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Personnel Competence and Maritime Transportation Safety Performance: The Mediating Roles of Bridge Resource Management, Education and Training, and Safety Facility Readiness in Ferry Crossing Operations

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Abstract: Maritime accidents in Indonesia remain dominated by human error, yet prior research has generally examined personnel competence, Bridge Resource Management (BRM), education and training, and safety facility readiness in isolation rather than within a single integrative model. This study addresses that gap by testing personnel competence as an antecedent of maritime transportation safety performance, both directly and indirectly through BRM implementation, education and training, and safety facility readiness as parallel mediators. A quantitative survey was conducted among 200 deck and engine officers serving on ferry vessels operating the Ketapang-Gilimanuk crossing, analyzed using Partial Least Squares Structural Equation Modeling. All eight hypothesized direct relationships were supported, and personnel competence significantly influenced education and training, which in turn strongly shaped both BRM implementation and safety facility readiness. Mediation testing showed that BRM implementation and education and training significantly transmitted the effect of personnel competence on safety performance, whereas safety facility readiness did not. A Focus Group Discussion clarified this finding, showing that standardized technical safety requirements leave limited variance for facility readiness to function as a differentiating mechanism, whereas human and organizational factors do. The novelty of this study lies in an integrative human resource readiness model in which education and training functions as the dominant conversion mechanism linking personnel competence to maritime safety performance.

Keywords: Personnel Competence, Bridge Resource Management, Education and Training, Safety Facility Readiness, Maritime Transportation Safety Performance.

INTRODUCTION

Maritime transport is a globally interconnected and high-risk industry, in which the safety of shipping operations depends heavily on the coordination of complex technical and human resources (Guven Kocak, 2015). The global commercial fleet comprised 98,140 vessels exceeding 100 gross tonnage in 2020, and vessel size has grown by as much as 1,500 percent over the past five decades, a trend that has correspondingly amplified the human, economic, and environmental consequences of maritime accidents (UNCTAD, 2020). Between 2010 and 2018, ten major incidents accounted for 91 percent of oil spills at sea (ITOPF, 2020), underscoring that the scale of modern shipping operations magnifies rather than diminishes the stakes of safety failure.

Indonesia, as the world's largest archipelagic state with roughly 70 percent of its territory covered by water, occupies a strategically important position along international shipping lanes, making maritime safety a matter of national connectivity, economic growth, and maritime security. Yet maritime accidents remain a persistent problem: incidents recorded through Indonesia's national search and rescue system rose from 850 in 2023 to 869 in 2024, with 450 incidents already recorded in the first half of 2025 (Andriansyah, 2025). Prior studies estimate that human error accounts for approximately 79 to 81 percent of maritime accidents in Indonesia, with collision and grounding, frequently traced to communication, coordination, and decision-making failures, as the dominant accident types (Agoes, 2005; Haryanto & Purwitasari, 2018). Human error has similarly been identified as the leading contributor to maritime accidents internationally, implicated in more than 75 percent of cases worldwide (Galieriková, 2019), although the complexity of maritime systems and inconsistent accident reporting standards continue to limit the precision with which its underlying causes can be identified (Goerlandt & Liu, 2024).

Reducing human error in maritime operations depends substantially on strengthening the competence of maritime personnel, understood as the knowledge, skills, and experience that enable individuals to perform operational duties safely and effectively (Zamlynskyi et al., 2025). International safety frameworks reflect this understanding directly: the Standards of Training, Certification and Watchkeeping for Seafarers Convention ties maritime safety to competence developed through structured education, training, and certification, while the International Safety Management Code links safety management to competent personnel, effective procedures, and a strong safety culture. Beyond personnel competence itself, prior research points to at least three complementary mechanisms through which competence is converted into safer operations. Education and training strengthen personnel's capacity to apply competence under operational risk (Dolzhenko et al., 2024; Klages et al., 2024; Sampson et al., 2022). Bridge Resource Management (BRM), a shipboard approach emphasizing communication, coordination, decision-making, and teamwork among bridge personnel, has been shown to improve situational awareness and reduce error at the point of operational decision-making (O'Connor, 2011; Praetorius et al., 2020; Röttger & Krey, 2021). Safety facility and infrastructure readiness, including navigation, communication, and emergency response equipment, determines a vessel's capacity to anticipate and manage emergencies (Lestari et al., 2022; Milev & Atanasova, 2025).

