometimes caused misunderstandings about other vessels' intentions, especially in complex traffic scenarios. Participants noted that while the system offered valuable visualizations, its limitations in interpreting seamanship, a nuanced and experience-based aspect of navigation could undermine safety. This emphasizes the need for cautious integration of decision support systems, ensuring that automated solutions complement rather than complicate traditional navigational practices.

2.8.1 Risks and challenges of maritime automation

Despite these advancements, automation also introduces new safety concerns, particularly regarding over-reliance on technology, loss of situational awareness, and inadequate human oversight (Bainbridge, 1983; Strauch, 2018). The "Ironies of Automation" concept suggests that while automated systems are meant to simplify tasks, they may instead create cognitive complacency, leading crew to trust systems blindly and struggle to intervene effectively in emergencies (Strauch, 2018). Additionally, there is often a disconnect between Work as Imagined (WAI) by designers and regulators and Work as Done (WAD) by maritime professionals in real-world conditions (Hollnagel, 2017; Aylward, 2022).

A major issue stemming from this gap is the lack of standardization in digital maritime systems (Koo et al., 2024). Variability in automation interfaces across different vessels forces seafarers to continuously adapt, increasing cognitive workload and reducing operational efficiency (Aylward, 2022). Without proper standardization, digital tools may hinder rather than enhance safety by introducing unfamiliar workflows and inconsistent user experiences (Koo et al., 2024). Addressing these challenges requires human-centred design approaches that integrate maritime professionals' practical experiences into the development of maritime automation technologies (Aylward, 2022).

Recognizing these risks, regulatory bodies such as IMO have emphasized the need for standardization in digital systems to minimize confusion and ensure operational consistency across international fleets (IMO, 2020). The IMO introduced the concept of e-navigation in 2006 to enhance the safety, security, and environmental protection of maritime operations through the harmonization and digitalization of marine navigation systems. E-navigation is defined as “the harmonized collection, integration, exchange, presentation, and analysis of marine information onboard and shore by electronic means to enhance berth-to-berth navigation and related services” (IMO, 2009). Its core goal is to improve safety and operational efficiency by reducing administrative burdens and ensuring seamless ship-to-shore communication.

To guide the development and implementation of e-navigation, IMO established the Strategy Implementation Plan (SIP), which outlines five key solutions:

- (1) improved, harmonized, and user-friendly bridge designs;
- (2) standardized and automated reporting processes;
- (3) enhanced reliability and integrity of navigation equipment;
- (4) integration of navigation information into graphical displays; and
- (5) improved communication with Vessel Traffic Services (VTS).

The SIP is an evolving framework, regularly reviewed to accommodate emerging user needs and technological advancements, ensuring that the e-navigation concept remains relevant and effective in enhancing maritime operations (IMO, 2018).

Building upon this, SOLAS Chapter V Regulation 15 sets foundational principles for bridge design and the arrangement of navigational systems. Though it operates at a higher, more general level, it emphasizes the facilitation of effective bridge resource management, minimizing distractions and fatigue, and ensuring the continuous availability of critical information through standardized symbols and efficient monitoring systems (SOLAS, 2002). However, while these principles are essential, their broad scope means that designers often lack specific guidance for implementing effective user interfaces.

To complement SOLAS, international standards such as ISO/IEC JTC 1/SC 35 provide detailed guidelines for user-system interfaces in ICT environments. This includes guidelines for user interface accessibility, cultural and linguistic adaptability, interaction methods across sensory modalities (visual, auditory, tactile), and the design of input and output devices to ensure that digital interfaces meet the diverse needs of all users, including those with specific requirements (ISO, 1998).

Further contributing to these efforts, the OpenBridge Design System, a system from a research project developed by Oslo University, offers open-source, user-centred guidelines specifically for maritime bridge interfaces. It aligns with international

standards, including IMO and ISO, ensuring intuitive, consistent, and accessible interfaces that reduce human error and enhance operational safety (OpenBridge, 2025).

2.8.2 Human-centred design and training gaps

Research by Hetherington et al. (2006) and Kitada (2023) emphasizes that automation does not eliminate human responsibility. Rather, it shifts the role of the crew members from active operators to system supervisors, which can lead to new forms of stress and operational challenges. Alarm fatigue, resulting from excessive and irrelevant system notifications, remains a major concern that increases the risk of overlooking critical warnings (Lundh et al., 2023). Furthermore, inconsistent automation interfaces across different vessels can create confusion, requiring additional training and adaptation for seafarers moving between ships (Kitada et al., 2019).

To address these challenges, the integration of Human-Centred Design (HCD) in maritime automation is crucial. According to ISO 9241-210:2019, HCD is “an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs, and requirements, and by applying human factors/ergonomics and usability knowledge and techniques.” HCD is vital for creating intuitive human-machine interfaces (HMI) that prevent errors and enhance decision-making, thereby improving safety and operational efficiency (Gauthier et al., 2019). Historical data on marine incidents underscores how poorly designed systems contribute to operational failures and safety risks (Gauthier et al., 2019; Aylward, 2022).

Differentiating between HCD and User-Centred Design (UCD) can be challenging. According to Tosi (2019), while both approaches prioritize the needs of people, UCD focuses on ensuring usability by addressing users’ needs during the product development process. HCD extends this approach by considering the entire user experience, including emotional and contextual factors. HCD involves iterative design, where users are engaged throughout the development process to refine solutions based on real-world feedback. While UCD emphasizes functionality and usability, HCD adopts a broader perspective that also accounts for emotional, contextual, and ergonomic factors. Figure 2 below illustrates the iterative nature of HCD, highlighting its five key phases, from understanding user needs to verifying design solutions.

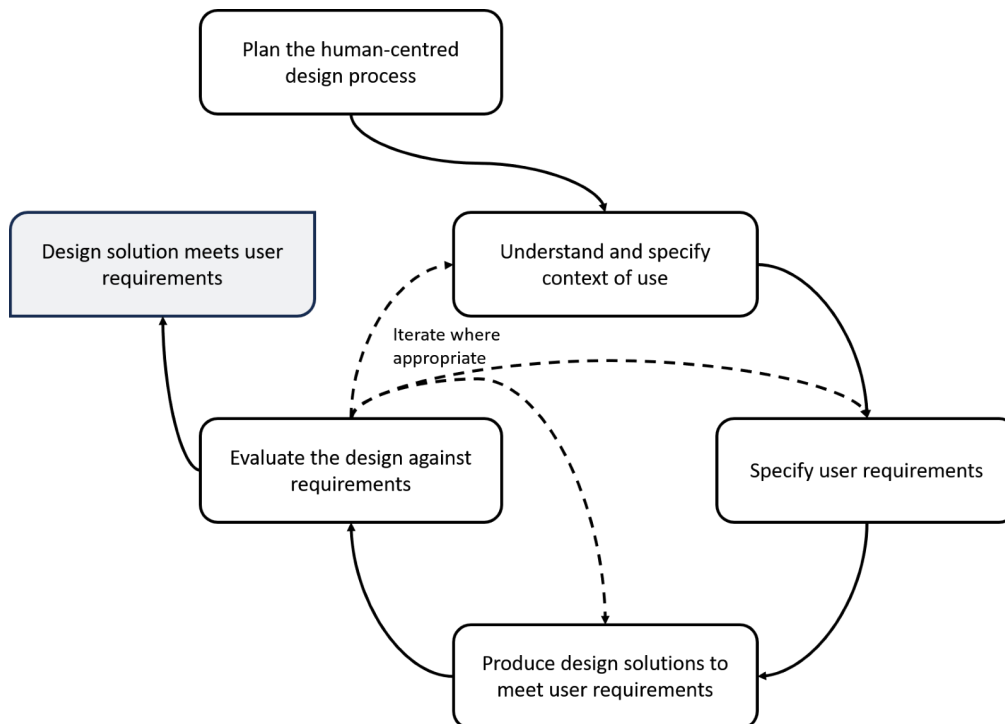


Figure 2. The human-centred design cycle (reproduced from Costa et al., 2015; ISO 9241-210:2010)

2.8.3 Bridging the gap between automation and safety

Although automation has clear benefits in reducing human errors related to navigation and vessel control, its effectiveness depends on how well human-machine interfaces (HMI) is designed and integrated into ship operations (Cheng et al., 2024). In some cases, automated decision-making tools have failed under unexpected conditions, leading to critical safety incidents due to inflexible programming and the inability of algorithms to adapt to real-time, complex situations (Aylward, 2022). Addressing these concerns requires a balanced approach, ensuring that automation enhances safety without compromising the role of human expertise. This includes improved user-centred design, standardized training programs, and regulatory updates that align technological advancements with human factors in maritime operations (Strauch, 2018). As automation continues to evolve, its successful integration into maritime safety systems will depend on bridging the gap between digital capabilities and human adaptability, ensuring that technology serves as a reliable aid rather than a potential point of failure in ship operations (Strauch, 2018).

2.8.4 The maritime autonomous surface ship (MASS)

In line with the development towards highly automated vessels. IMO has developed the Maritime Autonomous Surface Ships (MASS) framework, which categorizes ship autonomy into four degrees, ranging from automated decision support to fully autonomous ships (IMO, 2021; Aylward et al., 2022). In 2021, the IMO completed a regulatory scoping exercise to assess how existing IMO instruments might apply to these varying degrees of automation.

1. Degree One – Automated Processes and Decision Support: The ship is operated by onboard seafarers who oversee and control shipboard systems. While some processes may be automated and temporarily unsupervised, crew members are present to assume control when necessary.

2. Degree Two – Remotely Controlled with Seafarers Onboard: The ship is operated remotely from a shore-based location, but seafarers remain onboard to manage and take control of systems if required.
3. Degree Three – Remotely Controlled without Seafarers Onboard: The vessel is operated entirely from a remote location, with no crew present onboard to intervene.
4. Degree Four – Fully Autonomous Ship: The ship’s operating system is capable of independently making decisions and executing actions without human intervention.

The IMO is developing a code for MASS, expected to be ready for voluntary use in 2025. Between 2026 and 2028, an experience-building phase is planned to inform the development of a mandatory MASS code, anticipated to be finalized in 2030 and enter into force in 2032 (IMO, 2025).

3 Methods

This study employs a quantitative research design using a survey-based approach to examine “The impact of digitalization on maritime professionals’ environment and maritime safety” (Lundh et al., 2023). The survey consisted of 35 questions, developed with inspiration from Ragu-Nathan et al. (2008). Respondents answered using a 4-point Likert scale: 1 (Strongly Disagree), 2 (Disagree), 3 (Agree), and 4 (Strongly Agree). The survey was distributed via email to participants from previous studies titled “The impact of digitalization on maritime safety and the work environment of the crew” and “What to learn from support functions to improve maritime safety” (Lundh et al., 2023; Lundh et al., 2025), as well as through LinkedIn and Facebook to reach a broader range of maritime professionals.

3.1 Literature review

A literature review was conducted to support the study’s findings. This review focused on the role of digitalization in shaping maritime professionals’ working conditions, operational safety, and maritime industry regulations. It includes academic articles, industry reports, and case studies to identify key trends and challenges.

3.1.1 Snowballing

The literature review was conducted using the Snowballing technique as described by Naderifar et al. (2017). This method is chosen for its efficacy in comprehending the coverage of all existing literature and mitigating the drawbacks of other methods. In the paper, Naderifar et al. (2017), explain that the snowballing technique can improve the effectiveness in yielding the optimal outcome. The snowballing method encompasses numerous stages that are integral to the research process.

The Snowballing technique will be applied in the following steps:

1. Identification of a starting set of papers: A set of relevant papers will be identified as the starting point. These papers should be highly relevant to the research questions and recognized as significant in the field.
2. Forward snowballing: The references of the starting set of papers will be reviewed to identify additional papers. This process will be repeated iteratively until no more relevant papers are found.
3. Backward snowballing: The papers that cite the starting set of papers will be reviewed. This process will also be repeated iteratively until no more relevant papers are found.

An inclusion and exclusion process is implemented to filter research papers. The inclusion process targets papers that contain “seafarer” or “seaman” and “maritime professionals” and “digitalization” and “maritime safety” and “well-being” or “wellness” and “user-centred design” and “technostress” in the article title, abstract, keywords.

To address the research questions, a variety of bibliographic resources were employed, including Scopus, Google Scholar, Science Direct, and the Chalmers library. These platforms facilitated the acquisition of scholarly and scientific articles. In addition to using specific search terms and strings to unearth relevant sources, the search outcomes were arranged to highlight the most pertinent articles with a high citation frequency. Additionally, Naderifar et al. (2017) state that the forward snowballing method was

applied to uncover articles that are recent and yet to accumulate a significant number of citations, thereby ensuring the inclusion of the most current and applicable literature.

Additionally, AI tools such as Scopus AI (accessed through Chalmers' Scopus) were used to assist in filtering articles that best matched the research needs. Grammarly (Grammarly, 2025) was also utilized to support grammar checking and language refinement. The author confirms that the use of AI tools complied with Chalmers' regulations regarding acceptable use of AI in thesis work (Chalmers, 2023).

3.2 Procedure of data collection

The data collection was conducted through an online questionnaire and ensuring accessibility for participants across different maritime sectors. The survey was designed to assess the digitalization effect on maritime safety and the environment, providing structured responses through a Likert scale.

As of April 26th, 2025, 140 participants have completed the questionnaire. The target respondents include professionals from various maritime-related occupations, such as:

- Deck crew
- Engine crew
- Shipping company employees
- Port authorities
- Maritime administration officials
- Vessel Traffic Service (VTS) personnel
- Subcontractors
- Navy personnel

3.3 Data analysis

The collected responses will be analysed using descriptive statistics to summarize key findings (Kaur et al., 2018). Frequency distributions and percentages were calculated to summarize trends in participant responses. Results were visualized using bar charts and pie charts to aid interpretation. The discussion chapter then connected the quantitative findings to theoretical models and previous research. No inferential statistics (such as correlation or regression analysis) were applied, as the study's aim was exploratory and descriptive rather than predictive.

3.4 Ethical consideration

Participation in this study was voluntary, and respondents were informed about the purpose of the research before completing the survey. The questionnaire was designed to ensure anonymity and confidentiality, with no personally identifiable information collected. Respondents had the right to withdraw from the study at any point without providing a reason. By continuing to the actual questionnaire, the participants gave their consent to participate.

4 Results

This chapter presents the findings from the survey conducted to explore the impact of digitalization on maritime professionals' working environments and maritime safety. The results are organized according to key themes that reflect the study's research questions. Starting with demographic, the prevalence of digitalization related challenges, digitalization training and support, technical support and system integration, system complexity and user experience, their effect on workload and efficiency, implications for safety, and the experience of technostress, Both descriptive statistics and visual illustrations such as bar charts and pie charts are used to summarize the responses. The findings form the basis for analysis and discussion in the following chapters.

