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Regulatory Compliance, Human Competency, and Maritime Safety Perception in the Era of Electric Vehicle Transportation: Evidence from Indonesian Ferry Operations

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***Abstract*—** Indonesia's accelerating electric vehicle (EV) adoption has created a regulatory and institutional challenge of considerable urgency for domestic ferry operations, where solid-state battery fire risks intersect with persistent competency gaps among seafarers and structural limitations in multi-agency governance frameworks. This study investigates the relationships among regulatory compliance (X4), human resource capacity for fire mitigation (X3), and maritime safety perception (Y) in the context of EV cargo transport on the ASDP Padang–Mentawai ferry route. Using a concurrent mixed-method design — integrating Likert-scale surveys (N = 60; $\alpha = 0.892$), semi-structured interviews, and Focus Group Discussions (FGD) — data were collected from maritime students, lecturers, and active seafarers affiliated with Politeknik Pelayaran Sumatera Barat between February and June 2026. Regression analysis identified human resource capacity ($\beta = 0.43$, $p < 0.01$) as a stronger predictor of safety perception than regulatory compliance ($\beta = 0.31$, $p < 0.01$). FGD thematic analysis surfaced three structural governance gaps: seafarer competency deficits in thermal runaway management, fragmented inter-agency coordination between operators and regulators, and curriculum misalignment in maritime polytechnic institutions. The study contributes a Safety–Competency–Governance (SCG) framework for EV maritime safety management and provides empirically grounded curriculum and policy recommendations for Indonesia's maritime education and regulatory institutions.

Keywords—regulatory compliance; human competency; maritime safety perception; electric vehicle; Indonesian ferry; SE-DJPL No. 12/2024

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I. INTRODUCTION

When the Indonesian government issued Presidential Regulation No. 79/2023 mandating the acceleration of electric vehicle (EV) adoption as a cornerstone of national energy transition strategy, the implications for land transport infrastructure were immediately debated [1]. Far less attention was paid to a compounding consequence that unfolds at the water's edge: the hundreds of thousands of vehicles crossing Indonesia's inter-island ferry routes each year increasingly include electric models whose battery systems present fire hazard profiles that existing vessel safety architectures, regulatory frameworks, and seafarer training programs were not designed to manage [2]. Indonesia's archipelagic geography makes this an urgent operational problem rather than a theoretical one. The country's domestic ferry network, operated primarily through PT ASDP Indonesia Ferry and connecting more than 300 routes across the archipelago, is the backbone of inter-island mobility for both passengers and goods — and it now carries a growing proportion of cargo whose most significant risk characteristic is not its weight, volume, or chemical composition in the conventional sense, but the energy stored in its battery cells and the catastrophic consequences of that energy's uncontrolled release [3].

The regulatory response to this challenge has been incremental and, by the admission of ASDP's own corporate governance communications, imperfectly implemented. SE-DRJD No. 7/2024, issued by the Directorate General of Land Transportation in April 2024 specifically for the Lebaran transport period, established a provisional framework for EV loading zone designation, manifest recording, and crew patrol obligations [4]. SE-DJPL No. 12/2024, issued by the Directorate General of Sea Transportation as a standing guideline for Indonesian-flagged vessels carrying electric vehicles, extended these provisions into a more durable operational standard [5]. As of June 2026, however, ASDP publicly acknowledged that optimal implementation of these guidelines across the domestic network had not been achieved, and continued to emphasize the need for intensified coordination between Kemenhub, KSOP inspectors, vessel operators, and port charging infrastructure providers [5]. This

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acknowledgment, from the operator most directly responsible for EV cargo transport on domestic ferry routes, encapsulates the governance challenge that motivates the present study: the gap between the formal existence of a regulatory framework and its effective operationalization across a fragmented multi-actor system.

The governance gap would be troubling enough if EV fire risk were well-managed by experienced and trained seafarers who simply lacked regulatory guidance. The empirical evidence suggests otherwise. Mok et al. [6] demonstrated through longitudinal analysis of maritime accident data that ISM Code compliance — the foundational regulatory instrument for maritime safety management — does not consistently produce safety performance improvements unless it is accompanied by genuine organizational safety culture change and embedded seafarer competency. Shi et al. [7] showed through Bayesian network analysis that despite the STCW framework's extensive provisions for seafarer training, human error attributable to knowledge deficits and inadequate situational competency remains a leading contributor to maritime accidents. In the specific domain of energy transition-related operational measures, Dewan and Godina [8] found that seafarers' conceptual awareness of new energy-related requirements consistently outpaces their operational capacity to implement them — a pattern they attribute to the systematic lag between regulatory prescription and curriculum adaptation in maritime education institutions. These convergent findings from the international literature establish a theoretical expectation that the present study tests empirically: in contexts of rapid technological change, regulatory compliance awareness and operational human competency are decoupled, and this decoupling is the primary mechanism through which regulatory intent fails to translate into operational safety outcomes.

The Padang–Mentawai ASDP ferry route provides an analytically productive context for examining this decoupling. The route connects Padang, the provincial capital of West Sumatra, to the Mentawai Islands across a sea passage characterized by wave heights regularly exceeding four metres, humidity levels consistently above 85%, and transit times that can extend significantly under adverse weather conditions [9]. These environmental factors amplify the consequences of any competency or governance failure: a thermal runaway event occurring on this route would be geographically remote from shore-based fire services, with no realistic prospect of external emergency assistance within the critical first hours of the incident. The route's EV traffic has grown substantially since 2025, driven by Indonesia's national EV adoption policies and ASDP's broader network expansion, making the governance gap identified above not a future risk but a present operational reality [1]. Waskito et al. [9] identified comparable Indonesian domestic ferry routes as exhibiting precisely the unsafe control action patterns in the loading and transit interface that SE-DJPL No. 12/2024 was designed to address — yet found that structural barriers to compliance systematically undermined regulatory effectiveness.

