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Adoption of digital technologies in the maritime industry: Insights from Singapore

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Abstract

Following the global trend, diverse digital tools are being adopted in the maritime industry. This development is especially relevant for Singapore, an island maritime nation of great significance in global trade. Therefore, understanding the maritime stakeholders' perspectives is crucial in identifying critical factors affecting digital technology adoption. This study uses a mixed-methods approach that comprises in-depth interviews with three interviewees and a preliminary survey with 30 respondents. All respondents have encountered adopting digital technologies at their companies. The analyses reveal that the maritime industry recognizes digitalization as essential in addressing key challenges, including costs, cybersecurity, adaption to new technology, and sustainability, among others. Enabling policies such as standardization, cybersecurity measures, and information sharing are required at both industry and operational levels. In addition, digitization is identified as the most important trend, or the most disruptive technology, impacting Singapore's maritime industry in the long-term, followed by big data analytics. This investigation highlights the growing push for digital tool adoption in the maritime sector, addressing its unique characteristics. The preliminary framework contributes to addressing potential challenges and developing strategies for successful digitalization implementation.

1. Introduction

Global trade and transport places heavy reliance on the maritime industry. In recent years, the adoption of advanced technologies has expanded across various maritime sectors, and traditional business practices and procedures have been witnessing significant transformations (Kuhn et al., 2021; Razmjooei et al., 2023). Digital innovations have drastically changed the way that entities approach traditional issues in many sectors (Hooper & Holtbrügge, 2020; Cassia & Magno, 2022; Loh et al., 2024), including the shipping, port, and cargo sectors (Jović et al., 2022b; Chauhan et al., 2023). While the maritime industry has been seen as a conservative industry, and relatively slow to embrace technological advancements, it is currently undergoing significant transformation with the advent of digitalization (Sanchez-Gonzalez et al., 2019). The industry has been seeking digital solutions to improve operational efficiency, enable cost savings, and enhance sustainability, among other factors (Barata, 2021; Zeng et al., 2021; Jović et al., 2022b; Chauhan et al., 2023). The adoption of digital technologies is not without its challenges. These include the complexities of integrating digital tools into existing procedures; issues with security, human resource concerns, and the complex

stakeholder environments resonate as common themes (Fruth & Teuteberg, 2017; Kitada & Baum-Talmor, 2019; Annarelli et al., 2021; Jović et al., 2022b). The digitalization of applications and payments, along with decarbonization for sustainability, were predicted to be two major development trends in the shipping industry (Wang et al., 2023). This development is especially relevant for Singapore, an island maritime nation of great significance in global trade.

Singapore is well known for its strategic location and thriving maritime ecosystem. Since 1986, the country has built up its connections, becoming a central hub for over 200 shipping lines connecting more than 600 ports (MPA, 2023). With the intention of securing its position as a premier global marine hub, Singapore is investing in innovation and digitalization (Jakobsen et al., 2022). The Maritime and Port Authority of Singapore (MPA) has been focusing on supporting maritime companies and start-ups in the acceleration of digitalization plans (MPA, 2022). Some companies may face uncertainties when it comes to developing Singapore's digital maritime ecosystem. Adaptation and business expansion can be challenging for some multinational corporations, local start-ups, and small and medium-sized enterprises, mainly due to limited funds and/or workforce shortages. Capabilities related to the successful adoption of digital technologies should be identified to aid companies in innovating and improving productivity and efficiency. It can also be of benefit for the overall maritime industry to properly manage digitalization and be able to keep up with technological advancement (Essi et al., 2022). This study seeks inputs from participants in Singapore as the context, and their perspectives are especially significant given Singapore's status as a major global maritime hub. The findings would be relevant and would offer broader implications for the industry.

Digital technologies are accelerating and enabling the development of other technologies (Jensen et al., 2023). This acceleration also poses economic, social, and ethical challenges. As companies adapt to the surge of new technologies entering the market, emerging business models are disrupting established ones at an unprecedented pace. Given that the adoption of advanced digital tools is still relatively recent in the maritime industry, it is vital to prioritize identifying any potential challenges organizations may face when implementing these technologies. Developing robust strategies that address both technical and operational hurdles, while fostering a culture of digital innovation, has become a significant challenge for companies in the maritime industry. Digital technologies, in particular, encompass advanced technologies and digital infrastructures designed to optimize and streamline operations, as well as improve productivity and decision-making within the maritime context. Examples include using sensors to monitor vessel performance, and big data analytics to optimize vessel routing and reduce emissions. Despite the potential and the benefits of digital technologies, the associated challenges need to be identified and addressed for successful implementation and to ensure the maritime industry's ability to adapt to evolving market demands. If the challenges are not addressed, operational efficiency could be hindered, competitiveness can be reduced, and there could exist inefficiencies in processes, among other adverse effects.

The rapid development of digital technologies is transforming the industry, yet their adoption faces challenges. While commonly used tools and technologies may improve the efficiency of the industry, stakeholders must overcome various barriers. Given the complexity of these challenges, understanding the key adoption factors is essential, as well as exploring how stakeholders can leverage emerging opportunities to enhance competitiveness in the maritime industry. Therefore, these considerations lead to the formulation of the following research questions:

RQ1: What are the key factors that will affect the successful adoption of digital technologies in the maritime industry?

RQ2: How can stakeholders in the maritime industry leverage opportunities in the adoption of digital technologies?

Consequently, the findings provide insights for industry stakeholders, policymakers, and researchers. The remainder of the paper is organized as follows. The next section reviews the relevant literature. Then, the methodology is discussed, and the results are subsequently analyzed. Finally, the paper concludes with measures to create a supportive ecosystem for digitalizing the maritime industry, as well as practical implications.

