



The Transformation of Digital Technology-Based Maritime Transportation Systems in Enhancing Shipping Efficiency and Safety

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ABSTRAK

The development of digital technology has transformed the marine transportation system and created a huge opportunity to improve shipping efficiency and safety. This research aims to analyze the transformation of maritime transportation systems based on digital technology in improving operational efficiency and shipping safety. The research uses a qualitative approach with a case study method through in-depth interviews with 15 informants consisting of ship operators, port managers, and maritime authorities. Data was analyzed using thematic analysis techniques through the process of data reduction, data presentation, and conclusion drawn. The results of the study show that the application of digital navigation systems, real-time monitoring, and integration of logistics data is able to increase operational effectiveness, accelerate information distribution, and minimize the risk of marine accidents. This study concludes that digital transformation plays an important role in supporting safer, more efficient, and sustainable maritime transportation systems.

INTRODUCTION

Digital transformation has become one of the strategic issues in the development of modern marine transportation systems in various countries. Technological developments such as the Internet of Things (IoT), artificial intelligence, big data analytics, and digital navigation systems have driven significant changes to operational efficiency and global shipping safety. The maritime sector is currently required to be able to increase the speed of logistics distribution, reduce the risk of ship accidents, and strengthen the integration of shipping information in real-time. International maritime organizations also continue to encourage the implementation of shipping digitalization to create a safer, more efficient, and sustainable marine transportation system (Asmiati et al., 2023).

In the context of Indonesia as the largest archipelagic country in the world, the transformation of digital technology in the marine transportation sector is an increasingly urgent need. The high activity of distributing goods between regions, the growth of maritime trade, and the increase in national logistics mobility demand a more modern shipping system that is adaptive to technological developments. However, various problems are still found, such as distribution delays, weak port data integration, limited ship monitoring systems, and a high risk of marine accidents due to technical and human error factors (SULISTIANA, 2026). This condition shows that the digitalization of sea transportation is not only an innovation option, but also a strategic need in supporting national connectivity.

The development of digital technology in the maritime transportation system is basically supported by the theory of digital transformation which explains that the integration of information technology is able to increase organizational effectiveness through process automation, strengthening data communication, and optimizing digital system-based decision-making (Hariyono et al., 2024). In the field of sea transportation, the application of digital technology can be realized through the use of smart shipping systems, electronic navigation, vessel traffic management systems, and integrated port management. The implementation of this technology is considered to be able to improve navigation accuracy, speed up the logistics process, and minimize the potential for ship accidents due to delays in information and manual errors (Putra, 2024).

Several previous studies have discussed the implementation of digitalization in the maritime transportation sector. Research conducted by Indraprakoso, (2023) shows that the implementation of a digital monitoring system is able to improve port operational efficiency in Indonesia. Furthermore, research by SULISTIANA, (2026) found that the use of digital-based navigation technology contributes to improving shipping safety on domestic commercial ships. Meanwhile, an international study conducted by Hafidz et al. (2024) confirms that the integration of smart shipping technology can reduce operational costs and increase the effectiveness of global logistics distribution.

Nonetheless, previous research still has some limitations. Most studies focus more on the operational efficiency aspects of ports without

comprehensively integrating the shipping safety dimension. In addition, previous research tends to use a quantitative approach with a focus on technical analysis of the system, so it has not explored much of the experiences and views of maritime transportation actors related to the implementation of digital technology in daily operational practices (Khotimah et al., 2025). The research gap shows the need for a more in-depth study of the transformation of maritime transportation systems based on digital technology from an integrated operational and shipping safety perspective.

In addition, digital transformation in Indonesia's maritime sector still faces various challenges, such as limited technological infrastructure, low digital competence of human resources, and suboptimal data integration between ports and shipping operators (Enda et al., n.d.). These problems cause the implementation of digital technology to not run optimally in supporting the effectiveness of the national sea transportation system. Therefore, research is needed that is able to provide an empirical picture of how digital technology is applied in shipping activities and its impact on operational efficiency and safety.