4.1 Demographic profile of respondents

a. Age

Age

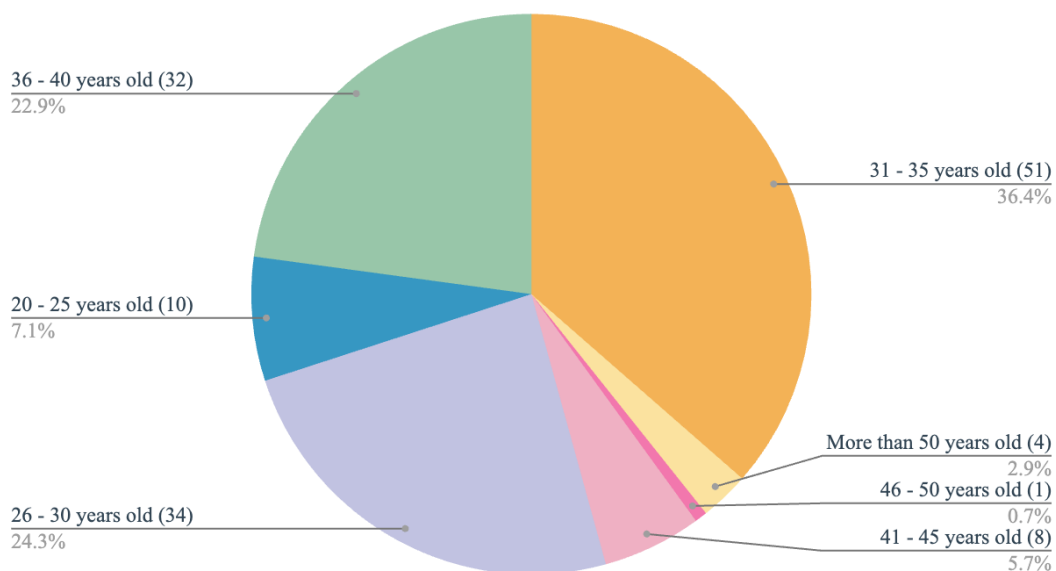


Figure 3. Age distribution

From Figure 3, the majority of respondents fall within the age range of 31–35 years old (36.4%), followed by 26–30 years old (24.3%) and 36–40 years old (22.9%). This indicates that most participants are in their early to mid-career stages. A smaller proportion of respondents belong to the 20–25 years old group (7.1%), while only 5.7% are between 41–45 years old. Additionally, a few respondents are above 50 years old (2.9%), with the lowest representation from the 46–50 age group (0.7%).

b. Gender

Gender

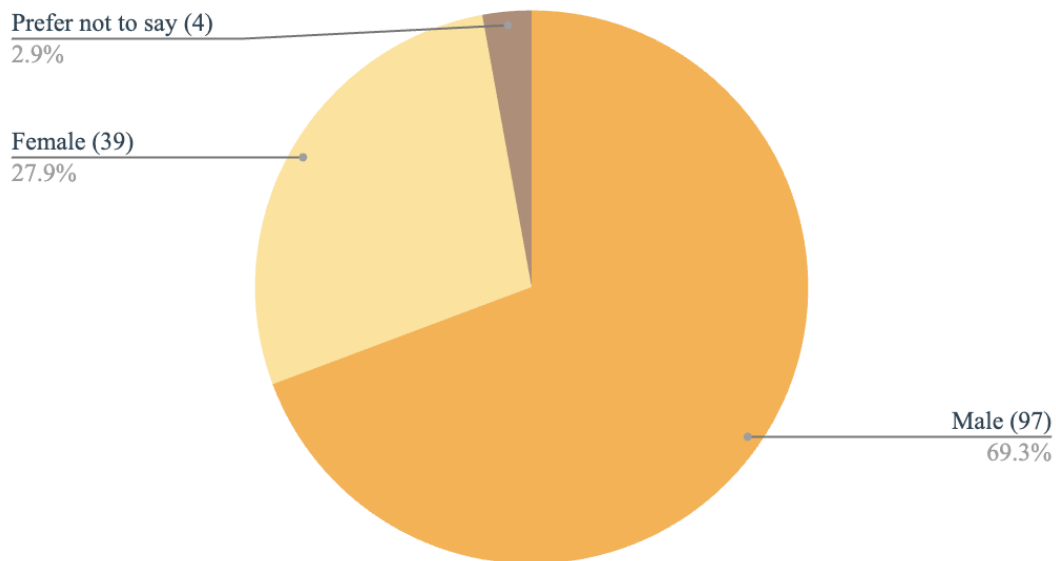


Figure 4. Gender distribution

Figure 4 shows that the majority of respondents identify as male (69.3%), while 27.9% identify as female. A small percentage of respondents (2.9%) chose "Prefer not to say."

c. Nationality

Nationality

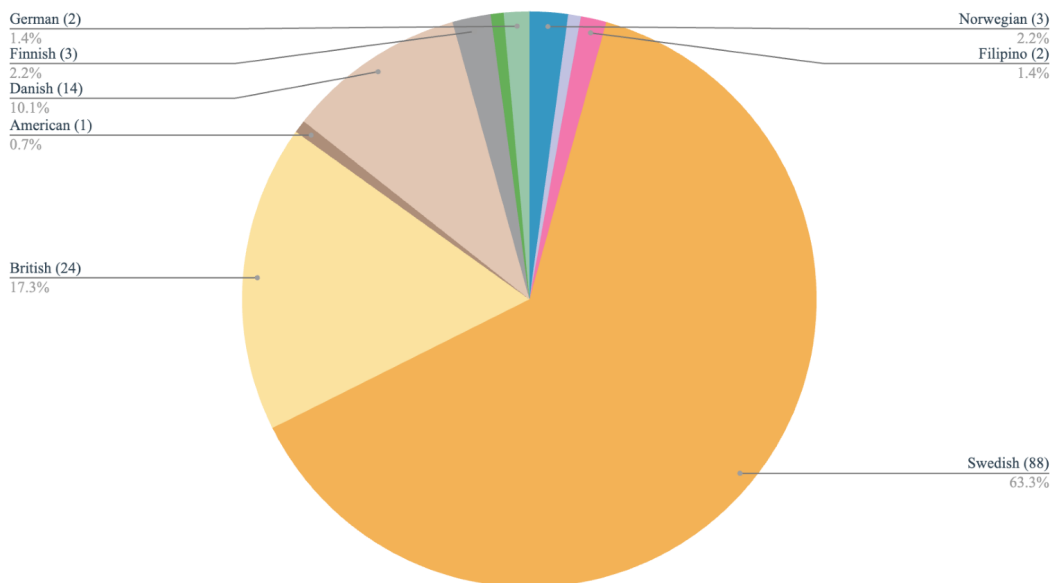


Figure 5. Nationality distribution

The majority of respondents are Swedish (63.3%), making up nearly two-thirds of the sample. The second-largest group is British (17.3%), followed by Danish (10.1%). Smaller proportions of respondents identify as Finnish (2.2%) and Norwegian (2.2%), with additional minor representations which are Filipino (1.4%), Singaporean (0.7%), German (1.4%), Turkish (0.7%), and American (0.7%) (Figure 5).

d. Vessel type

Count of Vessel Classification

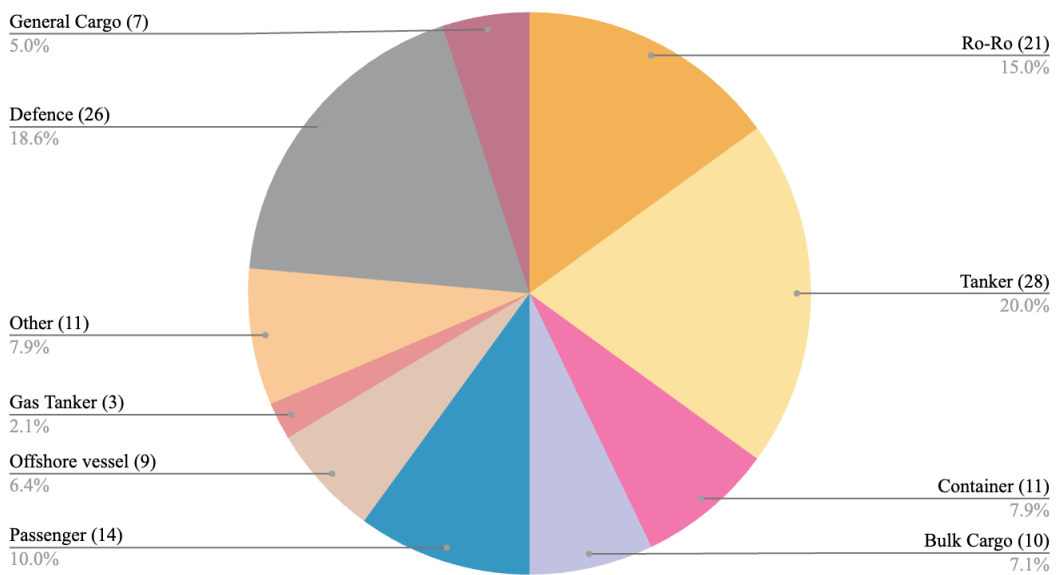


Figure 6. Vessel type distribution

Figure 6 shows that the majority of respondents were distributed equally among tanker vessels (20%), defence vessels (18.6%), and Ro-Ro vessels (15%). Smaller proportions of respondents work on passenger vessels (10%), container ships (7.9%), other types of vessels that are not classified on the list (7.9%), and bulk cargo (7.1%). The remainder are employed on offshore vessels (6.4%), general cargo ships (5%), and gas tankers (2.1%).

e. Position

Position Classification

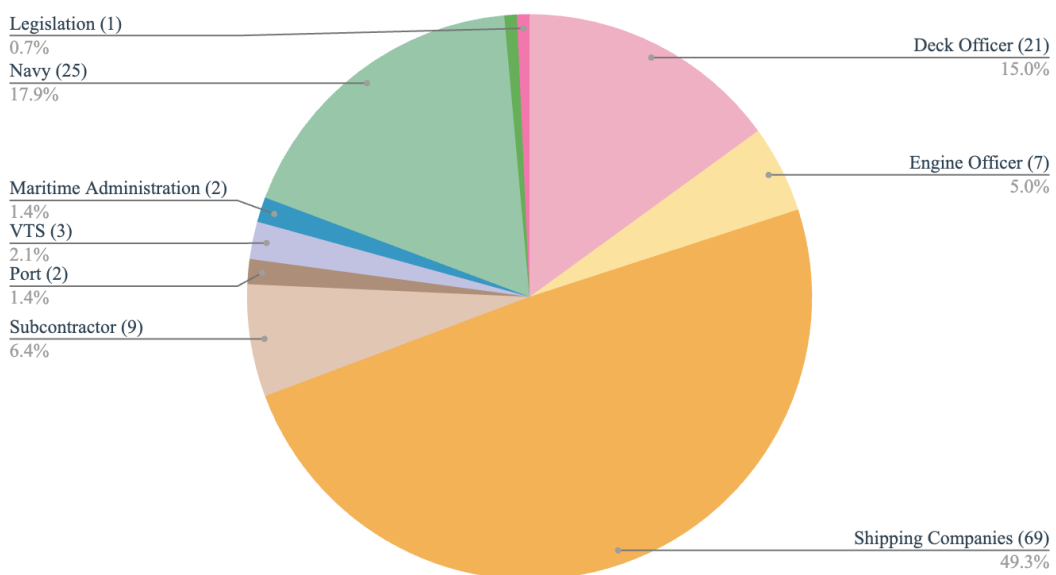


Figure 7. Position distribution

From Figure 7, the majority of respondents (49.3%) are employed in the shipping industry. Among specific seafaring roles, Deck Officers constitute 15.0%, while Engine Officers make up 5.0% of the sample. Beyond traditional seafaring roles, a significant proportion of participants come from the navy (17.9%), reflecting insights from a structured maritime environment. Other respondents include individuals working in subcontracting (6.4%), Vessel Traffic Services (VTS) (2.1%), Maritime Administration (1.4%), and port authorities (1.4%). A small fraction (0.7%) is involved in legislation and education.

f. Work experience

Work experience in current position

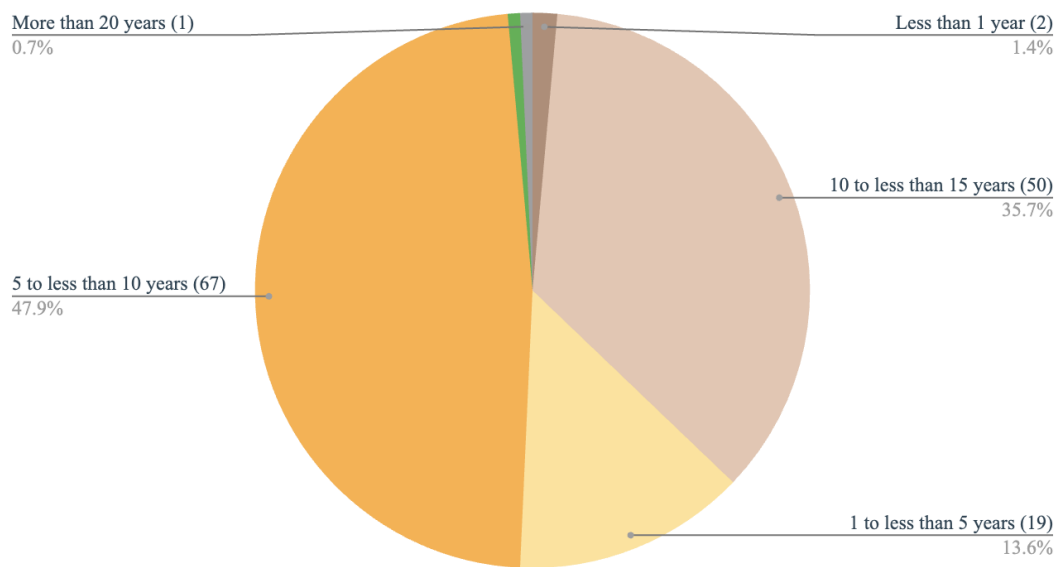


Figure 8. Work experience in the current position distribution

The majority of respondents have worked in the current position for 5 to less than 10 years, with a percentage of 47.9%. The second largest is 10 to less than 15 years (35.7%) followed by 1 to less than 5 years (13.6%). A smaller proportion is less than 1 year (1.4%), 15 to less than 20 years, and more than 20 years are both 0.7% (Figure 8).

g. Frequency of ICT use on a daily basis

Frequency of ICT use

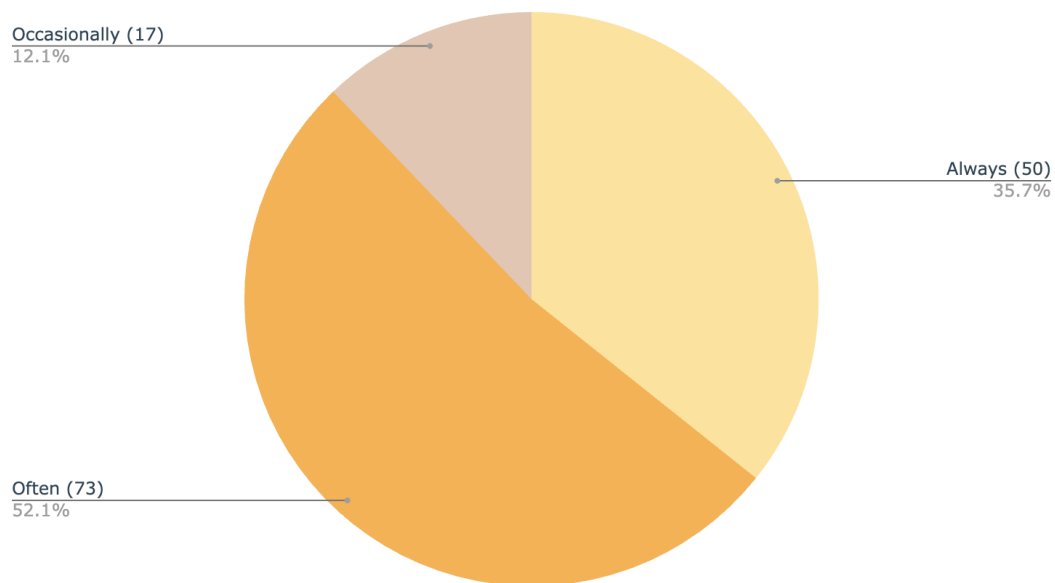


Figure 9. Frequency of ICT use distribution

Figure 9 illustrates that the majority of respondents often work with ICT (daily, but not continuously), with a percentage of 52.1%. Followed by a group who always use ICT (several times per day or continuously), which is 35.7%, and the last group is people who occasionally use ICT (1-3 times per week), with the percentage of 12.1%.