Against this backdrop, the institutional position of maritime polytechnic institutions — specifically Politeknik Pelayaran Sumatera Barat — takes on particular significance. Maritime polytechnics occupy the intersection between the regulatory system (whose requirements they translate into curriculum) and the operational system (whose seafarers they produce) [10]. Their capacity to respond to the competency demands created by EV cargo handling — and their current failure to do so, given the absence of dedicated EV safety modules in existing curricula — makes them both a central part of the governance gap and a critical lever for its resolution. Zheng et al. [11] demonstrated in the analogous context of China's energy transition training systems that embedding process safety knowledge in institutional education programs is the most durable mechanism for closing the gap between regulatory intent and operational practice — more durable than awareness campaigns, inspection regimes, or compliance mandates alone. The implication for Indonesia's maritime polytechnic system is clear, but the empirical evidence base for acting on it has been absent.

The present study addresses this evidence gap through three research objectives. First, to analyze the level of regulatory compliance with SE-DRJD No. 7/2024 and SE-DJPL No. 12/2024 among vessel operators, port authorities, and seafarers involved in EV cargo transport on the Padang–Mentawai route. Second, to examine the relationship between human resource capacity for EV fire mitigation, regulatory compliance, and overall maritime safety perception across three stakeholder groups: maritime students, lecturers, and active seafarers affiliated with Politeknik Pelayaran Sumatera Barat. Third, to identify the structural governance gaps that impede effective EV safety management and to formulate a competency and governance framework applicable to Indonesia's domestic ferry sector and its maritime polytechnic institutions.

The intellectual contribution of this study is threefold. Theoretically, it advances a Safety–Competency–Governance (SCG) integrative framework that positions human resource capacity as the mediating variable between regulatory compliance and safety perception — an analytical structure absent from the existing maritime EV safety literature. Empirically, it provides the first cross-stakeholder, mixed-method examination of EV regulatory compliance and competency gaps in the Indonesian domestic ferry sector. Institutionally, it generates actionable curriculum and policy recommendations grounded in empirical evidence rather than regulatory assumption, addressing the institutional lag that Dewan and Godina [8] identified as the systemic barrier to seafarer competency in maritime energy transition contexts. The study thus speaks to scholars in maritime safety management, maritime educators and policymakers in Indonesia and the broader ASEAN maritime region, and to the international debate on how regulatory frameworks can be designed to bridge

the persistent gap between prescription and practice in complex, multi-actor safety governance systems.

The intellectual contribution of this study extends beyond its specific empirical context in three directions. First, it tests and empirically substantiates the SCG framework proposition that competency mediates between regulatory compliance and safety outcomes — a proposition that has been theoretically articulated but never quantitatively tested across multiple stakeholder groups in a single study. Second, it provides cross-stakeholder evidence for the mechanism of this mediation: the competency gradient from lecturers through students to active seafarers reveals the institutional pathway through which the regulatory-competency gap is reproduced and amplified across Indonesia's maritime training and operational system. Third, it generates empirical evidence for a sequenced, three-track intervention agenda that prioritizes faculty development before curriculum revision, CPD programs for active seafarers before initial education reform, and inter-agency coordination mechanisms before further regulatory issuance — a sequencing that reverses the current institutional logic, which has prioritized regulatory production over competency investment.

The study's evidence base is drawn from February to June 2026, a period during which SE-DJPL No. 12/2024 had been in effect for over a year and public acknowledgment of its incomplete implementation by ASDP had appeared in the formal record [5]. This temporal positioning means the study captures not the immediate aftermath of regulatory issuance but the medium-term implementation landscape — a more diagnostically informative moment for identifying the structural barriers to effective governance than the first weeks after a new regulation is published.

The paper is organized as follows. Section 2 reviews the theoretical and empirical literature across four domains — EV maritime governance, regulatory compliance mechanisms, human competency in safety management, and maritime safety perception — building the conceptual foundation for the SCG framework. Section 3 describes the concurrent mixed-method design, sampling rationale, and analytical procedures. Section 4 presents quantitative regression findings, item-level compliance gap analysis, and three qualitative governance gap themes derived from FGD and interview data. Section 5 discusses the theoretical contributions of the SCG framework, the governance fragmentation mechanisms identified by qualitative analysis, and the three-track intervention agenda. Section 6 concludes with a synthesis of contributions and future research directions.

II. LITERATURE REVIEW

2.1 Understanding 2.1 Regulatory Frameworks for EV Maritime Safety: Between Prescription and Practice

The governance of EV transport on maritime vessels represents a relatively recent and rapidly evolving regulatory frontier. Internationally, the International Maritime Organization's SOLAS framework and the IMDG Code provide the foundational legal architecture for dangerous cargo at sea, but EVs as a cargo category occupy an ambiguous position within this framework: their battery systems are regulated as dangerous goods under certain conditions, yet the vehicles themselves are not classified as dangerous cargo in the conventional sense [12]. This regulatory ambiguity has left national maritime authorities to develop their own operational guidance within a partially specified international framework, producing a patchwork of national measures whose comprehensiveness and implementation effectiveness vary considerably [3].

