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Digital Innovation and Technology Driven Evaluation of Maritime Safety Systems Performance in Indonesia

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ABSTRACT

Maritime safety remains a critical challenge in complex shipping environments, where human error continues to dominate accident causation despite technological advancements. **This study aims** to evaluate maritime safety system performance in Indonesia through a digital innovation and technology-driven perspective by introducing Adaptive Safety Intelligence (ASI) as an integrative framework linking safety leadership, competency-based training, seafarer well-being, and empowerment. **A mixed-methods** design combining Structural Equation Modeling (SEM) with qualitative insights was used, involving data from 508 Indonesian seafarers and 30 stakeholders from shipping companies, regulators, and maritime management. The model shows strong validity and reliability, with R^2 values of 0.878 for ASI, 0.663 for seafarer autonomy and empowerment, and 0.676 for safety performance. **The findings** empirically confirm ASI as a central mediating construct that translates leadership, training, and well-being into improved empowerment and safety outcomes. **This study concludes** that maritime safety should be seen as an adaptive, human-centered, and digitally enabled system, emphasizing leadership-driven safety culture, well-being interventions, and integrated maritime systems for strengthening safety governance in Indonesia.

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1. INTRODUCTION

Indonesia as the largest archipelagic country in the world with 17,504 islands and a coastline of 99,093 km has enormous maritime potential. Indonesia's strategic position at the crossroads of global trade routes made it one of the countries with the most densely populated shipping activities in the world [1]. The IMO noted that about 90% of global trade is transported by sea, with more than 50,000 ships operating in international waters [2]. In the Indonesian context, there are more than 56,000 registered vessels in operation [3] and employing more than 417,000 seafarers [4]. However, behind the great maritime potential, there were still significant challenges related to maritime safety and the welfare of seafarers [5, 6].

Maritime safety remains a global concern, with the International Maritime Bureau noting 182 ship accidents worldwide in 2022-2023, 14% of which occurred in Southeast Asian waters, and the National Transportation Safety Committee (KNKT) reporting 41 accidents in Indonesian waters in 2023, a 12% increase

from the previous year. Human error was identified as the primary cause in 67% of incidents, followed by technical (21%) and natural (12%) factors. Studies highlighted key human error factors, including fatigue, psychological distress, insufficient training, poor safety management, and limited decision-making autonomy [7, 8]. Seafarers' well-being is also a growing concern, with a survey of 4,500 seafarers revealing that 28% experienced depressive symptoms, 21% high anxiety, and 58% chronic fatigue [9]. Despite the 2006 Maritime Labour Convention (MLC) setting global standards, implementation remains inconsistent [10, 11]. The technological revolution 4.0 has transformed shipping operations, offering opportunities for enhanced safety through advanced systems but also creating challenges related to the adaptability of seafarers and the development of their competencies, potentially introducing new safety risks [12, 13].

Studies on maritime safety initially focused on technical aspects and regulatory compliance but evolved toward a socio-technical perspective, acknowledging the complexity of human-system interactions [14–16]. Traditional approaches, which emphasized regulatory compliance and standard training, were deemed inadequate for addressing modern socio-technical systems' complexities [17]. Contemporary approaches highlighted the importance of safety culture, leadership, and adaptive capacity [18], though gaps remained in integrating mental health, empowerment, and adaptability into these models [19, 20]. This study adopts a socio-technical approach and complex adaptive systems to analyze maritime safety, viewing it as a dynamic interaction between human, technological, organizational, and environmental components, and applies the safety-II paradigm, focusing on how systems successfully adapt under varying conditions [21, 22].

This study aligns with Sustainable Development Goals (SDGs) 8 (Decent Work and Economic Growth) and SDGs 9 (Industry, Innovation, and Infrastructure) [23] by emphasizing maritime safety and seafarer well-being, essential for promoting decent work conditions, labor productivity, and workforce resilience. Through the ASI framework, it supports SDGs 8 by contributing to safer and more sustainable maritime employment. Additionally, the integration of adaptive learning and system-level resilience fosters innovation in safety management and strengthens maritime infrastructure, supporting SDGs 9. Policies aimed at improving logistics transportation systems in Indonesia further reinforce these objectives, strengthening infrastructure, navigation services, and safety regulations [3, 24].