Based on these problems, this study aims to analyze the transformation of the maritime transportation system based on digital technology in improving operational efficiency and shipping safety. This study specifically seeks to identify the form of implementation of digital technology in marine transportation activities, analyze its impact on the effectiveness of shipping operations, and evaluate its contribution in minimizing the risk of marine accidents. The research was conducted using a qualitative approach through in-depth interviews with ship operators, port managers, and maritime authorities to gain a more comprehensive understanding of the phenomenon being studied.

This research is expected to make a theoretical contribution to the development of the study of sea transportation techniques, especially related to digital transformation in the modern maritime transportation system. In addition, this research is also expected to be able to make a practical contribution to the government, shipping operators, and port managers in designing a more effective digital technology implementation strategy to improve operational efficiency and national shipping safety. Thus, the results of the research can be one of the important references in supporting the development of a modern, integrated, and sustainable marine transportation system.

LITERATURE REVIEW

Digital transformation in marine transportation systems

Digital transformation in marine transportation refers to the process of integrating information technology, automation systems, Internet of Things, big data, artificial intelligence, and digital platforms into shipping, port, and maritime logistics activities. In the context of modern marine transportation systems, digitalization serves not only as an administrative tool, but also as a strategic mechanism to accelerate the flow of information, improve coordination between maritime actors, and reduce reliance on manual processes. Laurenz, (2025) explained that IoT, big data, blockchain, and artificial intelligence are the main innovations that drive the efficiency and safety of maritime operations, especially through real-time monitoring of ships and port infrastructure. In line

with that, Bachtiar, (2025) emphasized that digitalization in maritime logistics is able to open up efficiency opportunities, although it is still faced with the issue of the level of digital maturity and readiness of shipping organizations.

Port digitalization and operational efficiency.

Shipping efficiency is closely related to the port's ability to manage ship flows, loading and unloading, documents, and logistics distribution quickly and integrated. In Indonesia, the development of digital technology at ports has included e-document-based services, digital customer systems, integration of sea-side and land-side activities, and port service automation. Safuan, (2023) show that Indonesian Ports have developed several digital technologies on the sea, land, and customer sides to support service efficiency. These findings are strengthened by Aulia (2025), which states that the digitalization of port operations has an impact on increasing efficiency, transparency, and productivity. Thus, digital transformation can be understood as an important instrument in reducing ship waiting times, accelerating administrative processes, and improving the quality of maritime logistics services.

Smart ports as a model for the development of modern marine transportation

The concept of smart port is a concrete form of applying digital technology in marine transportation engineering. Smart ports integrate IoT, monitoring systems, loading and unloading automation tools, data control centers, and communication platforms between stakeholders. Aulia (2025) found that the implementation of IoT-based smart ports can increase crane productivity by up to 35% and reduce the average waiting time of ships by 40%, although its implementation in Indonesia still faces problems with system integration and digital infrastructure. Implementation of smart ports and Port Community Systems at Tanjung Perak Port was able to increase productivity up to 56.09 box/ship/hour and reduce ship stay time. This shows that smart ports have a direct relevance to improving shipping operational efficiency.

Digital technology and cruise safety

Shipping safety is an important dimension in the digital transformation of the marine transportation system. Digital navigation systems, vessel traffic management systems, real-time monitoring, and data-driven route management can help reduce the risk of accidents due to information delays, navigation errors, and poor operational coordination. Saputra & Marsudi (2025) stated that port digitalization, real-time monitoring systems, and data-based route management are able to improve operational efficiency as well as shipping safety. In the context of policy, Saputra & Marsudi (2025) emphasized that the security of sea transportation is an important part of Indonesia's maritime policy, especially since this sector is directly related to regional connectivity and the protection of national shipping activities. Therefore, digitalization is not only oriented towards productivity, but also on operational risk mitigation.