2. Literature review

In a post-pandemic globalized world, companies are looking to streamline their processes to enhance efficiency, reduce cost, and improve sustainability. Customers are demanding faster and more cost-efficient deliveries with greater shipment visibility (Ekinci et al., 2018; Tran & Nguyen, 2020; Alamoush et al., 2022; Sorooshian et al., 2022). Digital tools have emerged as enablers of these objectives, particularly within the maritime industry, where multiple stakeholders play key and collaborative roles in the adoption of technologies (Fruth & Teuteberg, 2017; Annarelli et al., 2021; Sullivan et al., 2021; Ichimura et al., 2022; Iman et al., 2022). However, despite its importance, limited studies have explored how stakeholders can collaboratively facilitate adoption in the industry, presenting a research gap.

Digitalization entails several tools and technologies, each having advantages, limitations, and implementation considerations. Digitalization has revolutionized port operations and vessel automation through technologies like the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. The use of these has often shown improvement in decision-making and the efficiency of operations (Munim et al., 2020; Bui & Nguyen, 2021; Zhu & Hsieh, 2024). However, the adoption of these technologies can overlook organizational and workforce-level barriers, such as resistance to change and lack of technical expertise.

Ports and shipping companies worldwide are increasingly using digital technologies to monitor fleet and vessel performance, predict maintenance requirements, and improve safety (Camarero et al., 2020; Dalaklis et al., 2022). Notable examples include the Port of Rotterdam, which has implemented digital systems to optimize cargo visibility and container handling (Wired UK, 2019). In addition, Tuas Port not only serves as a physical port, but also as a digitally automated facility. In conjunction with the Maritime Green Initiative, Tuas Port is strategically positioned to become a resilient and future-ready port (Idris, 2022). It is also common to see port management implementing IoT technologies to monitor cargo flows and reduce accidents (Munim et al., 2020; Sharma & Kim, 2022). Furthermore, modern ships are equipped with sensors that collect data on temperature, pressure, and flow rates. This enables ports and ship-owners to leverage them with big data analytics (Yap et al., 2023) and AI for predictive maintenance and proactive measures to maximize efficiency (Jimenez et al., 2020; Chen et al., 2022). Despite the wide-ranging benefits, many existing studies primarily focus on specific technologies, with reduced attention paid to the broader integration of these systems across the industry.

Factors motivating businesses to leverage digital technologies include shifting customer preferences and greater cost-cutting pressures (Thai & Jie, 2018; Huang et al., 2019; Hsieh et al., 2024). Cost reduction can be achieved by eliminating waste, resulting in more efficient and sustainable operations (Gkerekos et al., 2019; Annarelli et al., 2021; Ichimura et al., 2022). Digital tools are known for eliminating manual tasks and optimizing processes, hence resulting in shorter turnaround times, higher productivity, and less waste (Kon et al., 2020; Liu et al., 2021; Sullivan et al., 2021). Maritime companies can also enhance their sustainability practices by employing digital tools (Lee et al., 2019; Zhou, et al., 2020; Essi et al., 2022; Jović et al., 2022b). The global maritime industry contributes close to 3 % of global Greenhouse Gas (GHGs) emissions (King, 2022). Increased public scrutiny and governmental intervention on sustainability gave rise to environmental regulations, putting pressure on ship-owners to keep abreast of the evolving market and

environmental demands (King, 2022; IMO, 2023; Mahmud et al., 2023). By optimizing vessels operations, fuel consumption can be reduced, leading to lower operational costs and carbon emissions, while retaining customer service levels. Companies such as Mediterranean Shipping Company (MSC) and Maersk Line are already leveraging digital tools for these purposes (MSC, 2019; Maersk, 2022). However, there is still limited research that explores the intersection of stakeholders and policy support for technological innovations to drive sustainability within the maritime sector.

Factors like the costs and limited access to technology in certain regions have often been cited as challenges to digitalization. The upfront investment for digital infrastructure is substantial, and some ports/operators in emerging markets might lack the infrastructure needed. Partnering and incentives can help to address these challenges for successful adaptation (Zhang et al., 2020; Gracia et al., 2022; Autsadee et al., 2023; Olapoju, 2023). The increased interconnectivity between operational technology (OT) and information technology (IT) exposes the maritime industry to a significant challenge of digitalization- cyber threats (Bielawski et al., 2022)- with maritime cyber-attacks having surged by 900 % from 2017 to 2020 (Greiman, 2019; Gold, 2021). Cyber-attacks can entail severe economic, reputational, safety, and/or environmental impacts, creating ripple effects in the global supply chain that can cost hundreds of millions of dollars (Canepa et al., 2021; Kapalidis et al., 2022), yet many organizations lack the expertise to address these threats effectively. Although frameworks such as the International Maritime Organization's (IMO) Maritime Cyber Risk Management Guidelines provide guidance, many shipowners struggle with adherence or agreement (IMO, 2019; ICS, 2020; Mohsendokht et al., 2024). There is a critical need for knowledge on how to build maritime cyber-resilience and integrate cybersecurity measures with broader digital transformation initiatives for competitive advantage (Greiman, 2019; Amro et al., 2022).

Critical workforce-related factors affecting the successful implementation of digital tools include specialized knowledge and skills which the existing maritime workforce may lack, leading to significant gaps (Kitada & Baum-Talmor, 2019; UNCTAD, 2019). Training and upskilling programs, along with organizational strategies, are essential for developing effective recruitment approaches to attract and retain skilled professionals with the necessary digital competencies (Caesar et al., 2020; Jović et al., 2022a), thereby addressing the skills gap. Moreover, resistance to change, due to job security concerns or a lack of understanding of the benefits of digital tools, have been mentioned as hindrances to adoption (Sanchez-Gonzalez et al., 2019; Caesar et al., 2020; Barata, 2021). Overcoming these requires effective management strategies and a supportive organizational culture that encourages innovation, collaboration, and continuous learning. Herein, local contexts and work culture in the industry should be taken into consideration, and tailored solutions should be regarded. Research in specific contexts, as in the current study, can suggest actionable insights to enhance the maritime industry's adoption of digital technologies, fostering collaboration, sustainability, and resilience.

