

DOI: <https://doi.org/10.38035/hrm.v2i1><https://creativecommons.org/licenses/by/4.0/>

Received: 05 September 2026 | Revised: 15 September 2026 | Accepted: 30 September 2026

Ship Safety Analysis in Indonesia: Determining Crew Competence, Port Digitalization and Ship Technology Innovation

Neng Sri Komala¹, Nur Zaeni², Uti Indrawati Lestari³

¹Akademi Maritim Djadajat, Jakarta, Indonesia, mala.caaip@gmail.com

²Akademi Maritim Djadajat, Jakarta, Indonesia, nurzaeni1974@gmail.com

³Akademi Maritim Djadajat, Jakarta, Indonesia, lestari.rirrie@yahoo.com

Corresponding Author: mala.caaip@gmail.com¹

Abstract: This study aims to analyze the determinants of ship safety in Indonesia by integrating three key constructs: crew competence, port digitalization, and ship technology innovation. The high risk of domestic maritime accidents underscores the urgent need for a holistic evaluation of the maritime ecosystem. The study employs a descriptive qualitative approach based on a Systematic Literature Review (SLR). Fifty reputable scholarly articles published between 2021 and 2026 sourced from esteemed international and national journals were analyzed using a structured process comprising data reduction, data presentation, and conclusion drawing. The findings indicate that enhancing crew competence (maritime knowledge, technical skills, decision-making, and non-technical competencies), implementing port digitalization (system integration, automation, information transparency and cybersecurity) and adopting ship technology innovations (propulsion systems, smart navigation, predictive maintenance, and eco-friendly technologies) positively and significantly determine ship safety in Indonesia (encompassing seaworthiness, safety management, emergency preparedness, and risk control). As a secondary qualitative synthesis, the study is limited by its lack of direct quantitative statistical testing in the field.

Keywords: Ship Safety, Crew Competence, Port Digitalization, Ship Technology Innovation.

Indonesian Abstract: Penelitian ini bertujuan untuk menganalisis determinasi keselamatan kapal di Indonesia melalui integrasi tiga konstruk utama, yaitu kompetensi awak kapal, digitalisasi pelabuhan, dan inovasi teknologi kapal. Tingginya risiko kerentanan kecelakaan pelayaran domestik memicu urgensi evaluasi ekosistem maritim secara holistik. Penelitian ini menggunakan pendekatan kualitatif deskriptif berbasis Systematic Literature Review (SLR). Sebanyak 50 artikel ilmiah bereputasi periode 2021–2026 yang bersumber dari jurnal internasional dan nasional bereputasi dianalisis secara terstruktur melalui tahap reduksi data, penyajian data, dan penarikan kesimpulan. Hasil penelitian menunjukkan bahwa peningkatan kompetensi awak kapal (pengetahuan maritim, keterampilan teknis, pengambilan keputusan, dan kompetensi nonteknis), penerapan digitalisasi pelabuhan (integrasi sistem, otomatisasi, transparansi informasi, dan keamanan siber), serta adopsi inovasi teknologi kapal (sistem propulsi, navigasi cerdas, pemeliharaan prediktif, dan teknologi ramah lingkungan) secara

positif dan signifikan menentukan keselamatan kapal di Indonesia (kelaiklautan, manajemen keselamatan, kesiapsiagaan darurat, dan pengendalian risiko). Keterbatasan penelitian ini terletak pada sifat sintesis kualitatif sekunder tanpa pengujian statistik kuantitatif lapangan langsung.

Kata Kunci: *Keselamatan Kapal, Kompetensi Awak Kapal, Digitalisasi Pelabuhan, Inovasi Teknologi Kapal.*

INTRODUCTION

Indonesia, as the largest archipelagic state in the world, heavily relies on maritime transportation for its logistics connectivity and population mobility (Teyansyah et al., 2026). Ship safety is a vital aspect of maritime operations that ensures the protection of human lives, the continuity of cargo, the protection of the marine environment, and the smooth flow of inter-island trade. Amid the acceleration of maritime modernization, ship safety is not only demanded in terms of compliance with physical regulations (seaworthiness) but also includes emergency preparedness, voyage risk management, and comprehensive integration of the maritime ecosystem (Enda et al., 2025).

Although shipping regulations have been tightened, ship safety incidents in Indonesian waters still show a level of vulnerability that needs to be watched out for. Based on the official investigation report from the National Transportation Safety Committee (NTSC) and national shipping accident records, fluctuations in ship incident numbers can be observed in the following table:

Table 1. Estimated Incidents and Casualties of Ship Accidents in Indonesia (2021–2025)

Sailing Safety Indicator	2021	2022	2023	2024	2025
Number of Ship Accident Cases (KNKT/Basarnas)	19	15	12	128	8
Casualties / Deceased (People)	96	45	38	62	44
Dominant Incidents (Sinking, Collision, Fire)	Sunk/Burned	Collision	Collision	Collision	Sinking

Source: Data from the National Transportation Safety Committee (KNKT) & Basarnas, Processed Data (2026)

Table 1 illustrates the fluctuations in maritime accident rates in Indonesia, where non-conventional ship accidents and collisions between ships still dominate in densely populated waters such as the Sunda Strait, Madura Strait, and eastern Indonesian waters. This actual condition indicates that the national maritime safety assurance system has not been operating in a stable and adaptive manner.