2. LITERATURE REVIEW

The maritime industry faces complex challenges that require an integrated approach. Despite advances in understanding seafarers' mental health and adaptive learning technologies, further research is needed to integrate these elements into a comprehensive framework [25, 26]. ASI emerged as a potential construct to bridge the gap between safety leadership, competence, mental health, and seafarer performance and empowerment [27, 28].

Table 1. State of the Art

Expert	Concept	Findings
Fajrin [29]	Safety Culture and Leadership	An investigation into how a safety culture is formed and the role of leadership in fostering it. This study identifies the relationship between authentic safety leadership and safety climate and safety behavior.
Fan [30]	Human Factor and Welfare	Emphasis on the cognitive, physical, and psychological aspects of seafarers in an operational context. reveals the significant impact of fatigue management on decisionmaking and situational awareness of seafarers.
Woods and Hollnagel [31]	Resilience Engineering	Focus on the capacity of the system to adapt to changes and disruptions and develop a Resilience Assessment Grid (RAG) framework to measure the adaptive capacity of maritime systems.
Wang [32]	Safety Intelligence and Analytics	The use of data and machine learning for incident prediction and prevention and demonstrates the predictive potential of big data analytics in identifying maritime accident precursors.

As summarized in Table 1, existing maritime safety studies focus on organizational constructs like safety culture and resilience engineering, offering limited insight into individual cognitive adaptation and learning. While data-driven models predict accidents based on historical patterns, they are reactive. In contrast, ASI focuses on individual seafarers, linking leadership, training, and well-being to empowerment and safety perfor-

mance in a proactive, human-centered framework [33].

The theoretical model from [29] uses a simple linear approach, explaining only 45.4% of safety variability. The maritime safety axis research introduces ASI as a revolutionary mediating variable, integrating cognitive flexibility, adaptive learning, and empowerment. This multidimensional model offers a more comprehensive framework compared to [29] focus on safety behavior. It fills a gap in the maritime safety literature by providing a contextual, sustainable approach, unlike Fan's technical, neurophysiological focus. While Hollnagel's RAG framework measures organizational resilience, this research integrates individual psychological factors with organizational resilience through ASI [34]. [32] data-driven models predict maritime accident risks using historical patterns but miss human-centered factors like safety leadership and psychological well-being, which the ASI framework addresses. This research bridges predictive technology with human development, focusing on enhancing seafarers' adaptive capacity, mental resilience, and empowerment to prevent incidents, crucial for Indonesia's maritime sector, where human error accounts for 67% of accidents.

ASI emerged to address the limitations of existing maritime safety models. While Safety Culture and High Reliability Organizations focus on leadership and culture, they don't explain individual adaptation mechanisms [35]. ASI fills this gap by providing a scalable adaptive construct with higher explainability. Resilience Engineering offers a system-level framework but lacks individual psychological and cognitive tools, which ASI operationalizes through adaptive learning and cognitive flexibility. The data-driven Safety Intelligence 4.0 approach relies on technical predictions but overlooks the human factor, a major cause of accidents in Indonesia [32]. ASI integrates human adaptive capacity into a more complete safety framework. While human factors research separates cognitive and physiological aspects from organizational structure, ASI combines them into a socio-technical model linking individual conditions to leadership, training, and empowerment. Safety-II introduces a shift in understanding operations but remains philosophical, while ASI translates these principles into measurable indicators like proactive risk identification and behavioral flexibility [36, 37].

Overall, the uniqueness of ASI framework lies in its integrative framework that combines psychological, organizational, and adaptive dimensions, its focus on the individual level, and its relevance to Indonesia's maritime context [38, 39]. As such, ASI offers a theoretical and practical contribution to improving safety in complex and resource-constrained operating environments. This research focus on ASI which serves as a central mediator that integrates the influence of safety leadership, competency-based training, and well-being on seafarer empowerment and safety performance, creating a holistic and sustainable maritime safety system. The following Figure 1.