4.2 Digitalization challenges and workload

From here, a 4-point Likert scale is used for all survey questions, where 1 indicates 'Strongly Disagree', 2 indicates 'Disagree', 3 indicates 'Agree', and 4 indicates 'Strongly Agree'. This scale is employed to assess the degree of agreement or experience reported by participants across various aspects of digitalization in maritime operations.

a. I frequently encounter issues with digital systems like system errors

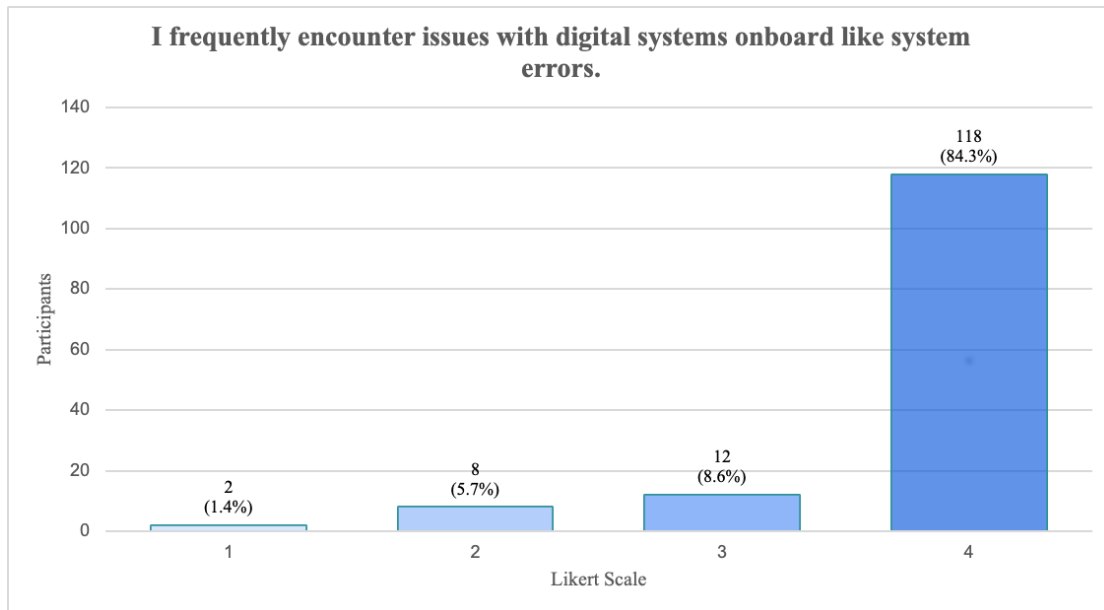


Figure 10. Frequency of system errors experienced

Figure 10 illustrates significant data toward agreement, with 84.3% (n = 118) of respondents selecting "Strongly Agree." A smaller portion selected "Agree" (8.6%, n = 12), while only a minority expressed disagreement, with "Disagree" (n = 8, 5.7%) and "Strongly Disagree" (n = 2, 1.4%).

b. I frequently encounter issues with digital systems like software bugs

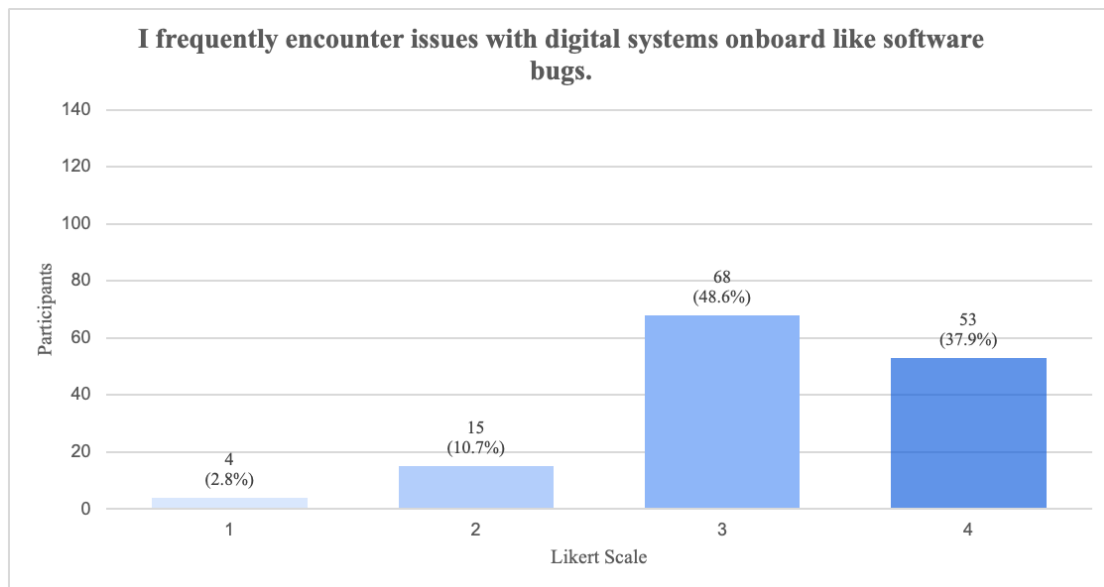


Figure 11. Frequency of software bugs experienced

In Figure 11, the responses reflect a high level of agreement among participants. A combined 86.5% of respondents either agreed (48.6%, n = 68) or strongly agreed (37.9%, n = 53) with the statement, indicating that software-related issues are a common challenge in maritime digital systems. Only a small minority (13.5%) reported disagreement, with 2.8% (n = 4) strongly disagreeing and 10.7% (n = 15) disagreeing.

c. I frequently encounter issues with digital systems like slow response time

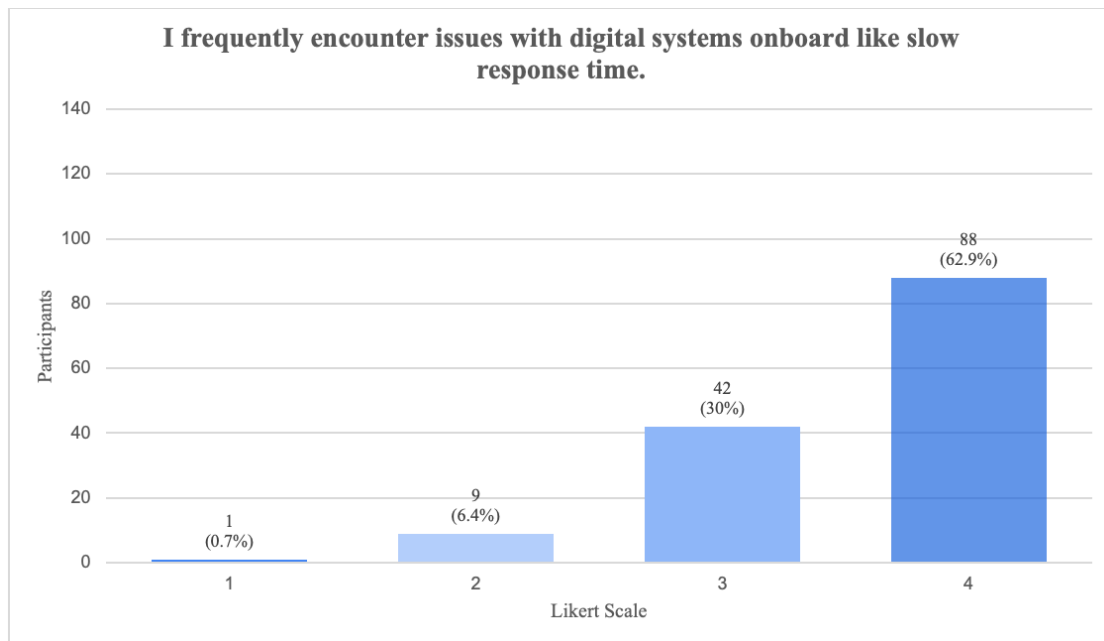


Figure 12. Frequency of slow response time experienced

In Figure 12, a substantial 92.9% of participants either agreed (30%, n = 42) or strongly agreed (62.9%, n = 88), indicating that sluggish system performance is a widespread concern. Only 7.1% of respondents showed disagreement, with 6.4% (n = 9) disagreeing and 0.7% (n = 1) strongly disagreeing.

d. Digital systems increase my daily workload

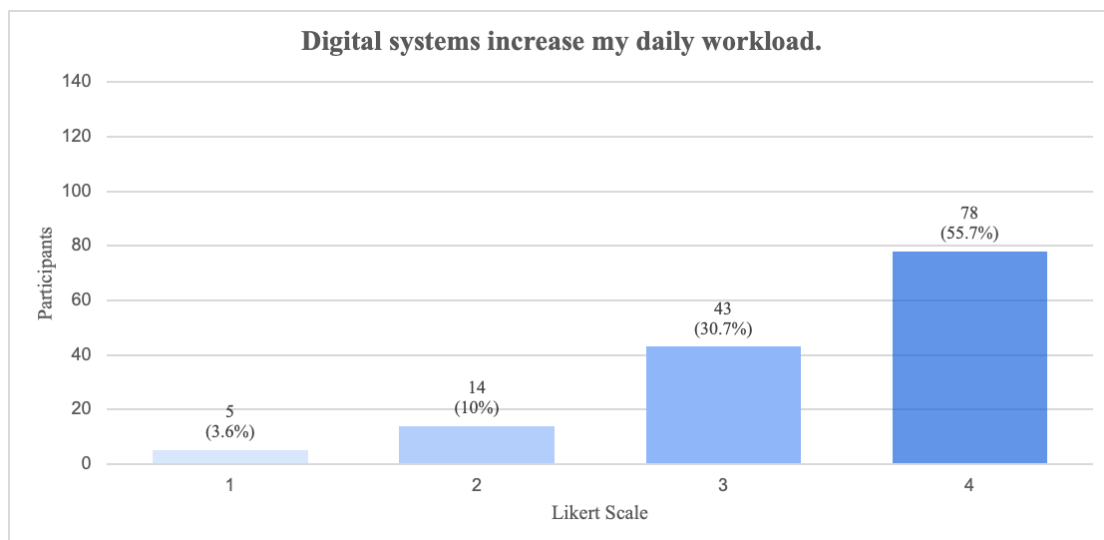


Figure 13. Impact of digital systems on daily workload

When asked whether digital systems increase their daily workload, the majority of respondents expressed agreement: 55.7% (n = 78) strongly agreed and 30.7% (n = 43) agreed, totalling 86.4% of all participants. In contrast, only 13.6% disagreed to some extent, with 10% (n = 14) selecting “disagree” and 3.6% (n = 5) choosing “strongly disagree” (Figure 13).

e. I often spend more time troubleshooting digital systems than performing my core duties

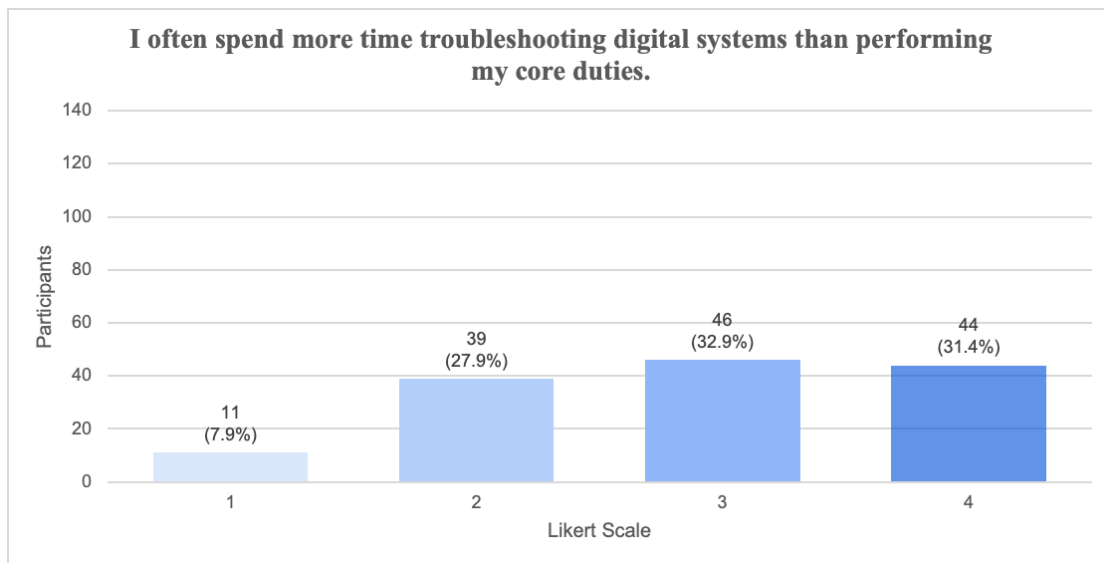


Figure 14. Time spent troubleshooting digital systems

The responses from Figure 14 reveal a relatively even distribution of perspectives on the impact of digital systems on core task performance. While 32.9% (n = 46) of respondents agreed and 31.4% (n = 44) strongly agreed that they often spend more time troubleshooting digital systems than on their primary responsibilities, 27.9% (n = 39) disagreed, and 7.9% (n = 11) strongly disagreed.

f. The number of digital systems has increased my administrative workload

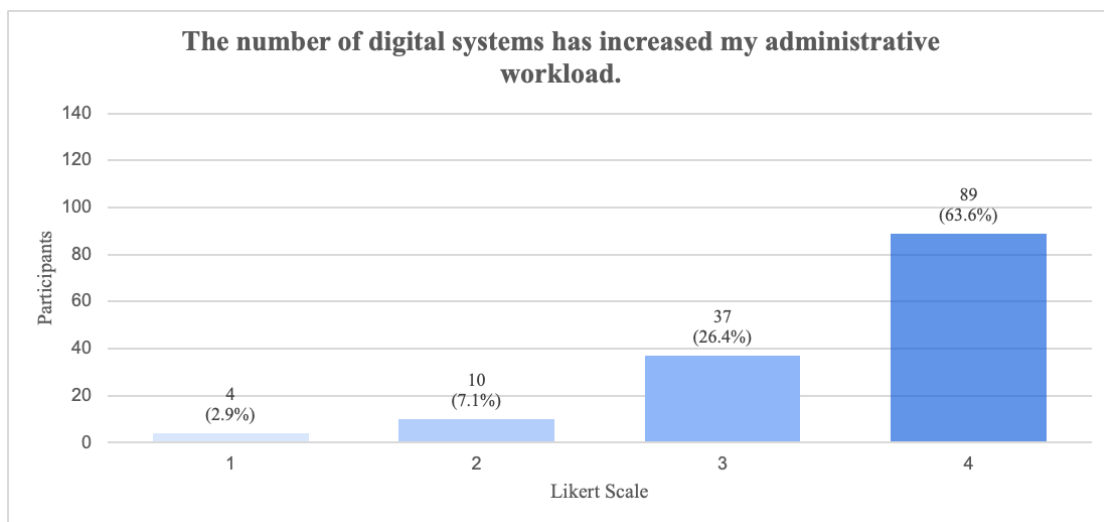


Figure 15. Impact of digital systems on administrative workload

Figure 15 shows a strong response among participants that digital systems have increased their administrative burden. A significant 63.6% (n = 89) strongly agreed with this statement, while another 26.4% (n = 37) agreed, indicating that nearly 90% of respondents perceive a rise in administrative tasks due to digitalization. Only a small minority (10% combined, n = 14) disagreed or strongly disagreed.

g. Digitalization has made my work less efficient and streamlined

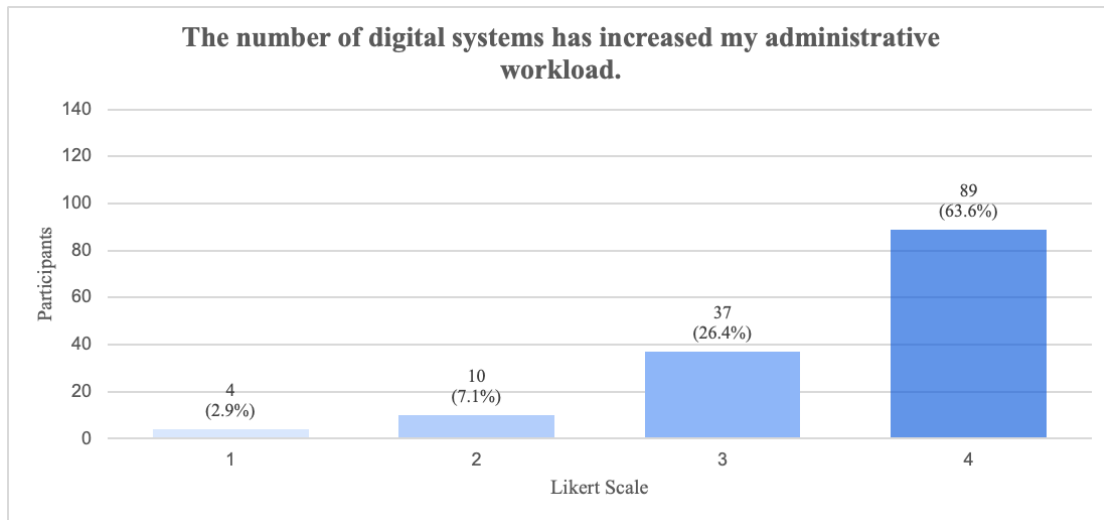


Figure 16. Digitalization's impact on work efficiency

The results from Figure 16 highlight a concern among participants regarding the unintended consequences of digitalization on work processes. 60.7% (n = 85) of respondents strongly agreed, and another 25% (n = 35) agreed that digitalization has reduced the efficiency and streamlining of their work. This means that 85.7% of participants expressed a negative impact, suggesting that digital tools may not be fulfilling their intended purpose of simplifying tasks. The low proportion of disagreement (only 14.3% in total, n = 20) indicates a widespread perception that digital systems may introduce complexity or operational delays, rather than supporting seamless workflows.