Integration of logistics data and coordination between stakeholders

One of the main problems in sea transportation is the weak integration of data between ships, ports, logistics operators, and maritime authorities. The digital system allows data on ship movements, docking schedules, loading and unloading activities, shipping documents, and logistics distribution to be managed more transparently. Sarjito (2023) as studied in the study on port information technology, emphasized the importance of information technology in port management to improve efficiency, productivity, and security. The digitalization of maritime logistics is influenced by both driving and inhibiting factors, including technological readiness, organizational coordination, and system integration capabilities. Thus, the success of digital transformation is highly dependent on the synergy between technology, governance, and human resource readiness.

Challenges in the implementation of sea transportation digitalization

Despite its great potential, the implementation of digital technology in Indonesia's marine transportation still faces various challenges. Limited communication infrastructure, uneven port readiness, low digital literacy of operators, and system interoperability problems are obstacles that often arise. Marbun & Gabriella (2025) noted that large ports such as Tanjung Priok, Tanjung Perak, and Makassar New Port have begun to implement digitalization and limited automation, but have not yet been fully integrated. The digitalization of shipping also brings new risks, especially cyberattacks and the need for stronger data protection systems. This shows that digital transformation needs to be accompanied by cybersecurity strategies, human resource training, and clear technology governance standards.

Research gaps

Previous studies have shown that most of the research still focuses on port digitalization, logistics efficiency, or smart port concepts separately. Research on the integrated relationship between digital technology, shipping efficiency, and shipping safety still needs to be strengthened, especially through a qualitative approach that explores the experiences of ship operators, port managers, and maritime authorities. Hawari & Adiyono (2024) prove that the adoption of digital technology has an effect on the efficiency of shipping companies, but the study emphasizes more on the efficiency aspect of the company than the operational safety dimension in depth. Therefore, this research has a contribution space by examining the transformation of the maritime transportation system based on digital technology in a more integrative manner.

Sintesis literature review

Based on a literature review, digital transformation in marine transportation systems has a strategic role in improving operational efficiency, accelerating information distribution, strengthening logistics integration, and minimizing the risk of marine accidents. Digitalization through digital navigation systems, smart ports, real-time monitoring, and logistics data integration can support the modernization of maritime transportation that is more adaptive to global and national needs. However, the success of its

implementation is largely determined by infrastructure readiness, human resource competence, system interoperability, and data security protection. Thus, the research entitled *The Transformation of Digital Technology-Based Maritime Transportation Systems in Enhancing Shipping Efficiency and Safety* is relevant to enrich the study of marine transportation techniques, especially in understanding digital transformation as an instrument to improve shipping efficiency and safety.

METHODOLOGY

Types of Research

This research uses a qualitative approach with a case study design to analyze the transformation of maritime transportation systems based on digital technology in improving operational efficiency and shipping safety. This approach was chosen because it is able to explore the experiences and views of sea transportation actors in depth regarding the implementation of digital technology in shipping activities (Khotimah et al., 2025).

Population and Sample

The research population includes maritime transportation actors involved in shipping operations and digital technology management. The sampling technique used purposive sampling with a total of 15 informants consisting of ship operators, port managers, and maritime authorities. The selection of informants is carried out based on their experience and involvement in the implementation of the maritime digital system (Kusumawati, 2025).

Research Instruments

The research instrument used semi-structured interview guidelines compiled based on indicators of digital transformation, operational efficiency, and shipping safety adapted from (Udar, 2024). Data validity is carried out through source triangulation and member checking to ensure the accuracy of the information.

Data Collection Procedure

Data collection was carried out through in-depth interviews in person and online with all informants. The research stages include problem identification, literature study, instrument preparation, interview implementation, data transcription, and verification of interview results before data analysis is carried out (Hidayat et al., 2025).

Data Analysis Techniques

Data were analyzed using thematic analysis through the stages of data reduction, data presentation, and conclusion drawing (Ananda et al., 2021). The analysis process is assisted using NVivo 14 software to facilitate the grouping of themes and interpretation of research data.

