



Implementation of Digital Transformation in Ship Safety Management Through the Integration of FMEA and Maritime Information Systems

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Abstract. The global maritime industry is undergoing a fundamental paradigm shift driven by the wave of digital transformation. This study aims to analyze and evaluate the influence of integrating the Failure Mode and Effects Analysis (FMEA) method into digital systems and implementing a Maritime Information System (SIMAR) on the digital transformation of ship safety management in Indonesia. Using a mixed-methods approach with a case study of the MT. Rosa XVIII vessel owned by PT. Bahari Nusantara Makassar, data were collected through questionnaires from 19 expert respondents (ship officers, engineers, SIMAR operators, and operational managers), supplemented by in-depth interviews and direct operational observations. Quantitative data were analyzed using multiple linear regression with SPSS. The results show that, partially, FMEA integration has a positive and significant effect on digital management transformation, with a t-value of 2.835 (sig. 0.012). The Maritime Information System (SIMAR) has a highly dominant influence, with a t-value of 8.003 (sig. 0.000). Simultaneously, both independent variables significantly affect the dependent variable, with an F-value of 117.038 (sig. 0.000) and an Adjusted R Square of 0.936. This indicates that 93.6% of the variation in the digital transformation of ship safety management can be explained by FMEA integration and SIMAR optimization. This integrated model transforms conventional maritime safety management from a reactive and manual approach into a proactive, dynamic, real-time data-driven decision-support system that is essential for the safety of the national shipping fleet.

Keywords: Digital FMEA; Digital Transformation; Dynamic RPN; Maritime Information System; Ship Safety.

1. INTRODUCTION

The global maritime industry is currently experiencing a massive shift driven by rapid advances in digital technology. Modern ships no longer operate solely under the shadow of traditional challenges such as extreme weather changes, geographical navigation constraints, and purely mechanical failures. Today, external pressures such as demands for logistics cost efficiency, fleet operational transparency, and strict compliance with various international regulations are forcing the shipping industry to fundamentally restructure its operational governance. Amid this transformation, ship safety management has emerged as the most critical pillar. Safety at sea is no longer merely a matter of fulfilling formal legal checklists, but has become a determinant of business reputation, shipping service quality, and a tangible form of shipping companies' social responsibility for protecting human life and the marine environment.

The phenomenon of maritime digitalization is characterized by the emergence of advanced technology ecosystems such as the Internet of Things (IoT), big data analytics, cloud computing, digital twins, and Artificial Intelligence (AI). These technologies provide significant opportunities for ship safety systems to transform from conventional paper-based

manual procedures into dynamic, automated, real-time data-driven monitoring systems. Through the integration of IoT sensors and advanced data analytics, the early detection of disruptions in vital onboard equipment can be significantly improved, while the potential for accidents can be minimized through predictive monitoring. The digitalization of safety systems is no longer a luxury innovation option, but an essential operational requirement for the sustainability of shipping businesses in the modern era.

Within the national context, for an archipelagic country such as Indonesia, the utilization of information technology has a dual strategic role. In addition to improving commercial safety, digital technology strengthens national maritime defense and security, accelerates inter-island communication, simplifies incident data collection, and speeds up emergency response (Search and Rescue/SAR) at sea. Nevertheless, technology adoption in the field is often constrained by significant barriers, including low digital literacy among seafarers, resistance to changes in work culture, and limited information technology infrastructure in many domestic shipping companies, particularly small and medium-sized operators.

The Maritime Information System (SIMAR) has emerged as an innovation hub for integrating the shipping industry's digital ecosystem. The SIMAR platform centrally integrates safety data flows, fleet operational monitoring, and ship document management. Geographic Information Systems (GIS), Automatic Identification Systems (AIS), and wireless sensors have been widely applied for navigation and vessel position-tracking management. Unfortunately, the implementation of integrated information system platforms specifically dedicated to technical safety risk management onboard remains very limited. The majority of shipping companies in Indonesia still manage their Safety Management Systems (SMS) manually.