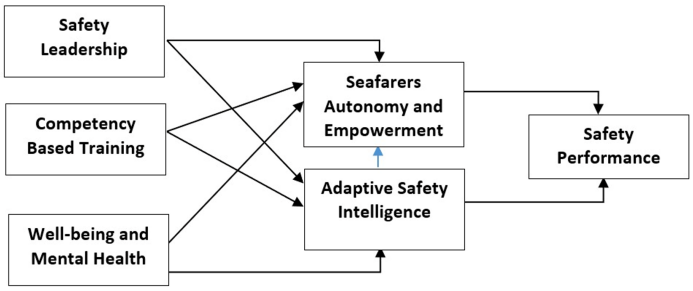

Figure 1. Research Hypotheses

- Hypothesis 1 Safety leadership creates an environment where seafarers develop the ability to adapt to dynamic safety situations. Leaders who provide example, open communication, and support in safety decision-making will enhance mariners' adaptive intelligence in the face of operational risks and challenges.

- Hypothesis 2 Structured and relevant competency-based training will improve the seafarer's ability to adapt to new situations. Training that focuses on developing practical skills, problem-solving, and decision-making will strengthen seafarers' ASI.

- Hypothesis 3 A healthy mental state and good well-being of seafarers are the foundation for the development of adaptive intelligence. Sailors with optimal mental health will be better able to think clearly, make informed decisions, and adapt to operational stresses.

- Hypothesis 4 Empowering safety leadership will increase mariners' autonomy in making safety decisions and feel empowered in their roles. Leaders who delegate responsibility and provide trust will develop a sense of empowerment in seafarers.
- Hypothesis 6 Training that improves competence will give sailors the confidence to act independently and feel empowered. Improving skills through targeted training will strengthen the autonomy of seafarers in carrying out their duties.
- Hypothesis 7 Strong safety leadership directly contributes to improving safety performance through standard-setting, monitoring, and the creation of a positive safety culture in the maritime work environment.
- Hypothesis 8 High adaptive intelligence will increase the sense of autonomy and empowerment of sailors as they feel more competent and confident in dealing with changing situations at sea.
- Hypothesis 9 ASI acts as a key mediator that connects all input factors (leadership, training, well-being) with safety performance. Sailors with high adaptive intelligence will show better safety performance.

Seafarers who feel empowered and have autonomy in safety decision-making will show better safety performance, as they feel responsible and have control over their working conditions.

3. RESEARCH METHODS

This study used a mixed-method approach with a sequential explanatory design, integrating quantitative and qualitative methods to understand the interaction between leadership, competence, mental health, and safety performance in the Indonesian maritime context. In the quantitative phase, SEM was used to explore and test the structural relationships between variables, identifying significant patterns and paths. The qualitative phase involved in-depth interviews and Focus Group Discussions (FGDs) to explore the underlying mechanisms and context of these relationships. The integration of both phases resulted in a comprehensive model with statistical validity and contextual depth.

The population of this study was Indonesian seafarers who work on various types of ships (tankers, cargo, passengers, and others) in national and international shipping companies and of shipping companies (state-owned enterprises, national private, foreign companies). Sample determination used stratified random sampling technique with stratification based on the type of ship (tanker, bulk carrier, container, passenger, offshore support vessel), position (officer and rating), work experience from less than 5 years to less than 10 years. Quantitative research involved 508 Indonesian seafarers from various shipping companies. For qualitative research, 30 participants selected by using purposive sampling with criteria as Senior seafarers, Shipping company management officials, regulator/government and seafarers.

Table 2. Variables and Indicators

Variables	Questionnaire	Indicators
Safety Leadership	SL1	Leader visibility in safety activities
	SL2	Consistent communication about safety
	SL3	Allocation of resources for safety initiatives
	SL4	Exemplifying safety behavior
	SL5	Responsiveness to safety issues
Competency-Based Training	CBT1	Conformity of the international standard curriculum
	CBT2	Use of real-scenario simulation methods
	CBT3	Post-training competency measurement
	CBT4	Frequency of refresher training
Well-being and Mental Health	WB1	Access to mental health services
	WB2	Quality of downtime
	WB3	Reported stress levels
	WB4	Work-life balance

Variables	Questionnaire	Indicators
Adaptive Safety Intelligence (ASI)	ASI1	Ability to identify new risk patterns
	ASI2	Flexibility in implementing safety procedures
	ASI3	Knowledge transfer capabilities between different contexts
	ASI4	Situational adaptability in safety decision-making
Safety Performance	SP1	Accident rate per 1000 working days
	SP2	Number of near-misses reported
	SP3	Severity of incidents
	SP4	Time lost due to injury
	SP5	Compliance with safety procedures
Seafarer's Autonomy and Empowerment	SAE1	Ability to make decisions
	SAE2	Ability to manage yourself
	SAE3	Ability to innovate
	SAE4	Ability to take risks
	SAE5	Ability to access information
	SAE6	Ability to advocate for their rights