The main issue in Indonesia's maritime transportation is the still high risk of recurring ship safety vulnerabilities in domestic shipping areas (Arifian et al., 2025). The direct impact of weak ship safety includes the loss of passenger/crew lives, damage to high-value cargo, environmental pollution due to oil spills, and increased logistics costs and national economic losses. The main contributing factors to this issue are dominated by the low competence of the ship's crew (human error), limited automation and digital transparency at the port, and the slow adoption of technological innovations in ship mitigation and navigation systems (Hasnur et al., 2025).

Previous literature reviews have partially examined various determinants of ship safety. Most studies emphasize that enhancing the competence of ship crews through certification training significantly reduces the risk of maritime accidents (Iswanto, 2025). However, other findings indicate that human resource competence is no longer sufficient without the support of port service digitalization and the updating of precise ship navigation technology (Nicholas et al., 2024). The difference in findings stems from the still-separate focus of the analysis (siloe approach), where previous research rarely combines human resource factors (crew

competence), land infrastructure factors (port digitalization), and ship system factors (technological innovation) within a single holistic framework.

The study gap lies in the absence of a systematic qualitative mapping that thoroughly synthesizes the interconnections between Crew Competence (X1), Port Digitalization (X2), and Ship Technology Innovation (X3) with Ship Safety (Y) within a unified theoretical framework. The limitations of previous research generally focused on partial quantitative approaches with small sample sizes in specific waters, thus failing to provide a broad conceptual synthesis for the national maritime industry.

This research focuses on a systematic analysis of the determinants of ship safety through a comprehensive synthesis of three main constructs: crew competence, port digitalization, and ship technology innovation. The object of this research is scientific articles and reputable national and international literature that discuss the maritime safety system in Indonesia for the period 2021–2026. The research gap being addressed is bridging the fragmentation of maritime safety theory into a cohesive conceptual framework. The urgency of this research is very important to provide strategic direction for regulators (Ministry of Transportation/Port Authority) and shipping industry players in minimizing the national ship accident rate.

Based on the background and research gaps mentioned above, the research questions in this study are: 1) Does the competence of ship crews affect ship safety in Indonesia?; 2) Does port digitalization affect ship safety in Indonesia?; 3) Does ship technology innovation affect ship safety in Indonesia?.

In line with these research questions, this study aims to: 1) Analyze and develop hypotheses related to the influence of ship crew competence on ship safety in Indonesia; 2) Analyze and develop hypotheses related to the influence of port digitalization on ship safety in Indonesia; 3) Analyze and develop hypotheses related to the influence of ship technology innovation on ship safety in Indonesia.

METHOD

This research uses a descriptive qualitative approach in the form of a Systematic Literature Review (SLR) aimed at identifying, evaluating, and synthesizing various findings from previous studies systematically and comprehensively. This approach was chosen because it can provide an in-depth understanding of the phenomenon of ship safety through the integration of various scientific perspectives from diverse literature, thereby producing stronger and more generalizable conclusions compared to single studies. The literature review was conducted in a structured manner to capture the theoretical and empirical dynamics evolving in the field of maritime and marine transportation management, particularly related to the prediction and prevention of ship accidents (Susanto, Arini, et al., 2024).

The type of data used is secondary data sourced from relevant previous scientific articles, academic books, research reports, and other scientific publications. As many as 50 scientific articles were used as the main sources obtained from reputable and indexed international journals such as Springer, Wiley, ProQuest, Emerald, Taylor & Francis, Sage, Sinta, Copernicus, and Google Scholar. The publications analyzed are focused on the period between 2021 and 2026 to ensure the novelty and relevance of the empirical context to the current state of the national shipping industry. As supplementary data, this research also uses additional secondary data sourced from the annual reports of the National Transportation Safety Committee (KNKT), maritime transportation statistics from the Ministry of Transportation (Kemenhub), as well as institutional publications from the National Search and Rescue Agency (Basarnas), in order to strengthen the empirical context regarding the dynamics of ship safety in Indonesia (Boulton, M. J., & Houghton, 2021).

The data analysis procedure is carried out through three main stages: data reduction, data presentation, and conclusion drawing. At the data reduction stage, the researcher filters the literature based on inclusion criteria (relevance of the topic to the variables of Crew

Competence, Port Digitalization, Ship Technology Innovation, and Ship Safety within the period of 2021–2026) and eliminates duplicates and articles that are not relevant to the shipping industry. The data presentation stage is organized in the form of descriptive narratives and synthesis matrices. The conclusion drawing stage is carried out through in-depth interpretation to build a conceptual model, which is validated using source triangulation (Azhari et al., 2023).