RESULTS AND DISCUSSION

Implementation of Digital Technology in the Maritime Transportation System

The results of the study show that digital technology transformation in the marine transportation system has been implemented through the use of digital navigation systems, real-time-based ship monitoring, *electronic document systems*, and integration of port logistics data. Most of the informants stated that the application of digital technology helps speed up the shipping operational process and facilitates coordination between work units. One of the ship operators explained that the use of digital navigation systems helps improve shipping accuracy and reduce human error in determining shipping routes. The OP-03 informant stated, "*Before using the digital navigation system, the route monitoring process was still mostly done manually, so there was a risk of delays and navigation errors*" (OP-03 interview, February 12, 2026).

Another informant from the ship operator also mentioned that digital technology makes the process of monitoring the condition of the ship faster and more accurate. "*Now the condition of the engine, weather, and position of the ship can be monitored directly in real-time so that operational decisions are made faster*" (OP-01 interview, February 10, 2026).

The port manager explained that the digital system based on data integration helps speed up the administration of ships entering and exiting the port. The PP-02 informant said that "*the use of digital systems accelerates the ship clearance process because ship data is directly connected to the port system*" (Interview PP-02, February 14, 2026).

In addition, the implementation of *the electronic document system* is considered to be able to reduce the use of manual documents which previously required a long verification time. "*In the past, the document verification process could take hours, now most of it is automated through digital systems*" (Interview PP-04, February 15, 2026).

Increased Shipping Operational Efficiency

The findings of the study show that the implementation of digital technology has a significant impact on shipping operational efficiency. The informant stated that the use of digital monitoring systems and integrated logistics platforms is able to speed up information distribution and reduce ship waiting times at ports. Informant PP-01 stated that "*coordination between work units is now faster because all ship data can be monitored through one integrated system*" (Interview PP-01, February 11, 2026).

The ship operator also explained that digitalization helps reduce operational costs through time savings and fuel use efficiency. "*With a digital navigation system, ship routes can be more optimal so that fuel consumption becomes more efficient*" (OP-05 interview, February 16, 2026).

In addition, most informants mentioned that digitalization speeds up the logistics distribution process and reduces delays in the delivery of goods. The PP-03 informant explained that "*the integration of logistics data helps the loading and unloading process to be more scheduled and reduces the queue of ships at the port*" (Interview PP-03, February 17, 2026).

The statement was reinforced by the OK-02 informant from the maritime authority who stated that "*the use of digital systems helps synchronize ship schedules and minimize operational delays*" (OK-02 interview, February 18, 2026).

The Impact of Digital Technology on Shipping Safety

The results of the interviews show that the application of digital technology contributes to improving shipping safety. An informant from the maritime authority stated that the real-time-based ship monitoring system helps speed up the detection of potential shipping disruptions and makes it easier to monitor ship activities in the waters. The OK-01 informant explained that *"with a digital monitoring system, the position of the ship can be monitored continuously so that the risk of losing communication can be reduced"* (OK-01 interview, February 13, 2026).

In addition, the use of a *vessel traffic management system* is considered to be able to minimize the risk of ship collisions and improve navigation accuracy. *"Digital navigation systems help provide early warning when ships are on a potentially dangerous course"* (OP-02 interview, February 14, 2026).

The ship operator also revealed that the digital system helps reduce *human error* in the manual navigation process. The OP-04 informant stated that *"the error reading of the shipping lane becomes smaller because the navigation data is already automatically updated by the system"* (OP-04 interview, February 16, 2026).

Meanwhile, the OK-03 informant explained that *"digitalization makes the process of reporting emergency conditions faster to be accepted by shipping authorities"* (OK-03 interview, February 19, 2026). The findings show that digital transformation not only improves efficiency, but also strengthens shipping risk mitigation systems.

Data Integration and Coordination Between Stakeholders

The research found that the integration of logistics data and digital communication is an important factor in supporting the effectiveness of maritime transportation systems. Before the implementation of digital technology, coordination between ports, ship operators, and maritime authorities tended to be slow because they still used a manual administration system. Informant PP-05 stated that *"in the past, ship schedule information was often received late, which had an impact on the loading and unloading process"* (Interview PP-05, February 20, 2026).