h. I do not have adequate time to learn and adapt to new digital tools

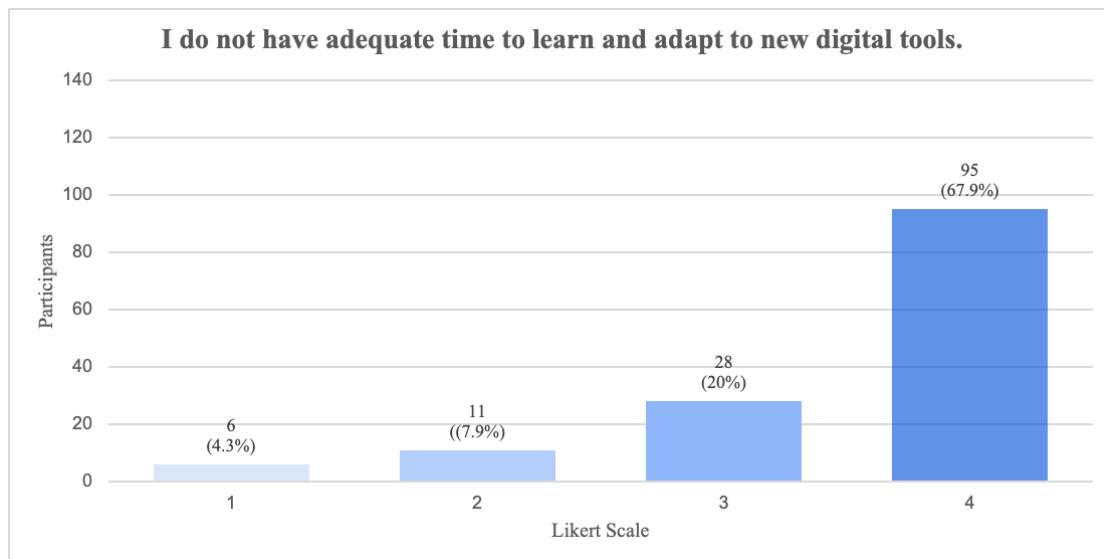


Figure 17. Time constraints for adapting to digital tools

The majority of participants indicated that they lack sufficient time to properly adapt to new digital technologies in their work environment. Specifically, 67.9% (n = 95) of respondents strongly agreed, and an additional 20% (n = 28) agreed, meaning that nearly 88% feel time-constrained when it comes to learning new digital systems. Only 12.2% in total (n = 17) expressed disagreement (Figure 17).

i. The lack of standardization in safety-critical digital equipment decreases operational efficiency and increases errors

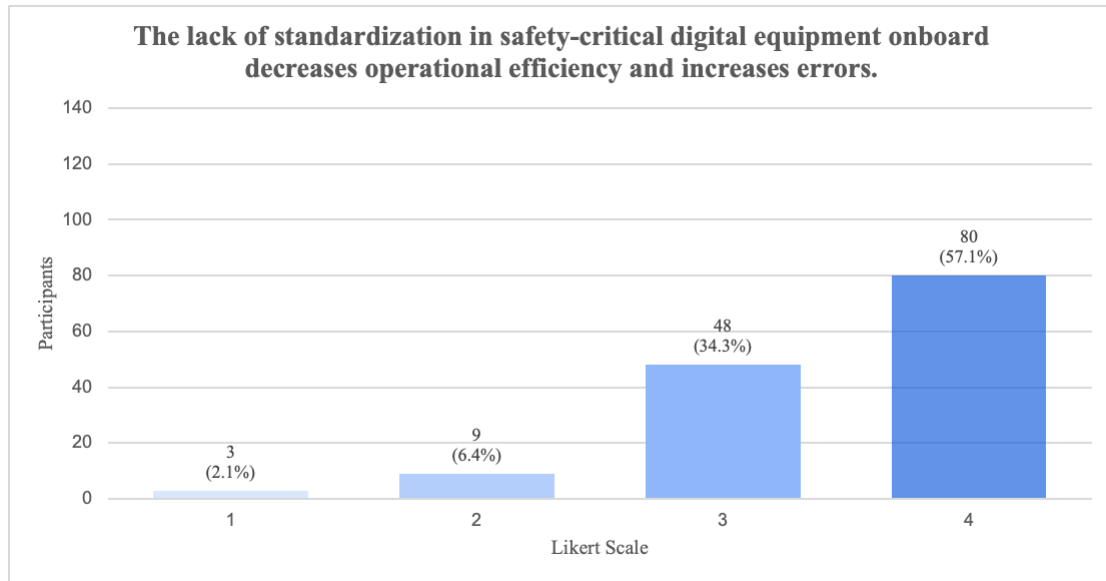


Figure 18. Impact of non-standardized digital systems on operational safety

Figure 18 shows that the majority of participants agreed that the lack of standardization in safety-critical digital systems negatively impacts operational efficiency and increases the likelihood of errors. Specifically, 57.1% (n = 80) strongly agreed and 34.3% (n = 48) agreed with the statement, amounting to over 91% expressing concern about the consequences of inconsistent system design. Only 8.5% (n = 12) of respondents disagreed or strongly disagreed.

4.3 Training and support

a. I do not receive sufficient training on new digital systems before they are implemented

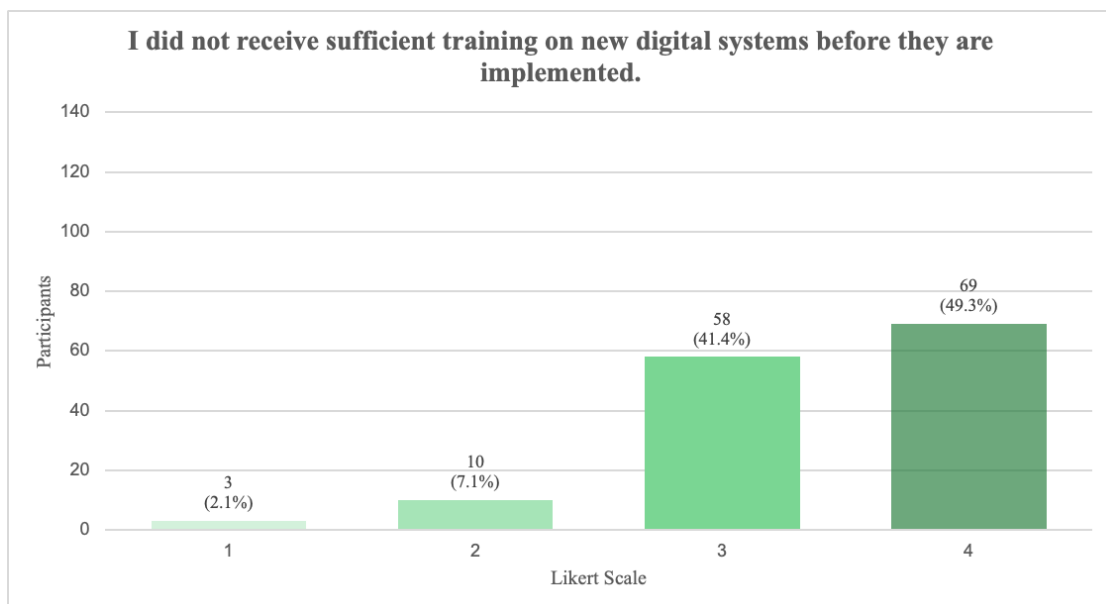


Figure 19. Training gaps in digital system implementation

Figure 19 shows that 49.3% (n = 69) of respondents strongly agreed, and 41.4% (n = 58) agreed, indicating that a combined total of over 90% of participants felt unprepared

when new digital tools were introduced. Only 7.1% (n = 10) disagreed, and a mere 2.1% (n = 3) strongly disagreed.

b. The training provided for digital systems is ineffective

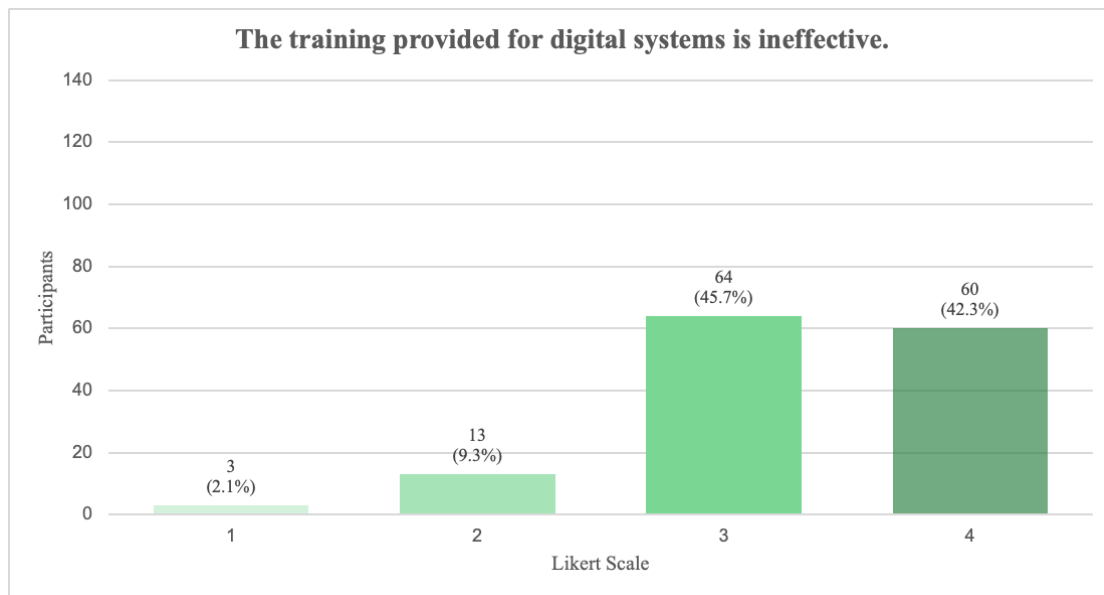


Figure 20. Perception of training effectiveness

A majority of respondents expressed dissatisfaction, with 45.7% (n = 64) agreeing and 42.3% (n = 60) strongly agreeing, totalling 88% who perceive the training as insufficient. Meanwhile, only 9.3% (n = 13) disagreed, and a minimal 2.1% (n = 3) strongly disagreed (Figure 20).

c. I do not feel confident using digital systems used

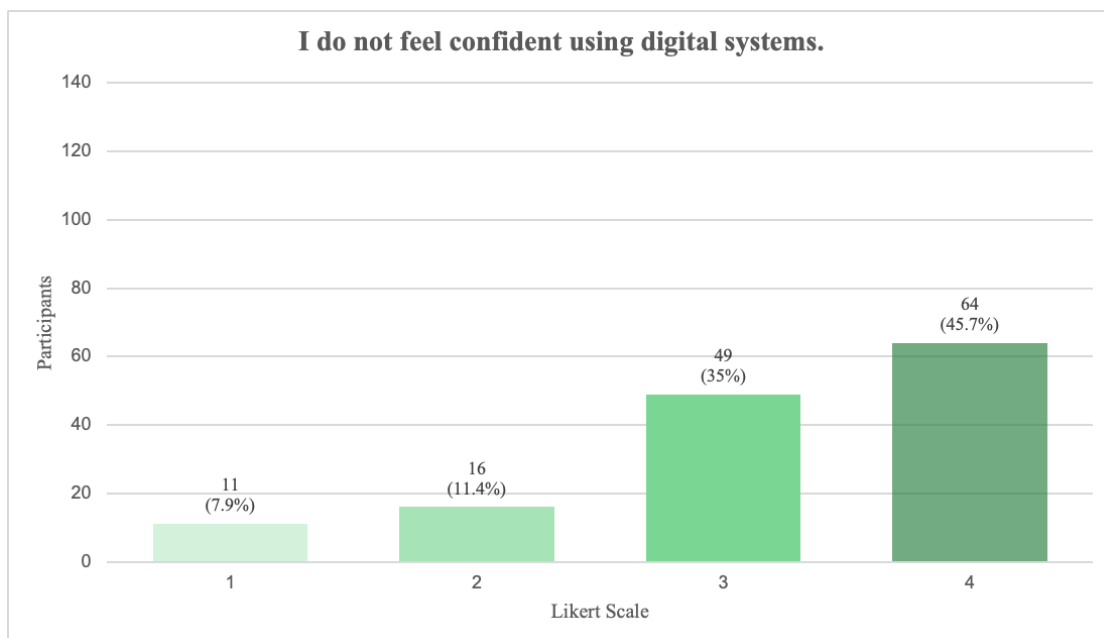


Figure 21. Confidence in using digital systems

Figure 21 shows that a considerable proportion of participants expressed uncertainty or lack of confidence, with 35% agreeing (n = 49) and 45.7% (n = 64) strongly agreeing, totalling 80.7% indicating some level of discomfort or insecurity. On the other hand, 11.4% (n = 16) disagreed and 7.9% (n = 11) strongly disagreed, showing that only a small minority feel confident using such systems.

d. I would not benefit from additional support to manage digital challenges

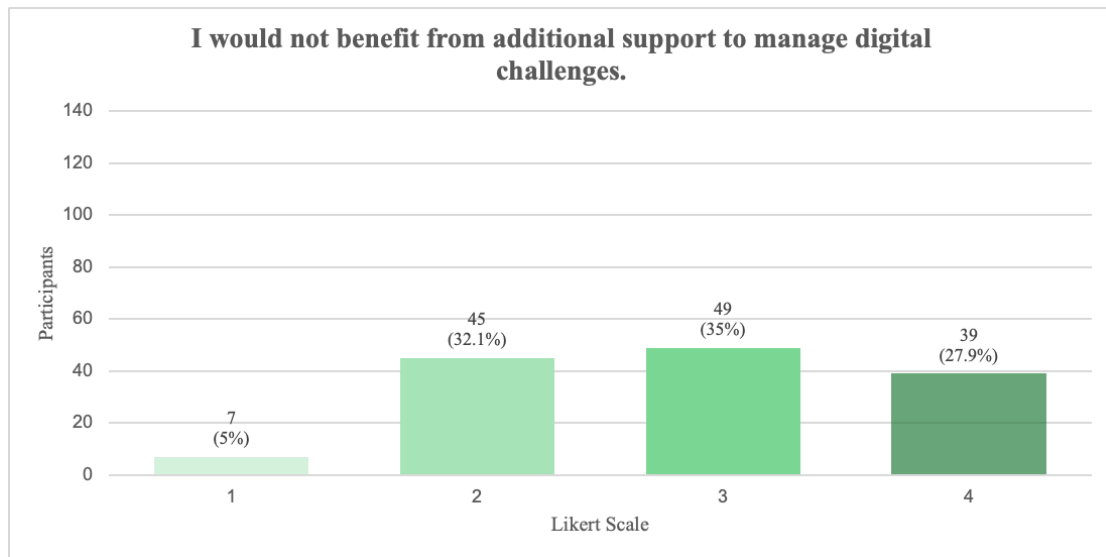


Figure 22. Need for support in managing digital challenges

From Figure 22, we can see that 5% (n = 7) strongly disagree and 32.1% (n = 45) disagree, expressed that they would indeed benefit from additional support. Meanwhile, 35% (n = 49) agreed and 27.9% (n = 39) strongly agreed, leaning toward not needing more support. This means that just under 40% of respondents indicated a perceived need for more support (by disagreeing), while a slight majority of 62.9% believed they are adequately managing digital challenges or do not require further assistance. While the majority feel self-sufficient, the fact that over one-third still desire more support is notable.

e. It is hard to get in touch with technical support when I experience issues with digital systems

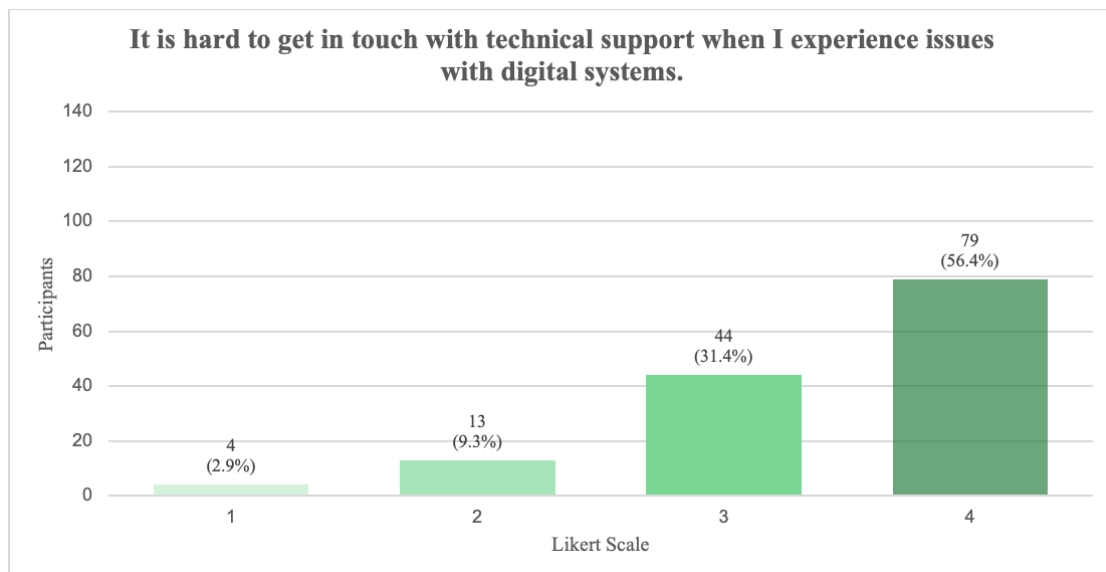


Figure 23. Access to technical support for digital systems

The distribution from Figure 23 reveals notable challenges in accessing assistance, with 56.4% of participants (n = 79) strongly agreeing with the statement, while 31.4% (n = 44) agreed. It means nearly 88% of respondents reported difficulty accessing timely

technical support. Only 12.2% in total expressed disagreement, with 9.3% (n = 13) disagreeing and 2.9% (n = 4) strongly disagreeing.

