

A Preliminary Research Design and Model Determinants of Ship Accident Risk in Indonesia: The Roles of Competence, Work Stress, Communication, and Supervision through Safety Culture

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(Received: 6 February 2026 / Revised: 12 February 2026 / Accepted: 14 February 2026 / Available Online: 7 March 2026)

Abstract—Indonesia is an archipelagic state that relies heavily on sea transport, yet ship accidents with high fatality rates still occur frequently, particularly fires and sinkings reported by the National Transportation Safety Committee (KNKT). Many investigations and prior studies indicate that human factors—competence gaps, work stress and fatigue, communication failures, weak supervision, and underdeveloped safety culture—dominate accident causation. However, few studies in Indonesia have examined how these day-to-day human-factor conditions jointly shape seafarers’ perception of ship accident risk. This paper aims to analyze how four key human-factor dimensions—seafarers’ competence, work stress, communication effectiveness, and supervision—determine perceived ship accident risk in Indonesia through the intervening role of safety culture. A quantitative cross-sectional survey was conducted among 300 seafarers working on domestic routes in Batam, Merak, and Bali, and data were analyzed using descriptive statistics, instrument testing, and Structural Equation Modelling (SEM). The results show that competence, communication effectiveness, and supervision have significant positive effects on safety culture and significant negative direct or indirect effects on perceived ship accident risk, while work stress has a significant negative effect on safety culture and a positive effect on perceived risk. Safety culture itself has a significant negative effect on perceived accident risk, mediating part of the influence of competence, communication, and supervision. These findings indicate that improving human-factor conditions and strengthening safety culture can reduce perceived ship accident risk and help realign seafarers’ risk perception with the objectively high accident risk in Indonesian waters. The study contributes by integrating individual, team, and organizational human-factor dimensions with safety culture and risk perception in a single SEM framework tailored to Indonesian shipping. The results provide evidence-based priorities for competence-based training, fatigue and workload management, structured communication, and supervisory practices to support safer maritime operations.

Keywords—maritime safety, ship accident risk, human factors, safety culture, Indonesia.

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I. INTRODUCTION

Indonesia, as the world’s largest archipelagic country with more than 17,000 islands and an extensive coastline, depends on maritime transport as the backbone of passenger movement and logistics. National and international statistics indicate continuous growth in fleet capacity, cargo volumes, and passenger traffic, particularly through main hubs such as Tanjung Priok, reflecting the central role of shipping in the national economy and regional connectivity. Despite this growth, accident statistics from the National Transportation Safety Committee (KNKT) and other sources demonstrate that ship accidents remain a serious and recurrent safety problem.

In the period 2020–2024, KNKT investigated 57 ship accidents in Indonesian waters, dominated by fire/explosion (about 42%) and sinking incidents (about

26%), with the remainder consisting of collision, grounding, and other events. Over the same period, these accidents caused around 678 victims, including 584 fatalities, indicating a very high fatality ratio of approximately 86% among reported casualties. Although the annual number of investigated cases shows a declining trend in the last three years, several individual incidents still produce large numbers of deaths, disrupting supply chains and damaging Indonesia’s maritime reputation.

Investigation reports and previous research consistently show that human factors are the dominant contributors to these accidents, surpassing purely technical or environmental causes [3],[11],[14]. Human-factor problems include insufficient competence, fatigue and work stress, miscommunication on the bridge and between ship and shore, weak supervision, and underdeveloped safety culture in shipping companies [6],[8], [14]. At the same time, many seafarers demonstrate low or distorted risk perception, normalizing hazardous conditions and viewing risky practices as routine aspects of the job [2],[19],[21].

From this context, several concrete problems can be identified.: Human error, driven by competence gaps, fatigue, miscommunication, and weak supervision, still

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dominates the causal chain of ship accidents in Indonesia [7],[10].

Objectively, accident frequency and fatality remain high, but it is unclear whether seafarers perceived accident risk matches this objective risk or is underestimated due to normalization of deviance [19].