This study used an explanatory sequential mixing method by [40] which is divided into three phases. The quantitative phase included instrument development, survey data collection from 500 respondents through online and offline methods, and analysis using SEM with AMOS 18. The qualitative phase included protocol development [41] semi-structured interviews [42], FGDs with 6-8 participants per group [43] and thematic analysis with triangulation [44]. The integration phase involved the synthesis of findings to develop a comprehensive model (Fetters) [45]), validation through workshops with key stakeholders [46] and the development of practical and policy recommendations. Each phase had a person in charge, a clear target time, and achievement indicators to ensure the quality of the research [47–49].

Quantitative analysis used SEM (AMOS 28) with five systematic stages, data screening, confirmatory factor analysis for construct validation (factor loadings >0.5, AVE >0.5), structural model testing (Chisquare/df <3, RMSEA <0.08, and mediated analysis with bootstrapping. Meanwhile, qualitative analysis applied a seven-step thematic approach with the help of NVivo 15, including data familiarization, coding, theme development, review, theme definition, perspective triangulation among seafarers, management, and regulators, and member checking for interpretation verification [50, 51]. The qualitative analysis used in-depth interviews with 40 respondents consisting of seafarers from national and international ships, regulators and shipping companies in Indonesia.

4. RESULT AND DISCUSSION

Based on the research that you've done, you can write your result in this section, there will be 2 sub-bab which are Problem and Research Implementation. Therefore if you have more results you can add more sub-bab on the section bellow:

4.1. Quantitative Analysis

Respondents in this study is 508 respondents, the majority were aged 26-35 years (54.1%), and had less than 5 years of work experience (42.3%). The majority of respondents work in cargo ships and tankers (71.1%), followed by those who work in offshore support vessels (22.3%) and the rest in containers (9%). The position as a machinist dominates (42.3%) followed by the position of Mualim (24%), Head of the Engine Room 10.9%, Captain 8.2%, Able Seaman 7.6% and Oiler as much as 6.4%. The positions with the fewest number of respondents were Chef (1.8%), Mess Boy (1.4%), and Electrician (1%).

In order to analyze the proposed research model, the data collected from 508 respondents were processed using Smart PLS, which enabled both measurement model and structural model testing through Partial Least Squares Structural Equation Modeling (PLS-SEM).

Table 3. Result of Reliability and Validity Tests

	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
Competency Based Training	0.958	0.959	0.970	0.889
Safety Leadership	0.984	0.984	0.987	0.939
Well-Being and Mental Health	0.938	0.941	0.953	0.801
Attitude Safety Intelligence	0.979	0.979	0.982	0.873
Safety Autonomy and Empowerment	0.937	0.946	0.951	0.764
Safety Performance	0.831	0.880	0.874	0.547

The results of the reliability and validity tests indicate that all indicators exhibit satisfactory measurement properties. The factor loadings of all items are above the threshold value of 0.70, confirming that each indicator appropriately represents its intended construct. Furthermore, the Average Variance Extracted (AVE) values exceed 0.50 across all constructs, providing evidence of adequate convergent validity.