Although each of these mechanisms has received empirical support, prior research has generally examined them in isolation: studies of personnel competence emphasize its direct link to operational safety (Crestelo Moreno et al., 2022; Theotokas et al., 2024; Viridi et al., 2022), studies of education and training emphasize program effectiveness (Belabyad et al., 2026; Lopes et al., 2025), and studies of BRM and safety facility readiness are typically treated as standalone predictors (Durluk et al., 2024; Kaitaro et al., 2024; Lincoln et al., 2024). This fragmentation leaves the relationship among human, organizational, and facility-based factors only partially explained, particularly within Indonesia's national maritime transportation context. This study addresses that gap by testing personnel competence as an antecedent of maritime transportation

safety performance, both directly and indirectly through BRM implementation, education and training, and safety facility readiness as parallel mediating mechanisms, and by using a Focus Group Discussion to interpret findings that quantitative testing alone could not fully explain.

Literature Review And Hypothesis Development

This study is grounded in Human Factors Theory as its grand theory. The theory explains that accidents in high-risk, technology-intensive systems, such as aviation, rail, and maritime transportation, rarely result from a single technical failure but from a combination of weaknesses across the layers of a system's safety defenses, including individual capability, procedures, training, technology, and organizational culture (Reason, 1990). Applied to the maritime context, Human Factors Theory positions human capability, reflected here in personnel competence, education and training, and BRM implementation, as central determinants of whether a technically sound system actually operates safely. This study is further supported by Safety Management System theory as a middle-range theory, which explains safety as the outcome of an organization's systematic management of policy, procedure, competence, communication, and physical resources, including safety facilities and infrastructure (Thai & Grewal, 2006; Wachter & Yorio, 2014). Together, these two theories justify a model in which personnel competence functions as the foundational human resource, converted into safety performance both directly and through the parallel organizational and technical mechanisms of Bridge Resource Management implementation, education and training, and safety facility readiness.

1. Personnel Competence and Its Direct Effects

Human Factors Theory holds that an individual's capacity to understand a situation, communicate, coordinate, and make decisions is central to the effectiveness of a work system. Personnel competence, comprising operational, technical, emergency-handling, communication, and decision-making capability, is therefore expected to strengthen each of the mechanisms through which safety is produced. Competent officers are better positioned to apply the communication, coordination, and decision-making principles that BRM requires (Campaniço Cavaleiro et al., 2020; O'Connor, 2011; Röttger & Krey, 2021), to absorb and apply structured education and training (Aranda et al., 2025; Dolzhenko et al., 2024), and, consistent with Safety Management System theory's view that human and technical resources are mutually reinforcing, to operate, inspect, and maintain safety facilities effectively (Cheberichko et al., 2023; Gundić et al., 2021). Accordingly:

H1. Personnel competence has a positive effect on BRM implementation.

H2. Personnel competence has a positive effect on education and training.

H3. Personnel competence has a positive effect on safety facility readiness.

2. Effects of BRM, Training, and Safety Facility Readiness on Safety Performance

Consistent with Human Factors Theory's emphasis on communication and coordination as safeguards against human error, BRM implementation is expected to reduce error at the point of operational decision-making and thereby improve safety performance (Campaniço Cavaleiro et al., 2020; O'Connor, 2011; Röttger & Krey, 2021). Education and training is expected to improve safety performance by strengthening personnel's ability to recognize, anticipate, and respond to operational risk (Dolzhenko et al., 2024; Kwasiborska & Kądzioła, 2023; Sampson et al., 2022). Consistent with Safety Management System theory's emphasis on the availability and reliability of safety resources, safety facility readiness is expected to reduce the likelihood and severity of accidents by ensuring that navigation, communication, and emergency equipment function as intended when needed (Budiman et al., 2024; Hu & Li, 2014). Accordingly:

H4. BRM implementation has a positive effect on maritime transportation safety performance.