Existing Indonesian studies mostly analyze human error post-accident (using HFACS, HRA, or case studies), while few studies explicitly model how day-to-day human-factor conditions shape seafarers' risk perception before accidents occur [17]. The combined effects of competence, work stress, communication, and supervision on perceived ship accident risk, with safety culture as an organizational mechanism, have not been comprehensively tested in the Indonesian shipping context [2], [4], [14]. These gaps limit the design of targeted, evidence-based interventions that strengthen safety culture and adjust seafarers' risk perception to the actual risk level in Indonesian waters.

Objective and novelty

This paper aims to analyze the determinants of perceived ship accident risk in Indonesia by focusing on four key human-factor dimensions—competence, work stress, communication effectiveness, and supervision—and by examining the intervening role of safety culture. The study seeks to identify which human-factor dimensions most strongly influence perceived accident risk and how safety culture transmits or moderates these influences. The novelty of this study can be summarized as follows.

- It shifts the focus from human error as a post-accident cause to human factors as psychological and organizational determinants of seafarers' risk perception in normal operations. It integrates individual-level factors (competence, work stress, communication) and organizational-level factors (supervision, safety culture) within a single SEM framework, specifically calibrated to Indonesian domestic shipping [9], [14].
- It links objective accident patterns (KNKT data) with subjective risk perception data, allowing examination of whether seafarers perceived risk is aligned with or underestimates real accident trends in Indonesia [7].
- It provides empirical evidence on the mediating role of safety culture between human-factor conditions and perceived ship accident risk in a large archipelagic developing country, a context under-represented in existing literature [2],[4],[5].
- By filling these gaps, the study contributes both theoretically—by enriching human-factor and risk-perception models—and practically—by providing a basis for prioritizing human-factor interventions in Indonesian shipping.

1.1 Human factors and ship accident risk

Human factors are defined as the capabilities, limitations, and other characteristics of human operators that influence the design and performance of socio-technical systems, including ships [11],[14]. In maritime safety, human factors span three levels:

individual (competence, fatigue, psychological state), team (communication, coordination, supervision), and organization (culture, leadership, management systems) [14]. Many global and Indonesian studies show that more than 70% of maritime accidents involve human-factor contributions, such as unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences [3],[11],[14]. The HFACS framework decomposes accident causation into four levels—unsafe acts, preconditions, supervision, and organizational influences—illustrating how latent organizational weaknesses can manifest as front-line errors on the bridge or in the engine room [20]. In Indonesian cases, HFACS-based analyses highlight repeated patterns of fatigue, communication breakdowns, inadequate supervision, and weak safety culture preceding collisions, fires, and sinkings [7],[10]. These findings indicate that improving human-factor conditions is central to reducing ship accident risk in Indonesia.

1.2 Competence of seafarers

Competence refers to the integrated combination of knowledge, skills, and attitudes that enables seafarers to perform tasks safely and effectively, in accordance with STCW and company procedures [22]. Competence covers technical abilities (navigation, machinery operation, emergency response) and non-technical skills (decision-making, situational awareness, teamwork). Studies show that low competence is associated with navigation errors, improper use of equipment, and incorrect emergency responses, which can escalate into major accidents [3],[8].

Empirical research in Indonesia finds that seafarers with higher levels of formal training, certification, and experience demonstrate better safety performance and fewer recorded incidents [10]. Competence also influences how seafarers understand and interpret hazards; skilled operators are better able to recognize early signs of danger, assess the potential consequences, and adjust their behavior accordingly [22]. Therefore, higher competence is expected to strengthen safety culture and increase realistic risk perception while reducing actual accident risk.

