

Implementing Risk Management to Enhance Navigation Safety in Indonesian Maritime Domain

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Abstract

This study examines the implementation of risk management to improve maritime safety at Teluk Bayur Port, aiming to (1) analyze risk management practices and (2) identify principal risk factors. A descriptive case-study design with supporting quantitative analysis was applied; data were collected by field observation, questionnaires (n = 90, purposive sampling) and documentation; analyses included descriptive percentages, simple regression, SWOT and risk assessment. Results show high awareness of risk management (87.7%) but a significant training gap (53.8% never trained). The main risk factor is adverse weather (82.7%), followed by inadequate infrastructure and human error. Quantitative analysis indicates a positive and significant effect of risk management implementation on maritime safety (regression coefficient $b = 0.432$; $r = 0.860$; $R^2 = 0.739$; $p = 0.000$), meaning 73.9% of safety variance is explained by implementation. Mitigation measures involve digital integration, training, and emergency procedures. Conclusion: risk management at Teluk Bayur is underway but not fully optimal or integrated; recommendations include regular training and simulations, infrastructure and navigation equipment modernization, strengthened inter-agency coordination, and data-driven risk management to shift from reactive to predictive and preventive safety practices.

Keywords: Risk Management; Navigation Safety; Indonesian Maritime Domain

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INTRODUCTION

Indonesia is one of the world's largest archipelagic countries, featuring a dense and functionally diverse maritime network ranging from cargo transport to inter-island passenger services. Its complex geography, characterized by an extensive coastline, ocean currents, and seasonal weather adds operational challenges to maritime safety (Sunitiyoso et al., 2022). In recent years, increases in commercial and fishing vessel traffic have amplified the potential for maritime accidents in national waters. Moreover, limited infrastructure, varying safety standards across ports, and uneven surveillance capacity complicate integrated risk management. These phenomena call for a systematic risk-management approach to sustainably improve maritime safety (Arifin et al., 2024). Consequently, studies on the implementation of risk management are both relevant and urgent in the Indonesian maritime context.

Teluk Bayur Port in West Sumatra is a major facility that serves cargo and passenger flows for western Sumatra and its hinterland. Physically, Teluk Bayur faces challenges arising from a relatively narrow bay morphology, channels that require precision maneuvers, and dependence on tidal conditions that affect navigable depths (Prabowo et

al., 2024). Bulk cargo and container handling activities, together with passenger and fishing vessel traffic, create heterogeneous and periodically dense traffic patterns. Furthermore, port development over recent decades has not always been accompanied by commensurate improvements in surveillance capacity and comprehensive risk-mitigation systems (Wu & Yang, 2024). These conditions increase the likelihood of operational safety incidents such as groundings, collisions, and cargo-handling accidents (Zhang et al., 2022). Against this background, Teluk Bayur constitutes an appropriate case study for analyzing the application of risk management in the context of maritime safety.

Maritime safety is crucial because it has direct implications for the lives of seafarers and passengers as well as for cargo integrity and logistics supply chains. For seafarers and crew, safety system failures can result in injuries or loss of life, making the protection of human life a primary priority (Wang et al., 2022). For the cargo and logistics sector, maritime incidents cause economic losses through damage to goods, delivery delays, and increased insurance costs (Pauksztat et al., 2022). In addition, maritime accidents may produce extensive environmental impacts, for example spills of hazardous substances that damage coastal ecosystems and local livelihoods. Therefore, safety is not merely a matter of regulatory compliance but also concerns operational continuity and port reputation (Bhatia et al., 2024). Strengthening preventive and mitigation measures is thus a synergistic necessity for stakeholders.

Risk management offers a systematic framework to identify, assess, and control hazards threatening maritime safety. The approach encompasses risk identification, probability and impact analysis, prioritization of mitigation measures, and continuous monitoring and evaluation (Meléndez & Goerlandt, 2025). By implementing risk management, ports and vessel operators can design operational procedures, navigation systems, and emergency plans that are more adaptive to actual field conditions (Ma et al., 2023). Moreover, risk management encourages the involvement of multiple parties, such as port authorities, masters, ship agents, and stevedores as part of a shared safety culture. Effective implementation also requires accurate operational data and ongoing personnel training programs (Phanphichit & Bartusevičienė, 2024). Thus, risk management becomes an important instrument for reducing both the frequency and the consequences of maritime incidents.