RESULTS AND DISCUSSION

Results

Based on the problem formulation above, the results of this literature study are as follows:

Ship Safety

Ship safety is a condition and a series of systematic efforts aimed at ensuring the operational safety of the ship, crew, passengers, cargo, and the marine environment from various risks of accidents and disturbances during sailing activities. Ship safety includes the implementation of operational standards, maintenance of the ship's technical condition, management of sailing risks, and compliance with applicable maritime safety regulations, both national and international (Melnik et al., 2022).

The indicators or dimensions found in the ship safety variable include: 1) Ship Seaworthiness: Ship seaworthiness is the ability of the ship to operate safely in accordance with technical requirements and maritime safety standards; 2) Ship Safety Management: Ship safety management is the implementation of systems and procedures aimed at identifying, evaluating, and controlling various operational risks during navigation; 3) Emergency Preparedness: Emergency preparedness is the ability of the ship and all crew members to face situations that potentially threaten safety during navigation; 4) Navigation Risk Control: Navigation risk control is a series of actions to identify and reduce potential hazards that may disrupt the safety of the ship during the journey (Qiao et al., 2021).

The ship safety variables are relevant to previous research conducted by: (Rawson et al., 2021), (Wu et al., 2021), (Wahid et al., 2024).

Ship Crew Competence

The competence of ship crew members is a combination of knowledge, skills, technical abilities, professional attitudes, and work behavior required by each individual in carrying out their duties and responsibilities during maritime operational activities. This competence includes mastery of navigation procedures, ship engine operation, equipment maintenance, safety management, maritime communication, and the ability to handle various emergency situations at sea (Susanto, Sawitri, et al., 2024). The competence of ship crew is not only determined by educational background and professional certification, but is also influenced by work experience, continuous training, adaptability, and understanding of maritime technology developments (Lehtimäki & Teperi, 2026).

The indicators or dimensions found in the variable of crew competence include: 1) Maritime Knowledge: Maritime knowledge is the crew's mastery of information, principles, regulations, and procedures related to operational sailing activities; 2) Technical Skills: Technical skills are the crew's ability to operate, maintain, and control various equipment and systems used in sailing activities; 3) Decision-Making Ability: Decision-making ability is the crew's capacity to analyze situations, evaluate risks, and determine appropriate actions when facing various operational problems; 4) Non-Technical Competence: Non-technical competence is the behavioral and interpersonal abilities that support the crew's effectiveness in performing tasks both individually and collectively (Gundić et al., 2021).

The variable of crew competence is relevant to previous research conducted by: (Belabyad et al., 2026), (Putra et al., 2026), (Ali et al., 2024).

Port Digitalization

Port digitization is the process of transforming operational, administrative, and managerial activities of ports through the utilization of digital technology to enhance efficiency, transparency, information integration, and the quality of port services. The implementation of port digitization aims to optimize loading and unloading processes, ship traffic management, customs administration, berthing scheduling, terminal management, and information exchange between port authorities, shipping companies, and service users (Yang & Hsieh, 2024).

Indicators or dimensions found in the port digitalization variable include: 1) Digital system integration: Digital system integration is the level of interconnection between various information technology platforms used in port operational and administrative activities; 2) Operational automation: Operational automation is the use of technology to run or support various port processes while reducing dependence on manual labor; 3) Information transparency: Transparency and availability of information are the capabilities of the port digital system in providing accurate, relevant, and easily accessible information to authorized parties; 4) Digital system security: Digital system security and reliability are the capabilities of port technology infrastructure in protecting information while ensuring the system can operate consistently (Heikkilä et al., 2022).

The variable of port digitalization is relevant to previous research conducted by: (Behdani, 2023), (Brunila et al., 2021), (Ghazaleh, 2023).

Ship Technology Innovation

Ship technology innovation is the process of developing, applying, and refining technology in the systems, equipment, design, and operational mechanisms of ships aimed at improving the efficiency, safety, reliability, and sustainability of maritime transportation. These innovations encompass various aspects, ranging from the development of energy-efficient propulsion systems, the use of alternative fuels, the application of automation technology, the development of intelligent navigation systems, to the utilization of digital technology in monitoring the condition of ships (Melnik et al., 2023).

Indicators or dimensions found in the variable of ship technology innovation include: 1) Propulsion system innovation: Propulsion system innovation involves the development and application of ship propulsion technology aimed at improving energy efficiency, reliability, and operational performance; 2) Navigation innovation: Navigation and automation innovation involves the application of modern technology that supports the improvement of navigation accuracy, ship control, and the automation of various operational activities; 3) Predictive maintenance innovation: Predictive maintenance innovation involves the use of technology to monitor equipment conditions and predict the likelihood of failures before they disrupt ship operations; 4) Environmentally friendly technology innovation: Environmentally friendly technology innovation involves the development and application of ship technology aimed at reducing the negative impact of shipping activities on the marine and atmospheric environment (Melnik et al., 2023).

