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A Socio-Technical Multifactor Risk Assessment of Work Accidents among Traditional Fishermen in Batam City, Indonesia

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ABSTRACT

Work accidents in small-scale fisheries are rarely triggered by a single hazard; they emerge from unsafe routines, harsh maritime exposure, and weak access to safety resources. This study assessed the multifactor risk of work accident experience among traditional fishermen in Batam City, Indonesia. A cross-sectional survey was conducted from January to August 2025 in Belakang Padang, Bulang, and Galang. Because no complete individual-level sampling frame was available, 285 active fishermen were recruited through incidental site-based sampling at landing points, fishing harbours, and pre-departure gathering areas. Work accident experience in the previous 12 months was treated as a binary outcome. Demographic, occupational, behavioural, environmental, and economic predictors were examined using bivariate analysis and multivariable logistic regression. Of the respondents, 150 (52.6%) reported at least one work accident. The final model showed the strongest adjusted association for high-risk occupational safety behaviour (AOR = 18.851; 95% CI: 9.103–39.037), followed by income at or below Batam's salary benchmark (AOR = 4.368; 95% CI: 1.970–9.689) and a high-risk work environment (AOR = 4.203; 95% CI: 1.895–9.325). These findings suggest that accident prevention in traditional fisheries should be treated as a socio-technical risk-control issue, where safer routines need support from protective resources and environmental hazard control.

1. INTRODUCTION

Small-scale fisheries should not be treated merely as hazardous informal work. They are socio-technical systems in which human judgement, vessel condition, weather exposure, fishing routines, and economic pressure meet under unstable maritime conditions. Unlike industrial fleets, traditional fishermen in Batam commonly operate small wooden vessels with limited engine capacity, basic fishing gear, and minimal protective equipment. Their daily work involves physical labour, navigation, gear handling, and direct exposure to strong winds, slippery decks, changing tides, and unpredictable sea conditions. In this setting, accidents rarely reflect one isolated hazard. They are more plausibly linked to the accumulation of unsafe routines, environmental exposure, and limited access to safety resources [1-3]. Recent maritime accident studies also show that human and organisational factors remain central contributors across vessel types [4].

Human factors are therefore critical, but they should not be read narrowly as individual negligence. Traditional fishermen often decide for themselves whether to wear protective equipment, check vessels before departure, prepare communication tools, or delay fishing during poor weather [5]. These decisions are shaped by experience, peer norms, time pressure, and the economic cost of not going to sea. Safety behaviour in small-scale fisheries is thus a work-system outcome, not simply a matter of personal compliance. Previous studies have shown that injury experience among fishermen is shaped by personal, situational, and environmental conditions acting together rather than separately [6-9].

Environmental exposure intensifies this vulnerability. Traditional vessels often lack stabilisers, railings, anti-slip surfaces, and standardised emergency equipment. Wet decks, manual gear handling, night fishing, deteriorating weather, and poor access to marine weather information increase the likelihood of falls, struck-by injuries, lacerations, and drowning events [10-13]. Economic constraint further reduces safety capacity. When income depends on catch volume, fuel price, and middlemen pricing, fishermen may postpone vessel maintenance, skip protective equipment, or continue fishing under marginal sea conditions [3, 14, 15]. Recent evidence also indicates that fishers routinely weigh physical danger against economic reward when deciding whether to go to sea [16].

These risks are especially relevant in Indonesia, where small-scale fisheries support many coastal households but remain weakly covered by formal occupational safety systems [17]. For informal fishermen, accident data are fragmented, safety training is limited, and access to insurance or emergency protection is uneven [17-19]. Batam City, located in the Riau Archipelago, represents this problem clearly:

traditional fishermen operate in busy inter-island waters, often with small uninsured vessels and limited institutional support in an archipelagic setting [20].

Although fishing hazards have been widely documented [8, 12, 18], fewer studies have integrated behavioural, environmental, and economic factors into a single risk-priority framework. Existing studies often stop at identifying associated factors, without translating them into ranked safety-control priorities [9]. This study addresses that gap by asking which human, environmental, and economic factors are independently associated with reported work accident experience among traditional fishermen in Batam, and how these factors can be converted into feasible control priorities. Its contribution is to approach traditional fishing accidents as events associated with constrained socio-technical safety capacity, rather than as isolated behavioural failures, and to translate field-based accident data into a safety engineering risk-priority framework aligned with risk management principles [21].

2. METHODOLOGY

2.1 Study area and safety risk context

The study was conducted in three island-based hinterland sub-districts of Batam City, Riau Archipelago Province, Indonesia: Belakang Padang, Bulang, and Galang. These areas were selected because traditional small-scale fishing remains a major livelihood and is carried out under informal safety conditions. Fishermen commonly operate small wooden vessels powered by single outboard engines and use basic fishing gear, including gill nets, hand lines, and fish traps. Their work is performed in coastal and inter-island waters where wind, waves, tides, and sudden weather changes directly affect daily fishing operations. Formal safety procedures are limited in this setting. Personal protective equipment is rarely standardised, vessel safety checks are mostly based on experience, and many fishermen rely on practical knowledge acquired through routine work rather than structured safety training [19, 22]. This setting provides a relevant field context for examining work accident risk as a socio-technical problem shaped by human behaviour, vessel and environmental conditions, and unequal access to safety resources.