After the implementation of the digital system, the data exchange process becomes faster, transparent, and integrated. *"Now all ship activities can be monitored in one dashboard so that coordination becomes easier"* (OK-04 interview, February 21, 2026).

In addition, digitalization allows the monitoring of logistics activities to be carried out simultaneously through an integrated information system. The OP-01 informant explained that *"the data on the distribution of goods is now easier to monitor so that the delivery process becomes more controlled"* (Interview OP-01, February 10, 2026). This has an impact on improving the quality of shipping services and reducing operational communication barriers.

Obstacles to Digital Technology Implementation

Although it provides various benefits, the results of the study show that the implementation of digital technology in sea transportation still faces a

number of obstacles. Some informants stated that the limitations of communication network infrastructure in several shipping areas caused the digital system to not run optimally. The OP-05 informant said that *"when the ship is in a certain area, the communication network is still often disrupted so that the monitoring system is not always stable"* (OP-05 interview, February 16, 2026).

In addition, the low digital competence of some operational personnel is an obstacle in the use of automation-based technology. *"There are still some operators who are not used to using digital systems to the maximum"* (Interview PP-02, February 14, 2026).

Some port managers also explained that data integration between agencies is still not fully synchronized so that some administrative processes are still carried out manually. The OK-05 informant stated that *"some interagency systems are not yet fully connected so the data exchange process is sometimes still slow"* (OK-05 interview, February 22, 2026). Other findings show concerns related to data security and potential cyberattacks on digital shipping systems. *"The more digital systems are used, the higher the risk of data security"* (OK-02 interview, February 18, 2026).

The results of the study show that digital transformation in the maritime transportation system is implemented through digital navigation systems, real-time-based ship monitoring, electronic document systems, and port logistics data integration. These findings show that digitalization not only serves as a technical tool, but has become a key mechanism in accelerating coordination, improving information accuracy, and reducing reliance on manual processes. This is in line with the concept of digital transformation which emphasizes the integration of digital technology to improve organizational effectiveness, decision quality, and speed of service. In the context of Indonesia's maritime, these findings support Bachtiar (2025) study which states that IoT, big data, blockchain, and artificial intelligence open up opportunities to improve efficiency, safety, and operational management of the maritime sector.

The next key finding shows that digital technology is able to improve shipping operational efficiency through accelerating information distribution, reducing ship waiting times, optimizing routes, and saving operational costs. The informant stated that the digital system facilitates the synchronization of ship schedules, speeds up the clearance process, and reduces loading and unloading delays. These findings are in line with Safuan (2023), who show that the development of digital technology in Indonesian ports on the sea, land, and customer sides aims to improve service performance and reduce national logistics costs. The Laurenz (2025) also emphasizes that the digitalization of port operations has an impact on increasing efficiency, transparency, and productivity.

In terms of shipping safety, this study found that real-time monitoring systems, digital navigation, and vessel traffic management systems help reduce the risk of information delays, navigation errors, loss of communication, and potential marine accidents. These findings reinforce the concept of risk mitigation in sea transportation, which is that safety depends not only on the capabilities of the crew, but also on the quality of information systems, data accuracy, and speed of response to risks. Indraprakoso (2023) stated that port digitalization, real-time

monitoring systems, and data-based route management are able to improve operational efficiency as well as shipping safety. Thus, digitalization plays a role as a risk prevention instrument, not just a tool for administrative modernization.

The results of the study also show that data integration is an important factor in building coordination between stakeholders, especially between ship operators, port managers, and maritime authorities. Before digitization, the coordination process tended to be slow because it relied on manual documents and separate communication. After the digital system is implemented, information about ship schedules, ship positions, loading and unloading activities, and distribution of goods can be monitored more quickly and transparently. These findings are in line with the study Simanjuntak et al. (2024), which shows that digital supply chain technology improves the visibility and efficiency of Indonesia's maritime logistics. Zeng et al. (2025) also emphasized that the success of maritime logistics digitalization is influenced by technological readiness, organizational coordination, and system integration capabilities.