In Indonesia, the two principal instruments — SE-DRJD No. 7/2024 and SE-DJPL No. 12/2024 — represent a substantive regulatory response to this governance gap [4], [5]. The former, issued by the Directorate General of Land Transportation for the 2024 Lebaran transport period, operationalized the minimum requirements for EV loading zones, manifest documentation, crew patrol obligations, and charging device prohibitions during high-traffic periods. The latter extended these requirements into a standing operational standard for Indonesian-flagged vessels, with provisions for designated EV stowage areas, ventilation standards, machinery space separation distances, and inter-agency oversight responsibilities. However, the regulatory prescriptions embedded in these instruments face the implementation challenges that Baig et al. [13] identified as structural features of domestic ferry safety governance in developing countries: fragmented multi-agency authority, limited inspection capacity, resource-constrained vessel operators, and the absence of route-specific risk assessment requirements that would tailor regulatory compliance obligations to the specific hazard profile of each route.

Wahid et al. [14] examined the implementation of safety management systems for traditional shipping in Indonesia through a Delphi methodology, finding that the primary barrier to SMS effectiveness was not the absence of regulatory prescription but the absence of standardized indicators for measuring implementation progress — an absence that allowed formal compliance to coexist with substantive safety management failure. This finding resonates with Mok et al.'s [6] longitudinal analysis of ISM Code effectiveness, which demonstrated that the Code's formal compliance requirements and its substantive safety outcomes can diverge substantially when organizational safety culture and competency development are not addressed alongside procedural documentation. Applied to the EV regulatory context, these findings suggest that SE-DJPL No. 12/2024's effectiveness will depend less on the clarity of its prescriptions than on the organizational infrastructure — training programs, inspection protocols, coordination mechanisms, and institutional incentives — that enables its implementation across a diverse and resource-constrained vessel fleet.

2.2 Human Competency as the Critical Mediator of Safety Governance

The relationship between regulatory compliance and safety outcomes in maritime settings is not direct but mediated — primarily by human competency. This theoretical position, supported by the preponderance of maritime safety research, holds that regulatory

frameworks establish the conditions for safe operations but cannot guarantee them absent the knowledge, skills, and behavioral dispositions required to operationalize regulatory requirements in dynamic, real-world contexts [7]. Shi et al. [7] demonstrated that STCW-framework competency requirements, despite their comprehensiveness, leave systematic knowledge gaps when the operational environment changes faster than the curriculum revision cycle — a condition that the EV cargo transition exemplifies with particular clarity.

Zheng et al. [11] examined the institutional learning mechanisms through which process safety knowledge is embedded in energy sector training systems in China, finding that the most durable competency outcomes were achieved when safety knowledge was integrated into foundational professional education rather than delivered through standalone awareness programs. Their framework distinguishes between declarative knowledge (knowing that a hazard exists), procedural knowledge (knowing what to do in response), and behavioral embedding (reliably doing it under operational stress) — a three-stage model that maps directly onto the competency gap observed in maritime EV fire management, where declarative awareness is relatively high but procedural knowledge and behavioral embedding are substantially absent. Lopes et al. [15] identified analogous competency structure gaps in maritime and port logistics education, finding that industry competency demands consistently outpaced academic curriculum responses in rapidly evolving domains — a pattern they linked to the institutional lag between regulatory and technological change and the formal curriculum revision processes of polytechnic institutions.

In the Indonesian maritime education context, Wulandari and Cahyadi [10] examined the integration of emerging technologies and sustainable practices in maritime engineering education, finding through qualitative analysis that curriculum adaptation to new technological requirements was consistently impeded by the absence of industry-validated competency standards, limited faculty exposure to current operational practices, and procurement constraints on practical training equipment. Simanjuntak et al. [16] demonstrated through a mixed-methods study of maritime English communication that effective competency development in maritime polytechnic settings requires frameworks that bridge operational demands and institutional pedagogical structures — a finding that has direct implications for the design of EV safety competency programs. Together, these Indonesian-contextual studies establish that the competency gap identified in the international literature is not merely reproduced in the domestic maritime education system but is amplified by structural features of Indonesian polytechnic governance that slow curriculum adaptation.

2.3 Maritime Safety Perception: Linking Governance and Competency to Outcomes

Safety perception — the subjective assessment of safety conditions, risks, and response capacity — has been established as a significant predictor of safety behavior and organizational safety performance in maritime settings [17]. Unlike objective safety metrics (incident rates, near-miss reports), safety perception captures the attitudinal and cognitive dimensions of safety management that mediate between formal regulatory requirements and actual seafarer behavior [6]. Sharma et al. [17] demonstrated through systematic review that cognitive and social factors in vessel traffic service operations — including mental model accuracy, situational awareness, and team communication quality — are as consequential for safety outcomes as technical system design. Their finding that high-stakes maritime safety decisions are shaped more by the quality of the cognitive models seafarers hold than by the formal procedures available to them has direct implications for the design of EV safety training programs, which must target cognitive model accuracy — specifically, accurate understanding of solid-state battery fire dynamics — rather than procedural compliance alone.

Bokau et al. [18] used FRAM analysis on Indonesian domestic ferry safety in Makassar Port to demonstrate that safety perception among port actors was shaped primarily by inter-agency coordination quality and trust — not by the formal adequacy of regulatory instruments. Their finding that coordination failures produced negative safety perceptions even when formal compliance was maintained suggests that governance fragmentation has an independent psychological effect on safety management behavior, beyond its direct operational consequences. This governance-perception relationship is particularly relevant for the multi-agency EV safety governance structure on the Padang–Mentawai route, where coordination among ASDP operators, KSOP inspectors, port charging providers, and Kemenhub occurs across institutional boundaries that are structurally prone to the coordination failures Bokau et al. documented.