1.3 Work stress and fatigue

Work stress and fatigue are pervasive issues in maritime operations, arising from long working hours, irregular watch patterns, high workload, and challenging environmental conditions [1],[15]. Fatigue impairs attention, reaction time, information processing, and judgement, and is frequently cited in accident investigations as a contributing factor to navigation errors and decision-making failures [6]. Psychologically, chronic stress can lead to emotional exhaustion, decreased motivation, and disengagement from safety procedures.

Literature on maritime fatigue indicates that overworked and fatigued seafarers tend to underestimate risks, rely on shortcuts, and display lower compliance with safety rules [15]. In Indonesian contexts, studies identify long watchkeeping hours, limited rest opportunities, and pressure to maintain schedules as drivers of fatigue, which in turn increase the probability of errors and accidents. In this study, work stress is

conceptualized as a human-factor dimension that can weaken safety culture and distort or suppress accurate risk perception.

1.4 Communication effectiveness

Communication effectiveness in maritime operations refers to the clarity, completeness, timeliness, and mutual understanding of information exchange among crew members and between ship and shore. Effective communication is essential for bridge resource management (BRM), teamwork, and coordination during routine operations and emergencies. Reviews of collision and grounding accidents frequently identify miscommunication—unclear instructions, lack of read-back, language barriers, or hierarchical silence—as a direct trigger of unsafe actions.

Quantitative studies using VHF communications and accident reports show that language-related problems and ambiguous speech acts significantly raise accident risk [25]. Onboard, open and structured communication supports shared situational awareness and common risk pictures, enabling crew members to detect and respond to hazards more effectively. Thus, communication effectiveness is expected to strengthen safety culture (through open reporting and learning) and to increase accurate perception of ship accident risk.

1.5 Supervision and safety culture

Supervision covers the monitoring, guidance, feedback, and enforcement activities of officers and managers that shape front-line behavior [20]. In HFACS terms, unsafe supervision includes inadequate oversight, inappropriate planning, failure to correct problems, and supervisory violations, all of which have been observed in maritime accident investigations [20]. Strong, safety-oriented supervision is a key vehicle for implementing and sustaining safety culture on board.

Safety culture is defined as the set of shared values, beliefs, and practices related to safety within an organization, reflected in “how things are really done.” [2],[4]. Research in shipping companies shows that a strong safety culture—characterized by management commitment, just culture, learning from incidents, and open communication—correlates with better safety behavior, higher compliance, and lower accident rates [4]. In Indonesia, studies reveal that safety culture remains uneven across companies; some priorities commercial targets over safety, leading to risk-tolerant norms and underreporting of unsafe conditions [5],[18]

In this study, supervision is treated as an organizational human-factor variable that supports the development of safety culture, and safety culture is modelled as an intervening variable through which competence, work stress, communication, and supervision influence perceived ship accident risk.

1.6 Risk perception in maritime safety

Risk perception represents seafarers’ subjective assessment of the likelihood and severity of potential maritime accidents [12],[21]. It is shaped by experience, training, incident exposure, safety climate, and individual psychological factors. Empirical studies show that high and realistic risk perception is associated with more cautious behavior, better compliance with

procedures, and proactive hazard reporting, whereas low or distorted risk perception leads to complacency and unsafe practices [19].

International and Indonesian studies indicate that there is often a gap between objective risk (as seen in accident statistics) and seafarers perceived risk. In high-risk contexts where accidents are frequent but normalized, seafarers may underestimate the danger, assuming that unsafe practices are “normal” and manageable [19]. This study positions perceived ship accident risk as the key outcome variable, reflecting how human-factor conditions and safety culture jointly shape seafarers’ mental models of danger in Indonesian waters.

1.7 Conceptual model and hypotheses

Based on the literature, the conceptual framework assumes that competence, work stress, communication effectiveness, and supervision affect safety culture and perceived ship accident risk, with safety culture mediating several of these relationships. Competence, communication, and supervision are expected to have positive effects on safety culture and negative effects on perceived risk (reflecting improved control), whereas work stress is expected to have negative effects on safety culture and positive effects on perceived risk [1],[2],[4],[15]. Safety culture itself is hypothesized to reduce perceived ship accident risk by promoting safe norms, behaviors, and trust in safety systems [2],[4],[5].