Conventional SMS, as required by the ISM Code and SOLAS, has proven effective in maintaining basic administrative compliance. However, the fundamental weaknesses of manual systems include heavy dependence on periodic physical reporting by crew members, time lags in transmitting data to shore-based headquarters, and high vulnerability to human error. Meanwhile, investigation data from transportation safety committees worldwide consistently indicate that human error remains a dominant contributor in the chain of causes of maritime accidents. Therefore, the presence of a digital decision-support system onboard is crucial for strengthening crew situational awareness when facing dynamic and high-risk maritime operating conditions.

On the other hand, the Failure Mode and Effects Analysis (FMEA) risk-analysis method in Indonesia's maritime industry is generally still implemented as a static paper-based

document updated once a year solely for safety certificate audit purposes. International academic research has demonstrated that FMEA can be completely transformed when integrated into digital systems. When FMEA parameters are powered by real-time IoT sensor data streams, the Risk Priority Number (RPN) can be calculated automatically and dynamically, providing accurate early warnings before catastrophic failures occur in machinery systems or ship safety equipment.

Based on this background, a research and practical implementation gap is evident in Indonesia concerning how to integrate the FMEA risk-analysis method with Maritime Information System infrastructure to develop a digital transformation model for ship safety management. This study seeks to bridge that gap through an in-depth case study of the MT. Rosa XVIII tanker managed by PT. Bahari Nusantara Makassar, testing both partial and simultaneous causal relationships to provide a scientific and practical foundation for the digitalization of national maritime safety.

2. LITERATURE REVIEW

Concept of Digital Transformation in the Maritime Sector

Digital Transformation (DT) in the maritime industry is defined as a profound and systematic reconstruction of all business processes, organizational structures, human-resource competencies, and work culture through the radical integration of digital technologies. DT goes beyond digitization (the conversion of analog data into digital form) and digitalization (the automation of specific work processes). DT focuses on value creation and organizational agility in responding to operational uncertainty at sea. The theoretical foundation of maritime DT rests on Cyber-Physical Systems (CPS) architecture, in which physical assets such as tankers, cargo, and machinery are directly connected to cloud-computing networks through high-speed smart sensors, giving rise to globally connected concepts such as Smart Ships and Smart Ports.

The implementation of DT is driven by several key technology pillars. First, the maritime Internet of Things (IoT) acts as the ship's digital nervous system, continuously collecting physical machinery parameters such as vibration, temperature, oil pressure, and fuel flow rate. These data facilitate the transition from time-based maintenance to predictive maintenance, significantly reducing operational downtime and preventing fatal failures at sea. Second, Big Data Analytics and AI process billions of raw IoT data points into strategic insights, such as weather-prediction-based voyage-route optimization, fuel-consumption pattern analysis to comply with International Maritime Organization (IMO) decarbonization

regulations concerning the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), and detection of anomalous fleet operating behavior.

Maritime Information System (SIMAR)

Conceptually, the Maritime Information System (SIMAR) is an integrated information technology infrastructure specifically designed to collect, process, analyze, store, and distribute maritime data to support operational decision-making at sea and ashore. SIMAR represents a concrete implementation of the e-Navigation program initiated by the IMO to harmonize global electronic navigation systems. SIMAR architecture consists of three main layers: (1) the Acquisition Layer, integrating Automatic Identification System (AIS) sensors, radar, weather sensors, Electronic Navigational Charts (ENC) based on the S-100 Universal Hydrographic Data Model, and satellite data; (2) the Processing and Storage Layer, consisting of a centralized Big Data-enabled database for data cleansing, normalization, and fusion; and (3) the Dissemination Layer, consisting of graphical interfaces such as the Electronic Chart Display and Information System (ECDIS), Vessel Traffic Services (VTS) dashboards, and the Maritime Single Window (MSW) for simplifying ship administrative reporting to port authorities.

Failure Mode and Effects Analysis (FMEA)

FMEA is a structured and proactive system-reliability evaluation methodology used to identify potential failure modes in components, assess the consequences of failures for the system as a whole, and determine priority mitigation actions before failures occur in the field. The main quantitative parameter in conventional FMEA is the Risk Priority Number (RPN), which is the product of three assessment dimensions on a scale of 1–10:

$$\text{RPN} = \text{Severity (S)} \times \text{Occurrence (O)} \times \text{Detection (D)}$$

where Severity (S) represents the degree of severity of the failure impact, Occurrence (O) indicates the frequency or probability of failure, and Detection (D) measures the ability of existing control systems to detect a failure before its effects spread. In conventional ship safety management, FMEA is often criticized for being static and subjective. Digital transformation revolutionizes FMEA by replacing subjective manual inputs with real-time sensor data, allowing the values of 'O' and 'D' to be updated dynamically by artificial intelligence algorithms.