The concept of safety perception has also been examined in relation to the risk perception literature, which distinguishes between objective risk (the actuarial probability of a harmful event) and perceived risk (an individual's subjective assessment of that probability and its consequences) [28]. In maritime settings, perceived risk is shaped not only by technical knowledge but by prior experience, social communication, institutional trust, and the quality of safety management systems that individuals observe in their operational environment [6]. For EV cargo specifically, the novelty of the hazard means that perceived risk is likely to be calibrated against conventional fire experience rather than against accurate solid-state battery fire dynamics — a calibration error that could lead seafarers to systematically underestimate the risk and respond with suppression techniques (CO_2, dry powder) that are inappropriate for sustained battery thermal management. The present study's integration of safety perception as the dependent variable Y is designed to capture this calibration dynamic: it treats safety perception not merely as an attitudinal outcome but as a diagnostic indicator of whether regulatory compliance and competency development have been sufficient to produce accurate risk mental models among the relevant stakeholder groups.

2.4 Maritime Governance Frameworks for Domestic Ferry Safety

The governance literature on domestic ferry safety in developing countries identifies a consistent structural pattern: national regulatory frameworks of reasonable comprehensiveness are undermined by multi-agency fragmentation, resource asymmetries, and the absence of route-specific risk assessment requirements [13]. Baig et al. [13] proposed a Safety–Sustainability Governance (SSG) framework for domestic ferry sectors, built around Principles, Criteria and Indicators (PCIs) that operationalize governance quality across technical, organizational, and institutional dimensions. Their framework's central insight — that governance effectiveness requires alignment across regulatory, operational, and educational institutions rather than excellence in any single domain — provides the conceptual template from which the present study derives its SCG framework. The SCG framework adds competency as an explicit mediating construct, positioned between regulatory compliance (the governance input) and safety perception (the governance outcome), reflecting the empirical evidence reviewed above that human resource capacity is the variable through which regulatory intent is — or fails to be — translated into safety behavior.

2.5 Research Gap and Conceptual Position

The literature reviewed above converges on a coherent but empirically underspecified theoretical position: in the EV maritime safety governance context, the relationship between regulatory compliance and safety outcomes is mediated by human competency, and both variables are shaped by institutional governance quality in the maritime education and regulatory coordination systems. However, no published study has tested this theoretical structure empirically in the Indonesian domestic ferry sector, examined it across the three stakeholder groups most directly implicated (students, educators, and active seafarers), or used it to generate actionable curriculum and governance recommendations for a specific route and institutional context. The present study addresses this tripartite gap through a concurrent mixed-method design that generates both statistical evidence for the proposed mediation structure and qualitative evidence for the mechanisms through which it operates.

III. METHOD

This study employed a concurrent mixed-method design to examine the relationships among regulatory compliance, human resource competency, and maritime safety perception in the context of EV cargo transport on the ASDP Padang–Mentawai route. The mixed-method design was selected because the research objectives require both the statistical generalizability that quantitative analysis provides and the mechanistic depth that qualitative inquiry enables — a methodological rationale consistent with Zhao et al.'s [19] approach to barrier analysis in maritime capability development [20]. Data collection was conducted between February and June 2026, involving field observation at Pelabuhan Bungus Padang and stakeholder engagement through Politeknik Pelayaran Sumatera Barat's institutional networks.

The study population comprised three stakeholder groups directly implicated in EV maritime safety governance: maritime students in their final two years of study, lecturers and instructors with maritime safety or engineering specializations, and active seafarers — deck officers and ratings — with operational experience on the Padang–Mentawai or comparable ASDP routes. Purposive sampling was employed, selecting participants on the basis of direct relevance to the research objectives: EV cargo handling experience, maritime safety management responsibility, or curriculum development authority relating to safety education [21]. A total of N = 60 valid respondents were recruited across the three groups. For the qualitative components, 10 participants with the most substantive operational or institutional experience were selected for in-depth individual interviews, and 12 participated in the three-session structured FGD, using snowball sampling to reach theoretical saturation.

The primary quantitative instrument was a five-point Likert-scale questionnaire comprising 32 valid items after instrument testing, distributed across five variable clusters: EV knowledge (X1), cargo stowage practices (X2), fire mitigation human resource capacity (X3), regulatory compliance (X4), and maritime safety perception (Y). Internal consistency was confirmed at $\alpha = 0.892$. The qualitative instruments comprised semi-structured interview guides tailored to each stakeholder group and a three-session FGD protocol covering regulatory compliance assessment, competency gap identification, and governance improvement recommendations. Documentary analysis examined SE-DRJD No. 7/2024, SE-DJPL No. 12/2024, ASDP operational SOPs, SOLAS Chapter II-2, and ISM Code provisions [12].

Quantitative data were analyzed using descriptive statistics and multiple regression, with regulatory compliance (X4) and fire mitigation capacity (X3) entered as predictors of safety perception (Y). Qualitative data were analyzed using the Miles–Huberman–Saldaña interactive model through three coding cycles: open coding of transcript and FGD data, axial coding to develop inter-theme relationships, and selective coding to generate the structural gap themes reported in the findings [21]. Cross-group comparison was conducted to identify stakeholder-specific patterns that the aggregate analysis might obscure. Triangulation integrated quantitative distributions, qualitative themes, and FGD consensus findings, with discrepancies between data sources treated as analytically productive rather than resolved by privileging one method [20].