4.4 Technical support and system integration

a. The support staff does not have sufficient knowledge of the maritime work environment to provide effective assistance

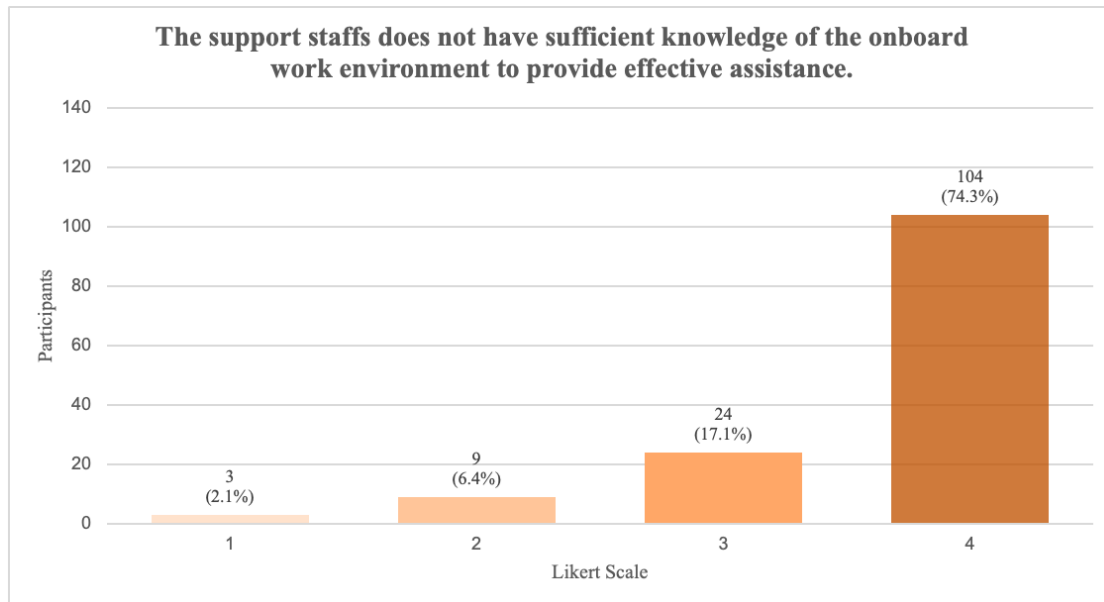


Figure 24. Knowledge gaps in support staff

Figure 24 clearly shows a strong consensus, which is 74.3% (n = 104) of respondents strongly agreeing, while 17.1% (n = 24) agreed, totaling over 91% who believe that support personnel lack the necessary understanding of onboard realities. In contrast, only 2.1% (n = 3) strongly disagreed and 6.4% (n = 9) disagreed with the statement.

b. When I contact the technical support for digital system issues, they do not understand the operational challenges

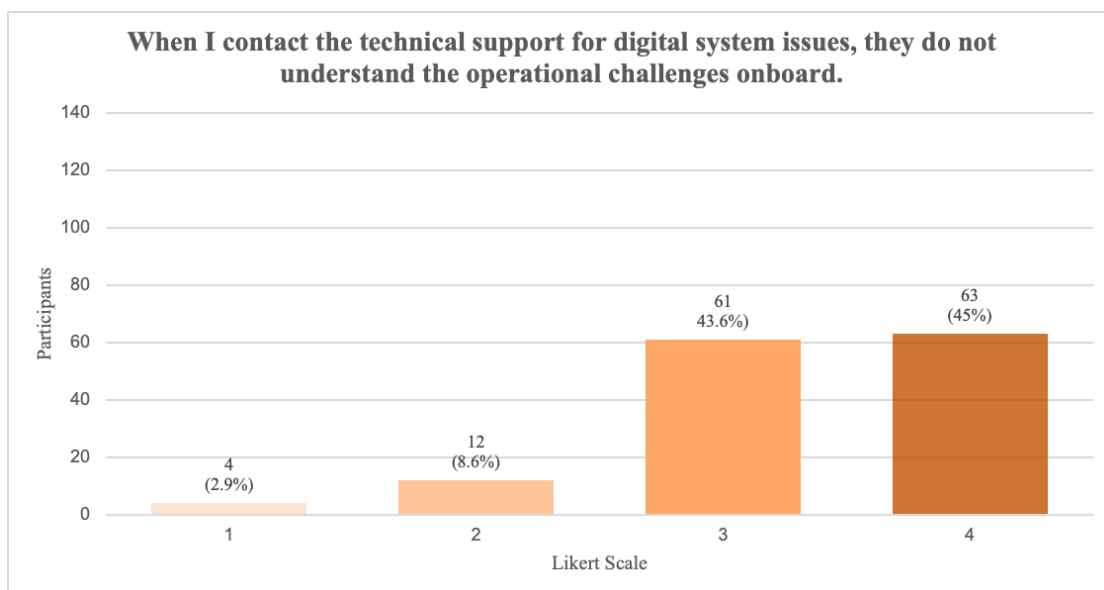


Figure 25. Technical support's understanding of operational challenges

From Figure 25, the data again points to a strong consensus, which is 43.6% (n = 61) agreeing and 45% (n = 63) strongly agreeing with the statement, totalling 88.6% of

respondents who perceive a knowledge gap between technical support and the realities of shipboard operations. Only 8.6% (n = 12) disagreed, and 2.9% (n = 4) strongly disagreed.

c. I did not receive clear and practical guidance from the support staff when dealing with digital system problems

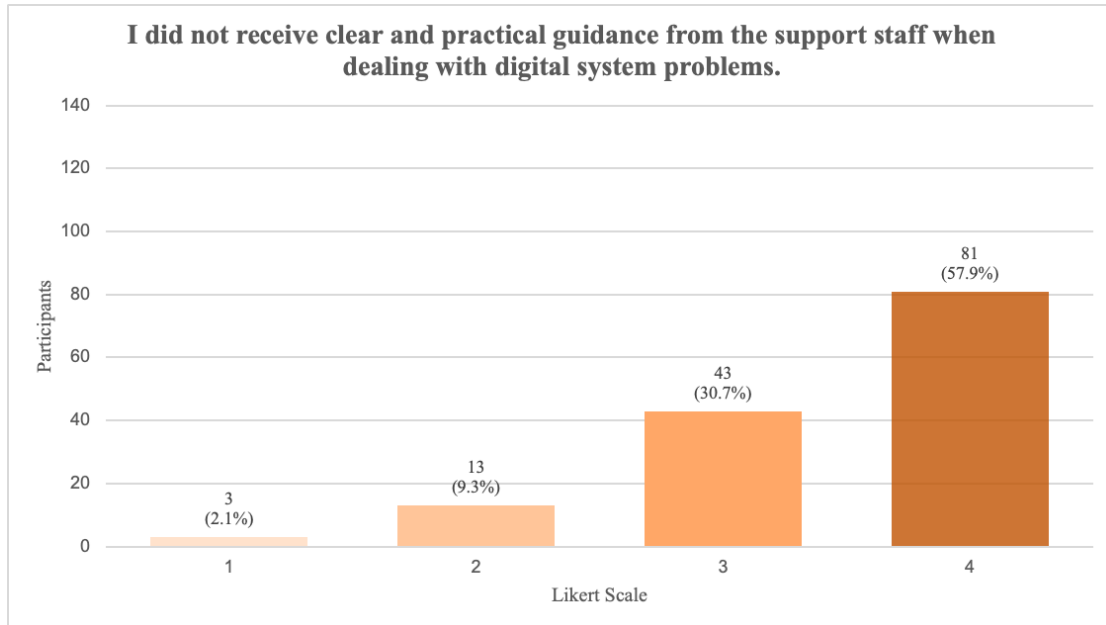


Figure 26. Clarity and practicality of support guidance

A significant proportion of participants expressed dissatisfaction with 57.9% (n = 81) strongly agreeing, and 30.7% (n = 43) agreed with the statement, indicating that nearly 89% of respondents struggle with inadequate guidance from support personnel. In contrast, only 9.3% (n = 13) disagreed and 2.1% (n = 3) strongly disagreed, suggesting that only a small minority found the provided guidance sufficient and actionable (Figure 26).

d. Support staff training sufficiently considers awareness of real-world maritime conditions and challenges

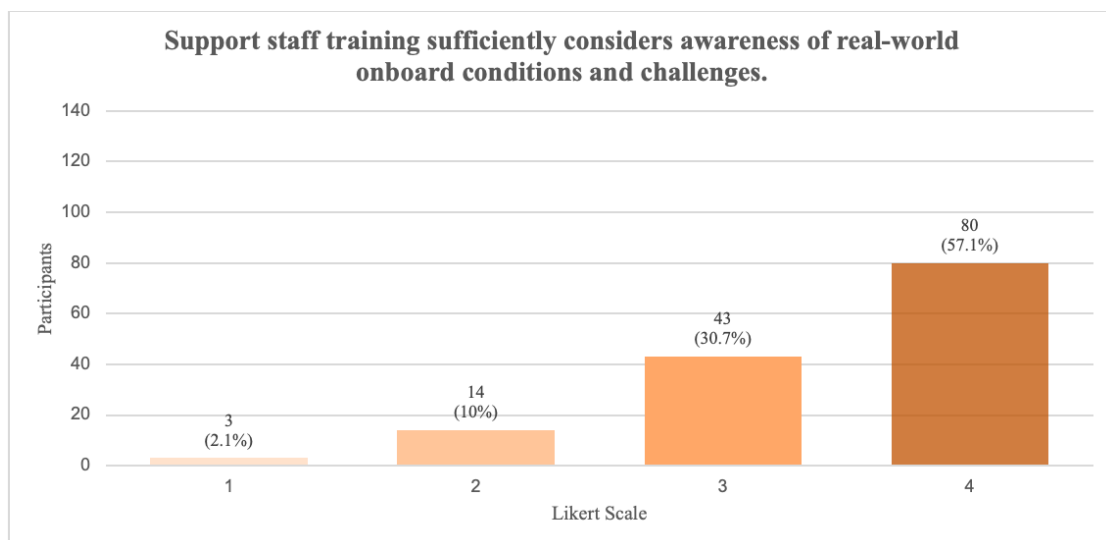


Figure 27. Relevance of support staff training to operation realities

The responses in Figure 27 indicate a high level of agreement, where 57.1% (n = 80) of respondents strongly agreed, and 30.7% (n = 43) agreed that the training provided to support staff lacks contextual understanding of seafaring operations. In contrast, 10% (n = 14) disagreed, and only 2.1% (n = 3) strongly disagreed. This trend reveals a critical gap in context-sensitive training for digital system support personnel.

e. The assistance provided by shore-based support is ineffective in resolving digital system-related issues

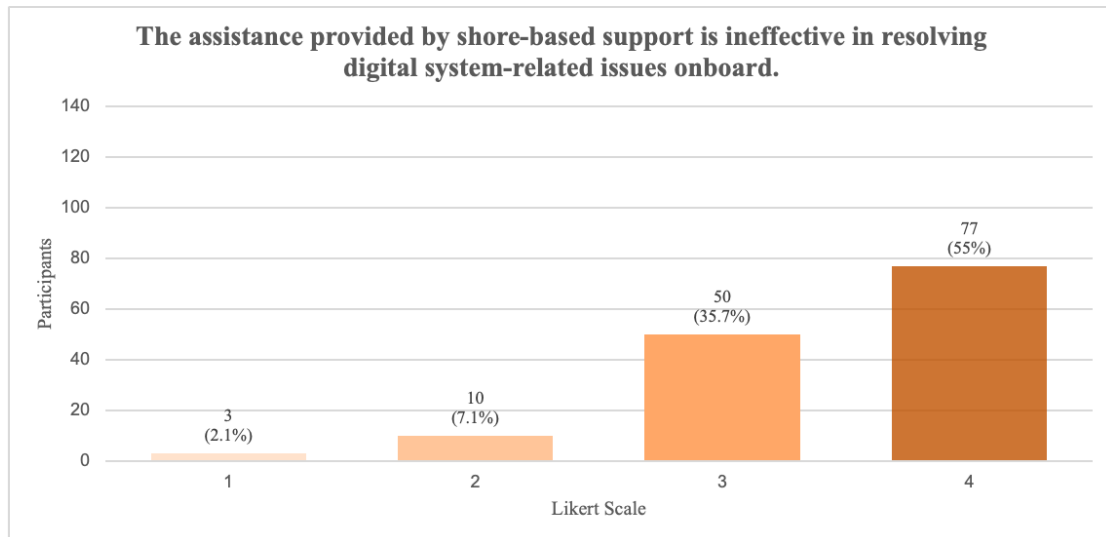


Figure 28. Ineffectiveness of shore-based support in digital issue resolution

From Figure 28, a significant majority expressed dissatisfaction with 55% (n = 77) of respondents strongly agreeing, and 35.7% (n = 50) agreed that shore-based support does not effectively address maritime digital problems. A smaller portion of the sample disagreed (7.1%, n = 10) or strongly disagreed (2.1%, n = 3), indicating a minority of participants found the current support sufficient.