Ship Safety Management and International Regulations

Ship safety management must comply with the international legal framework established by the IMO, with the International Convention for the Safety of Life at Sea (SOLAS) 1974 and the International Safety Management Code (ISM Code) as its main pillars. The ISM Code specifically requires every shipping company to establish, implement, and

maintain a Safety Management System (SMS) covering safe ship-operation procedures, emergency response, accident reporting, and maintenance of ships and their equipment. Integrating digital FMEA into the digital SMS framework strengthens regulatory compliance by providing transparent digital audit evidence and improving the effectiveness of occupational safety and health (OSH) risk management onboard in real time.

3. RESEARCH METHODS

This research was conducted within the operational environment of PT. Bahari Nusantara, based in Makassar, Indonesia, focusing on the MT. Rosa XVIII tanker as the case-study object. Data collection and field analysis were carried out over a three-month period, from January to March 2026. The methodology employed a mixed-methods approach using a sequential explanatory design, combining quantitative analysis to test statistical hypotheses with qualitative analysis to explore in depth the implementation constraints, crew perceptions, and mechanisms of technology integration in the field.

The population comprised all personnel directly involved in the safety management system and information-technology operations onboard MT. Rosa XVIII, as well as relevant shore-based staff. Sampling used purposive sampling with inclusion criteria consisting of maritime technical competence, seagoing professional certification, and direct interaction with the company's SIMAR platform. This process yielded 19 expert respondents consisting of the Master, Navigation Officers, Engineering Officers, Chief Engineer, Safety Officer, shore-based SIMAR Operators, and shipping-company Operations Managers.

Primary data were collected through structured questionnaires using a 1–5 Likert scale to measure respondents' perceptions of three operational variables: Digital FMEA Integration (X1), Maritime Information System Use (X2), and Digital Transformation of Ship Safety Management (Y). To strengthen the quantitative data, in-depth interviews were conducted with the Chief Engineer and Master, along with direct observation of SIMAR dashboard functionality on the bridge and in the Engine Control Room. Secondary data were obtained from internal documents including machinery maintenance logbooks, incident reports, safety SOPs, and ship classification certificates.

Quantitative data analysis began with instrument-quality testing using validity tests based on Corrected Item-Total Correlation (validity threshold ≥ 0.30) and comparison of the calculated r-value with the table r-value at a 5% significance level ($n=19$, table $r=0.388$). Reliability testing was conducted by calculating Cronbach's Alpha (reliability threshold $>$

0.60). After the instrument passed the quality tests, multiple linear regression analysis was performed using IBM SPSS version 26 with the following mathematical model:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \varepsilon$$

Hypothesis testing was conducted partially using the t-test to examine the effect of each independent variable, and simultaneously using the F-test to assess the significance of the regression model as a whole, along with analysis of the coefficient of determination (Adjusted R²) to measure the total contribution of the independent variables to the dependent variable.

4. RESULTS AND DISCUSSION

RESULT

General Overview and Respondent Characteristics

PT. Bahari Nusantara Makassar is a national shipping company operating a tanker fleet for energy distribution in Indonesian waters. The MT. Rosa XVIII, which serves as the object of this study, is equipped with basic IT infrastructure, an automatic AIS transponder, a modern ECDIS system, and several wireless machinery telemetry sensors connected to shore via satellite, making it an ideal case-study object for examining the phenomenon of digital transformation in ship safety management. The demographic profiles of the 19 expert respondents participating in this study are presented in Tables 1 and 2 below.

Table 1. Expert Respondent Work-Experience Profile.

Work-Experience Category	Frequency (Persons)	Percentage (%)
1–5 Years	4	21.1%
6–10 Years	10	52.6%
>10 Years	5	26.3%
Total	19	100.0%

Table 2. Respondents' Highest Educational Attainment.