IV. RESULT AND ANALYSIS

4.1 Descriptive Profile and Variable Distributions

Table 1 presents the descriptive statistics for all five variable clusters across the full sample and by stakeholder group. The cross-group variation in X3 and X4 scores is the most analytically significant feature of the descriptive profile.

TABLE 1.
DESCRIPTIVE STATISTICS BY VARIABLE AND STAKEHOLDER GROUP (N = 60)

Variable	Full Sample M (SD)	Students M (SD)	Lecturers M (SD)	Seafarers M (SD)
X1 — EV Knowledge	3.72 (0.61)	3.68 (0.58)	3.91 (0.54)	3.61 (0.67)
X2 — Cargo Stowage	3.18 (0.74)	3.22 (0.71)	3.44 (0.68)	2.97 (0.79)
X3 — HR Fire Capacity	2.89 (0.82)	2.97 (0.77)	3.31 (0.74)	2.61 (0.79)
X4 — Regulatory Compliance	3.45 (0.69)	3.38 (0.65)	3.78 (0.61)	3.29 (0.72)
Y — Safety Perception	3.61 (0.71)	3.58 (0.68)	3.84 (0.63)	3.47 (0.74)

The cross-group pattern is structurally revealing. Lecturers return the highest means on all variables, reflecting their professional engagement with regulatory knowledge and institutional safety frameworks. Active seafarers — the group with direct operational responsibility for EV fire management aboard vessel decks — return the lowest means on X3 (M = 2.61) and X4 (M = 3.29), creating a competency gradient that is precisely inverted from what effective safety governance requires: those with the most direct operational responsibility hold the weakest competency and compliance profiles. This inversion is theoretically consistent with Dewan and Godina's [8] finding that seafarers implementing novel energy-related procedures face structural knowledge gaps that standard maritime training programs do not address, but the magnitude of the X3 gap between lecturers (M = 3.31) and seafarers (M = 2.61) — a difference of 0.70 standard deviation units — is larger than the existing literature anticipated and has direct implications for the targeting of intervention resources.

The full-sample X4 mean of 3.45 — categorized as "good" — indicates that regulatory awareness across the stakeholder community is at a functional level, providing the awareness base that Zheng et al. [11] identified as the necessary but insufficient precondition for effective competency development. The X3 mean of 2.89, however, indicates that this awareness has not been translated into the procedural knowledge and behavioral readiness that effective emergency response requires.

4.2 Regression Analysis: Regulatory Compliance and HR Capacity as Predictors of Safety Perception

Multiple regression analysis was conducted with regulatory compliance (X4) and human resource fire mitigation capacity (X3) as predictors of maritime safety perception (Y). Table 2 presents the results.

TABLE 2.
MULTIPLE REGRESSION: X4 AND X3 PREDICTING MARITIME SAFETY PERCEPTION (Y)

Predictor	B	Std. Error	β	t	p
Constant	1.08	0.34	—	3.18	.002
X4 — Regulatory Compliance	0.34	0.11	0.31	3.09	.003
X3 — HR Fire Mitigation Capacity	0.49	0.10	0.43	4.90	< .001

Note: $R = 0.689$, $R^2 = 0.475$, $F(2,57) = 25.77$, $p < .001$

The model explains 47.5% of the variance in maritime safety perception ($R^2 = 0.475$). Both predictors make statistically significant independent contributions, but the standardized coefficients reveal a theoretically significant asymmetry: X3 (β = 0.43) exerts substantially stronger influence on safety perception than X4 (β = 0.31). This differential is consistent with the mediation structure proposed in the SCG framework: regulatory compliance shapes the informational and procedural environment within which safety decisions are made, but human resource capacity — the competency to act effectively on that regulatory knowledge under operational conditions — is the more proximal determinant of how safe the operational environment feels to those working within it.

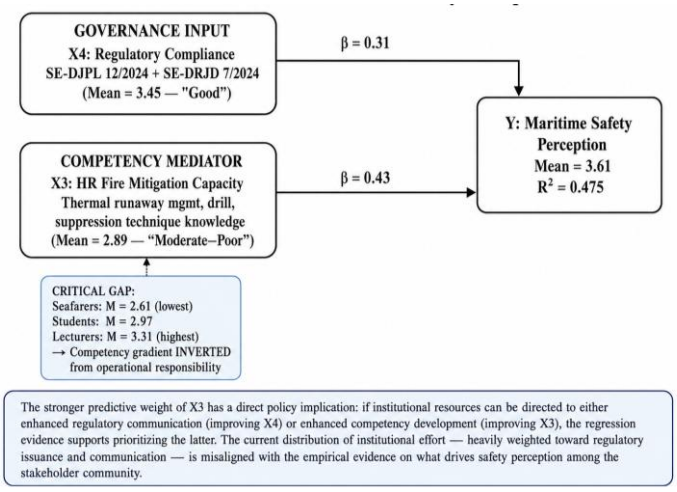

Figure 1. SCG Framework: Regulatory Compliance and HR Competency as Predictors of Maritime Safety Perception

The stronger predictive weight of X3 has a direct policy implication: if institutional resources can be

directed to either enhanced regulatory communication (improving X4) or enhanced competency development (improving X3), the regression evidence supports prioritizing the latter. The current distribution of institutional effort — heavily weighted toward regulatory issuance and communication — is misaligned with the empirical evidence on what drives safety perception among the stakeholder community.