3. Methodology

Data pertinent to this study was collected through a series of expert interviews and surveys, with a focus on professionals familiar with the operational aspects of maritime companies. The intent was to gain insights into the projected trajectory of digitalization and the potential challenges faced during implementation within maritime business operations in Singapore. The analytical methodology adopted in this study employed a convergent mixed method approach, amalgamating both quantitative and qualitative techniques, in which both the interviews and the survey were conducted simultaneously. The in-depth interviews offered detailed and meaningful insights from personal experience of industry professionals (Mohiuddin et al., 2020), while the survey collected quantitative data from a larger group of respondents that can validate and expand on the themes

identified during the interviews. Hence, this approach was used as it integrates qualitative insights from the interviews with quantitative data from survey to provide a holistic perspective on the topic.

The in-depth interviews were one-on-one interviews that were conducted online, and each lasted approximately one hour. Each interview was guided, with the main focus being on challenges in, and the motivations for, adopting digital technologies in their companies. The interviewees were asked to discuss questions across three categories: (1) an overview of the Singapore market, including the challenges, problems, and the current status of technology adoption, as well as the key trends; (2) their company's strategies and projects, focusing on difficulties encountered during implementation; and (3) future opportunities in promoting the adoption of digital technologies, including implementation strategies and recommendations. A total of three complete interviews were used in the analysis for this study. The three professionals had extensive experience in the maritime industry. The first interviewee, a quality management engineer, was employed at a large shipyard enterprise and was actively involved in the planning and research stages of shipbuilding, utilizing digital tools to streamline the manufacturing process. The second interviewee was Vice President at a seaborne trade management company and had an impressive understanding of the container shipping industry and global freight management, with over six years of experience leading the successful implementation of digital technology initiatives. The last interviewee was a regional communication manager at an international quality assurance and risk management company specializing in marketing communication for digital technologies initiatives in the maritime business, with more than six years of experience in implementing maritime digitalization projects in Southeast Asia, the Pacific, and India. These interviewees were selected through the authors' professional networks. As the selection of these interviewees consisted of respondents from different sectors and with different roles, broad and meaningful perspectives on digital technologies in the maritime industry could be provided.

The survey questionnaires were also focused on the challenges and opportunities of digital technology adoption in the industry, including areas pertinent to the industry's digital landscape, perceptions on the importance of different trends and technologies impacting the industry, challenges and potential solutions, and future opportunities in advancing digital innovation within the respondents' respective organizations. The questionnaires were sent to respondents residing in Singapore. Comprising a good mix of ordinal scale, structured question format, and open-ended questions, for a comprehensive collection of opinions and perspectives, the questionnaires were distributed electronically. Convenience sampling was used, and targeted respondents were those with an understanding of, and an ability to, assess trends in technology adoption in the maritime industry, as well as the ability to identify the possible challenges faced when adopting digital technologies. This sampling refers to a way of selecting participants from the target population based on ease of access (Golzar, et al., 2022) and thus ensured that inputs could be gathered from individuals who were readily available and possessed the necessary knowledge to contribute to this study. Clarity about the study's objectives and the survey's intent was ensured prior to their participation. The survey was structured into two parts: (1) an overview of the operating area, to understand the current status and challenges, and (2) driving forces for adopting and implementing new trends and technologies, including identifying the most impactful trends and technologies for the future (e.g., sustainability, AI, IoT) to capture emerging innovations. Additionally, the survey aimed to identify gaps, analyze opportunities, and explore potential solutions to challenges while examining specific technologies or strategies companies plan to adopt in the coming years. The questionnaires adopted a user-friendly design and were created in the form of a clickable form, enabling respondents to conveniently check their selections. The survey comprised 15 questions in total: Multiple-choice and ordinal scale questions were used to allow respondents to easily rank trends and technologies and select challenges from a list, and open-ended questions were included to enable respondents to

elaborate on their perspectives, particularly regarding opportunities and strategies for implementing digital technologies. In addition, text boxes were provided for responses to open-ended questions, thereby facilitating ease of expression and user engagement. A total of 30 complete responses were used in the analysis, and the respondents' characteristics are summarized in **Table 1**.

Table 1 Demographics of survey respondents (n = 30).

	Responses (%)		**Responses (%)**
Respondent experience		**Type of company**	
≥ 10 years	15 (50 %)	Multinational Corporation	16 (53 %)
10 - 6 years	9 (30 %)	Small & Medium Enterprises	8 (27 %)
≤ 5 years	6 (20 %)	Start-ups	6 (20 %)
Respondents experience		**Company domain**	
Business development	11 (36 %)	Smart shipping	11 (37 %)
Marketing	7 (23 %)	Overall maritime	10 (33 %)
Research and development	6 (20 %)	Port technologies	7 (23 %)
Others *(logistics; offshoring; engineering; manufacturing; claims; general management)*	6 (20 %)	Others *(logistics and shipping; mobile offshore classification)*	2 (7 %)

Source: Authors

At least half of the respondents had more than 10 years of experience and were from multinational corporations. As can be seen from **Table 1**, the respondents' profile is diverse, with varied domains of expertise. These indicate that the responses gathered are from experienced professionals familiar with various roles and expertise within the maritime industry, thereby enhancing the relevance and applicability of the findings.