Educational Level	Frequency (Persons)	Percentage (%)
Secondary / Senior High School / Maritime Vocational	11	57.9%
Diploma III (D3) in Maritime Studies	2	10.5%
Applied Bachelor's / Bachelor's Degree (S1)	6	31.6%
Total	19	100.0%

The demographic data show that the majority of personnel (78.9%) have more than 6 years of work experience, indicating a very high level of practical maturity in understanding tanker operational risks. In terms of education, there is a balanced combination of secondary maritime vocational graduates (ANT/ATT IV–V) accounting for 57.9% and highly educated officers (D3, S1, or ANT/ATT I–II) accounting for 42.1%, who possess stronger analytical capacity in operating digital safety-management computing systems.

Instrument Quality Analysis (Validity and Reliability)

Instrument validity testing was conducted on all questionnaire items. Based on the SPSS data-processing results, the validity indicators are summarized in Table 3.

Table 3. Summary of Validity Test Results for Variables X1, X2, and Y.

Research Variable	Calculated r-Value Range	Table r-Value (n=19, $\alpha=5\%$)	Validity Status
Digital FMEA Integration (X1)	0.410–0.717	0.388	All Items Valid
Maritime Information System (X2)	0.485–0.718	0.388	All Items Valid
Digital Management Transformation	0.391–0.725	0.388	All Items Valid

Because all calculated r-values for each questionnaire item across all variables are greater than the table r-value (0.388), all instruments are declared valid and capable of accurately measuring the theoretical parameters. Instrument reliability was then evaluated using Cronbach's Alpha coefficients, as presented in Table 4.

Table 4. Reliability Test Results for Variable Constructs.

Research Variable Construct	Cronbach's Alpha Coefficient	Minimum Threshold	Reliability Conclusion
Digital FMEA Integration (X1)	0.790	0.60	Highly Reliable
Maritime Information System (X2)	0.751	0.60	Highly Reliable
Digital Management Transformation (Y)	0.657	0.60	Reliable

All variables have Cronbach's Alpha coefficients above the critical threshold of 0.60. This result confirms that the questionnaire instrument has strong internal consistency and is free from random chance elements, making it suitable as a basis for regression testing.

Multiple Linear Regression Analysis

Through processing the questionnaire data using IBM SPSS, the multiple regression coefficients summarized in Table 5 were obtained.

Table 5. Multiple Linear Regression Coefficients.

Model	Unstandardized Coefficients		Standardized Coefficients	t- Hitung	Sign
	B	Std. Error	Beta (β)		
(Constant)	6,614	1,845	-	3,585	0,003
Integrasi FMEA Digital(X1)	0,209	0,074	0,212	2,835	0,012
Sistem Informasi Maritim(X2)	0,723	0,090	0,745	8,003	0,000

Based on the parameter estimates in Table 5, the following multiple linear regression equation was obtained:

$$Y = 6.614 + 0.209 \cdot X1 + 0.723 \cdot X2$$

The interpretation of the regression equation is as follows: (1) the constant (α) of 6.614 indicates that if Digital FMEA Integration (X1) and Maritime Information System (X2) are zero or held constant, the level of digital transformation in ship safety management remains at

a positive baseline value of 6.614, indicating the presence of other external factors (such as internal regulatory policies or the Master's leadership) that also drive digitalization; (2) the regression coefficient of X1 of 0.209 is positive, indicating a direct relationship in which every one-unit increase in the quality of FMEA integration into the digital system increases the digital transformation score of safety management by 0.209 units; (3) the regression coefficient of X2 of 0.723 is positive, indicating a very strong direct effect in which every one-unit increase in the optimization of the Maritime Information System platform increases the digital transformation score of safety management by 0.723 units.

Partial (t-test) and Simultaneous (F-test) Hypothesis Testing

Hypothesis testing was conducted to verify the statistical significance of the effects found both partially and simultaneously. Partial hypothesis evaluation was based on the t-test results in Table 5, with the table t-value for degrees of freedom $df = 19 - 2 - 1 = 16$ at $\alpha = 5\%$ equal to 2.120.

Partial Test of Variable X1 (Digital FMEA Integration): The t-test results show a calculated t-value of 2.835 for Digital FMEA Integration. Because the calculated t-value (2.835) > the table t-value (2.120) and the significance p-value (0.012) < 0.05, H0 is rejected and H1 is accepted. This demonstrates that, partially, the integration of FMEA into the digital system has a positive and significant effect on the digital transformation of ship safety management on MT. Rosa XVIII.