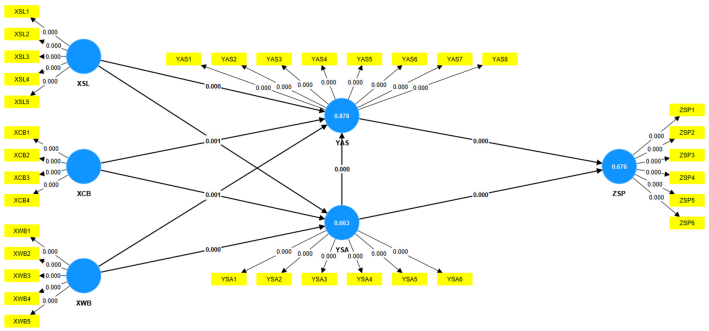

Figure 2. Bootstrapping Analysis

Figure 2 shows that most structural paths are statistically non-significant, with near-zero coefficients, indicating weak direct effects among constructs. However, the model explains a high proportion of variance, particularly for Adaptive Safety (R^2 = 0.878), Seafarer's Well-being and Empowerment (R^2 = 0.663), and Safety Performance (R^2 = 0.676). SEM results highlight ASI as a central mediating construct, consolidating the effects of safety leadership, training, and well-being before influencing empowerment and safety performance. Despite weak direct effects, the model's high explanatory power reflects maritime safety as a complex socio-technical system. The findings emphasize ASI's integration of adaptive capacity, aligning with resilience-oriented and Safety-II perspectives. Safety Leadership and Competency-Based Training have weak effects, while Well-Being moderately influences Safety Performance. The model's strong performance is driven by mediation mechanisms, linking leadership, training, and psychological conditions to empowerment and safety performance.

These findings reinforce the view that safety in maritime contexts is not shaped by a single dominant factor, but by a series of small contributions working together. Theoretically, this places ASI as a core mechanism in the modern safety model based on the principles of adaptation and resilience. In addition, the consistent role of well-being emphasizes the importance of psychological factors as a foundation for seafarers' adaptive abilities. This model is therefore more appropriately understood as a layered system of influence that reflects the socio-technical complexity of maritime operations. It means that although individual path effects are not significant, the model as a whole is capable of explaining the variance in key constructs. This highlights the importance of model-level explanatory power rather than focusing solely on individual path significance. Future studies may benefit from re-examining the measurement indicators, increasing sample size, or considering alternative model specifications to better capture the underlying relationships.

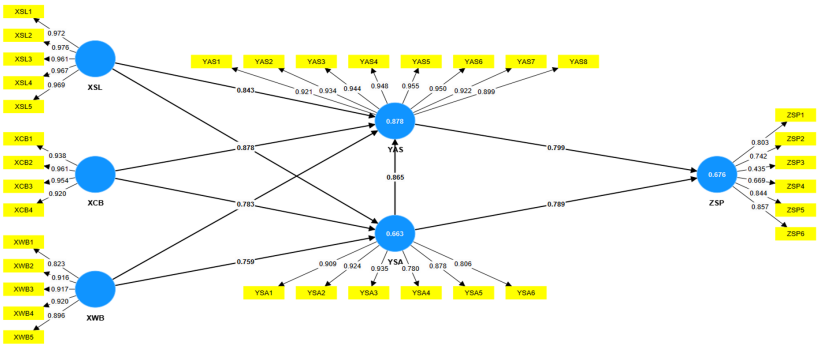

Figure 3. Measurement and Structural Model Results

The Figure 3 demonstrate that the majority of the indicators have factor loadings above the recommended threshold of 0.70, indicating that the items are valid measures of their respective latent constructs. This confirms that the observed indicators adequately capture the conceptual dimensions intended in the study. Regarding the structural model, the coefficient of determination (R^2) values indicated strong explanatory power across several endogenous constructs. Specifically, the construct ASI records an R^2 of 0.878, reflecting a very high level of variance explained. Similarly, Competency Based Training → Adaptive Safety shows an R^2 of 0.865, also within the strong category. Meanwhile, WellBeing and Mental Health → ASI demonstrates an R^2 of 0.663, which is categorized as moderate to strong, and the construct Safety Performance achieves an R^2 of 0.676, likewise indicating a satisfactory level of explanatory power.

Overall, these findings confirm that the model possesses both good indicator validity and substantial explanatory strength. This suggests that the measurement instruments are reliable and appropriate, and that the structural model is robust enough to support further hypothesis testing and theoretical interpretation.

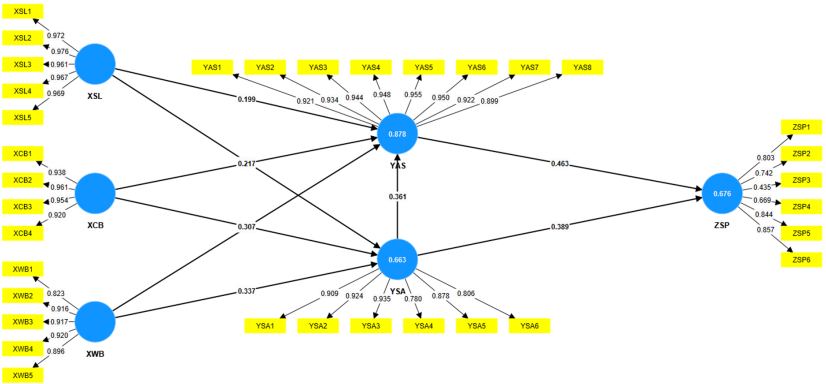

Figure 4. Structural Model Results Path coefficients

In Figure 4, an assessment of the structural model reveals that the path coefficients between the latent variables vary from low to moderate but remain consistently positive.