Several previous studies have examined the relationship between risk management and maritime safety in port and regional waters contexts. Liou & Tseng (2024) highlighted the effectiveness of checklist-based risk assessment procedures in reducing navigational incidents at regional ports, reporting a decrease in minor events following the adoption of new protocols. Relling et al., (2022) investigated the role of technologies such as Vessel Traffic Service (VTS) and Automatic Identification System (AIS) in improving early hazard detection and reducing collision risk in port approaches. Sprajcer et al., (2022) focused on human factors, finding that maneuver simulation training and fatigue management significantly reduce operational errors. Laine et al., (2021) evaluated the implementation of an integrated risk-management framework in archipelagic ports, emphasizing the need to align local policies with international standards for greater effectiveness. Overall, prior research demonstrates the benefits of risk management while also indicating implementation gaps in ports that possess distinctive geographic and operational characteristics, such as Teluk Bayur.

Given the complexity of threats and the consequences of maritime incidents, structured and contextualized risk-management implementation is key to ensuring safe operations. Preventive measures such as risk mapping, enhancement of navigation infrastructure, emergency communication procedures, and regular training can reduce the

probability of hazardous events and minimize their impacts when they occur (Tao et al., 2024). Successful implementation also depends on interagency coordination and port management commitment to provide technical and human resources. In addition, measuring safety performance through quantifiable indicators enables continuous evaluation and evidence-based improvement (Mitra et al., 2024). Therefore, a study that assesses how risk management is applied at Teluk Bayur will offer practical and policy contributions to strengthening maritime safety in Indonesian waters (Rahayu et al., 2024). This research is also expected to yield recommendations adaptable by other ports facing similar challenges.

Based on the foregoing background, this study aims to provide an empirical analysis of the implementation of risk management in efforts to enhance maritime safety at Teluk Bayur Port. Specifically, the study will: (1) analyze the implementation of risk management to improve maritime safety at Teluk Bayur Port; and (2) identify the main risk factors that potentially disrupt maritime safety at the port.

METHOD

This study employed a qualitative descriptive method with a case-study approach to examine how the implementation of risk management can enhance maritime safety in Indonesian waters, using Teluk Bayur Port as the case study. The study focused on the identification, evaluation, and mitigation of risks encountered during maritime operations as well as on the implementation of effective safety procedures (Ma et al., 2024). Teluk Bayur was selected due to its distinctive operational characteristics and geographic challenges compared with other ports, thereby providing a comparative perspective on risk-management practice. The research also evaluated the extent to which the applied risk-management system can anticipate potential hazards and reduce accidents in the navigational area. Data were collected through field observation, questionnaires, and documentation.

The study population comprised all organizational units responsible for maritime safety at Teluk Bayur Port, West Sumatra. This includes the Harbour Master's Office/Port Authority (KSOP Teluk Bayur), Pelindo, and personnel directly involved in port services, both in vessel operations and cargo handling. A purposive sampling technique was employed to select respondents based on their relevance and experiential knowledge of the topic; the sample consisted of 90 respondents, including port personnel/operators, ship operators, port authority officials, and users of shipping services/shipping companies.

Data analysis combined qualitative descriptive techniques with quantitative approaches using: (a) descriptive percentage analysis and simple regression correlation analysis; (b) SWOT analysis to identify strengths, weaknesses, opportunities, and threats in the implementation of risk management; and (c) Risk Assessment to identify, evaluate, and mitigate the risks faced in maritime operations and to assess the application of effective safety procedures (Liu et al., 2023).

RESULT AND DISCUSSION

The demographic analysis of respondents shows characteristics that strongly support the validity and reliability of the study results. Of the 90 respondents, the majority (85.2%) were male, reflecting gender dominance in the maritime and port industry. Work-experience composition indicates high credibility, with 72% of respondents having more than 10 years of experience in shipping/port operations, while only 10% had less than 5 years of experience.

A notable aspect is the institutional composition of the respondents: 91.4% came

from maritime transport government agencies. This provides a highly relevant perspective because respondents possess in-depth understanding of regulations, operations, and maritime safety challenges. The age distribution also indicates professional maturity, with 58% older than 45 years, suggesting substantial experience and professional judgment in assessing safety risks.