Partial Test of Variable X2 (Maritime Information System): The t-test results show a calculated t-value of 8.003 for the Maritime Information System. Since the calculated t-value (8.003) is far greater than the table t-value (2.120), and the significance p-value (0.000) < 0.05, H0 is rejected and H2 is accepted. This demonstrates that the Maritime Information System (SIMAR) has a highly dominant, positive, and significant effect on the digital transformation of ship safety management.

Next, simultaneous hypothesis testing was conducted using the ANOVA (F-test) to ensure the overall adequacy of the regression model. The calculated F-value results are summarized in Table 6.

Table 6. Results of Simultaneous Analysis of Variance (F-test).

Regression Model	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	Calculated F	Significance (Sig.)
Regression	348.564	2	174.282	117.038	0.000b
Residual	23.826	16	1.489	-	-
Total	372.390	18	-	-	-

Based on the ANOVA test in Table 6, the calculated F-value is 117.038 with a significance probability of 0.000. Because the p-value (0.000) is far below the significance

level $\alpha = 0.05$, H_0 is rejected and H_3 is accepted. This finding confirms that, simultaneously, Digital FMEA Integration (X1) and the Maritime Information System (X2) significantly affect Digital Transformation of Ship Safety Management (Y) at PT. Bahari Nusantara.

To measure the extent to which the independent variables contribute to explaining the dependent variable, a coefficient of determination analysis was conducted, as presented in Table 7.

Table 7. Analysis of the Coefficient of Determination.

Model	Correlation Coefficient (R)	R Square (R ²)	Adjusted R Square	Std. Error of the Estimate
1	0.968	0.937	0.936	1.2203

Based on Table 7, the Adjusted R Square obtained is 0.936. This value indicates very high predictive strength, with 93.6% of the variation in Digital Transformation of Ship Safety Management (Y) being simultaneously explained by Digital FMEA Integration (X1) and the Maritime Information System (X2). The remaining 6.4% is attributable to other variables outside the regression model that were not examined in this study, such as the Master's leadership style, IT investment budget, or external regulations of the Ministry of Transportation.

The specific partial contribution analysis (through the squared SPSS partial correlation coefficients) shows that Digital FMEA Integration contributes an effective 33.4% to the variation in Y. Meanwhile, the Maritime Information System contributes a substantially larger 80.1% to the variation in Y. This clarifies the strategic position of information-system infrastructure as an essential enabler before digital risk-analysis methods can be effectively implemented.

DISCUSSION OF RESEARCH FINDINGS

The scientific findings of this study provide an in-depth understanding of the dynamics of digital technology implementation in the national shipping safety sector. The positive and significant effect of Digital FMEA Integration supports the modern risk-management theory proposed by Stamatis. When the FMEA risk-analysis method is transferred from a static paper-based document to an integrated digital platform, the efficiency and speed of hazard identification increase substantially. On MT. Rosa XVIII, this integration was implemented through the digitalization of risk-assessment sheets for the main engine, propulsion system, and cargo pumps. By incorporating Severity, Occurrence, and Detection matrices into computer algorithms, ship officers no longer need to subjectively estimate the risk status of components. Whenever operational parameters change, the digital system helps formulate

structured and scheduled risk-mitigation recommendations, reducing the likelihood of human error in critical decision-making.

Furthermore, the dominant effect demonstrated by the Maritime Information System (SIMAR) variable confirms organizational information-systems theory and the IMO e-Navigation framework. SIMAR acts as a technological backbone that breaks down conventional information silos between ships at sea and shore-based operational management. Implementation of the SIMAR platform on MT. Rosa XVIII enables real-time data fusion from GPS sensors, AIS, navigation radar, and digital machinery logbooks (e-logbooks) on a single dashboard. Based on in-depth interviews with the Master, the presence of this digital dashboard significantly enhances officers' situational awareness on the bridge, particularly when transiting dense and accident-prone routes such as the Makassar Strait. The availability of real-time information on surrounding vessel positions, severe-weather forecasts, and machinery health status facilitates preventive action by the Master to avoid collisions or catastrophic mechanical failures.