A frequency analysis was performed on the collected responses as this statistical method facilitates a clear understanding of the distribution and recurrence of specific responses, providing initial insights into the prevalent trends, drivers, and barriers within the adoption process in the maritime sector. For example, the most common challenges were identified by frequency counts. Then, qualitative data from the open-ended questions were analyzed using content analysis and thematic analysis methods. Content analysis enabled the systematic categorization of responses into groups through coding and identifying key patterns and trends. In this phase, responses could be systematically coded into predefined categories, e.g., opportunities, and implementation strategies. These allowed the identification of key patterns and trends based on the frequency and context of these codes. Thematic analysis was then applied to these categorized responses for deeper analysis of the data, facilitating the identification, analysis, and interpretation of the overarching themes highlighted during data collection.

As such, the interviews were to provide preliminary insights, with the findings complemented by the survey results. Collectively, these methods provide a thorough understanding of the magnitude and nature of the study, thereby facilitating a nuanced investigation of digitalizing the industry. As the study serves as a preliminary exploration of this topic, descriptive statistical methods were primarily used to summarize the data. This approach was appropriate as it provides a fundamental understanding of the topic and reveals key patterns that can inform future, more detailed studies. Additionally, the thematic perspectives from the interviews complemented the quantitative findings, ensuring depth in the analysis.

4. Results and discussion

This section presents the research findings and their analysis, followed by a discussion of their implications. Section 4.1 outlines the key results derived from the study, and Section 4.2 discusses the results, highlighting important implications.

4.1 Research findings and analysis

Hereafter, interview participants will be referred to as 'interviewees', and survey participants as 'respondents'. The information gathered from the interviews suggests that the challenges posed by the COVID-19 pandemic have intensified the drive for adopting digital technologies within the maritime industry. The interviewees unanimously agreed that fostering a digital climate was essential to enhance services and limit physical interaction, hence remaining active and relevant during the pandemic years. The sentiment is in alignment with that of the survey respondents, who identified robotics, big data, AI, and blockchain technologies as emerging technology trends that are likely to make a significant impact on the industry. Both the interviewees and respondents concurred on the significance of cultivating the appropriate mindset and readiness to assimilate new digital technologies within maritime organizations. They also highlighted the importance of setting clear objectives that align with local and international standards as the crucial first step in the successful adoption of digital technologies.

All respondents (100 %) indicated that their companies were open to embracing digital technologies. From the survey results, trends of disruptive technologies were reviewed, and the most disruptive trends identified include digitalization, big data, robotics, cybersecurity, autonomous shipping, and automation. These "disruptions" were not necessarily perceived negatively, suggesting the potential these technologies have for the maritime industry. Respondents also identified additive manufacturing, smart document exchange, smart shipping, and digital cargo as key digital technologies applicable in the maritime industry. This information is beneficial for companies providing these digital services, and can serve as a guide for those seeking to maintain pace with potential competitors by implementing digital technologies.

Inquiring about the current challenges in Singapore's maritime digital technology, respondents were asked to indicate all the options they considered applicable. The 'Adoption of digitalization tools' emerged as the major challenge faced in the industry, identified by 97 % of the respondents, thereby highlighting the significance of this study. The second most significant challenge, indicated by 47 % of the respondents, was 'Cyber security challenges'. The third challenge, reported by 20 % of the respondents, was 'Tighter environmental regulations.' A smaller percentage of 7 % also stated a perceived 'Resistance to change' challenge in the industry. Furthermore, respondents were asked to elaborate further on the challenges they had previously indicated; responses were analyzed based on the frequency with which a topic was mentioned. Responses indicated that they perceived that most maritime companies are typically hesitant to invest highly in advanced digital tools and are resistant to changes, unless provided with successful case studies or examples of implementation. Other challenges, such as lack of awareness, insufficient readiness within the organization (including shortage of appropriated labor skills), and digitalization-associated costs, were mentioned as challenges that can hinder the successful adoption of digital technologies. At a national level, most respondents (73 %) credited that the maritime industry in Singapore aligns with global trends in digital technology adoption, pointing out that Singapore is continuously improving to boost port productivity and shipping efficiency. Nonetheless, nearly one in four respondents (23 %) felt that the current digitalization process in Singapore's maritime companies falls short of international standards, indicating that there is room for improvement.

Regarding the internal challenges and motivations existing at the respondents' companies related to the adoption of digital technologies, as shown in **Figure 1**, a total of 5 motivations and 13 challenges were classified. For challenges, responses highlighted that maritime companies are cognizant of the increased competition, and are thus consistently assessing their strategies to improve

competitiveness; this is a positive approach, yet it could be seen as a challenge in adopting digital technologies, as this is always prioritized. Considering that the shift towards implementing digital technologies often requires substantial economic and time investments, the cost of adopting digital technologies was also frequently mentioned as an internal challenge.