4.3 Regulatory Compliance Gap Analysis

Deeper analysis of the X4 item-level responses reveals a pattern that the aggregate mean conceals: respondents are significantly more confident in their knowledge of regulatory requirements (items 4.1.1–4.1.3, M = 3.71) than in their assessment of actual implementation effectiveness (items 4.1.4–4.1.5, M = 3.12) and the adequacy of current regulations to cover the solid-state battery-specific risks (items 4.2.1–4.2.2, M = 3.18). This knowledge–implementation gap — significant at $p < .05$ by paired-samples comparison — is structurally consistent with Wahid et al.'s [14] finding that formal SMS indicator compliance in Indonesian traditional shipping routinely overstates actual safety management effectiveness. It also aligns with Mok et al.'s [6] demonstration that ISM Code awareness and ISM Code operational effectiveness are empirically decoupled variables in maritime organizational settings.

Figure 2 illustrates the item-level X4 score distribution across the three regulatory subdimensions

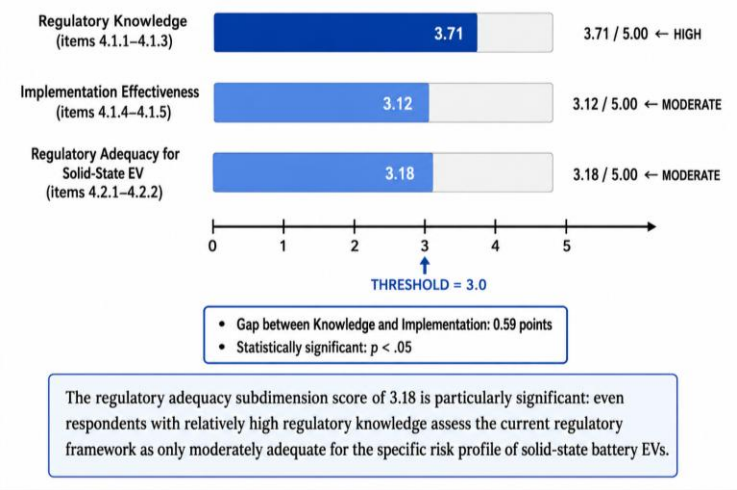

Figure 2. Regulatory Compliance Sub-dimension Item Mean Scores (X4)

The regulatory adequacy subdimension score of 3.18 is particularly significant: even respondents with relatively high regulatory knowledge assess the current regulatory framework as only moderately adequate for the specific risk profile of solid-state battery EVs. This finding supports Baig et al.'s [13] argument that domestic ferry safety governance requires route-specific risk assessment instruments rather than generalized national guidelines, and suggests that SE-DJPL No. 12/2024 — while a necessary advance — requires supplementation with solid-state-battery-specific technical annexes and route-specific compliance indicators.

4.4 Qualitative and FGD Findings: Governance Gap Themes

Thematic analysis of interview transcripts and FGD records across three sessions produced three structural governance gap themes, each of which explains a distinct mechanism through which regulatory compliance fails to produce the operational safety outcomes it intends.

Theme 1: Seafarer Competency Deficits in Thermal Runaway Management

This theme emerged with the greatest salience and cross-group consistency of the three. All stakeholder groups independently identified the absence of specialized EV fire management training as the most operationally consequential gap in the current safety governance system. Active seafarers reported complete absence of training specific to solid-state battery thermal runaway — including correct suppression media selection, sustained water cooling protocols, re-ignition monitoring procedures, and evacuation coordination for EV fire scenarios. Several informants with extensive ASDP experience reported having received no updated safety briefings since SE-DJPL No. 12/2024 was issued, indicating that the regulatory instrument has not been accompanied by the training cascade that implementation requires.

Lecturers acknowledged that Politeknik Pelayaran Sumatera Barat's current curriculum does not include EV fire safety as a dedicated topic in any module, and that faculty themselves have limited formal training in this domain. This faculty knowledge gap is a structural barrier to curriculum adaptation that cannot be resolved through curriculum revision alone — it requires targeted professional development investment in the teaching staff before EV safety content can be effectively delivered to students. The implication drawn from Zheng et al.'s [11] institutional learning framework is that curriculum adaptation must be preceded by faculty capacity building, sequencing that current institutional planning at the institution does not appear to reflect.

Theme 2: Fragmented Inter-Agency Coordination Between Operators and Regulators

The second structural gap concerns the coordination architecture across the three principal institutional actors in EV cargo governance: ASDP vessel operators, KSOP port inspectors, and Kemenhub's Directorate General of Sea Transportation. FGD informants across all groups identified a consistent pattern of coordination failure: EV manifest recording requirements specified in SE-DJPL No. 12/2024 are inconsistently enforced by KSOP inspectors across different sailings, creating an uneven compliance landscape in which some vessels are carefully documented and others are not; ASDP operational management has not issued vessel-specific implementation guidance translating the Ministerial circular into the route-specific procedures and checklists that deck officers require; and port charging facility operators at Pelabuhan Bungus operate without SoC management protocols linked to vessel departure schedules, meaning that EVs routinely board with unknown and potentially high battery charge states.

Bokau et al.'s [18] FRAM analysis of Indonesian port safety provides the theoretical framework for understanding this coordination failure: the safety of maritime operations is a system property that emerges from the interaction of multiple actors, and coordination failures between actors produce safety performance variability that no single actor's compliance can compensate for. The multi-agency governance fragmentation documented in the present study's FGD findings is structurally analogous to the coordination failures Bokau et al. identified at Makassar Port — but with the additional complexity of a novel cargo hazard (solid-state EV batteries) for which inter-agency coordination norms have not yet been established.