- The path from Safety Leadership to ASI shows a coefficient of 0.199, indicating a small yet positive influence.
- The path from Competency Based Training to ASI is 0.217, suggesting a slightly stronger effect compared to Safety Leadership but still within the low–moderate range.
- The influence of Well-being and Mental Health on ASI is more substantial, with a coefficient of 0.337, making it the strongest predictor of ASI among the three constructs.
- Regarding the outcome variable Safety Performance, the path ASI → Safety Performance has the highest coefficient of 0.463, demonstrating a relatively strong positive relationship.

- In comparison, the direct effects Competency Based Training → Safety Performance (0.361) and Well-Being and Mental Health → Safety Performance (0.389) are moderate, but weaker than the indirect contribution of ASI.

The explanatory power of the model is also noteworthy. The construct Adaptive Safety records an R^2 value of 0.878, which is considered very high, indicating that its variance is strongly explained by the predictors. Similarly, the construct Safety Performance achieves an R^2 value of 0.676, falling within the moderate–strong range, suggesting that the model sufficiently explains the variance in Safety Performance.

Table 4. Coefficient of Determination

Construct	R-square	R-square Adjusted
Adaptive Safety Intelligence (ASI)	0.878	0.877
Seafarer's Autonomy and Empowerment	0.663	0.661
Safety Performance	0.676	0.675

The results of Table 4 show that the construct ASI has an R^2 value of 0.878 (adjusted R^2 = 0.877), which is categorized as very high. This indicates that the independent variables explain a substantial proportion of the variance in ASI. For the construct Seafarer's Autonomy and Empowerment, the R^2 value is 0.663 (adjusted R^2 = 0.661), which falls within the moderate to strong range. This suggests that the predictors are able to explain the variance in Seafarer's Autonomy and Empowerment to a satisfactory degree.

The Safety Performance construct has an R^2 value of 0.676 (adjusted R^2 = 0.675), indicating moderate to strong explanatory power and confirming the model's ability to account for Safety Performance variance. Overall, the model demonstrates high explanatory power for Adaptive Safety and moderate to strong power for Seafarer's Autonomy, Empowerment, and Safety Performance, supporting its adequacy for further hypothesis testing and interpretation. The outer loading analysis shows most indicators exceed the 0.70 threshold, confirming their validity. Indicators below 0.70 may be removed, but can be retained if theoretically important for content validity. These findings confirm the convergent validity of the measurement model, making the constructs suitable for structural model analysis.

Table 5. Hypothesis Testing Results

Path	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	t-table	T Statistics (—O/STDEV—)	P Values
SL → ASI	0.199	0.200	0.053	1.964	3.738	0.000
SL → SAE	0.223	0.225	0.076	1.964	2.922	0.003
CBT → ASI	0.217	0.218	0.063	1.964	3.438	0.001
CBT → SAE	0.307	0.306	0.092	1.964	3.330	0.001
WB → ASI	0.244	0.241	0.050	1.964	4.857	0.000
WB → SAE	0.337	0.335	0.067	1.964	5.061	0.000
SAE → ASI	0.361	0.362	0.054	1.964	6.694	0.000
ASI → SP	0.463	0.456	0.095	1.964	4.853	0.000
SAE → SP	0.389	0.396	0.099	1.964	3.914	0.000

The results of the Table 5 indicate that several structural paths are statistically significant, while others are not. The level of significance is determined by the t-statistics and p-values obtained through bootstrapping.

- Paths with t-statistics greater than 1.96 (or p-values < 0.05) are considered significant, thus supporting the proposed hypotheses. This suggests that the independent variables exert a meaningful effect on their respective dependent constructs.
- Conversely, paths with t-statistics below 1.96 (or p-values > 0.05) are deemed non-significant, leading to the rejection of the corresponding hypotheses. These results imply that the proposed relationships along these paths are not empirically supported.