Table 1. Maritime Safety Risk Factors

Risk Factor	Number of Respondents	Percentage (%)	Rank
Adverse weather (storms, fog, strong winds)	67	82.7%	1
Inadequate port infrastructure	19	18.5%	2
Vessel accidents (collisions, berthing incidents)	17	17.3%	3
Navigation equipment failure	13	13.6%	4
Marine pollution	6	7.4%	5
Security issues (sabotage, terrorism)	5	6.2%	6
High vessel traffic density	4	4.9%	7

Source: Processed Research Data, 2025

The analysis revealed a highly significant finding: adverse weather dominates as the primary risk factor, identified by 82.7% of respondents as a threat to maritime safety. This result is consistent with Teluk Bayur’s geographic setting on Sumatra’s western coast, which faces the Indian Ocean and experiences more extreme weather conditions than sheltered waters. The frequency of disruptions due to adverse weather was reported by 49.4% of respondents as “quite frequent,” indicating that these events are not sporadic but constitute a recurring operational challenge. This pattern necessitates the development of specialized weather-related risk-management protocols that are more sophisticated, including more accurate early-warning systems and comprehensive emergency-response procedures.

Inadequate port infrastructure ranks second with 18.5% of mentions, followed by vessel accidents (17.3%) and human error (14.8%). Although these percentages are relatively lower than the weather factor, the combination of these three factors creates a complex risk matrix because they interact with one another. Infrastructure inadequacy can exacerbate the impacts of adverse weather, while human error often serves as a contributing factor in the escalation of a minor incident into a major accident. Equipment failure, mentioned by 9.9% of respondents, indicates that maintenance practices are relatively good, but still require attention given the critical nature of navigation and safety equipment in the port environment.

One of the most crucial findings is the large training gap: 53.8% of respondents reported that they have never participated in risk-management or maritime safety training. This shows that, despite a high level of awareness of risk management (87.7%), respondents’ technical competence and readiness to handle risks remain very limited. Awareness without training can lead to false confidence, which is dangerous when confronted with emergency situations. Emergency-response simulations are also suboptimal: only 6.3% of respondents reported participating in monthly simulations, although such frequency is ideally required in high-risk environments like ports.

Table 2. Port Human Resources Readiness for Risk Management

Safety Training Experience		
Training Status	Respondents	Percentage
No	49	53.8%
Yes	41	46.2%
Total	90	100%

Frequency of Risk Management Training		
Frequency	Respondents	Percentage
Annually	39	43.0%
Never	22	25.3%
Rarely	22	25.3%
Every 2-3 years	7	6.3%
Total	90	100%

Frequency of Emergency Simulations		
Simulation Frequency	Respondents	Percentage
Once a year	45	51.9%
Never	24	25.3%
Every 3 months	14	16.5%
Monthly routine	7	6.3%
Total	90	100%

Involvement in the Risk-Management Process		
Level of Involvement	Respondents	Percentage
Only informed	47	55.6%
Never involved	25	25.9%
Direct participation	18	18.5%
Total	90	100%

Routine Risk Assessment		
Assessment Status	Respondents	Percentage
Yes	68	79.0%
No	22	21.0%
Total	90	100%

Risk-Management Methods Used		
Method	Mentions	Percentage
ISO 31000	13	16.2%
FMEA	12	15.0%

HAZOP	10	12.5%
Internal Port Methods	33	45.0%
Don't know	22	31.2%
Availability of Incident Reporting		
Reporting Status	Respondents	Percentage
Yes	65	77.2%
Don't know	19	20.3%
No	6	2.5%
Total	90	100%

The overall awareness of risk management reaches 87.7%, indicating that the concept of risk management is well recognized among port practitioners. However, a significant gap in training emerged: 53.8% of respondents have never attended formal risk-management or maritime-safety training. This gap is critical because awareness without proper training can create false confidence and potentially dangerous situations. Respondents may be aware of the existence of risk-management practices but lack adequate skills to implement them or respond effectively during risk events. Gap analysis identifies HR training as the area with the highest gap level (53.8%), categorized as a "Very High" priority. This finding is alarming given that the human factor is a critical success factor in risk-management implementation (Crestelo Moreno et al., 2022). Lack of proper training can result in: (a) inconsistent risk identification without standardized training, personnel may have varying competencies in identifying potential hazards; (b) inadequate emergency response untrained staff may commit critical errors during emergencies that escalate risks; and (c) poor compliance with procedures theoretical knowledge of procedures differs from practical implementation, which requires hands-on training (Lange & Cummins, 2021). The gap in active participation (45.7%) indicates that, although risk-management procedures exist, stakeholder engagement remains suboptimal. This may be caused by: (a) a top-down approach that does not involve frontline workers in risk assessment and mitigation planning; (b) lack of ownership because procedures are perceived as management directives rather than shared responsibilities; and (c) communication barriers across organizational hierarchy levels (Ta et al., 2022).