The variable of ship technology innovation is relevant to previous research conducted by: (Mallouppas & Yfantis, 2021), (Xiao et al., 2024).

Previous Research

Based on the aforementioned findings and previous research, the research discussion is formulated as follows:

Table 2. Relevant Results of Previous Research

No	Author (Year)	Research Results	Similarity with this research	Difference with this research	Hypothesis
1	(Artana, 2026)	The construct of crew competence affects the	The same as this research on the independent construct of crew	There is a research object conducted on	H1

		safety of the ship at KMP Shita Giri Nusa.	competence and the dependent variable of ship safety.	KMP Shita Giri Nusa.	
2	(Djari et al., 2026)	The digitalization construct of the port affects ship safety at Siwa Port.	The similarity with this research lies in the independent construct of port digitalization and the variable of ship safety.	There is a research object conducted at Siwa Port.	H2
3	(Akseptori & Praharsi, 2025)	The Construction of Ship Technology Innovations Affects Ship Safety in Paciran, Lamongan	The same as this research on the independent construct of ship technology innovation and the dependent variable of ship safety.	There is a research object conducted in Paciran, Lamongan.	H3

Discussion

Based on the background, problem formulation, research objectives, and previous research results mentioned above, the discussion in this study is as follows:

The Influence of Crew Competence on Ship Safety

Based on a literature review and relevant previous research, it is known that crew competence affects ship safety in Indonesia.

To avoid ship accidents and improve ship safety in Indonesia, the maritime transport operators (ships) need to pay attention to and implement four indicators of crew competence, which include: 1) Maritime knowledge: Ship operators and stakeholders are required to conduct continuous training and comprehensive testing related to international maritime regulations (SOLAS, MARPOL, STCW, COLREG) as well as local navigation rules. The ship's crew must be equipped with a deep understanding of navigation in narrow/congested waters, the characteristics of Indonesian sea lanes, and maritime weather based on the latest BMKG data; 2) Technical skills: Organizers must ensure that all officers and crew members (ABK) have valid skill certifications and are proficient in operating modern navigation equipment (such as ECDIS, ARPA Radar, AIS) and ship engine systems; 3) Decision-making ability: Officers must be provided with Crisis Management and Risk Assessment training to make quick, accurate, and rational decisions in critical situations; 4) Non-technical competencies: Implementing the Bridge Resource Management (BRM) and Engine Room Resource Management (ERM) systems to build interactive communication, assertive leadership, teamwork, and fatigue management (Sulistiana & Rachman, 2023).

If the organizers of maritime transport (ships) and stakeholders are able to pay attention to or implement the four indicators of crew competence, it will positively impact ship safety in Indonesia, which includes: 1) Ship seaworthiness: Technically competent crew members with adequate knowledge can ensure that all physical aspects of the ship, navigation systems, and machinery operate according to seaworthiness standards before departing from the port; 2) Ship safety management: Non-technical competence and good regulatory understanding will encourage full compliance with the ISM Code (International Safety Management Code) and the disciplined and consistent implementation of daily operational Standard Operating Procedures (SOPs); 3) Emergency preparedness: Sharp decision-making ability and regular emergency simulations make all crew members ready, alert, and not panicked in executing the Emergency Response Plan (such as fire handling, leakage, or Abandon Ship procedures); 4) Voyage risk control: The integration of maritime knowledge, technical skills, and precise decision-making enables the crew to identify, calculate, and minimize potential voyage hazards (such as collision, grounding, or high waves) early on (Suryani & Lusiani, 2024).

Previous research that has been conducted by (Artana, 2026), which states that there is an influence between the competence of the ship's crew and the safety of the ship in Indonesia.

The Impact of Port Digitalization on Ship Safety

Based on a literature review and relevant previous research, it is known that port digitalization affects ship safety in Indonesia.

To avoid ship accidents and improve ship safety in Indonesia, the maritime transport operators (ships) need to pay attention to and implement four indicators of port digitalization, which include: 1) Digital system integration: Ship operators and port authorities must interconnect ship information system platforms (Automatic Identification System / AIS and Ship Management System) with port digital platforms (Inaportnet, Vessel Traffic Management System / VTMS, and Port Management System); 2) Operational automation: Port operators and pilot operators must apply automation technology in the processes of berthing traffic, ship piloting, and cargo loading and unloading; 3) Information transparency: Port stakeholders together with BMKG and Maritime Navigation must provide an open digital platform that presents real-time data on maritime weather conditions, tidal levels, waterway depth, and ship traffic density; 4) Digital system security: Ship operators and port managers must strengthen cybersecurity infrastructure and data resilience. Port stakeholders together with BMKG and Maritime Navigation must provide an open digital platform that presents real-time data on maritime weather conditions, tidal movements, waterway depth, and ship traffic density; 4) Digital system security: Ship operators and port managers must strengthen cybersecurity infrastructure and data resilience. This step is taken by implementing navigation data encryption, protection against hacking of ship/port control systems, and providing backup recovery systems to ensure that pilotage operations and safety communications do not fail while sailing (Dewi, 2023).