The findings highlight which relationships in the model are supported by data and which need refinement. Despite high explanatory power (R^2 values), several non-significant structural paths are due to ASI's mediating role, which absorbs variance from safety leadership, training, and well-being before transmitting effects to empowerment and safety performance. This causes direct relationships to appear weak while indirect effects remain meaningful. The close proximity of human-centered constructs may suppress individual path significance without affecting the model's robustness. Maritime safety outcomes emerge from complex interactions, making non-significant direct paths consistent with adaptive frameworks.

4.2. Qualitative Analysis

In the qualitative phase, the data were analyzed using NVivo software, which facilitated thematic coding and produced a word cloud to visualize the most dominant themes emerging from the respondents' narratives.

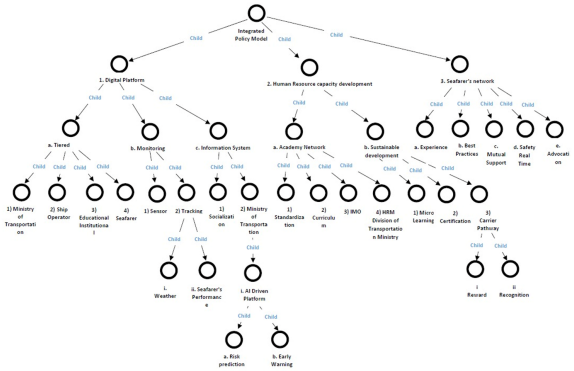

Figure 5. Integrated Policy Model

Figure 5 shows a hierarchical organizational chart or decision tree structure. The diagram displays multiple levels of interconnected nodes represented by circles, with connecting lines showing relationships between different elements.

At the top level, there appears to be a root node labeled "Safety Management Program" which branches down into several main categories. The structure then continues to branch out into multiple sub-levels, with each node containing what appears to be text labels (though some are difficult to read clearly in this image quality).

The chart uses a traditional top-down hierarchical format, with branches extending from parent nodes to child nodes. Some nodes appear to have multiple connections, indicating complex relationships within the organizational structure. The lower levels of the hierarchy contain numerous terminal nodes, suggesting detailed sub-categories or specific elements within the overall framework.

Based on the visible text fragments, this appears to be related to maritime safety management, possibly showing the breakdown of safety management components, procedures, or organizational responsibilities within a maritime context. The structure suggests a comprehensive framework with multiple layers of detail, from high-level concepts down to specific operational elements.

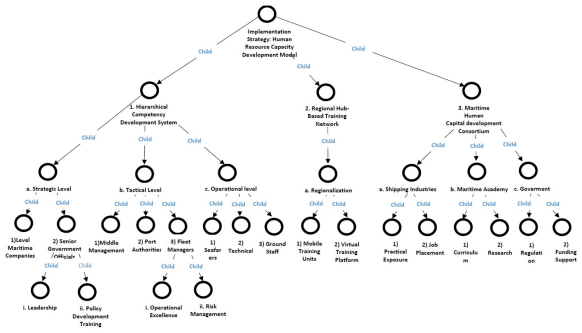

Figure 6. Plan of Integrated Model Implementation

Figure 6 presents a hierarchical organizational chart for a ”Safety Implementation Program for Maritime Transportation” as indicated at the top node. The structure is organized into three main branches:

- Left Branch - Human Resource Development System: This branch focuses on personnel-related aspects and includes sub-categories for Legal Storage, Legal Data, and Legal Compliance. The terminal nodes under this branch include elements such as Legal Maritime Companies, Safety Equipment Management, Mobile Management, Port Authorities, Ship Managers, and several operational components like Legal, Training, and Onboard Staff.
- Middle Branch - Safety Policy Navigation Network: The central branch appears to concentrate on policy and navigation safety aspects. It branches down to show Policy Framework and includes terminal nodes for elements like Planning Units and Platform operations.
- Right Branch - Management/Human Development Components: The right side of the chart deals with management and human development aspects, including Safety Competent Development and various operational elements. Terminal nodes include components like Job Equipment, Certification, Research, Population, and Landing Support.