Theme 3: Curriculum Misalignment at Maritime Polytechnic Institutions

The third structural gap theme concerns the institutional failure of maritime polytechnic curricula to keep pace with the competency demands created by EV cargo handling. This theme emerged most forcefully from the lecturer and student groups, who provided detailed accounts of the mismatch between regulatory expectations (as embodied in SE-DJPL No. 12/2024) and the knowledge produced by current instructional programs. Informants identified three specific curriculum gaps: the absence of any module on EV battery fire dynamics and suppression; the absence of practical drills or simulator exercises involving EV fire scenarios; and the absence of systematic instruction on EV manifest management, loading zone protocols, and SoC threshold enforcement. Wulandari and Cahyadi [10] documented analogous curriculum alignment failures in Indonesian maritime engineering education, attributing them to institutional governance structures that slow curriculum revision and to resource constraints that limit practical training infrastructure investment.

The implication of this theme, read in conjunction with the competency gradient finding from the quantitative analysis (seafarers M = 2.61, students M = 2.97, lecturers M = 3.31), is that the curriculum gap is already producing graduated cohorts who are better prepared for EV cargo handling than the currently active seafarer population — but still substantially below the competency level that effective safety management requires. This relative improvement represents an institutional trajectory in the right direction, but at a pace that is mismatched with the rate at which EVs are entering the ferry route's cargo mix.

V DISCUSSION

5.1 The SCG Framework: Theoretical Contribution and Empirical Grounding

The study's central theoretical contribution is the empirical grounding of the Safety–Competency–Governance (SCG) framework, which positions human resource competency (X3) as the critical mediating variable between regulatory compliance (X4) and maritime safety perception (Y). The regression finding that X3 exerts a substantially stronger influence on safety perception ($\beta = 0.43$) than X4 ($\beta = 0.31$) provides quantitative support for the SCG framework's core proposition: that governance effectiveness in novel cargo hazard contexts depends more on the competency of the actors charged with implementing regulatory requirements than on the formal quality of the requirements themselves. This is not a finding that diminishes the importance of regulatory quality — the significant independent contribution of X4 confirms that regulatory compliance matters — but rather one that specifies the mechanism through which regulatory quality translates into safety outcomes: through the human competency that gives regulatory requirements operational meaning.

This finding extends the theoretical contribution of Mok et al. [6], who demonstrated at the organizational level that ISM Code compliance and ISM Code effectiveness are empirically decoupled, by specifying the individual-level mechanism of this decoupling: it is the gap between regulatory awareness (captured by X4) and the operational competency to act on that awareness (captured by X3) that explains why formal compliance does not guarantee operational safety performance. Zheng et al.'s [11] institutional learning framework predicted this decoupling on theoretical grounds, but the present study is the first to test it empirically in the EV maritime safety context across multiple stakeholder groups. The cross-group competency gradient — lecturers (X3 = 3.31) to students (X3 = 2.97) to seafarers (X3 = 2.61) — reveals the institutional pathway through which this decoupling is reproduced: the educational system produces graduates with higher competency than the currently active seafarer cohort, but both fall below the threshold required for effective EV fire management, and the active seafarer cohort — who bear the greatest operational responsibility — remain the most severely underequipped.

5.2 Governance Fragmentation as Safety Risk

The three structural gap themes identified through FGD analysis provide qualitative evidence for the mechanisms through which governance fragmentation produces safety performance deficits that regulatory prescriptions alone cannot address. The competency deficit theme (Theme 1) implicates maritime education institutions as the primary site of governance failure at

the individual-knowledge level. The inter-agency coordination theme (Theme 2) implicates the regulatory and operational governance architecture at the systemic level. The curriculum misalignment theme (Theme 3) bridges these two levels, showing how institutional lag in curriculum development translates systemic governance fragmentation into individual competency gaps. Together, these three themes constitute a causal chain — from fragmented governance architecture through institutional curriculum inertia to individual competency deficit — that the SCG framework captures analytically and the mixed-method design reveals empirically.

Baig et al.'s [13] SSG framework for domestic ferry governance provides a useful comparative reference for this analysis. Their finding that governance effectiveness requires alignment across regulatory, operational, and educational institutions — rather than excellence in any single domain — is substantiated by the present study's evidence: the regulatory domain (X4 = 3.45) shows relatively good performance, while the competency domain (X3 = 2.89) shows substantially weaker performance, and the gap between them is the primary mechanism of safety governance failure on this route. This alignment gap is not accidental: it reflects the structural disconnection between the Kemenhub regulatory apparatus that issues compliance instruments and the Ministry of Transportation's maritime polytechnic network that trains the seafarers required to implement them — a disconnection that neither institutional domain can resolve unilaterally.

5.3 Practical Implications: A Three-Track Intervention Agenda

The study's practical implications follow directly from the three structural gap themes. Track One — addressing the competency deficit — requires the development of a dedicated EV maritime safety competency module at Politeknik Pelayaran Sumatera Barat, covering solid-state battery fire dynamics, thermal runaway management procedures, suppression technique selection, re-ignition monitoring protocols, and EV cargo zone management. This module should be delivered in both initial education (for students) and continuing professional development formats (for active seafarers), with the CPD delivery prioritized given the severity of the competency deficit in the active seafarer population. Faculty professional development in EV fire safety must precede and accompany curriculum development — consistent with Zheng et al.'s [11] sequencing requirement for institutional learning in energy transition contexts.