If the organizers of maritime transportation (ships) and stakeholders are able to pay attention to or implement four indicators of port digitalization, it will positively impact ship safety in Indonesia, which includes: 1) Ship seaworthiness: The transparent digital inspection and verification of ship seaworthiness certificates make it easier for the Port Authority to detect technical deficiencies early, allowing only truly seaworthy ships to sail; 2) Ship safety management: Automated and integrated operational processes support the disciplined implementation of the ISM Code, minimize safety document manipulation, and accelerate the evaluation of ship operational risk management; 3) Emergency preparedness: The availability of interconnected digital systems allows port navigation transmitter stations and SAR/Basarnas teams to instantly detect distress signals, enabling quick and accurate evacuation and emergency assistance to be sent to the ship's location coordinates; 4) Voyage risk control: Transparency in weather information and digital-based ship movement monitoring (VTS) reduces the potential danger of ship collisions in busy waterways, decreases the risk of grounding due to shallow channels, and minimizes the threat of severe weather at sea (Safuan, 2022).

Previous research that has been conducted by (Djari et al., 2026), which states that there is an influence between port digitalization and ship safety in Indonesia.

The Impact of Ship Technology Innovation on Vessel Safety

Based on a review of the literature and relevant prior research, it is evident that ship technology innovation influences vessel safety in Indonesia.

To prevent accidents and enhance vessel safety in Indonesia, maritime transport operators must focus on and implement four key indicators of ship technology innovation: 1) Propulsion system innovation: Operators and shipyards must adopt modern, efficient, and highly reliable propulsion technologies (such as hybrid engines, azimuth thruster systems, or dual-fuel technology); 2) Navigation innovation: Operators must equip their fleets with digital-based, intelligent navigation and automation systems, such as state-of-the-art Electronic Chart Display and Information Systems (ECDIS), high-precision ARPA radar, integrated Automatic Identification Systems (AIS), and intelligent autopilot systems; 3) Predictive maintenance innovation: Operators and stakeholders (such as classification societies like BKI) must implement sensor-based (IoT) condition monitoring and data analysis technologies for critical engine components and the ship's hull; 4) Eco-friendly technology innovation: Operators need to integrate environmentally friendly technologies, such as Ballast Water Management

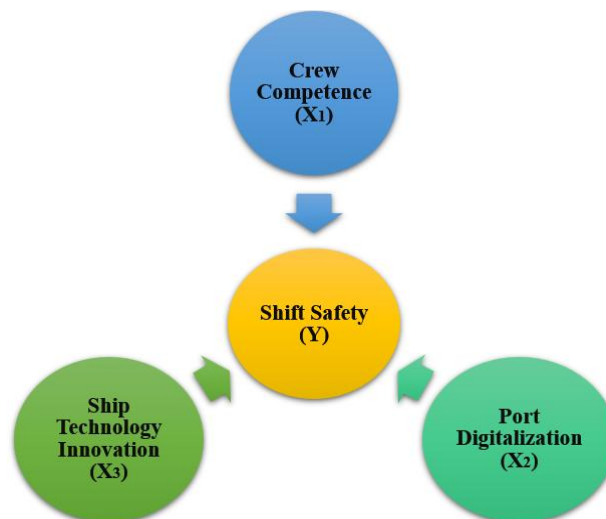
Systems (BWMS), emission scrubbers, and environmentally safe, automatic fire detection and suppression systems. The use of these technologies helps prevent internal explosions, engine room fires, and marine pollution, while also ensuring vessel stability during cargo loading (Feilie et al., 2025).

If maritime transport operators and stakeholders effectively adopt or implement four key indicators of ship technology innovation, it will positively impact vessel safety in Indonesia across the following areas: 1) Vessel seaworthiness: The implementation of predictive maintenance and propulsion innovations ensures that the physical condition, machinery, and hull structure consistently operate at peak performance, thereby facilitating the verification and issuance of seaworthiness certificates by the Harbormaster or BKI; 2) Vessel safety management: Innovations in navigation and digital engine condition monitoring support automated logbook recording and compliance with ISM Code standards, thereby minimizing the scope for human error in daily operational procedures; 3) Emergency preparedness: Advanced navigation technology integrated with automatic emergency signal transmitters (EPIRB/SART) and automated fire-suppression systems enables an instantaneous response to critical situations in the event of an accident; 4) Navigation risk control: A combination of reliable propulsion systems and smart navigation equipment drastically reduces the risks of grounding, collisions in congested waterways, and sinking due to adverse weather conditions (Mawardi, 2025).