Each major branch further subdivides into multiple levels, with connecting lines showing the hierarchical relationships. The chart uses a systematic approach to break down the complex maritime safety implementation program into manageable components, from high-level policy areas down to specific operational elements. This structure suggests a comprehensive framework for maritime safety management that addresses human resources, policy implementation, and operational management aspects.

Figure 7. Word Clouds

Based on the word cloud themed Maritime Safety Axis, it can be seen that several main themes and concepts are the center of the study. The dominant themes that emerged were ”culture”, ”support”, ”training”, ”policy”, and ”competitiveness”. These are the things that point to the core focus areas of maritime safety research.

5. MANAGERIAL IMPLICATIONS

This study highlights several key managerial implications for improving maritime safety in Indonesia, with direct relevance for industry leaders, policymakers, and seafarers. The findings indicate that shipping companies need to move beyond procedural compliance by strengthening leadership-driven and human-centered safety practices, while investing in legitimate vessel inspections, digital technologies, and competency-based training to support integrated systems such as the Maritime Single Window and IoT-based navigation. Although these measures may increase short-term operational costs, they enable more accurate access to weather and navigation information, improving voyage planning and long-term operational efficiency. At the policy

level, the government plays a critical role in reinforcing safety governance through stricter oversight against counterfeit documentation, enhanced institutional capacity, improved inter-port communication, and the provision of integrated maritime infrastructure. For seafarers, these initiatives contribute to improved occupational safety, timely access to critical safety information, and more efficient administrative processes, despite stricter certification and operational requirements. While offering strong managerial and policy insights, the study also acknowledges the need for further methodological refinement, particularly in strengthening safety performance indicators and addressing multicollinearity issues to enhance practical applicability.

Beyond these strategic directions, the findings of this study provide concrete guidance for day-to-day maritime safety management. Shipping companies can operationalize ASI by embedding adaptive learning routines into existing Safety Management Systems, such as structured near-miss reflection sessions, scenario-based safety briefings during toolbox meetings, and regular crew-led risk discussions. Ship officers and supervisors should be encouraged to apply participatory safety leadership by granting seafarers greater decision latitude in dynamic risk situations, supported by clear escalation and feedback mechanisms rather than rigid procedural enforcement. From a policy perspective, maritime regulators may strengthen safety oversight by complementing compliance-based inspections with indicators related to learning practices, empowerment, and well-being support on board. These practical measures enable safety performance to be managed as an adaptive and continuous process, thereby enhancing the real-world applicability of the ASI framework for both operational management and maritime safety governance.

6. CONCLUSION

This study demonstrates that maritime safety in Indonesia is best understood as an adaptive and socio-technical phenomenon rather than a purely technical or compliance-driven issue. By integrating safety leadership, competency-based training, and seafarer well-being within the ASI framework, the findings provide empirical evidence that safety performance emerges from the interaction of human, organizational, and psychological factors. The results highlight ASI as a central mediating mechanism that translates leadership practices, training effectiveness, and well-being into empowerment and improved safety outcomes.

The structural model exhibits strong explanatory power, particularly for ASI, indicating that the proposed framework captures the complexity of maritime safety dynamics effectively. Although several direct path coefficients appear relatively modest, their collective contribution through mediation reinforces the importance of system-level integration over linear causal dominance. Notably, seafarer well-being emerges as a critical leverage point, underscoring the need to reposition mental and physical health as strategic elements of maritime safety management rather than supplementary considerations.

From a practical perspective, the study offers meaningful implications for both maritime practitioners and policymakers. Shipping companies are encouraged to embed adaptive learning, participatory safety leadership, and empowerment-oriented practices into daily operations, while regulators may enhance oversight by complementing compliance-based inspections with indicators related to learning, well-being, and adaptive capacity. Despite its contributions, this study acknowledges limitations related to measurement refinement and contextual specificity. Future research may extend the ASI framework through longitudinal designs, cross-national comparisons, and deeper integration with digital safety technologies to further strengthen its applicability across diverse maritime settings.

7. DECLARATIONS

7.1. About Authors

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Conceptualization: SD; Methodology: AT; Software: KK; Validation: SD and KK; Formal Analysis: SD; Investigation: KK; Resources: SD and AT; Data Curation: SD; Writing Original Draft Preparation: WB

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7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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