H5. Education and training has a positive effect on maritime transportation safety performance.

H6. Safety facility readiness has a positive effect on maritime transportation safety performance.

3. Education and Training as an Antecedent of BRM and Safety Facility Readiness

Beyond its role as an outcome of personnel competence, education and training is itself expected to strengthen the two remaining mechanisms in the model. Structured training builds the communication, coordination, leadership, and decision-making skills that BRM requires (O'Connor, 2011; Röttger & Krey, 2021), and it builds personnel's understanding of the function, operation, and maintenance of safety equipment, which supports the readiness of safety facilities (Dolzhenko et al., 2024; Sampson et al., 2022) Accordingly:

H7. Education and training has a positive effect on BRM implementation.

H8. Education and training has a positive effect on safety facility readiness.

4. Mediating Roles of BRM, Training, and Safety Facility Readiness

The hypotheses developed above imply that personnel competence affects maritime transportation safety performance not only directly but also indirectly, through BRM implementation, education and training, and safety facility readiness as parallel mediating mechanisms, and that education and training additionally mediates the effect of personnel competence on the other two mechanisms. This mediation logic follows directly from Human Factors Theory and Safety Management System theory: competence alone does not guarantee safety unless it is converted into effective communication and coordination, applied through continuous learning, and supported by reliable technical resources (Coredikris & Batubara, 2019; Gundić et al., 2021; Nie et al., 2021; Pennie et al., 2007). Accordingly:

H9. Personnel competence has a positive indirect effect on maritime transportation safety performance through BRM implementation.

H10. Personnel competence has a positive indirect effect on maritime transportation safety performance through education and training.

H11. Personnel competence has a positive indirect effect on maritime transportation safety performance through safety facility readiness.

H12. Education and training has a positive indirect effect on BRM implementation as a pathway from personnel competence.

H13. Education and training has a positive indirect effect on safety facility readiness as a pathway from personnel competence.

METHODS

This study adopted a quantitative explanatory design intended to test causal relationships among personnel competence, BRM implementation, education and training, safety facility readiness, and maritime transportation safety performance. Data were collected through a structured questionnaire using a five-point Likert scale and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS, selected for its suitability in testing complex models involving both direct and indirect relationships (Hair et al., 2022).

The study population comprised deck and engine officers, specifically Masters, Chief Officers, Second and Third Officers, and Engineers, serving on the 54 ferry vessels actively operating the Ketapang-Gilimanuk crossing in 2025. A two-stage random sampling procedure was applied: all 54 vessels were included as primary sampling units given their simultaneous operation on a single route, and officers on duty during shift rotation were then randomly sampled within each rank to ensure balanced representation across command levels. Minimum sample size was determined using G*Power based on four predictors, an effect size of 0.15, a significance level of 0.05, and a power of 0.95, yielding a minimum requirement of 129 respondents; the study targeted 200 respondents to obtain more stable parameter estimates for a model involving five latent constructs and multiple mediating relationships.

Personnel competence was measured with five indicators covering operational, technical, emergency-handling, safety communication, and decision-making capability (Cheberiachko et al., 2023; Gundić et al., 2021; Spencer & Spencer, 2008). BRM implementation was measured with five indicators covering navigational communication, confirmation of operational information, team participation, leadership, and systematic decision-making (Campaniço Cavaleiro et al., 2020; O'Connor, 2011; Röttger & Krey, 2021). Education and training was measured with four indicators (Aranda et al., 2025; Dolzhenko et al., 2024; Sampson et al., 2022), and safety facility and infrastructure readiness with five indicators covering the availability, feasibility, reliability, and operational readiness of safety equipment (Budiman et al., 2024; Fischer et al., 2025; Hu & Li, 2014). Maritime transportation safety performance, the outcome construct, was measured with five indicators covering accident prevention, operational risk control, procedural compliance, and the maintenance of safe operations (IMO, 2018; Reason, 1990). All indicators were adapted from prior maritime safety and human resource research, refined through expert consultation, and pilot-tested prior to full-scale distribution.