Implementation of Risk Management and Its Effect on Maritime Safety at Teluk Bayur Port, West Sumatera

The results of the analysis concerning the effect of risk management implementation on maritime safety at Teluk Bayur Port indicate that, when risk management is implemented, maritime safety at Teluk Bayur Port tends to improve. The analysis was constructed using the implementation of risk management (X) as the independent variable and maritime safety at Teluk Bayur Port (Y) as the dependent variable. Responses from the survey were processed into tables to determine whether the implementation of risk management influences maritime safety at Teluk Bayur; the detailed results of the relationship between implementation (X) and safety (Y) are provided in the Table 3.

Table 3. Regression Analysis Results

		Coefficients ^a				
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	18.515	.627		29.525	.000
	Risk Management Implementation_X	.432	.027	.860	15.802	.000

a. Dependent Variable: Maritime Safety_Y

Source: Data processed in SPSS

Based on the simple linear regression analysis shown above, the constant (a) equals 18.515 and the regression coefficient (b) equals 0.432. Thus, the simple linear regression equation is: $\hat{Y} = 18.515 + 0.432X$. From this equation it is evident that the implementation of risk management has a positive effect on maritime safety, as indicated by the regression coefficient of 0.432. This means that for every one-unit increase in the implementation of risk management, maritime safety increases by 0.432 units, assuming other factors remain constant. Conversely, a one-unit decrease in risk management implementation is associated with a 0.432-unit decrease in maritime safety. The constant value of 18.515 suggests that if risk management implementation were absent ($X = 0$), the estimated baseline level of maritime safety would be 18.515 units, implying that other factors outside variable X also contribute to a minimal level of safety.

Next, the correlation test was used to determine the degree of association between the independent and dependent variables: the higher the correlation, the stronger the relationship.

Table 4. Correlation Coefficients

		Correlations	
		Risk Management Implementation_X	Maritime Safety_Y
Risk Management Implementation_X	Pearson Correlation	1	.860**
	Sig. (2-tailed)		.000
	N	90	90
Maritime Safety_Y	Pearson Correlation	.860**	1
	Sig. (2-tailed)	.000	
	N	90	90

** . Correlation is significant at the 0.01 level (2-tailed).

Source: Data processed in SPSS

The Pearson correlation analysis yields $r = 0.860$ between the implementation of risk management and maritime safety. This value indicates a strong, positive relationship (r in the range 0.80–1.00). In other words, better implementation of risk management at the port is associated with higher levels of maritime safety. The significance value (two-tailed) is 0.000, indicating that the relationship is highly significant statistically ($p << 0.05$). Therefore, the null hypothesis (H_0) claiming no relationship between risk management implementation and maritime safety is rejected, and the alternative hypothesis (H_1) is accepted. This finding reinforces the evidence that risk management implementation plays an important role in creating safer maritime operations.

Next, the correlation test was used to determine the degree of association between the independent and dependent variables: the higher the correlation, the stronger the relationship.

Table 5. Coefficient of Determination Results

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.860 ^a	.739	.736	1.48519

a. Predictors: (Constant), Risk Management Implementation_X

Source: Data processed in SPSS

The R Square value of 0.739 indicates that 73.9% of the variance in maritime safety can be explained by the implementation of risk management. The remaining 26.1% of variance is accounted for by other factors outside the model, such as weather conditions, equipment readiness, government policies, or crew competence. The t-test is used to determine the extent to which an individual explanatory (independent) variable contributes to the variation in the dependent variable. Decision-making for the t-test uses the t-calculated value from the coefficients table: if t-calculated > t-table then H₀ is rejected and H₁ is accepted. Alternatively, significance (p-value) is also used: if p < 0.05 then H₀ is rejected. The t-table value was determined using a significance level of 0.05 and df = n - k - 1, where n is the sample size and k is the number of variables; thus the t-table value equals 1.987.

Table 6. Hypothesis Test Results

Coefficients^a						
Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	18.515	.627		29.525	.000
	Risk Management Implementation_X	.432	.027	.860	15.802	.000

a. Dependent Variable: Maritime Safety_Y

Source: Data processed in SPSS

From Table 6, the t-calculated value for the implementation variable is 15.802 with a significance (p-value) of 0.000. This p-value is smaller than 0.05, indicating that the effect of the independent variable on the dependent variable is statistically significant. For corroboration, the t-calculated value (15.802) was compared with the t-table value (1.987) for df = 88 (n = 90, k = 1). Because t-calculated (15.802) > t-table (1.987), the test falls in the rejection region for H₀; thus H₀ is rejected and H₁ is accepted. Consequently, it can be concluded that the implementation of risk management has a positive and significant effect on maritime safety. This finding underscores that the more optimal the implementation of risk management at the port, the higher the level of perceived maritime safety (Liou & Tseng, 2024). This result is an important indicator for port managers to integrate risk management systems as a core component of comprehensive maritime safety strategy (Nsikan et al., 2023). Based on data analysis from direct observation, respondent interviews, and documentary studies, a SWOT analysis was obtained as summarized in Table 7.