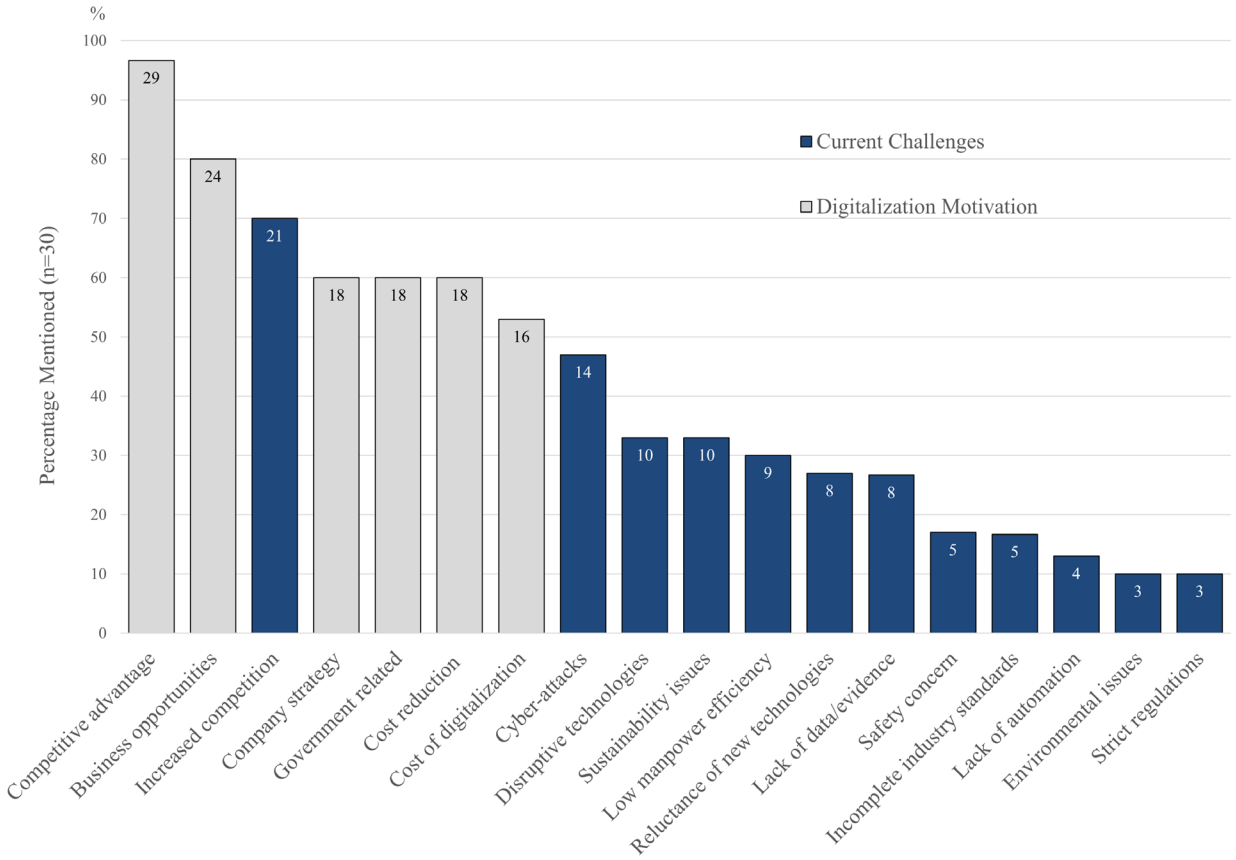

Figure 1 Perceived challenges and motivations for adopting digital technologies.
Source: Authors

Similarly, issues with the cost of adoption and the resources allocated to run associated projects were raised by the interviewees. They also expressed concerns about the integration and implementation of advanced digital technologies, noting that cost, time, and having sufficient manpower equipped with the necessary skills can be challenging for many companies to fulfil. Cybersecurity was mentioned as another challenge. With the introduction of more advanced technologies, it is essential to possess the necessary technological defenses and a robust team to prevent infiltrations into the systems within maritime companies. This view is supported by the interview findings, with interviewees acknowledging that many companies are employing more resources to ensure that their data are secured, while highly-skilled hackers are finding more ways to hack into the companies' security systems. Hence, the interview findings emphasized that it would be a challenge for companies to constantly invest in and look for new alternatives to ensuring that there is data and cyber security in the long run.

Despite the challenges, companies are motivated to implement digital tools. Most of the motivations mentioned in the survey relate to gaining a competitive advantage, followed by the pursuit of more business opportunities. This shared sentiment among the respondents and interviewees reflects a positive sign of the companies' willingness in adopting advanced digital technologies. Other motivations mentioned included planned company strategies, government incentives/regulations, and cost reduction.

Considering the current challenges and motivation, respondents identified the criticality of thirteen disruptive technologies or trends impacting the maritime industry in Singapore. They were asked to rank the top five most important trends or technologies from thirteen options. **Figure 2** illustrates the importance of each technology or trend by calculating how frequently it was ranked in the top five, and how often it was ranked as the most crucial.

According to **Figure 2**, smart systems are identified as the most important trends or disruptive technologies impacting the Singapore maritime industry in the long term, with 25 out of 30 respondents ranking them in the top five, and eleven ranking them as the top option. Cybersecurity is the most widely concerning issue (86.67 % of respondents); however, only 13.33 % ranked it as the most crucial. Moreover, sustainability and big data analytics play critical roles, with 56.67 % of respondents (seven ranking it as the top concern), and 66.67 % of respondents (four ranking it as the top concern), respectively. Automation, autonomous shipping, and robotics may also remain key concerns in the long term.