Previous research has been conducted by (Akseptori & Praharsi, 2025), which states that there is an influence of ship technology innovation on ship safety in Indonesia.

Conceptual Framework

The conceptual framework is determined based on the problem statement, research objectives, and prior studies relevant to the topic of this literature-based research:



Source: Author, 2026

Figure 1. Conceptual Framework

Based on Figure 1 above, the constructs of crew competence, port digitalization, and vessel technology innovation influence vessel safety in Indonesia. However, in addition to these constructs, there are other influencing variables, including:

- Organizational safety culture: (Bisbey et al., 2021), (Saputra et al., 2021), (Kaltah et al., 2021).
- Cargo risk management: (Petek et al., 2026), (Freichel et al., 2022), (Putri, 2024).
- Infrastructure quality: (Rab et al., 2023), (Sénquiz-Díaz, 2021), (Wagner et al., 2022), (Ben Haj Ahmed et al., 2023).

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Based on a comprehensive literature synthesis, it is concluded that ship safety in Indonesia is significantly determined by three key constructs: 1) Crew Competence (X1), Port Digitalization (X2), and Ship Technology Innovation (X3). Strengthening indicators related to maritime knowledge, technical skills, port digital integration, and the adoption of smart navigation technologies has been shown both theoretically and empirically to reduce the vulnerability to ship accidents and enhance the operational seaworthiness of Indonesia's maritime sector.

Limitations

This study has a limitation in that it focuses on a qualitative synthesis based on a Systematic Literature Review (SLR), without involving direct quantitative field testing using questionnaires or primary statistical data. Furthermore, the literature scope is restricted to the 2021–2026 publication period, which may not fully capture all regulatory changes regarding non-convention shipping in highly remote waters.

Recommendations

Based on the conclusions and limitations outlined above, this study recommends the following: 1) For the Ministry of Transportation and Port Authorities: Mandating standardized, continuous certification for ship crews and accelerating the integration of digital Vessel Traffic Systems (VTS) across all Indonesian ports; 2) For Shipping Companies: Allocating investment toward upgrading ship navigation equipment with predictive maintenance capabilities to reduce the incidence of technical failures; 3) For Future Research: Quantitatively testing this conceptual model using SEM-PLS, drawing samples directly from ship captains, harbormaster authorities, and port management in both Western and Eastern Indonesia.

REFERENCES

- Akseptori, R., & Praharsi, Y. (2025). *GPS Forelite: Inovasi Teknologi LoRa Berbasis AI dalam Meningkatkan Keselamatan Nelayan Kecil di Paciran, Lamongan*.
- Ali, H., Candra Susanto, P., & Saputra, F. (2024). Faktor-Faktor Yang Mempengaruhi Manajemen Transportasi Udara: Teknologi Informasi, Infrastruktur dan Kompetensi Sumber Daya Manusia. *Jurnal Siber Transportasi Dan Logistik*, 1(4), 121–134. <https://creativecommons.org/licenses/by/4.0/>
- Arifian, N., Putra, R. W., & Alhafidh, N. I. (2025). Kebijakan Keselamatan Dan Keamanan Maritim Dalam Menunjang Sistem Transportasi Laut. *Jurnal Cakrawala Bahari*, 8(2), 277–286.
- Artana, N. K. D. A. P. (2026). PENGARUH KOMPETENSI CREW DALAM MELAKSANAKAN LASHING SYSTEM TERHADAP KESELAMATAN OPERASIONAL DI KMP SHITA GIRI NUSA. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 11(02), 223–231.
- Azhari, D. S., Afif, Z., Kustati, M., & Sepriyanti, N. (2023). Penelitian mixed method research untuk disertasi. *Innovative: Journal Of Social Science Research*, 3(2), 8010–8025.
- Behdani, B. (2023). Port 4.0: a conceptual model for smart port digitalization. *Transportation Research Procedia*, 74, 346–353.
- Belabyad, M., Kontovas, C., Pyne, R., & Chang, C.-H. (2026). Skills and competencies for operating maritime autonomous surface ships (MASS): a systematic review and bibliometric analysis. *Maritime Policy & Management*, 53(1), 1–26.
- Ben Haj Ahmed, R., Bouzir, A., Benhadj Mbarek, M. H., & Benammou, S. (2023). The impact of logistics performance index on port infrastructure quality: comparative study Tunisia Morocco. *Archives of Transport*, 67.