Although the results support the initial goal that digitalization improves shipping efficiency and safety, the findings also point to the presence of several inhibiting factors. The main obstacles include limited communication networks in certain regions, low digital competence of some operators, lack of synchronization of systems between agencies, and increasing data security risks. This finding is in line with Choirunissahapsari (2025), who stated that the implementation of IoT-based smart ports in Indonesia still faces obstacles to system integration and digital infrastructure readiness. In addition, Progoulakis et al. (2023) emphasized that the digitalization of ships and ports can open up cyber attack risk gaps, so the digital security aspect needs to be an integral part of maritime safety strategies.

The difference between this study and the previous study lies in the focus of the analysis. Many previous studies have emphasized port digitalization in terms of technical efficiency, productivity, or logistics costs. This study expands this perspective by showing that digital transformation also has a direct impact on shipping safety and the quality of coordination between stakeholders. With a qualitative approach, this study provides a more contextual understanding of the experience of maritime actors in using digital technology in daily operational activities. This reinforces the study of Progoulakis et al. (2023), who assessed that the digital maturity of ports is not only determined by smart infrastructure, but also integration, governance, and cybersecurity.

Theoretically, this research contributes to the development of marine transportation engineering by emphasizing that digital transformation needs to be understood as a socio-technical system, which is a combination of technology, humans, organizations, and governance. The efficiency and safety of shipping is not only explained through the existence of technology, but also through user readiness, data integration, institutional coordination, and digital system protection. In practical terms, the results of this study imply that governments, shipping operators, and port managers need to strengthen network infrastructure, improve human resource training, develop data interoperability standards, and build maritime cybersecurity systems.

The weakness of this study lies in the limited number of informants and the scope of cases that do not yet represent all the characteristics of ports and shipping lanes in Indonesia. In addition, this study uses a qualitative approach so that the results emphasize the depth of understanding rather than statistical generalization. Further research is recommended using a mixed method approach involving more ports, ship operators, and shipping authorities in order to test the relationship between digitalization, operational efficiency, safety, and logistics costs in a more measurable manner.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, it can be concluded that the transformation of the maritime transportation system based on digital technology plays an important role in improving operational efficiency and shipping safety. The application of digital navigation systems, real-time-based ship monitoring, electronic document systems, and logistics data integration has been proven to be able to speed up operational processes, improve coordination between stakeholders, reduce distribution delays, and minimize the risk of marine accidents due to human error and information delays. The research findings also show that the digitalization of marine transportation not only serves as a technological modernization, but has become a strategic instrument in supporting a more effective, transparent, safe, and sustainable shipping system. In addition to contributing to the development of marine transportation engineering, this research strengthens the concept of digital transformation as a socio-technical system influenced by technological integration, human resource readiness, and institutional governance.

However, the implementation of digital technology in the marine transportation sector still faces various obstacles, such as limited communication network infrastructure, low digital competence of operational personnel, suboptimal system integration between agencies, and increasing cybersecurity risks. Therefore, governments, shipping operators, and port managers need to strengthen maritime digital infrastructure, improve human resource training, and build more integrated data security and information interoperability systems. Further research is recommended to use a mixed method approach with a wider scope of regions and participants in order to produce a more comprehensive analysis of the relationship between digitalization, operational efficiency, shipping safety, and the sustainability of the national maritime transportation system.

FURTHER STUDY

The next study is recommended to use a mixed method or quantitative approach involving a larger number of respondents and a wider coverage of the port area in order to obtain more representative and measurable results. In addition, subsequent research can develop an analysis of the influence of digital technology on logistics costs, the sustainability of maritime transportation, the satisfaction of shipping service users, and the effectiveness of maritime cybersecurity policies. Further studies also need to explore the implementation of artificial intelligence, blockchain, and Internet of Things based technology in

marine transportation systems to obtain a more comprehensive picture of maritime digital transformation in Indonesia.

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