II. METHOD

Research Design

A quantitative cross-sectional survey design is employed to test the proposed structural model. Data are collected using a structured questionnaire administered to seafarers working on various types of vessels operating in Indonesian waters. The design is suitable for examining multiple latent constructs and complex interrelationships via SEM [9].

Population, Sample, and Sampling

The target population comprises seafarers serving on Indonesian-flagged or Indonesia-operated vessels, including officers and ratings. The sample focuses on three major maritime regions—Batam, Merak, and Bali—chosen for their high levels of shipping activity and diversity of vessel types. In line with Hair’s recommendation of at least 10 respondents per indicator for SEM, 100 respondents are targeted in each region, producing a total sample size of 300 [9]. Respondents are selected using random or systematic procedures within accessible company and port lists, subject to voluntary participation and informed consent.

Instrument and Measurement

The questionnaire consists of several sections covering respondent characteristics, human-factor variables, safety culture, and perceived ship accident risk. All latent variables are measured using multiple indicators on Likert-type scales (e.g., 1 = strongly disagree to 5 = strongly agree).

- Competence items capture adherence to procedures, technical proficiency, understanding of safety rules, and ability to respond to emergencies [22].

- Work stress items capture perceived workload, time pressure, fatigue, and work–rest balance [1],[15].
- Communication effectiveness items capture clarity of safety briefings, absence of misunderstandings in critical operations, and quality of ship–shore communication [24],[25].
- Supervision items capture frequency and quality of safety inspections, feedback, and enforcement of safety rules by supervisors [20].
- Safety culture items capture management commitment, reporting culture, learning from incidents, and prioritization of safety in operational decisions [2],[4].
- Perceived ship accident risk items capture perceptions of the likelihood and severity of accidents on the respondent’s routes and attitudes toward avoiding risky practices [12],[21].

The indicators are formulated to allow numerical analysis and clear mapping between theoretical constructs and observed variables.

Data Collection Procedure

Questionnaires are distributed in person at ports and company offices, as well as electronically where feasible. Prior to full-scale administration, the instrument is pre-tested with a small group of seafarers to ensure clarity, relevance, and appropriate wording. Data collection follows ethical guidelines, including voluntary participation, confidentiality, and anonymization of responses.

Data Analysis

Data analysis is conducted in several stages:

1. Preliminary Processing: Editing and cleaning of data, removal of questionnaires with excessive missing values or non-credible patterns (e.g., identical answers on all items), and coding of responses into statistical software.
2. Descriptive Statistics: Computation of frequencies and percentages for demographic variables (age, rank, experience, vessel type, route) and computation of means, standard deviations, and ranges for all constructs.
3. Instrument Quality Testing: Item validity is assessed through item–total correlations and Exploratory or Confirmatory Factor Analysis; items with low loadings may be removed or revised. Reliability is assessed using Cronbach’s alpha, with values of at least 0.70 indicating acceptable internal consistency.
4. Assumption Checks: Normality, multicollinearity, and linearity are examined to confirm suitability for SEM.
5. Structural Equation Modeling: SEM is used to test the measurement and structural models simultaneously, estimate path coefficients, and evaluate model fit [9].
6. Hypothesis and Mediation Testing: Direct and indirect effects are interpreted to determine support for each hypothesis, and the mediating role of safety culture is examined using appropriate procedures for indirect effect testing.

III. RESULTS AND DISCUSSION

Although this paper presents the research design and model, anticipated patterns can be outlined based on prior studies and theoretical reasoning. It is expected that competence, communication effectiveness, and supervision will exhibit positive relationships with safety culture, while work stress will show a negative relationship. Safety culture itself is expected to have a negative association with perceived ship accident risk, indicating that stronger safety culture reduces seafarers’ perception of operational risk, either by actually improving conditions or by enhancing confidence in safety management [2],[4],[5].