The measurement model was evaluated for convergent validity using outer loadings and average variance extracted, and for discriminant validity using the Heterotrait-Monotrait Ratio (HTMT), applying the conservative 0.85 threshold given the conceptual proximity between education and training and the other constructs (Henseler et al., 2015). Internal consistency reliability was assessed using Cronbach's Alpha and Composite Reliability. The structural model was evaluated using the coefficient of determination, effect size, and collinearity statistics, with hypothesis significance tested through bootstrapping (t-statistic > 1.96, p-value < 0.05) (Hair et al., 2022). Specific indirect effects were tested through bootstrapping to assess mediation, and predictive relevance was assessed using PLSpredict, comparing PLS-SEM prediction error against a linear model benchmark (Shmueli et al., 2019). Following the quantitative stage, a Focus Group Discussion was conducted with maritime regulators, academics, port operators, and shipping association representatives to confirm and deepen the interpretation of findings, particularly the hypothesis that quantitative testing did not support; discussion transcripts were analyzed using thematic analysis.

RESULTS AND DISCUSSION

Respondent Profile

Of the 200 respondents, 37.5 percent were engineers and 35.0 percent were second or third officers, with the remaining 27.5 percent holding senior command positions as Master or Chief Officer, indicating that the sample represents multiple levels of operational responsibility on board. Most respondents (64%) had more than five years of experience in the shipping industry and were between 30 and 50 years of age (67%), and 80 percent held a maritime diploma or higher, indicating that respondents were experienced and professionally qualified to assess the constructs under study.

Table 1. Respondent Profile

Category	Group	n	%
Rank	Master	12	6
	Chief Officer	43	21.5
	Officer (2nd/3rd)	70	35
	Engineer	75	37.5
Tenure	< 5 years	42	21
	5-10 years	78	39
	11-15 years	50	25
	> 15 years	30	15
Age	< 30 years	46	23
	30-40 years	82	41

	41-50 years	52	26
	> 50 years	20	10
Education	Maritime Diploma III	92	46
	Maritime Diploma IV	68	34
	Professional certification	28	14
	Other	12	6

Source: Survey data (2026)

Measurement Model (Outer Model)

All indicator loadings exceeded the 0.70 threshold, ranging from 0.806 to 0.885, and average variance extracted exceeded 0.50 for all constructs, ranging from 0.696 to 0.746, confirming convergent validity. Cronbach's Alpha and Composite Reliability values ranged from 0.886 to 0.908, exceeding the 0.70 threshold and confirming internal consistency reliability.

Table 2. Convergent Validity and Reliability

Construct	Items	Loading Range	AVE	CA	CR
Personnel Competence	5 (KP1-KP5)	0.837-0.876	0.727	0.906	0.908
BRM Implementation	5 (BRM1-BRM5)	0.806-0.866	0.696	0.891	0.893
Education and Training	4 (PP1-PP4)	0.839-0.885	0.746	0.886	0.887
Safety Facility Readiness	5 (KSP1-KSP5)	0.827-0.860	0.706	0.896	0.897
Safety Performance	5 (KK1-KK5)	0.822-0.846	0.705	0.895	0.896

Source: Processed data (2026)

Discriminant validity was assessed using HTMT (Table 4). All values fell below the 0.90 threshold, but two pairs involving education and training, with BRM implementation (0.880) and with safety facility readiness (0.864), exceeded the more conservative 0.85 threshold, while remaining below the more lenient 0.90 threshold; the discriminant validity of all constructs is therefore considered acceptable.