- Bisbey, T. M., Kilcullen, M. P., Thomas, E. J., Ottosen, M. J., Tsao, K., & Salas, E. (2021). Safety culture: An integration of existing models and a framework for understanding its development. *Human Factors*, 63(1), 88–110.
- Boulton, M. J., & Houghton, C. (2021). The Role of the Researcher in Qualitative Research: A Critical Reflection. *International Journal of Qualitative Methods*, 20, 1–12.
- Brunila, O.-P., Kunnaala-Hyrkki, V., & Inkinen, T. (2021). Hindrances in port digitalization? Identifying problems in adoption and implementation. *European Transport Research Review*, 13(1), 62.
- Dewi, S. M. (2023). Digitalisasi Pelabuhan dalam Perspektif Administrasi Publik Studi Kasus Penerbitan Surat Persetujuan Berlayar dengan Sistem Inaportnet. *Journal of Research and Development on Public Policy*, 2(2), 215–234.
- Djari, J. A., Nurhidayati, I. I., & Fitria, E. (2026). PENGARUH DIGITALISASI PELAYANAN MELALUI SISTEM INAPORTNET TERHADAP KINERJA OPERASIONAL KAPAL DI PELABUHAN SIWA. *JURNAL SAINS DAN TEKNOLOGI MARITIM*, 26(2), 322–328.
- Enda, D., Widodo, T., Efendi, Z., & Am, A. N. (2025). *OPTIMALISASI OPERASI DAN KESELAMATAN MARITIM BERBASIS TEKNOLOGI DAN KECERDASAN BUATAN*. CV PUSTAKA INSPIRASI MINANG.
- Feilie, A. A. L., Syafriyani, I., & Yulastina, R. (2025). INOVASI SISTEM KEAMANAN PELAYARAN (SIKAPAL UNTUK KESELAMATAN TRANSPORTASI LAUT KEPULAUAN SAPEKEN (STUDI DI DINAS KOMUNIKASI DAN INFORMATIKA). *Prosiding Seminar Nasional Fakultas Ilmu Sosial Dan Ilmu Politik*, 2(1), 215–225.
- Freichel, S. L. K., Wörtge, J. K., Haas, A., & ter Veer, L. (2022). Cargo accumulation risks in maritime supply chains: A new perspective towards risk management for theory, and recommendations for the insurance industry and cargo shippers. *Logistics Research*, 15(1), 1–19.
- Ghazaleh, M. A. (2023). Smartening up ports digitalization with artificial intelligence (AI): A study of artificial intelligence business drivers of smart port digitalization. *Management and Economics Review*, 8(1), 78–97.
- Gundić, A., Vujičić, S., Maglić, L., & Grbić, L. (2021). Reducing a human factor in cruise ships accidents by improving crew competences. *TransNav*, 15(2), 415–421.
- Hasnur, J., Putra, R. W., & Fitri, D. (2025). Penggunaan Sistem Teknologi Digital untuk Kelancaran Logistik Tugboat di PT. Kartika Samudra Adijaya. *Jurnal Cakrawala Bahari*, 8(2), 246–256.
- Heikkilä, M., Saarni, J., & Saurama, A. (2022). Innovation in smart ports: Future directions of digitalization in container ports. *Journal of Marine Science and Engineering*, 10(12), 1925.
- Iswanto, R. (2025). Peningkatan Efektivitas Program Pelatihan Maritim terhadap Kinerja Awak Kapal di MT Pearl Kaja. *Jurnal Ilmu Sosial Dan Humaniora*, 4(2), 371–382.
- Kalteh, H. O., Mortazavi, S. B., Mohammadi, E., & Salesi, M. (2021). The relationship between safety culture and safety climate and safety performance: a systematic review. *International Journal of Occupational Safety and Ergonomics*, 27(1), 206–216.
- Lehtimäki, M., & Teperi, A.-M. (2026). Developing behavioural markers of high-speed workboat crews' competencies. *International Journal of Occupational Safety and Ergonomics*, 32(1), 44–57.
- Mallouppas, G., & Yfantis, E. A. (2021). Decarbonization in shipping industry: A review of research, technology development, and innovation proposals. *Journal of Marine Science and Engineering*, 9(4), 415.
- Mawardi, K. (2025). Perkembangan Teknologi Sistem Pemadam Kebakaran Modern untuk Meningkatkan Keselamatan Kapal. *Ocean Engineering: Jurnal Ilmu Teknik Dan Teknologi Maritim*, 4(4), 11–39.
- Melnyk, O., Onyshchenko, S., Onishchenko, O., Lohinov, O., Ocheretna, V., & Dovidenko, Y.