4.5 System complexity and user experience

a. The usability of digital systems is not user-friendly and not easy to navigate

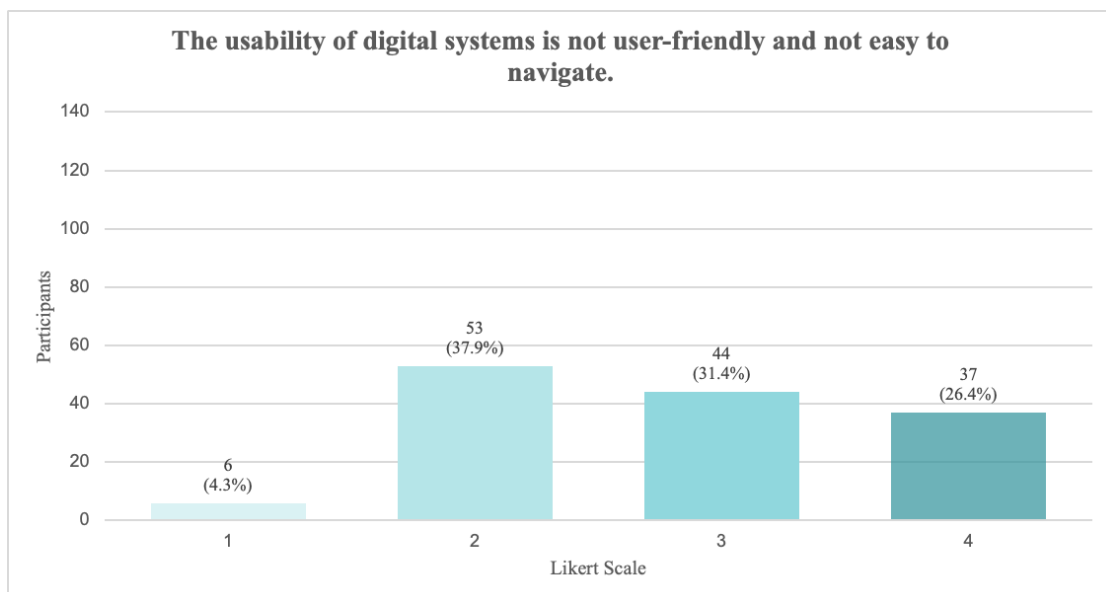


Figure 29. Digital systems usability

From Figure 29, we can see that 37.9% (n = 53) of respondents disagreed (Likert 2), indicating they found the systems generally user-friendly. Meanwhile, 31.4% (n = 44) agreed, and 26.4% (n = 37) strongly agreed, showing that nearly 58% perceived usability problems to some extent. Only 4.3% (n = 6) strongly disagreed, highlighting minimal strong opposition to the statement.

b. I experience alarm fatigue due to excessive or irrelevant system notifications

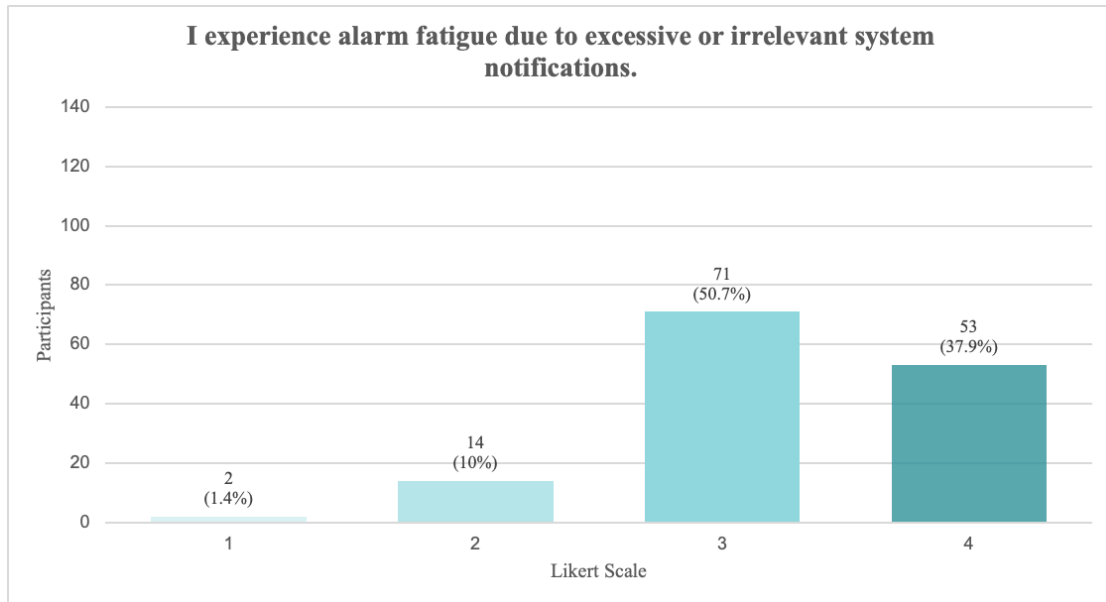


Figure 30. Alarm fatigue and notification overload

A substantial 50.7% (n = 71) agreed and 37.9% (n = 53) strongly agreed, suggesting that nearly 89% of respondents experience some degree of alarm fatigue. Only 10% (n = 14) disagreed, and 1.4% (n = 2) strongly disagreed with the statement (Figure 30).

c. Frequent software updates introduce bugs that increase my workflow

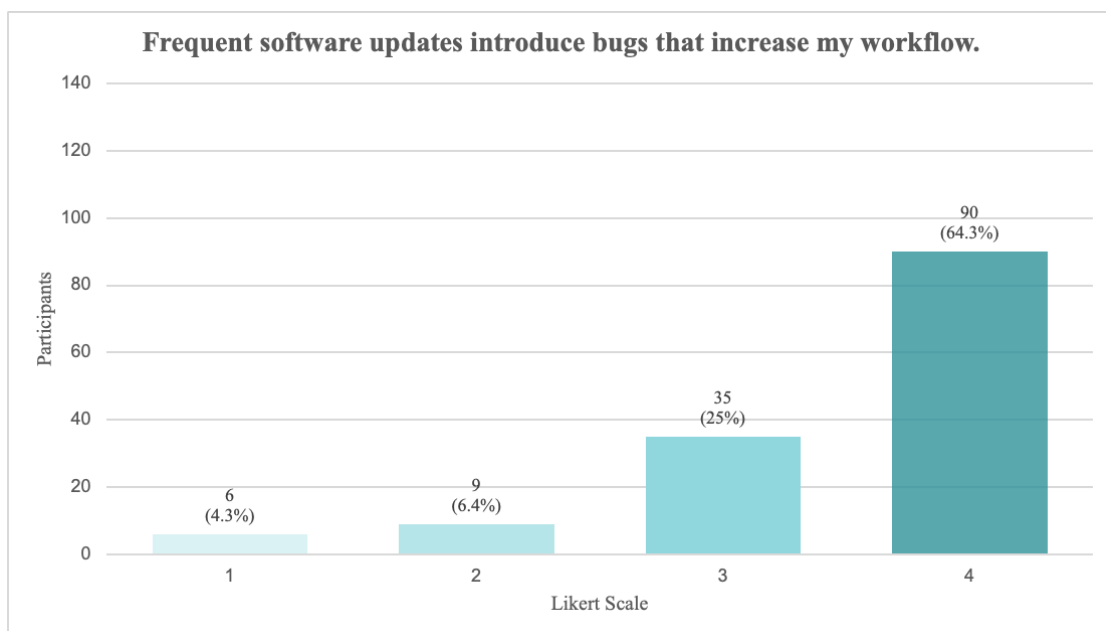


Figure 31. Impact of software updates on operational workflow

Figure 31 shows that the majority of participants, 64.3% (n = 90), strongly agreed, while 25% (n = 35) agreed with the statement. Only a small portion of respondents disagreed: 6.4% (n = 9) selected 2, and 4.3% (n = 6) selected 1 (strongly disagree). These results indicate a significant level of dissatisfaction with the stability and reliability of software updates. Nearly 90% of respondents agreed that updates not only fail to enhance functionality but also actively create disruptions, leading to increased workload.

d. System updates often require additional troubleshooting before they function properly

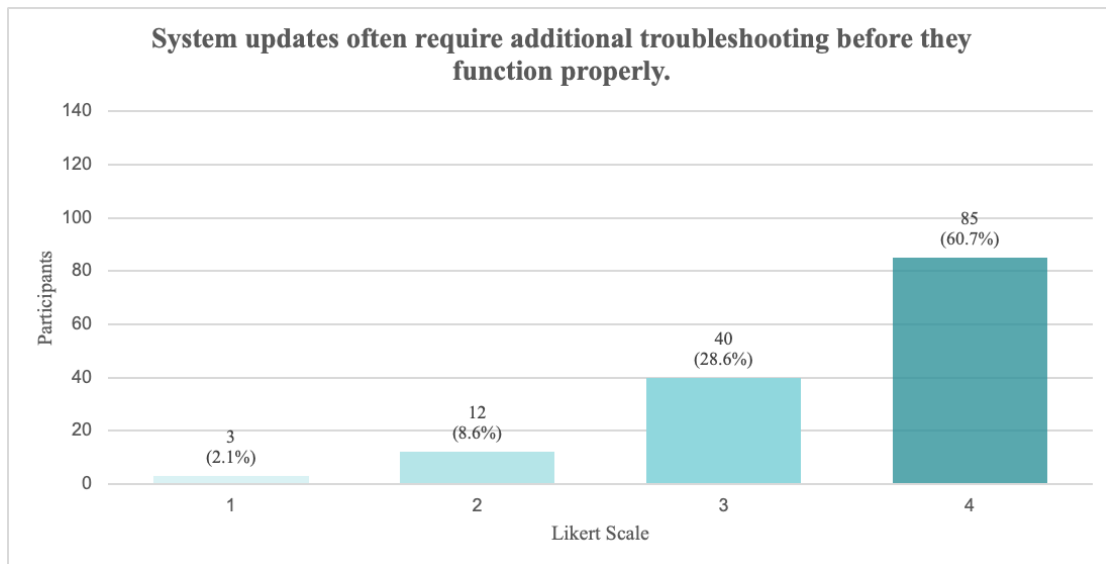


Figure 32. Reliability of system updates

From Figure 32, 60.7% (n = 85) of respondents strongly agreed, and 28.6% (n = 40) agreed, indicating a widespread perception that updates frequently introduce operational issues. A minority disagreed (8.6%, n = 12), and only 2.1% (n = 3) strongly disagreed, suggesting that most participants share a negative view of the update process.

e. The complexity of software systems negatively affects my performance

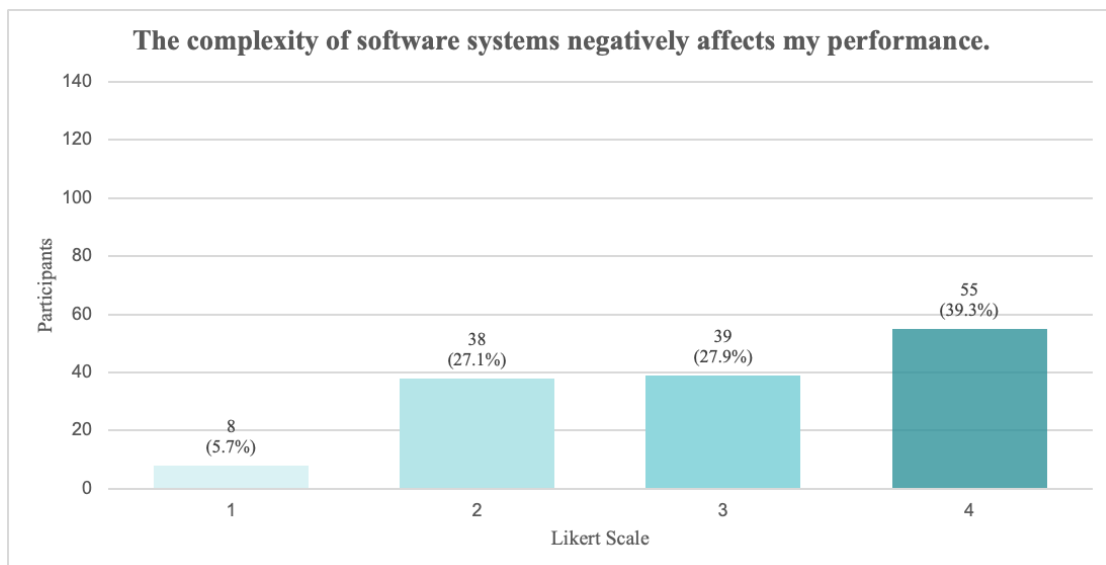


Figure 33. Impact of system complexity on performance

A notable 39.3% (n = 55) of participants strongly agreed, while 27.9% (n = 39) agreed. Combined, these responses represent 67.2% of the sample acknowledging that complex software systems hinder their performance. Meanwhile, 27.1% (n = 38) disagreed, and only 5.7% (n = 8) strongly disagreed (Figure 33).

f. The presence of too many stand-alone systems increases the risk of mistakes

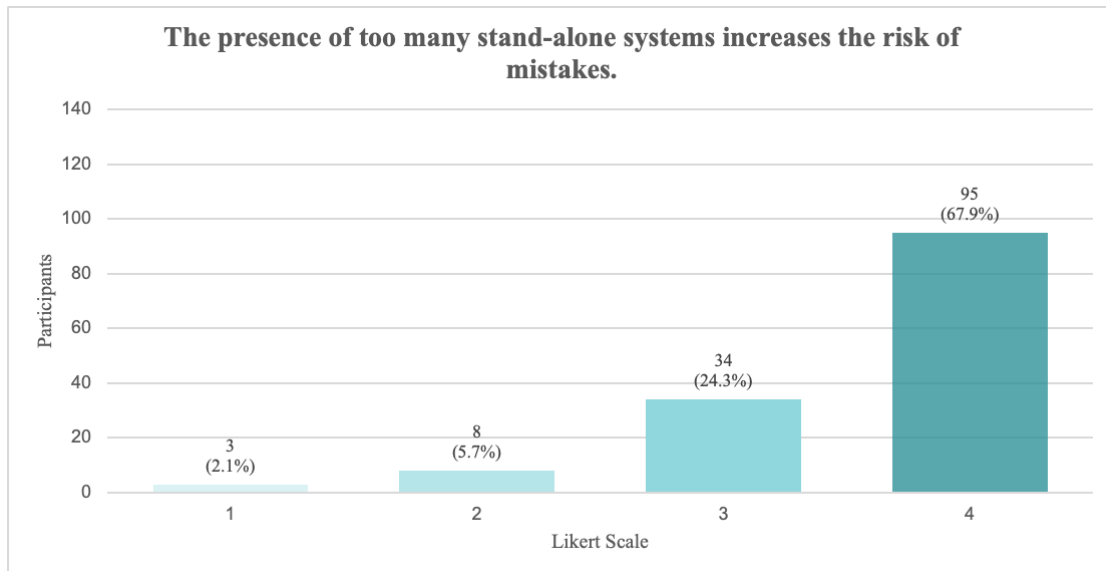


Figure 34. Systems stand alone and risk of operational mistakes

A significant 67.9% (n = 95) of respondents strongly agreed, while an additional 24.3% (n = 34) agreed. Only a small minority disagreed (5.7%, n = 8) or strongly disagreed (2.1%, n = 3). These findings suggest that the system’s stand-alone poses a recognized challenge in the maritime context (Figure 34).

4.6 Digitalization and safety

a. Digital systems used compromise overall safety

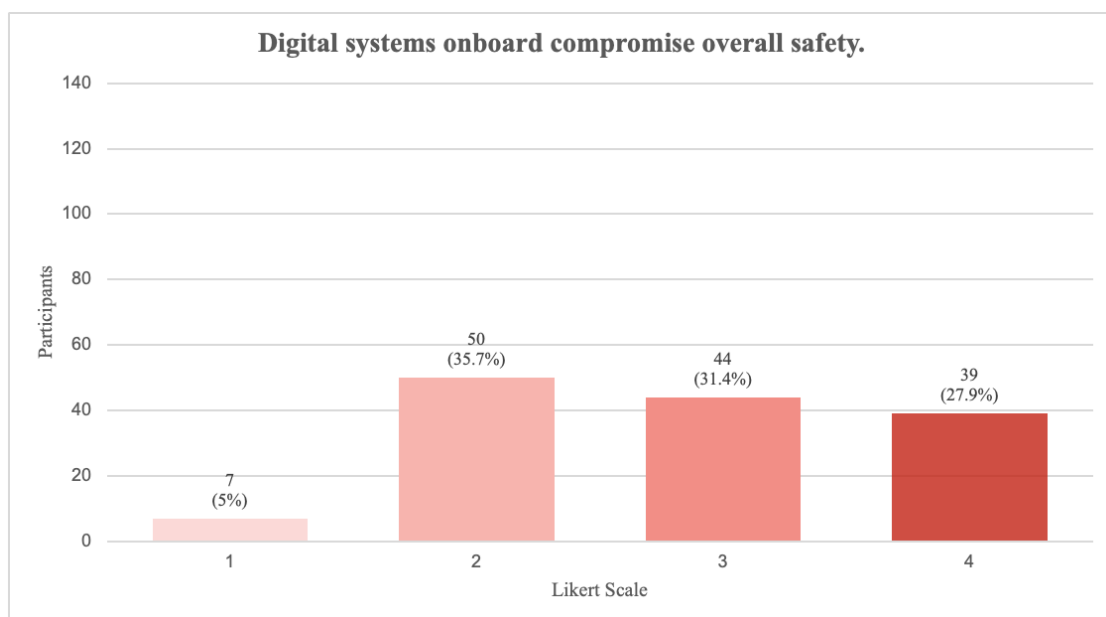


Figure 35. Impact of digital systems on maritime safety

From Figure 35, we can see that 35.7% of respondents disagreed (n = 50), while 31.4% (n = 44) agreed, and 27.9% (n = 39) strongly agreed, while only a minority strongly disagreed (5%, n = 7).