Table 3. Discriminant Validity (HTMT)

	BRM	KSP	KK	KP	PP
BRM Implementation					
Safety Facility Readiness	0.773				
Safety Performance	0.772	0.786			
Personnel Competence	0.819	0.710	0.663		
Education and Training	0.880	0.864	0.822	0.808	

Source: Processed data (2026)

Structural Model (Inner Model)

Bridge Resource Management implementation recorded the highest R^2 (0.672), indicating that personnel competence and education and training jointly explain 67.2 percent of its variance, while maritime transportation safety performance recorded an R^2 of 0.608. The largest effect size in the model was personnel competence on education and training ($f^2 = 1.119$), followed by education and training on safety facility readiness ($f^2 = 0.497$) and on BRM implementation ($f^2 = 0.394$). The direct effects of BRM implementation, education and training, and safety facility readiness on safety performance were individually weak in effect size (f^2 between 0.056 and 0.084). All VIF values ranged from 1.000 to 3.485, below the conservative threshold of 5.0, indicating no multicollinearity concern.

Table 4. R^2 and f^2

Path	R^2	f^2	Category
BRM Implementation → Safety Performance	0.608	0.056	Weak
Safety Facility Readiness → Safety Performance		0.084	Weak
Education and Training → Safety Performance		0.074	Weak

Personnel Competence → BRM Implementation	0.672	0.183	Moderate
Education and Training → BRM Implementation		0.394	Strong
Personnel Competence → Safety Facility Readiness	0.607	0.036	Weak
Education and Training → Safety Facility Readiness		0.497	Strong
Personnel Competence → Education and Training	0.528	1.119	Strong

Source: Processed data (2026)

Predictive relevance, assessed using PLSpredict, showed positive $Q^2_{predict}$ values for all indicators, confirming predictive relevance across the model. Bridge Resource Management implementation, safety facility readiness, and safety performance showed lower PLS-SEM prediction error than the linear model benchmark for all of their indicators, indicating high predictive power, while education and training showed lower prediction error for three of its four indicators, indicating moderate predictive power (Table 5).

Table 5. PLSpredict Summary

Endogenous Construct	$Q^2_{predict}$ range	Indicators PLS-SEM < LM	Power
Education and Training	0.348-0.451	3 of 4	Moderate
BRM Implementation	0.336-0.411	5 of 5	High
Safety Facility Readiness	0.248-0.321	5 of 5	High
Safety Performance	0.198-0.303	5 of 5	High

Source: Processed data (2026)

Hypothesis Testing

Bootstrapping results (Table 7) show that all eight hypothesized direct relationships (H1-H8) were statistically supported ($p < 0.05$, $t > 1.96$). Table 8 presents the results of specific indirect effects testing: four of the five hypothesized mediation pathways were supported (H9, H10, H12, H13), while H11, the indirect effect of personnel competence on safety performance through safety facility readiness, was not supported ($\beta = 0.051$, $t = 1.723$, $p = 0.085$), despite both of its component paths, H3 and H6, being independently significant.