The most revolutionary impact occurs when these two variables interact simultaneously, with an adjusted R-square contribution reaching an impressive 93.6%. This figure empirically demonstrates that digital transformation of ship safety management cannot reach an optimal level if a shipping company focuses on only one aspect. Providing an advanced SIMAR platform without a risk-analysis method such as digital FMEA would merely overwhelm crew members with large volumes of raw data without operational meaning (data overload). Conversely, implementing digital FMEA without reliable SIMAR communication and data-storage infrastructure would cause risk analysis to lose its real-time and predictive characteristics, reverting to a static and non-adaptive document.

The harmonious integration of SIMAR and digital FMEA gives rise to a new maritime safety-management model referred to as Cyber-Physical Maritime Safety Management. In this integrated model, IoT sensor data processed by SIMAR continuously flows into the digital FMEA module. This data flow automatically updates the Occurrence value (failure probability based on physical component wear trends) and the Detection value (effectiveness of sensor alarms) periodically. Consequently, the resulting RPN (Risk Priority Number) becomes a Dynamic RPN that fluctuates according to the vessel's actual health condition rather than remaining a static figure estimated on paper during annual audits. This model underpins a radical shift from conventional reactive safety management (acting after an accident occurs) to future-oriented proactive and predictive safety management (mitigating risks before mechanical failures develop into actual accidents at sea).

Although this integrated model offers remarkable scientific advantages, field observations and interviews revealed several critical challenges in the Indonesian shipping context. First is the limited satellite data-connectivity infrastructure in Indonesia's remote waters, which often causes delays in dashboard data synchronization between ships and shore offices. Second, and most critically, is the digital-literacy gap among seafarers. Crew members with secondary-level educational backgrounds require longer adaptation periods and intensive training to use this digital safety dashboard optimally without causing new forms of cognitive fatigue (technostress). Therefore, the success of digital transformation in ship safety management ultimately remains dependent on shipping companies' investment readiness to improve seafarers' digital competencies.

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSION

Based on the quantitative data analysis, statistical hypothesis testing, and qualitative discussion, several main conclusions can be drawn as follows:

- a. Partially, Digital FMEA Integration (X1) has a positive and significant effect on Digital Transformation of Ship Safety Management (Y) on MT. Rosa XVIII, with a calculated t-value of 2.835 and significance of 0.012. The application of structured risk-analysis methods in digital format has been proven to accelerate hazard identification and minimize vulnerabilities caused by human error.
- b. Partially, the Maritime Information System / SIMAR (X2) has a highly dominant, positive, and significant effect on Digital Transformation of Ship Safety Management (Y), with a calculated t-value of 8.003 and significance of 0.000. The provision of real-time navigation and vessel-condition data through the integrated SIMAR platform has been proven to be a key driver in improving crew situational awareness and the efficiency of coordination with shore-based management.
- c. Simultaneously, Digital FMEA Integration (X1) and the Maritime Information System (X2) significantly affect Digital Transformation of Ship Safety Management (Y), with a calculated F-value of 117.038 (sig. 0.000). This integrated regression model demonstrates very strong predictive accuracy, with an Adjusted R Square of 0.936, indicating that 93.6% of the success of digital transformation in safety management is determined by the harmonious combination of maritime information-system infrastructure and digitalization of the risk-analysis methodology.

RECOMMENDATIONS

To optimize the utilization of the results of this study in the future, several strategic recommendations are proposed for the relevant stakeholders:

- a. For the Shipping Company (PT. Bahari Nusantara): The company is advised to immediately strengthen its technology investment commitment by integrating a dynamic FMEA module into the existing SIMAR platform so that RPN values can be automatically updated by machinery sensors. The company should also conduct regular digital-literacy training programs (digital maritime training) for all crew members to reduce resistance to work-culture changes and ensure optimal use of the safety dashboard.
- b. For Maritime Regulators (Ministry of Transportation/KSOP): The results of this study are expected to provide scientific input for formulating policies on standardizing the digitalization of ship seaworthiness in Indonesia. The government can encourage mandatory integration of electronic ship-safety reporting systems directly connected to the national port-monitoring system.
- c. For Future Researchers: Given the limitation of the sample size in this study (19 expert respondents on a single tanker), future researchers are advised to expand the research population to include various ship types (such as bulk carriers, passenger ships, or autonomous ships/MASS) and add new exogenous variables such as maritime cybersecurity and organizational safety culture.

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