b. Digital systems failures create additional safety risks

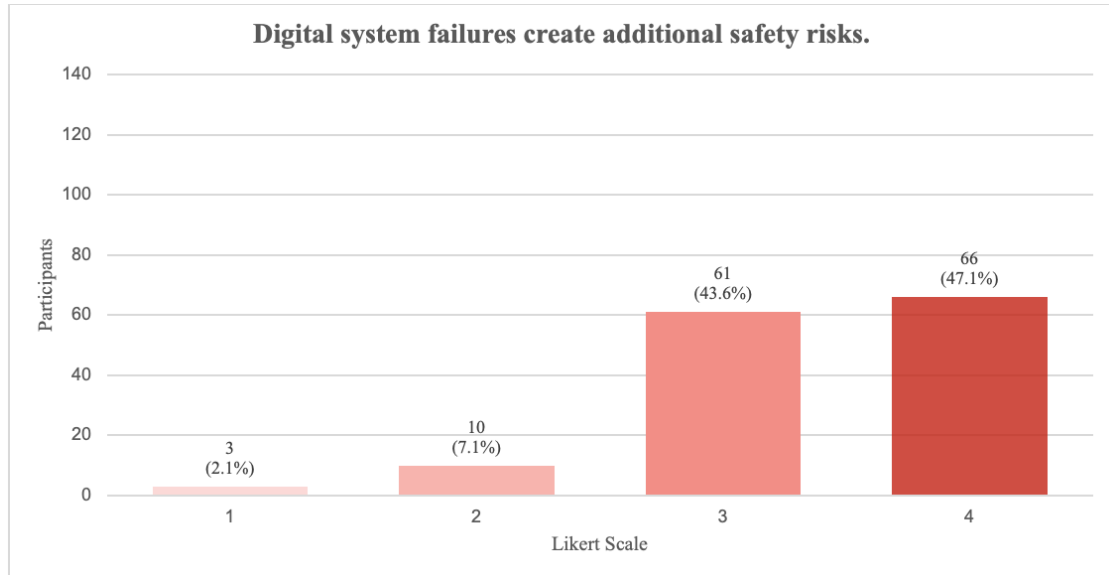


Figure 36. Safety risks from digital system failures

From Figure 36, the majority of respondents agreed (43.6%, n = 61) or strongly agreed (47.1%, n = 66), totalling 90.7% of all responses. In contrast, only a small percentage disagreed (7.1%, n = 10) or strongly disagreed (2.1%, n = 3).

c. I am not feeling confident in decision-making systems

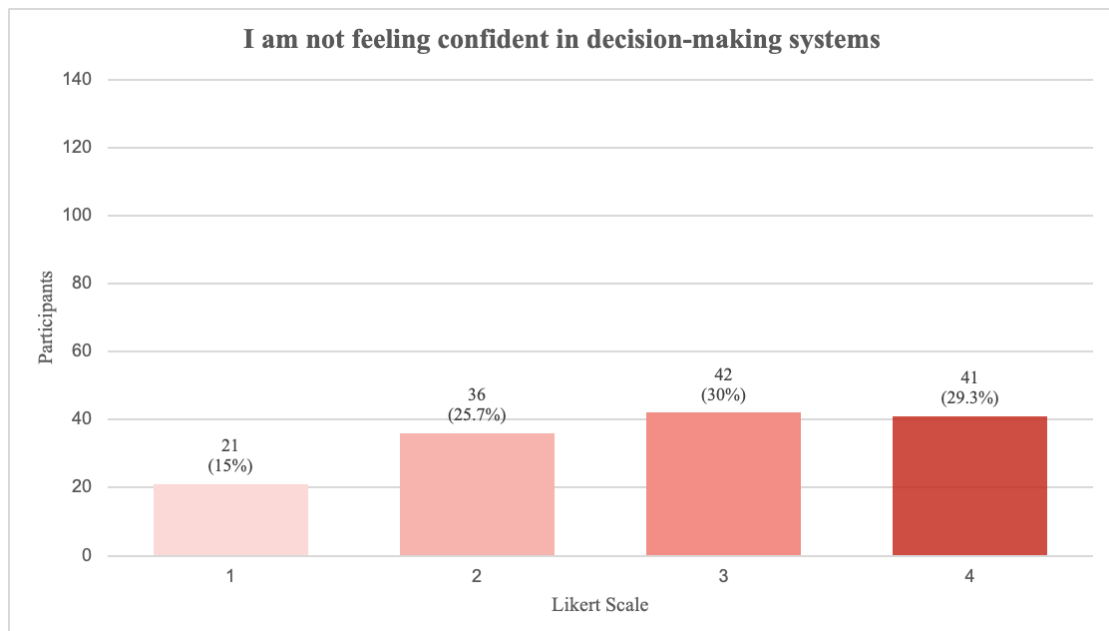


Figure 37. Trust in the decision-making system

Figure 37 shows that a total of 59.3% of participants agreed (30%, n = 42) or strongly agreed (29.3%, n = 41). Meanwhile, 40.7% expressed disagreement (25.7%, n = 36) or strongly disagreed (15%, n = 21).

d. Digital tools have failed at a critical moment in my experience

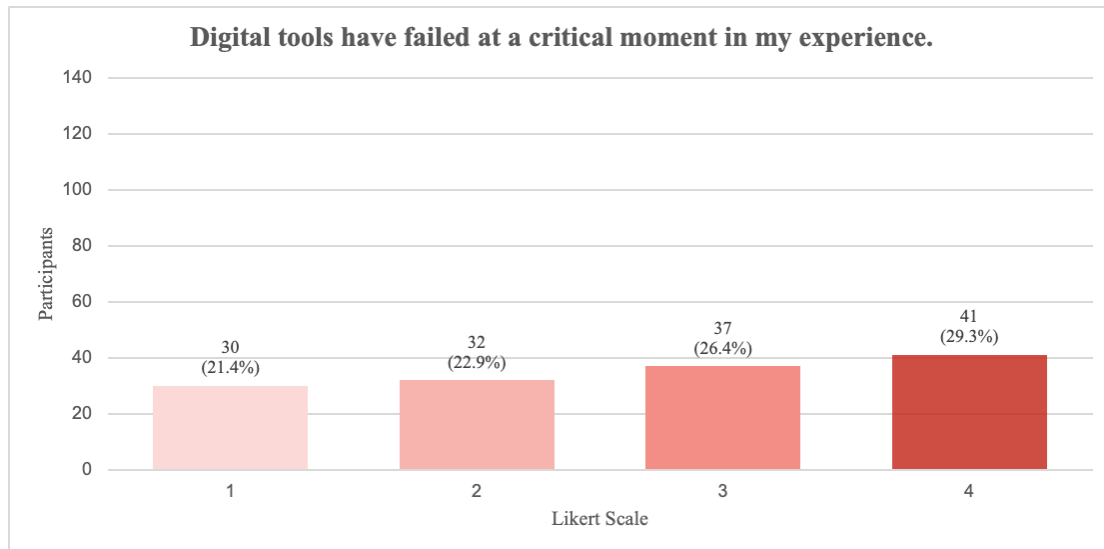


Figure 38. System reliability during critical moments

Figure 38 distribution is nearly balanced with strongly disagreed (21.4%, n = 30), disagreed (22.9%, n = 32), agreed (26.4%, n = 37), and strongly agreed (29.3%, n = 41).

4.7 Technostress and mental well-being

a. Adapting to new digital systems causes me stress

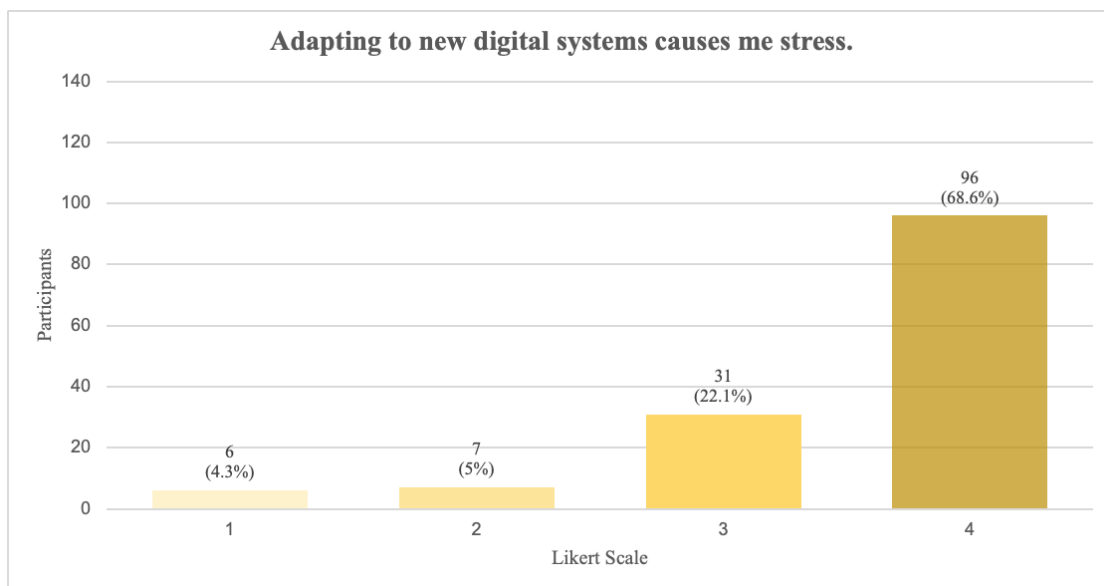


Figure 39. Stress from adapting to the new digital systems

From Figure 39, we can see that 68.6% of respondents strongly agreed (n = 96), and 22.1% agreed (n = 31), indicating that a large majority of participants experience stress when adapting to new digital systems. Only 5% disagreed (n = 7) and 4.3% strongly disagreed (n = 6), showing minimal opposition to the statement.

b. I feel overwhelmed by the number of different digital tools I need to use

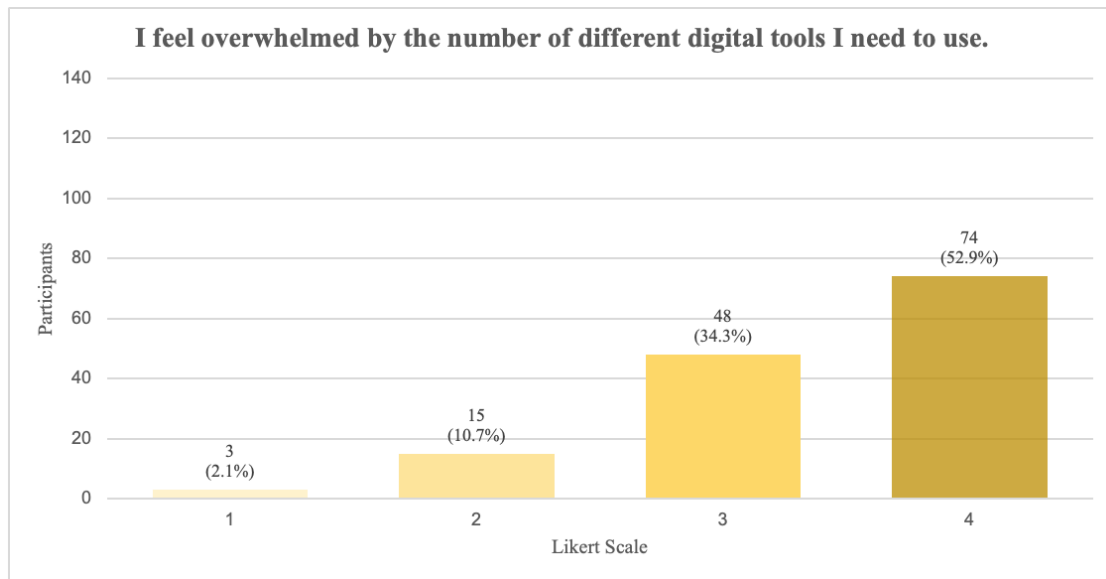


Figure 40. Overwhelmed by digital tools

Figure 40 reveals that a substantial majority of respondents expressed feeling overwhelmed by the multitude of digital tools they are required to manage. Over half of the participants strongly agreed with the statement (52.9%, $n = 74$), and an additional 34.3% agreed ($n = 48$), underscoring a strong sense of digital overload among maritime professionals. On the other end of the scale, only 10.7% disagreed ($n = 15$), and a very small 2.1% strongly disagreed ($n = 3$).

c. I experience frustration when digital systems do not work as expected

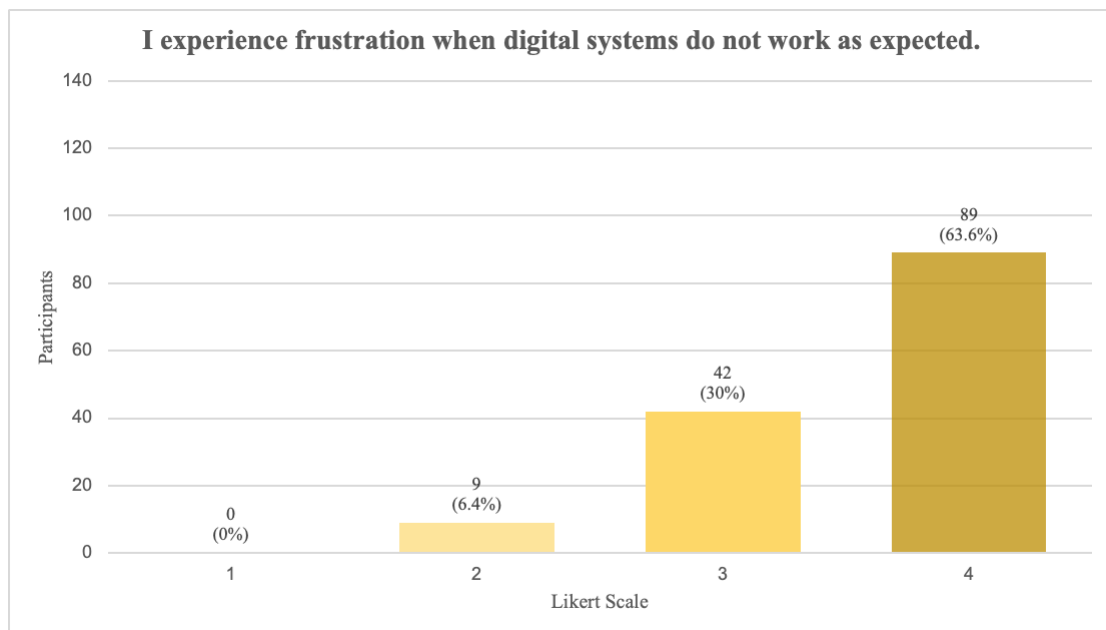


Figure 41. Frustration due to system malfunction

Figure 41 shows a clear picture of maritime professionals' emotional responses when digital systems fail to perform as expected. A dominant 63.6% of respondents strongly agreed ($n = 89$), with another 30% agreeing ($n = 42$), making it evident that frustration

is a widespread experience in such situations. Only a small fraction disagreed (6.4%, n = 9), and notably, no participants strongly disagreed.

d. I feel pressured to learn new technologies faster than I am comfortable with

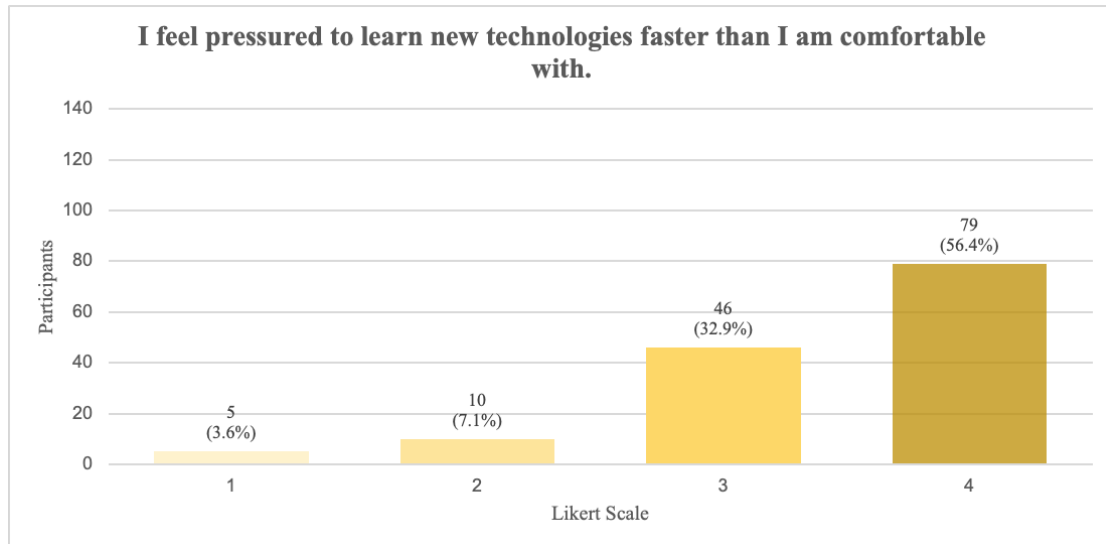


Figure 42. Pressure to quickly learn new technologies

Figure 42 reveals a strong sentiment among maritime professionals feeling pushed to adapt to new technologies at a pace faster than they find comfortable. A majority 56.4% (n = 79) of respondents strongly agreed with the statement, while another 32.9% (n = 46) agreed, combining to nearly 90% expressing some level of pressure. Only 7.1% (n = 10) disagreed and a minimal 3.6% (n = 5) strongly disagreed, indicating very few feel adequately supported in the learning process.