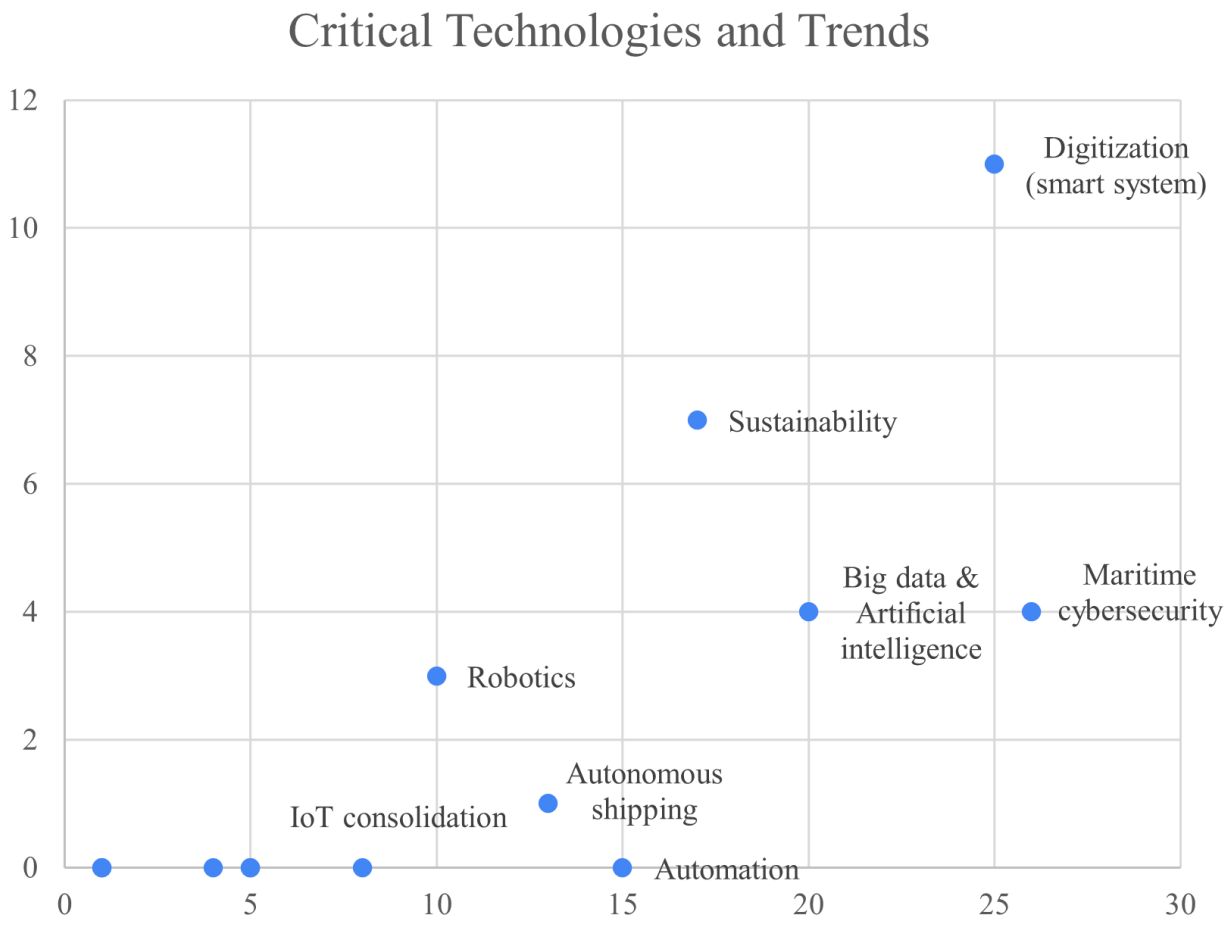

Figure 2 Criticality of disruptive technologies or trends.
Source: Authors

Survey responses from the open-ended questions also helped to shed light on possible alternatives that maritime companies can consider when embracing adoption. Several respondents highlighted the importance of collaborating with relevant stakeholders- a fact that was also indicated previously in the literature. They also indicated the need for a structured organizational readiness approach, as well as companies' willingness to invest money and resources (mostly related to training workforce) in digital tools, as necessary steps for maritime companies to achieve successful adoption

of digital technologies. The importance of compliance with local and international standards was also mentioned by some respondents as they strive towards achieving a competitive edge in today's market where digital tools could be leveraged. Additionally, respondents suggested that maritime companies should be receptive to changes and have an open mindset to adopt more advanced digital tools in their business operations.

A fishbone diagram, categorizing responses under a cause-and-effect scheme, is used to consolidate the information obtained from the surveys and interviews, as shown in **Figure 3**. Herein, the 'causes' are presented in four sections- people, cost, organization, and technology- and addressing or targeting these causes can eventually lead to the positive 'effect' of the successful adoption of digital technologies in the maritime industry. Companies should initially focus on addressing causes within their control, such as providing training and upskilling programs for employees and ensuring readiness for organizational changes. For challenges more difficult to control, such as 'people' behavior/attitude, and 'technology' challenges, companies should stay informed on the latest regulations and developments and/or work closely with relevant authorities and stakeholders to facilitate a seamless and successful digital transition.

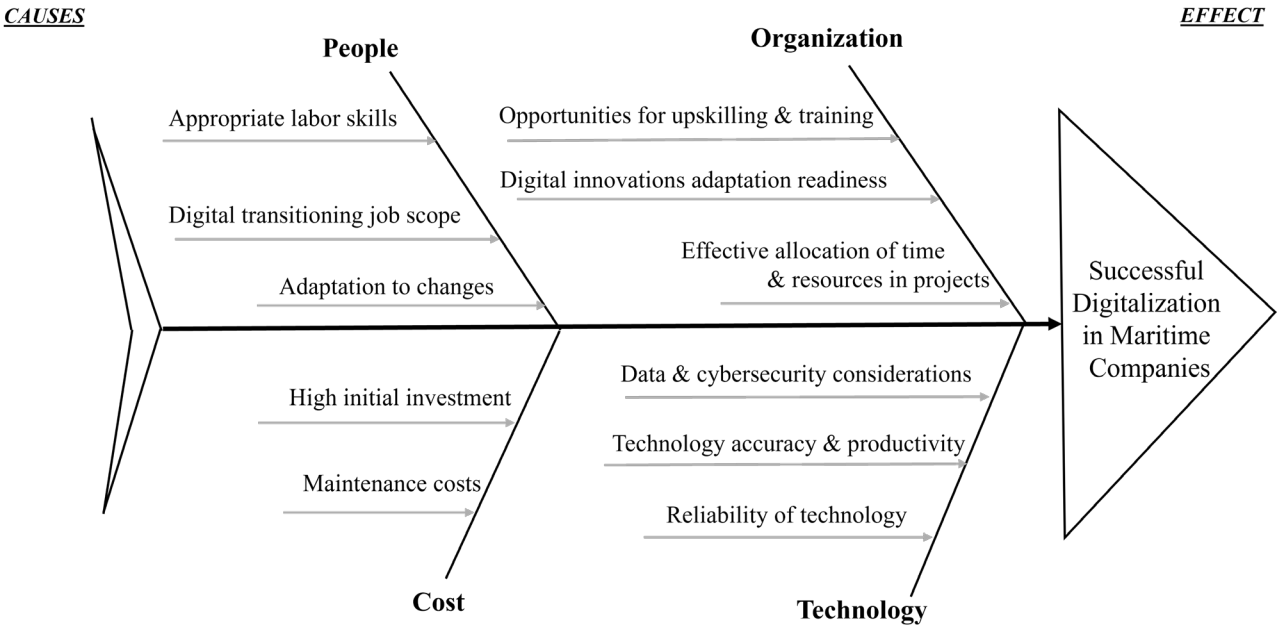

Figure 3 Causes for the successful adoption of digital technologies in maritime companies in Singapore.
Source: Authors