Table 7. SWOT Analysis of Risk Management Implementation at Teluk Bayur Port

Strengths	Weaknesses
Port management commitment to enhancing	Training has not been uniformly

Strengths	Weaknesses
safety	delivered to all human resources
Existence of standard operating procedures (SOPs) and routine training, albeit not yet comprehensive	Limited safety outreach to stakeholders
Established procedures for handling marine pollution	Navigation equipment and technologies are not up-to-date Incident reporting remains non-transparent and unsystematic
Opportunities	Threats
Stakeholder expectations for new SOPs and safety training	Extreme weather and geographic risks (high waves, fog, earthquakes, and tsunamis)
Support for implementing the ISPS and ISM Codes	Narrow navigation channels combined with large vessels that increase collision risk
Opportunities for inter-agency collaboration and management digitalization	Low safety-culture awareness among service users and local communities

The study results indicate that risk-management implementation at Teluk Bayur Port has been carried out following the principles of risk identification, analysis, evaluation, and mitigation. The primary objective of these measures is to enhance maritime safety and to prevent incidents that could disrupt port operations.

Table 8. Risk-Mitigation Matrix

Primary Risk	Detailed Mitigation	Effect of Mitigation
Workplace accidents involving stevedores (TKBM)	SIMON TKBM, mandatory PPE (personal protective equipment), OHS (K3) training, OHS audits, CCTV, attendance	Reduced injuries/fatalities; better control of workforce
Vehicle/truck accidents	STID, digital access control, roadworthiness inspections, evacuation routes	Prevention of illegal trucks; faster evacuation
Fire/explosion	Fire-fighting equipment audits, drills, evacuation routes, alarms, CCTV	Faster response; safer evacuation
Natural disasters (tsunami/earthquake)	Breakwaters, evacuation routes, signage, simulation drills	Asset protection; directed evacuation
Human error/negligence	Training, education, digital SOPs, incident feedback	Reduced incidents due to human error
Illegal practices/extortion	Anti-extortion commitment, digital payment systems, NLE integration	Cleaner governance; reduced social risk
Pollution/environmental damage	Green port initiatives, emission reduction, environmental audits	Reduced health risks and pollution

Risk mitigation at Teluk Bayur Port is now digital, integrated, and collaborative, with emphasis on transparency, efficiency, and strengthening a workplace safety culture (Li et al., 2023; Utama et al., 2024; Surucu-Balci et al., 2024). All systems have been and will continue to be evaluated to ensure optimal protection for workers, service users, port assets, and the surrounding environment (Bertrand et al., 2024). The implementation of risk management at Teluk Bayur can be pursued more systematically by deploying more advanced technologies to monitor weather conditions and vessel movements in real time (Anand et al., 2024; Liang et al., 2024). Upgrading port infrastructure, such as berths and modern navigation aids is also key to reducing current risks (Sepehri et al., 2024). With a more efficient monitoring system, the likelihood of accidents caused by extreme weather or equipment failure can be minimized (Bjørn et al., 2024). In addition, improving the quality of training for ship crews and port personnel will enhance their preparedness for emergencies and reduce the potential for human errors that lead to accidents

Overall, effective implementation of risk management at Teluk Bayur Port is expected to improve maritime safety not only for operating vessels but also for protecting port assets and the surrounding environment (Puig & Darbra, 2024; Alamoush et al., 2024). Therefore, it is recommended to strengthen collaboration among port authorities, shipping companies, and other relevant agencies in managing these risks (Nikkhah et al., 2024; Papamichael et al., 2024). More advanced mitigation measures and more intensive training will guide the port toward a safer, more efficient, and sustainable maritime system in the future.

Based on the findings above, it can be concluded that the implementation of risk management at Teluk Bayur Port has begun but remains at the stage of strengthening basic capacity. The port requires further development strategies, particularly regarding the integration of digital-based risk-management systems, enhancement of human-resource competencies, and more solid cross-institutional coordination. In the context of maritime safety, the main risk factors identified indicate that improvements cannot be achieved solely through technical measures but must also address regulatory aspects, organizational culture, and comprehensive port governance. A comprehensive, data-driven approach to risk management is therefore critical to realizing a port that is safe, efficient, and sustainable in the future.

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