Table 6. Direct Hypothesis Testing Results

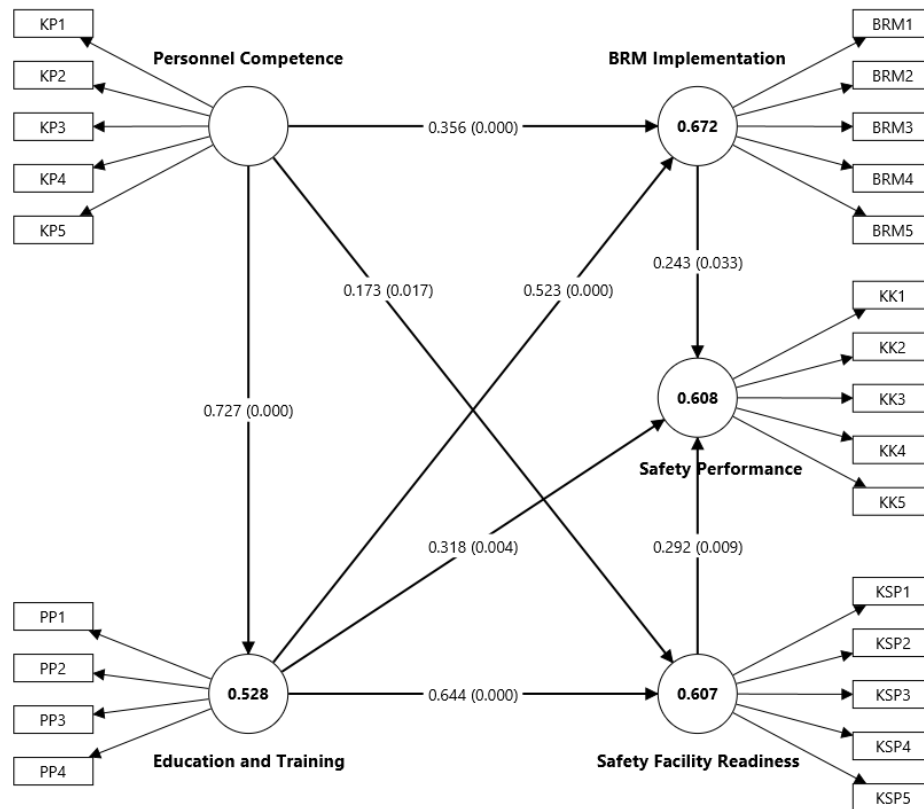
Hypothesis	VIF	β	SD	t-stat	p	Result
H1. Personnel Competence → BRM Implementation	2.119	0.356	0.086	4.137	0.000	Supported
H2. Personnel Competence → Education and Training	1.000	0.727	0.037	19.676	0.000	Supported
H3. Personnel Competence → Safety Facility Readiness	2.119	0.173	0.073	2.372	0.018	Supported
H4. BRM Implementation → Safety Performance	2.707	0.243	0.117	2.079	0.038	Supported
H5. Education and Training → Safety Performance	3.485	0.318	0.108	2.936	0.003	Supported
H6. Safety Facility Readiness → Safety Performance	2.579	0.292	0.111	2.632	0.009	Supported
H7. Education and Training → BRM Implementation	2.119	0.523	0.073	7.173	0.000	Supported
H8. Education and Training → Safety Facility Readiness	2.119	0.644	0.07	9.219	0.000	Supported

Source: Bootstrapping output (2026)

Table 7. Indirect Hypothesis Testing Results

Hypothesis	β	SD	t-stat	p	Result
H9. Competence $\rightarrow$ BRM $\rightarrow$ Safety Performance	0.087	0.042	2.063	0.039	Supported
H10. Competence $\rightarrow$ Training $\rightarrow$ Safety Performance	0.231	0.082	2.836	0.005	Supported
H11. Competence $\rightarrow$ Safety Facility $\rightarrow$ Safety Performance	0.051	0.029	1.723	0.085	Not supported
H12. Competence $\rightarrow$ Training $\rightarrow$ BRM	0.38	0.054	6.985	0.000	Supported
H13. Competence $\rightarrow$ Training $\rightarrow$ Safety Facility	0.468	0.053	8.875	0.000	Supported

Source: Bootstrapping output (2026)


Figure 1. Bootstrapping Result (β and p-value)

Focus Group Discussion Results

Because H11 was not statistically supported, a Focus Group Discussion was conducted with maritime regulators, academics, port operators, and shipping association representatives to interpret this finding. Thematic analysis (Table 8) produced three themes. First, technical standardization: informants explained that mandatory classification audits and periodic inspections have brought safety equipment across vessels to a broadly comparable technical standard. Second, the dominance of human factors: informants consistently attributed operational incidents more to decision-making error, communication breakdown, and weak coordination than to equipment unavailability. Third, technology as a precondition rather than a differentiator: safety facilities were described as a necessary operating condition rather than the mechanism that explains variation in safety performance once that condition is met.