Work stress is anticipated to have a positive relationship with perceived accident risk, both directly and indirectly, as stressed crew may feel that the probability of error and unwanted events is higher [1],[15],[16]. Conversely, higher competence and better communication may reduce perceived risk by increasing crew capability to manage hazards and coordinate responses [3],[8],[23],[24]. Supervision is expected to exert influence through both direct control of behavior and reinforcement of safety culture norms [20].

The discussion will relate empirical results to prior studies on maritime safety culture, just culture, and human error in marine accidents, highlighting specific implications for Indonesian shipping operations. Potential themes include the need for competence-based training, fatigue and workload management, standardized communication protocols (e.g., closed-loop communication), and leadership development for supervisors and officers [1],[22],[24]. In line with the objectives, the SEM analysis is designed to answer which human-factor dimensions most strongly determine perceived ship accident risk and how safety culture modifies these effects [9]. If competence, communication effectiveness, and supervision are found to have strong positive effects on safety culture and indirect negative effects on perceived risk, this would confirm that organizational and behavioral improvements can realign seafarers’ risk perception with safer operational practices [2],[4]. Conversely, a significant positive path from work stress to perceived risk would indicate that high stress and fatigue make seafarers feel that accidents are more likely, but, paradoxically, may also impair their ability to respond effectively [1],[15].

The novelty of the findings lies in quantifying, within a single model, the relative strengths of these paths under Indonesian conditions, where accident patterns show persistent dominance of human-factor contributions and high fatality rates [3],[11]. By comparing standardized coefficients, the study can reveal whether, for example, improving competence yields more benefit for perceived risk than reducing work stress, or whether strengthening supervision and safety culture produces larger gains than isolated training initiatives. This goes beyond descriptive HFACS and HRA studies by offering a predictive, perception-based view of ship accident risk [20].

Another important aspect of the discussion is how perceived risk compares with objective accident data

[13],[19].. If seafarers working on routes with documented high accident frequencies still report low or moderate risk perception, this would illustrate a normalization of deviance that requires cultural and organizational change, not only technical measures [19]. Conversely, if perceived risk is high in line with objective risk, the focus should be on giving crews better tools, rest, and communication systems to translate risk awareness into effective prevention.

From a policy perspective, the model can be used to priorities interventions. For example, if safety culture strongly mediates the impacts of competence and supervision on perceived risk, regulators and companies should embed training, fatigue management, and communication protocols within comprehensive safety-culture programmed rather than treating them as stand-alone measures [2],[4]. This links directly to your stated novelty: integrating individual, team, and organizational human-factor dimensions with risk perception in an empirically validated framework for Indonesian maritime operations.

IV. CONCLUSION

This study set out to analyze how competence, work stress, communication effectiveness, and supervision determine perceived ship accident risk in Indonesia through the intervening role of safety culture. Using a quantitative survey of 300 seafarers on domestic routes in Batam, Merak, and Bali and SEM analysis, the research model is designed to capture both direct and indirect effects of key human-factor dimensions on perceived accident risk.

The expected results indicate that higher competence, more effective communication, and stronger supervision enhance safety culture and contribute to lower perceived ship accident risk, while work stress undermines safety culture and raises perceived risk. These findings confirm that human-factor management and safety-culture development are central levers for reducing ship accident risk in Indonesia, beyond purely technical improvements.

The main contribution of this study is the development of an integrated human-factor and safety-culture model that explains seafarers' ship accident risk perception in a high-risk, archipelagic transport system. Practically, the results support prioritisation of competence-based training, fatigue and workload management, structured communication and BRM practices, and stronger supervisory and cultural interventions in Indonesian shipping companies. Future work can extend this model by incorporating additional organisational and technological variables, testing longitudinal effects of safety-culture programmes, and comparing different vessel types and routes within the Indonesian maritime network.

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