- (2022). Basic aspects ensuring shipping safety. *Zeszyty Naukowe. Transport/Politechnika Śląska*, 117, 139–149.
- Melnyk, O., Shcherbina, O., Mykhailova, I., Obnyavko, T., & Korobko, T. O. (2023). Focused research on technological innovations in shipping industry: review and prospects. *Transport Development*, 1(16), 164–174.
- Nicholas, N. D., Dillah, A. R., Najmudin, F., & Verawati, K. (2024). Peluang dan Tantangan Sumber Daya Manusia dalam Penyelenggaraan Pelabuhan Cerdas (Smart Port) Nasional di Masa Revolusi Industri 4.0. *Amaliah: Jurnal Pengabdian Kepada Masyarakat*, 8(1), 286–298.
- Petek, E., Ozkan-Ozen, Y. D., & Yavas, V. (2026). Risk management in air cargo logistics: a bibliometric analysis. *International Journal of Management and Enterprise Development*, 25(1), 82–98.
- Putra, R. W., Wirza, E., Nazarwin, N., & Ardian, D. (2026). Ship Crew Behavior, Maritime Safety Culture, and Shipping Operational Performance. *Maritime Park: Journal of Maritime Technology and Society*, 189–205.
- Putri, M. A. (2024). Peran manajemen risiko dalam logistik pada manajemen rantai pasokan: Dwelling time di pelabuhan. *Jurnal Ilmiah Wahana Pendidikan*, 10(24), 63–71.
- Qiao, W., Liu, Y., Ma, X., & Lan, H. (2021). Cognitive gap and correlation of safety-I and safety-II: a case of maritime shipping safety management. *Sustainability*, 13(10), 5509.
- Rab, S., Yadav, S., Wan, M., & Aswal, D. K. (2023). An insight on quality infrastructure. In *Handbook of metrology and applications* (pp. 113–132). Springer.
- Rawson, A., Brito, M., Sabeur, Z., & Tran-Thanh, L. (2021). A machine learning approach for monitoring ship safety in extreme weather events. *Safety Science*, 141, 105336.
- Safuan, S. (2022). Penerapan Teknologi Digital di Pelabuhan Indonesia untuk Menurunkan Biaya Logistik Nasional Application of Digital Technology in Indonesian Ports and Contribute to Lowering National Logistics Costs. *Jurnal Manajemen Transportasi & Logistik (JMTRANSLOG)*, 9(03).
- Saputra, Y., Widyantoro, M., Eko Putra, F., & Nika Andini, P. (2021). Analisis Safety Performance Index Dengan Pendekatan Behavior-Based Safety Pada Industri Manufaktur Komponen Otomotif. *Journal of Industrial and Engineering System*, 2(1), 13–20. <https://doi.org/10.31599/jies.v2i1.492>
- Sénquiz-Díaz, C. (2021). Transport infrastructure quality and logistics performance in exports. *ECONOMICS-Innovative and Economics Research Journal*, 9(1), 107–124.
- Sulistiana, O., & Rachman, S. (2023). ANALISIS KOMPETENSI AWAK KAPAL PENYEBERANGAN DI KAWASAN TIMUR INDONESIA. *Journal of Syntax Literate*, 8(7), 4832.
- Suryani, D., & Lusiani, L. (2024). Pengaruh Sistem Navigasi di atas Kapal Terhadap Kompetensi Crew Kapal MV. Mochtar Prabu Mangkunegara. *Saintara: Jurnal Ilmiah Ilmu-Ilmu Maritim*, 8(2), 45–53.
- Susanto, P. C., Arini, D. U., Marlita, D., Yuntina, L., & Saribanon, E. (2024). Mixed Methods Research Design Concepts: Quantitative, Qualitative, Exploratory Sequential, Exploratory Sequential, Embedded and Parallel Convergent. *International Journal of Advanced Multidisciplinary (IJAM)*, 3(3), 471–485.
- Susanto, P. C., Sawitri, N. N., Ali, H., & Rony, Z. T. (2024). ANALYSIS OF COMPETENCY AND JOB SATISFACTION ON THE PERFORMANCE OF WAREHOUSE STAFF IN LOGISTICS COMPANIES IN JAKARTA. *ICHES: International Conference on Humanity Education and Society*, 3(1).
- Teyansyah, S. P., Permana, E., & Larutama, W. (2026). Keterbatasan Indikator LPI dalam Menilai Kinerja Logistik Negara Kepulauan: (Studi Kasus: Indonesia dan Filipina). *Jurnal Teknologi Dan Manajemen Industri Terapan*, 5(2), 1248–1259.
- Wagner, N., Kotowska, I., & Pluciński, M. (2022). The impact of improving the quality of the port's infrastructure on the shippers' decisions. *Sustainability*, 14(10), 6255.

- Wahid, A., Jinca, M. Y., Rachman, T., & Malisan, J. (2024). *Influencing Factors of Safety Management System Implementation on Traditional Shipping*. *Sustainability* 2024, 16, 1152.
- Wu, B., Tang, Y., Yan, X., & Soares, C. G. (2021). Bayesian Network modelling for safety management of electric vehicles transported in RoPax ships. *Reliability Engineering & System Safety*, 209, 107466.
- Xiao, G., Wang, Y., Wu, R., Li, J., & Cai, Z. (2024). Sustainable maritime transport: A review of intelligent shipping technology and green port construction applications. *Journal of Marine Science and Engineering*, 12(10), 1728.
- Yang, Y.-C., & Hsieh, Y.-H. (2024). The critical success factors of smart port digitalization development in the post-COVID-19 era. *Case Studies on Transport Policy*, 17, 101231.