Table 8. Thematic Analysis of Focus Group Discussion Findings

Illustrative Informant Statement	Conceptual Code	Theme
“Almost every vessel now complies with regulation for safety equipment; classification and port authority audits are conducted routinely.”	Compliance with safety standards	Technical standardization of safety systems
“What usually causes problems is not a lack of safety equipment, but how the crew reads the situation in the field.”	Situational interpretation by crew	Dominance of human factors
“Safety equipment matters, but functions more as a supporting system; what determines outcomes is still the decisions made by the crew.”	Technology as decision support	Technology as a precondition

Source: FGD results (2026)

Discussion

1. Personnel Competence and Its Direct Effects

Personnel competence significantly strengthened Bridge Resource Management implementation (H1), education and training (H2), and safety facility readiness (H3), with the effect on education and training markedly stronger than on the other two mediators. This indicates that personnel competence functions primarily as a foundation for learning capacity, consistent with Human Factors Theory's emphasis on individual capability as the starting point of a high-reliability work system, and with Zamlynskyi et al. (2025) and Gundić et al. (2021), who link stronger crew competence to more effective operational and decision-making capability.

2. Effects of BRM, Training, and Safety Facility Readiness on Safety Performance

Bridge Resource Management implementation (H4), education and training (H5), and safety facility readiness (H6) each significantly and directly improved maritime transportation safety performance, with education and training exerting the strongest direct effect. This pattern supports the view that safety performance is jointly determined by human, organizational, and technical factors operating in parallel, consistent with Campaniço Cavaleiro et al. (2020) and Röttger and Krey (2021), who find that BRM effectiveness depends on the non-technical competence and decision-making capacity of bridge personnel rather than procedural compliance alone.

3. Education and Training as Antecedent of BRM and Safety Facility Readiness

Education and training additionally strengthened Bridge Resource Management implementation (H7) and safety facility readiness (H8), both with large effect sizes. Combined with the strong effect of personnel competence on education and training itself, this pattern positions education and training as the central conversion mechanism of the model: personnel competence gains most of its operational value once it is developed further through structured training, which then propagates into both team-level coordination and technical readiness, consistent with Dolzhenko et al. (2024) and Sampson et al. (2022).

4. Mediating Roles of BRM, Training, and Safety Facility Readiness

BRM implementation and education and training both significantly mediated the relationship between personnel competence and safety performance (H9, H10), and education and training further mediated the relationship between personnel competence and BRM implementation (H12) and safety facility readiness (H13), the two largest indirect effects in the model. Safety facility readiness, however, did not significantly mediate the relationship between personnel competence and safety performance (H11), even though its two component paths were each independently significant, a pattern examined further through the Focus Group Discussion below. Overall, education and training emerged as the dominant mediating

mechanism in the model, indicating that personnel competence is converted into safety outcomes primarily through continuous learning rather than through any single mechanism alone.

5. Interpreting the Non-Significant Mediation of Safety Facility Readiness

The Focus Group Discussion clarifies why H11 was not supported despite theoretical grounds to expect a mediating role for safety facility readiness (Coredikris & Batubara, 2019; Nie et al., 2021). Because mandatory classification audits and periodic inspections have brought safety equipment across vessels to a broadly comparable technical standard, safety facility readiness leaves limited variance to differentiate safety outcomes between vessels. Informants consistently attributed operational incidents more to decision-making error, communication breakdown, and weak coordination than to equipment unavailability, and described safety facilities as a necessary operating condition rather than the mechanism that explains variation in safety performance once that condition is met. Integrating the quantitative and qualitative findings indicates that, in this operating environment, safety facility readiness functions as a structural foundation for safe operations rather than as the primary channel through which personnel competence is converted into safety performance, a role instead carried out by education and training and BRM implementation.