Track Two — addressing inter-agency coordination failures — requires the formalization of a coordination protocol among KSOP inspectors, ASDP operations management, and port charging facility operators that specifies: (a) EV manifest verification responsibilities and inspection frequency standards; (b) SoC management procedures at port charging stations, including maximum SoC thresholds for boarding on routes with identified suppression capacity limitations; and (c) incident reporting pathways between vessel operators and Kemenhub for thermal events or pre-thermal runaway indicators detected during transit. This coordination protocol should be formalized as a route-specific annex to SE-DJPL No. 12/2024, tailored to the environmental and infrastructure conditions of the Padang–Mentawai route. Track Three — addressing curriculum misalignment — requires a formal mechanism for regulatory change to trigger curriculum review at maritime polytechnics, modeled on the professional standards linkage mechanisms that Lopes et al. [15] identified as the most effective approach to closing the competency-demand gap in maritime logistics education.

5.4 Limitations and Future Research

The study's primary limitation is its single-route, single-institution frame, which was chosen for analytical precision and contextual depth but at the cost of external validity. The findings are most directly applicable to ASDP routes with comparable environmental profiles — remote, high-wave, high-humidity passages where external emergency support is limited and vessel generation is comparable to the Padang–Mentawai fleet. While this focus enables empirical precision and contextual depth, it limits the generalizability of the findings to other ASDP routes and other Indonesian maritime polytechnics. The regression model's cross-sectional design constrains causal inference: the finding that X3 predicts Y more strongly than X4 establishes a significant association, not a demonstrated causal mechanism. Future research should test the SCG framework on other high-traffic ASDP routes — particularly Merak–Bakauheni, where EV volumes are substantially higher — and should include longitudinal designs capable of evaluating whether curriculum interventions reduce the competency gradient identified here. The study's N = 60 sample, while adequate for the regression analysis reported, limits the statistical power available for sub-group analyses; future replication with larger samples would strengthen the cross-group comparison findings. Additionally, the rapid evolution of solid-state battery technology means that the competency requirements mapped in this study will themselves evolve, necessitating periodic review of both the research framework and the curriculum recommendations derived from it.

5.5 Implications for Maritime Policy and Regional Maritime Safety Governance

Beyond the immediate Padang–Mentawai operational context, the study's findings carry implications for Indonesia's broader maritime governance architecture and for the regional maritime safety governance debate in ASEAN. Indonesia operates the largest domestic ferry network in Southeast Asia, and the regulatory instruments it develops for EV cargo transport will inevitably influence the governance approaches adopted by neighboring archipelagic states — the Philippines, Malaysia, and the Pacific island nations — as EV adoption accelerates across the region. The SCG framework's emphasis on competency as the critical mediator of regulatory effectiveness offers a transferable analytical tool for these governance contexts, where the

same structural features — fragmented multi-agency authority, institutional lag in maritime education curricula, and resource asymmetries between regulatory production and training infrastructure — are present.

The study also speaks to a broader policy debate about the sequencing of regulatory and competency investment in maritime energy transition governance. The finding that X3 ($\beta = 0.43$) outweighs X4 ($\beta = 0.31$) in predicting safety perception suggests that, given finite institutional resources, the marginal return on investment in competency development exceeds the marginal return on additional regulatory clarification at the current state of the governance system. This is not an argument against regulatory development — SE-DJPL No. 12/2024 is a necessary and valuable instrument — but rather an argument for rebalancing institutional attention and resources toward the training and coordination infrastructure that enables regulatory requirements to be operationalized. Lopes et al.'s [15] finding that maritime education institutions consistently underinvest in industry-aligned competency development relative to the rate of technological change provides comparative regional support for this argument, suggesting that the resource rebalancing recommendation is not specific to the Indonesian context but reflects a structural tendency in maritime education governance that requires deliberate institutional correction.

The governance coordination theme identified through FGD analysis further suggests that the most cost-effective short-term intervention may not be new regulation or new curriculum but the formalization of existing coordination relationships among KSOP, ASDP, and port charging providers through a route-specific coordination protocol. Such protocols — specifying responsibility allocation, information-sharing mechanisms, and escalation pathways for EV-related safety incidents — require no new regulatory authority and no curriculum revision process, and could be developed and piloted on the Padang–Mentawai route within a short implementation timeline. Wahid et al.'s [14] experience with Delphi-based safety indicator development for traditional Indonesian shipping provides a methodological template for developing such protocols through participatory expert consultation rather than unilateral regulatory imposition, increasing the likelihood of effective uptake by the operational actors whose behavior the coordination protocol seeks to coordinate.

VI CONCLUSION

This study has provided the first empirically This study has provided the first empirically grounded, cross-stakeholder examination of regulatory compliance, human resource competency, and maritime safety perception in the context of EV cargo transport on Indonesia's domestic ferry network. The findings demonstrate that regulatory compliance (X4) and human resource fire mitigation capacity (X3) are both significant predictors of maritime safety perception, but that competency exerts substantially stronger predictive influence — a finding that inverts the current allocation of institutional effort, which is concentrated on regulatory issuance rather than competency development. The cross-group competency gradient, with active seafarers returning the lowest X3 scores despite bearing the greatest operational safety responsibility, identifies the critical intervention target. The three structural governance gap themes — competency deficits, inter-agency coordination failures, and curriculum misalignment — constitute the causal chain through which governance fragmentation produces safety performance deficits that regulatory prescription alone cannot resolve. The Safety–Competency–Governance framework advanced by this study provides an analytically coherent and empirically grounded architecture for EV maritime safety governance reform, applicable beyond the Padang–Mentawai route to Indonesia's broader domestic ferry network and to other developing-country maritime systems navigating the intersection of energy transition policy and operational safety management.

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