4.2 Discussion

Additional analysis was conducted based on responses to clarify approaches to achieve an ecosystem for the adoption of digital technologies in the maritime industry. A combination of triangulation of content analysis and thematic analysis was employed for interpretation. The thematic context diagram is shown in **Figure 4**, illustrating the three primary themes that have been found to have an impact on digitalizing the maritime industry. These are fundamental drivers (intrinsic to the organisations and the immediate environment), organisational willingness, and digital readiness. Moreover, to address the above concerns by the respondents, enabling policies need to be in place to build a supportive ecosystem for digitalizing the maritime industry. The policies are proposed at the industry level and at the operational level, respectively, to offer a holistic view.

The maritime industry's advanced technologies are being driven by a combination of internal and external factors. These factors may be presented as challenges for the business model and industry

trends that organisations are compelled to contend with. Most respondents have expressed their concerns of their organisations facing increasing competition, and they recognise the potential of digitalization as a strategic tool to provide advantages and open new business opportunities. Several responses also highlighted the need for collaboration and standardization across the industry. The findings support that data standardization is one of the key drivers for future changes in the maritime industry (Inkinen et al., 2021). These are not only seen as essential for success, but they can also facilitate compliance with increasingly stringent emissions regulations on the industry.

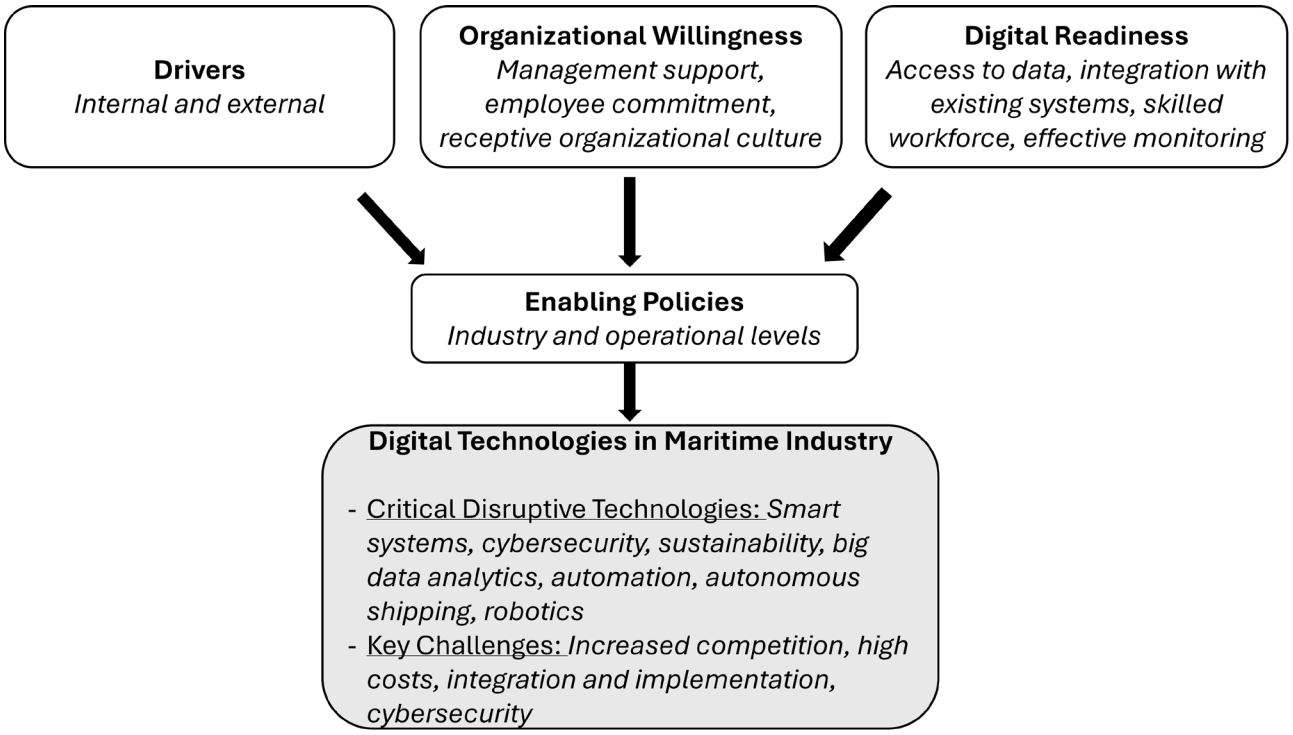

Figure 4 Thematic context diagram.
Source: Authors

This construct calls for a forward-looking organization, with an impetus from management in adopting digital technologies and with strong commitment from employees. Consequently, the emphasis is on a two-pronged approach. Most respondents have advocated for managerial encouragement and commitment to adopting and exploring new digital technologies. Additionally, respondents have emphasized the necessity for cultivating the appropriate mindset, alongside harnessing pertinent professional and communication skills, to facilitate the management and planning of the adoption process. This is intended to ensure the relevance and competitiveness of knowledge and context of application, such that substantive results and benefits can be generated for both the organization and its operating environment.