e. I worry that I will make mistakes due to the complexity of digital systems

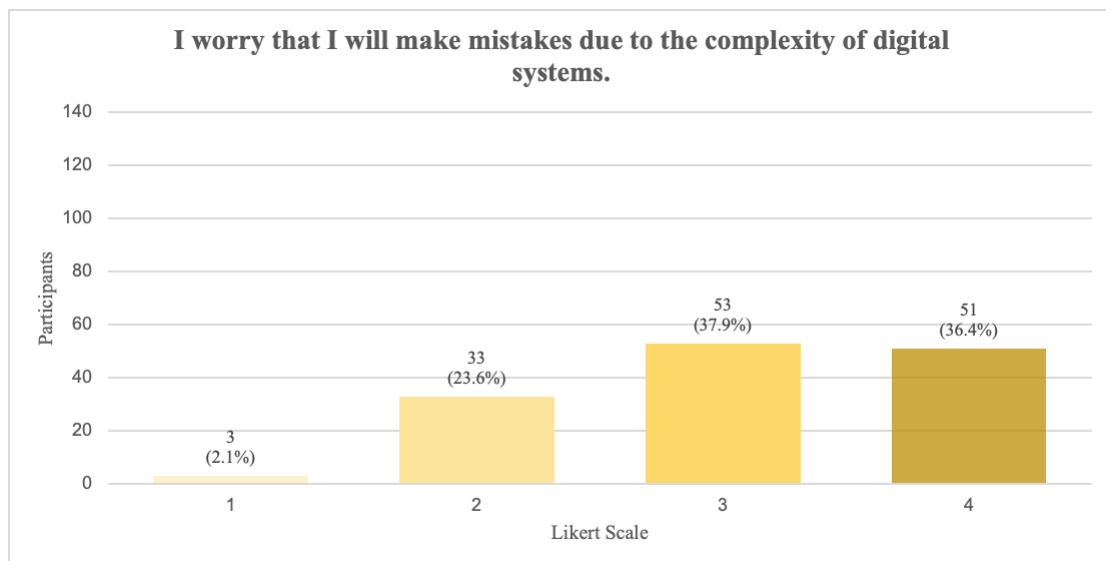


Figure 43. Concern about making mistakes due to system complexity

Figure 43 highlights a notable level of apprehension among participants regarding the complexity of digital systems. Over one-third of respondents (37.9%, n = 53) agreed, and a close 36.4% (n = 51) strongly agreed, that they worry about making mistakes

when navigating complex digital tools. Meanwhile, 23.6% (n = 33) disagreed, and only 2.1% (n = 3) strongly disagreed.

f. I feel that my workload has increased due to digitalization rather than decreased

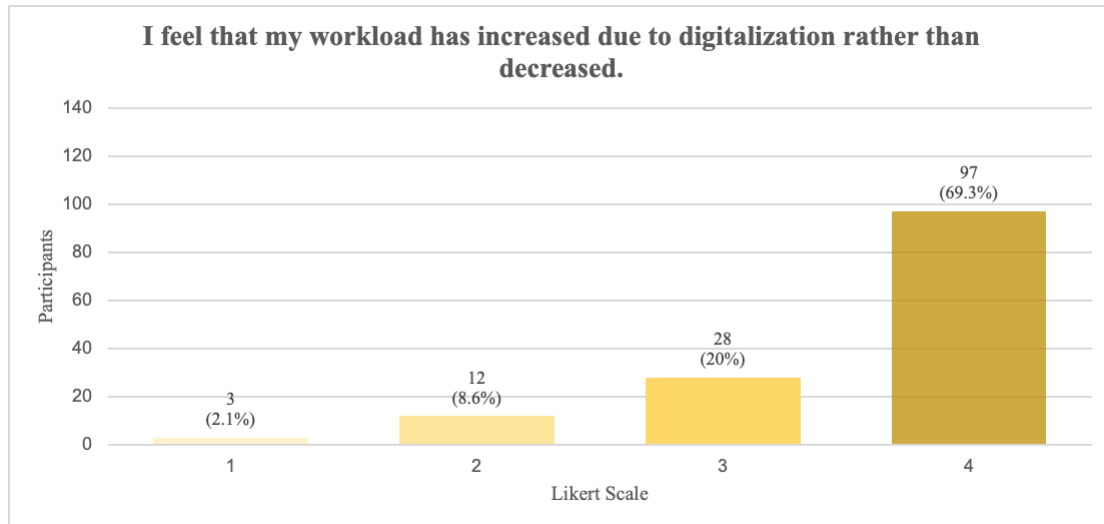


Figure 44. Impact of digitalization on workload

Figure 44 shows a clear picture of growing discontent regarding digitalization's effect on workload. A significant 69.3% (n = 97) of participants strongly agreed that digitalization has increased their workload rather than reduced it, while an additional 20% (n = 28) agreed. On the other side of the scale, only 8.6% (n = 12) disagreed, and a mere 2.1% (n = 3) strongly disagreed, making up a very small minority.

5 Discussion

This chapter analyses the survey results in relation to the research questions and the theoretical background presented earlier. It aims to provide a deeper understanding of how digitalization is influencing maritime professionals' working conditions, operational efficiency, maritime safety, and mental well-being by linking the quantitative findings to established theoretical frameworks and previous results. The discussion highlights not only areas where digitalization offers benefits but also critical challenges that require attention from industry stakeholders, system designers, and policymakers.

5.1 The magnitude of the problems associated with digitalization

While digitalization has been introduced as a means to increase efficiency and reduce errors in maritime operations, this study illustrates that it also brings considerable technical and operational challenges. Unlike previous studies that focused on qualitative approaches and theoretical risks (Lundh et al., 2023; Kitada et al., 2023), this research quantifies the maritime professionals' lived experiences. It's highlighting that more than 80% of respondents report frequent system errors, software bugs, and slow response times (Figures 10–12).

These issues go beyond minor technical glitches. They create real stressors that undermine both safety and trust in automation, especially when failures affect mission-critical systems like ECDIS, radar, or engine monitoring (Mayer et al., 1995). Additionally, 57.8% of respondents indicated that digital systems are not user-friendly (Figure 29), and 67.2% reported that software complexity directly disrupts their performance (Figure 33). This underscores that poor user-centred design and overly complicated interfaces are not just inconvenient, as they can actively reduce efficiency and increase operational risk, as mentioned in Strauch's (2018) and Kitada & Ölçer's (2015) research.

This became evident in the MARCO POLO grounding (Statens haverikommision, 2025), where outdated software and poor maintenance routines caused navigation systems to fail during a GPS rollover. Interestingly, these findings challenge the assumption that newer is always better. Previous research has identified updates as a source of causing problems (Lundh et al, 2023), and the results from this study confirm that nearly 90% of the respondents agreed that frequent software updates introduce bugs that can increase the workflow (Figure 31). While automation aims to streamline operations, its growing complexity and reliance on accurate data input (Strauch, 2018) may actually be introducing new types of vulnerability (Figure 31).

5.2 The effects of digitalization issues on workload and efficiency

From this study, many maritime professionals reported that digital systems have not only added to their daily workload but also made certain tasks more time-consuming. As shown in Figure 13 and Figure 15, nearly 90% agreed that the administrative workload has increased, and 86.4% said digital tools add to their daily responsibilities. These numbers reflect a clear disconnect between how these tools are designed to work and how they are actually experienced.

This gap relates to Hollnagel's (2017) concept of "Work as Imagined" (WAI) vs "Work as Done" (WAD). In theory, digital tools are expected to streamline operations. But in

practice. Maritime professionals often have to find workarounds. As highlighted in Figure 23, the vast majority of respondents expressed difficulty in accessing timely assistance. Many digital tools used are standalone systems, which complicates support. When systems malfunction, maritime professionals often don't know which vendor or team to contact, mostly leading to delays, especially when there's no clear line between onboard IT responsibilities and shore-based support (Lundh et al., 2025).

This problem is more challenging in smaller companies that lack in-house IT teams, unlike the larger shipping companies, which can afford continuous vendor support. Without a reliable support structure, maritime professionals are left with limited support when they need to resolve digital issues that can have operational and safety-critical consequences (Ragu-Nathan et al., 2008; World Maritime University, 2023). It's in line with Aylward's (2022) research, stating that the lack of standardized integration across platforms and vendors adds to this burden and creates unnecessary complexity.

Taken together, these factors show a clear picture of how digitalization has reshaped workload dynamics in onboard and shore-based environments. Rather than delivering efficiency like its goals, digital tools frequently demand more of maritime professionals' time, introduce uncertainty, and increase the cognitive and operational load.

5.3 The impact of digitalization challenges on maritime safety

While system failures and increased workload present tangible issues, their most critical consequence is the erosion of safety. This study reveals that the current state of digitalization introduces uncertainty in critical decision-making environments. Although digital tools are intended to support safer operations, 59.3% of participants expressed a lack of confidence in decision-making systems (Figure 37), and 55.7% confirmed that these systems have failed them at critical moments (Figure 38). These experiences highlight a crucial gap, which is that trust in automation is not guaranteed by functionality alone. It is earned through reliability, clarity, and relevance in high-stakes contexts (Lee & See, 2004).

Endsley's (1995) model of Situational Awareness offers an explanation to understand this safety degradation. When Level 1 (perception) is compromised, such as through delayed or inaccurate feedback, or Level 3 (projection) fails to help the user anticipate outcomes, the system may impair rather than aid safe navigation. For example, if decision-making tools display outdated or incomplete data, maritime professionals may misjudge the situation or hesitate at key moments. This disconnect can lead to misinterpretation or delayed reactions, all of which elevate risk. Furthermore, the risk is amplified by findings from Aylward (2022). The use of a decision support system sometimes led operators to violate more COLREG rules. Since COLREG compliance is fundamental to avoiding collisions and maintaining navigational safety, an increase in rule violations will weaken the intended safety benefits of digitalization.

Moreover, safety is not just a matter of isolated incidents, it is deeply linked to how users perceive their ability to act under pressure (La Torre et al., 2018). If tools are perceived as unreliable or overly complex, as shown in previous sections, where the maritime professional found system usability and software design complex difficult to navigate (Figure 29), they can negatively impact their performance (Figure 33). In such cases, the member may second-guess automated recommendations or, worse, ignore them entirely. This misalignment increases the likelihood of human error, particularly

during high-pressure scenarios when quick, confident decision-making is essential (Aylward, 2022).

Yet, we still need to see everything from another perspective. Over-reliance on digital systems can be just as dangerous as the grounding case of the CMA CGM Libra in 2011. As highlighted by the UK P&I Club (2021), this incident emphasized the importance of maintaining critical thinking and situational awareness, even in the presence of digital aids. When maritime professionals place blind trust in automation without validating the system's input, small errors can go unnoticed until they lead to major consequences. This illustrates that the balance between human judgment and digital assistance is not just a design issue but a behavioural and training challenge as well.

5.4 Technostress experienced by maritime professionals

As digitalization continues to expand across maritime operations, many maritime professionals find themselves struggling to keep pace. This study reveals that technostress, defined by Ragu-Nathan et al. (2008) as the inability to adapt to or cope with new technologies. A substantial proportion of participants reported stress when adapting to digital systems (Figure 39) and feeling overwhelmed by the sheer number of digital tools in use (Figure 40). These reactions highlight a growing tension between technological advancement and human adaptability.

One of the clearest expressions of this strain is frustration when systems fail, an issue reported by the majority of respondents (Figure 41). But beyond the emotional toll, technostress has deeper operational consequences. As Brod (1984) noted, when users are unable to manage technological demands, their performance, confidence, and well-being all suffer. In this study, a large proportion felt under pressure to quickly learn new systems and worried about making mistakes, a concern that is amplified by the increasing complexity of digital interfaces. In this study, nearly 75% worried that system complexity could lead them to make mistakes (Figure 43).

This burden is not evenly distributed across all maritime professionals. While younger members may adapt more easily to frequent software changes, they are still susceptible to information overload. In contrast, older or more traditionally trained members may face steeper learning curves and higher anxiety when navigating unfamiliar software interfaces, as explained by Cooper et al. (1989). This digital divide may cause communication or coordination challenges within mixed-experience professionals, further compounding operational stress.

Moreover, these stressors rarely operate in isolation. Maritime professionals are not only expected to learn and operate multiple standalone systems, but also to navigate them in high-stakes conditions with limited support. Without intuitive interfaces or user-centred logic, digital tools demand high cognitive effort, which can accumulate into chronic stress. This cumulative effect, described by Allen et al. (2008) as a precursor to fatigue and burnout, is particularly concerning for crews working long rotations in isolated environments. In the absence of standard training programs and reliable support structures, the mental burden often falls disproportionately on individual maritime professionals.

This experience is consistent with the discussion of poor User-Centred Design (UCD) addressed in earlier sections. Digital tools, when not aligned with the cognitive and operational realities of end-users, contribute directly to stress, uncertainty, and decreased performance. As the World Maritime University (2023) pointed out, the

absence of standardized training and digital support structures only intensifies these challenges, especially for maritime professionals in smaller companies or on vessels with limited access to IT resources.

5.5 Method discussion

This study employed a quantitative research design to explore the impact of digitalization on the maritime industry, building on previous qualitative work. The study shifts from understanding ‘what’ and ‘how’ digitalization affects maritime work environments to also addressing ‘how much’ and ‘how often’. This mixed methods progression enhances the validity of the research by deepening both the breadth and depth of insight.

However, some limitations should be acknowledged regarding validity. Although the study aimed to capture the experiences of seafarers, the participant pool included a large proportion of shore-based personnel, such as those working in maritime administration, ports, and shipping offices. This distribution may have biased the results. Therefore, while the findings remain highly relevant to the maritime industry as a whole, they may not fully represent the realities of crew members at sea.

The consistency of the results is likely to hold if the survey were repeated under similar conditions. The structured design of the questionnaire and the standardized Likert scale response format help minimize ambiguity and enhance repeatability. That said, the inclusion of more seafarers in a future sample, or alternatively, excluding shore-side respondents altogether, might lead to different insights.

6 Conclusion

- Maritime professionals widely experience frequent system errors, software bugs, and performance issues. Based on the questionnaire, over 80% of respondents reported operational disruptions. These problems often stem from poor user interface design, overly complicated interfaces that increase operational risks.
- Digital tools often increase daily and administrative workloads, with many respondents reporting that they made certain tasks more time-consuming and complicated. It worsens by how the companies don't get assistance and support from IT teams, especially smaller companies without an in-house IT department, and only rely on vendor support.
- Digital systems intended to enhance maritime safety can compromise it when they are unreliable, overly complex, or fail during critical moments. Yet, over-reliance on digital tools, as seen in the CMA CGM Libra case, highlights the need to maintain human oversight and critical thinking in parallel with automation.
- Maritime professionals experience technostress due to rapid expansion in digitalization, and many of them struggle to keep up, with over 75% of the respondents worried that system complexity could lead them to make mistakes. In addition, the fact that maritime professionals need to learn and operate many standalone systems in high-stakes conditions with limited support adds to their stress.

6.1 Future research suggestions

While this study provides valuable insights into the perceived impact of digitalization on maritime professionals and maritime safety, it also highlights areas where further exploration is needed. For example, a comparative study across different company sizes could reveal how digitalization challenges differ between large shipping firms with in-house IT teams and smaller operators with limited support structures. This could help identify specific organizational factors that influence digital tool effectiveness and technostress levels. As discussed in the “Method discussion” section, the next study can also be targeted exclusively at seafarers, not including maritime professionals who work at the shore-based.

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