The novelty of this study lies in demonstrating, within a single integrative model, that education and training rather than technical safety facility readiness functions as the dominant conversion mechanism linking personnel competence to maritime transportation safety performance, a distinction that prior research examining these factors in isolation has not been able to establish. By combining quantitative mediation testing with Focus Group Discussion confirmation, this study further shows that the absence of a significant mediating effect does not necessarily indicate that a factor is unimportant; rather, it can reflect that the factor has reached a standardized operating threshold at which human and organizational mechanisms become the primary source of variation in safety outcomes. This finding contributes to Human Factors Theory by clarifying that, in operating environments where technical compliance is already high, safety performance gains are more effectively pursued through strengthening human capability and organizational coordination than through further technical investment alone.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

This study demonstrates that personnel competence functions as the foundation from which maritime transportation safety performance is built, both directly and through three parallel mechanisms: Bridge Resource Management implementation, education and training, and safety facility readiness. Personnel competence significantly strengthens all three mechanisms, confirming that individual capability is the entry point through which human factors translate into organizational and technical safety outcomes. Each of the three mechanisms, in turn, directly and significantly improves safety performance, indicating that human, organizational, and technical factors operate in parallel rather than through any single dominant pathway.

Among the three mechanisms, education and training occupies a distinctive position. It exerts the strongest direct effect on safety performance among the three mediators, significantly strengthens both BRM implementation and safety facility readiness, and mediates the effect of personnel competence on both. This pattern confirms education and training as the central conversion mechanism of the model: personnel competence is realized more fully once it is developed further through structured, continuous training, which then propagates into stronger team coordination and more reliable technical readiness.

At the level of mediation, BRM implementation and education and training both significantly transmit the effect of personnel competence on safety performance, whereas safety facility readiness does not, despite both of its component relationships being independently significant. Focus Group Discussion findings clarify this result: because maritime safety regulation mandates a high and broadly uniform technical standard for safety equipment across vessels, safety facility readiness leaves comparatively little room to differentiate safety outcomes between vessels, whereas human and organizational factors continue to vary and therefore continue to explain variation in safety performance. This finding should not be read as evidence that safety facilities are unimportant; rather, it indicates that once a technical standard is broadly met, further safety gains are more effectively pursued through strengthening human capability and organizational coordination.

Taken together, these findings support a Maritime Human Resource Readiness Optimization Model in which personnel competence forms the foundation of maritime safety, is converted into operational and technical capability primarily through structured education and training, and is reinforced through effective BRM and reliable safety facilities. This integrative account extends Human Factors Theory by clarifying the conditions under which human and technical mechanisms each carry more or less explanatory weight within a maritime safety system..

Limitations

This study has several limitations. The sample was drawn exclusively from officers serving on ferry vessels operating a single crossing route, the Ketapang-Gilimanuk strait, so the findings should not be generalized to Indonesia's maritime sector as a whole without further testing across other vessel types and routes. The cross-sectional design captures perceptions at a single point in time and cannot establish how these relationships evolve as regulatory standards or fleet technology change. The study also relies on self-reported perceptual data collected through a structured questionnaire, which may be subject to common method bias, and it examines only personnel competence, Bridge Resource Management implementation, education and training, and safety facility readiness, leaving other potentially relevant factors, such as weather conditions, vessel characteristics, and organizational safety culture, outside the scope of the model.

Recommendations

Shipping companies operating ferry crossings are advised to treat education and training as the priority investment for converting personnel competence into safety performance, particularly through simulation-based refresher training in BRM and structured emergency decision-making drills, rather than assuming that technical competence or safety equipment alone will translate into safer operations. Maritime training institutions and regulators are advised to strengthen non-technical competence, communication, coordination, and decision-making, within certification curricula, and to establish accreditation standards for BRM training providers, including instructor qualification and simulator adequacy. Future research should extend this model to other vessel types, routes, and national contexts, incorporate organizational safety culture and vessel-level technical variables, and consider longitudinal or multigroup designs to test whether the dominant mediating role of education and training observed here holds across different regulatory and operational environments.

Author Contributions

All authors made significant contributions to this study. These contributions included research conceptualization, development of the theoretical framework, data collection, data analysis, interpretation of results, manuscript preparation, scholarly revision, and final approval

of the manuscript for publication. All authors confirm that they have read and approved the final version of the article.

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