Furthermore, the digital readiness of the industry as a whole, and within individual organizations, is heavily reliant on the accessibility of the necessary data and the ability of existing systems to integrate with new technologies. The mediating factor in such scenarios typically lies in the requisite knowledge to translate data into meaningful results. To successfully implement and utilize a digital tool, it is important to have a skilled workforce and effective monitoring measures to assess the performance of such technologies. Clearly understanding the objectives underlying the usage of a specific digital tool is also crucial.

At the industry level, the two important bearings are the facilitation of the adoption process and the protection of stakeholders. Regulations and policies should aim to minimize the risks and

barriers associated with the adoption of digital technologies. Regulators should aim to prioritize several key areas, including enhancing cybersecurity measures, reviewing existing laws to ensure there are no conflicts between digitalization and legal provisions, preventing unfair advantages for bigger players, reducing barriers that hinder the participation of smaller players, and promoting information sharing between all parties involved. Given that many respondents expressed concerns about the costs of implementation, another regulation could focus on alternatives to mitigate these costs, so to incentivize companies to embark on their implementation journey, such as offering grants and subsidies to motivate the industry.

The other important consideration, which is also a major challenge at the industry level, is to stipulate the liabilities of different parties and address the ethical issues surrounding data privacy and usage. At present, there is a lack of clarity regarding the regulation of algorithms and the establishment of liability due to the involvement of numerous factors and parties. Compounding the issue, various technological tools involve different parties to varying extents. However, the issue of data privacy and usage has far-reaching implications and should be approached with the intention of striking a delicate balance between protecting consumers and the rights of businesses. More specifically, the collaborative development of a roadmap or framework by the industry, regulators, and academics would provide a systematic approach to the implementation process. A supportive ecosystem with safeguards would promote interest in and compliance with the adoption of digital technologies of the industry.

At the operational level, the principal components encompass both internal initiatives and collaboration with external parties. A significant amount of work needs to be undertaken at this level. Several respondents indicated the need for a supportive organizational culture in the implementation and adoption of digital technologies. This implies a need for adaptable employees and management with a receptive mindset at the organizational level. Encouragement and commitment from top management can serve as a catalyst for change, fostering motivation within the organization to experiment with new digital technologies and bolstering receptiveness to these new innovations.

The above calls for the organization to define clear objectives of adopting digital technologies to ensure efforts in this area are constructive, as the initial step. This should provide guidelines regarding the necessary skills for new and existing employees, as well as principles for potential and ongoing collaborations with other industry partners. In addition to the right skills, the implementation process requires access to the right kind of data, performance monitoring of digital tools, adherence to international standards, and the ability of the current system to accommodate new technologies. Collaborations with external parties may facilitate such conditions. For instance, organizations may contemplate collaborating with cybersecurity consultants and investing in employee training. Business owners such as shipowners and port operators often lack the expertise and experience needed to enhance their cybersecurity. In contrast, cybersecurity consultants are equipped with the expertise in identifying vulnerabilities and expediting the development of protection and detection measures. Building cyber resilience requires proper training for employees and management to prevent human errors that can result in cyber incidents. To capitalize on opportunities, partnerships between organizations are crucial. It is, therefore, essential to have suitable and standardized platforms that enable various sectors to communicate and share valuable insights on acquiring and enhancing technological capabilities.

5. Conclusions

Findings from the interviews and survey indicate that the maritime industry recognizes the need for adopting digital technologies as a response to the challenges, challenges which in some cases were exacerbated by the COVID-19 pandemic. Interviewees and survey respondents agreed upon the importance of fostering a digital climate within maritime organizations to enhance services and remain active and relevant in the current market. It was also highlighted that having well-defined

objectives that align with local and international standards is crucial for the successful adoption of digital technologies.

Survey respondents also provided valuable insights into common challenges and motivations related to adopting digital technologies in the maritime industry within companies. The major challenges identified were digitalization costs, cybersecurity challenges, adaptation to disruptive technologies, and sustainability issues. The challenges could hinder successful digitalization implementation unless addressed effectively. On the other hand, the motivations for implementing digital tools were primarily driven by gaining a competitive advantage and pursuing more business opportunities.

Theme were identified to be drivers, organizational willingness, and digital readiness. From these, it is explained that enabling policies need to be in place at the industry and operational levels. At the industry level, policies should aim to standardize approaches facilitating the implementation process, enhancing cybersecurity measures, reducing barriers for smaller players, and promoting information sharing. Additionally, clear regulations addressing the liabilities of different parties and ethical issues surrounding data privacy and usage are needed. At the operational level, organizations should foster a supportive culture. This could be done by defining clear objectives, acquiring or providing the necessary skills and data, adhering to standards, and collaborating with external parties such as cybersecurity consultants.

Overall, the study highlights the importance of adopting digital technologies in the maritime industry and provides valuable insights into the challenges, motivations, and enabling factors for successful implementation. By addressing these factors and embracing digital technologies, maritime companies can enhance their competitiveness, explore new business opportunities, and navigate the industry's evolving landscape. However, as a preliminary study focusing on the Singapore market context, the smaller sample size and the use of convenience sampling limits the generalizability of the findings and may lead to over or under representing specific viewpoints. Future research, thus, should consider expanding the scope and sample size to be more representative of the entire industry. An international collaborative study could be conducted to contrast differences and outline similarities. Future research could also consider including other sectors requiring digitalization to broaden the scope and applicability of findings. In addition, incorporating more advanced statistical tests, such as correlation or regression analysis, could provide deeper insights into the topic and shed light on how specific challenges are perceived differently based on organizational roles or experience levels. Based on these, an overall framework for successful digital technologies implementation could be created.

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