2.2 Study design and participants

A cross-sectional field survey was used to support an exploratory multifactor risk assessment among traditional fishermen operating in Belakang Padang, Bulang, and Galang, three hinterland sub-districts of Batam City. Because no complete individual-level sampling frame was available, given the informal nature of fishing work, irregular landing schedules, and fishermen's mobility across locations according to weather, season, and catch opportunities, incidental site-based sampling was used to reach respondents in their actual work settings. Recruitment was conducted at common landing points, fishing harbours, and pre-departure gathering areas between January and August 2025. The minimum sample size was calculated using the single-proportion formula for an unknown population, $n = Z^2 \times p(1-p) / d^2$, with a 95% confidence level, an assumed proportion of 0.50, and a 6% margin of error, yielding a minimum requirement of 267 respondents. A total of 285 respondents were included in the final analysis, exceeding the minimum requirement. Because this was a non-probability, site-based sample, the findings should not be interpreted as statistically representative of all traditional fishermen in Batam City. The sample was designed to generate field-based analytic evidence on factors associated with reported accident experience among fishermen reachable at selected landing points, fishing harbours, and pre-departure gathering areas. This approach is appropriate for an exploratory risk assessment in an informal and mobile fishing population, but it limits prevalence estimation and broader population-level generalisation. Eligible respondents were active traditional fishermen, had at least 12 months of fishing experience, operated from one of the three study sub-districts, and provided informed consent. Data were collected through structured face-to-face interviews using a pre-tested questionnaire administered by trained enumerators.

2.3 Risk domains and variables

Candidate predictors were grouped into six risk domains to reflect the main pathways through which reported accident experience may emerge in small-scale fisheries: human factors, environmental exposure, economic constraints, work organisation, workload, and demographic background. Human factors were represented by occupational safety behaviour, environmental exposure by work environment, and economic constraint by income relative to the Batam salary benchmark. Income was measured as respondents' average monthly income from fishing activities and was categorised against the 2025 Batam City Minimum Wage (UMK Kota Batam), Rp4,989,600 per month, based on Governor of Riau Islands Decree No. 1434 of 2024 [23]. Work organisation covered fishermen's organisation membership and insurance status, while workload included daily work duration and work period. Age, education, and gender were treated as demographic control variables. Table 1 presents the operational variables and their safety engineering interpretation. The workload domain was retained because task allocation and mental workload have been used to guide risk-control design in Indonesian safety-engineering research [24].

2.4 Measurement of accident outcome

The primary outcome was self-reported work accident experience during the previous 12 months. A work accident was defined as any unplanned event occurring during fishing-related activities, including preparation before departure, fishing operations at sea, landing, or handling of fishing equipment, that caused physical injury, required self-care or external assistance, interrupted work, or created an immediate risk of injury. The outcome was coded as binary: 1 for respondents who reported at least one work accident and 0 for those who did not. The outcome did not distinguish accident type, accident frequency, injury severity, medical treatment, or workdays lost. Therefore, the dependent variable captures whether respondents had experienced at least one fishing-related accident during the previous 12 months, rather than the clinical severity or economic consequence of the accident. This operationalisation was selected to reduce recall burden in a field survey setting, but it limits the practical interpretation of the accident outcome.

Table 1. Risk domains, operational variables, and safety engineering interpretation

Risk Domain	Variable	Safety Engineering Interpretation
Human factor	Occupational safety behaviour	Unsafe routines, non-use of protective equipment, weak pre-departure checks
Environmental exposure	Work environment	Sea condition, slippery surfaces, unstable vessels, weather exposure
Economic constraint	Income relative to salary benchmark	Limited capacity to buy protective equipment, maintain vessels, or access communication tools
Work organisation	Fishermen's organisation, insurance status	Institutional support and access to safety resources
Workload	Work duration, work period	Fatigue and cumulative exposure duration
Demographic background	Age, education, gender	Contextual and control variables

2.5 Measurement of human and environmental risk indicators

Human and environmental risk indicators were measured using two structured instruments developed for this study. Item generation was based on literature on occupational safety in small-scale and commercial fisheries [5, 8-10, 25] and field observations of routine fishing practices in the study sites. The occupational safety behaviour scale consisted of 32 items covering pre-departure equipment checks, use of personal protective equipment, safe handling of fishing gear, fatigue management, and emergency communication readiness. The work environment scale consisted of 20 items covering vessel condition, deck and working surfaces, weather and sea exposure, fishing gear condition, and on-board hazards. Content validity was reviewed by three experts in occupational safety and maritime work, while a pre-test was conducted with 30 fishermen from a non-study sub-district to assess item clarity, response distribution, and interview duration. Internal consistency in the main survey was acceptable, with Cronbach's alpha of 0.889 for the safety behaviour scale and 0.846 for the work environment scale. To improve measurement transparency without using a separate appendix, Table 2 presents the main measurement domains and representative sample items for the occupational safety behaviour and work environment instruments. To reduce common-method bias, the order of construct blocks was rotated across enumerators, response anchors were framed around observable behaviours rather than evaluative judgments, and respondents were assured that no individual identity would be reported [26]. Each instrument used a binary response format. Median-based dichotomisation was used to create operational high-risk and low-risk categories that could be translated into field-level risk priorities. This cut-off should not be interpreted as a clinically validated threshold. To address potential information loss from dichotomisation, an additional robustness analysis was conducted using the original continuous scores for occupational safety behaviour and work environment, as reported in Section 3.3. Table 3 summarises the indicators.

Table 2. Domains and representative sample items of the measurement instruments

Construct / Domain	Sample Item
Safety behaviour: pre-departure checks	Checking engine condition before departure.
Safety behaviour: PPE use	Using a life jacket or other flotation device during fishing activities.
Safety behaviour: fishing gear handling	Handling nets, hooks, ropes, and fishing tools in a safe manner.
Safety behaviour: fatigue management	Avoiding continued fishing activities when physically exhausted.
Safety behaviour: emergency communication	Preparing a mobile phone, radio, or other communication tool before going to sea.
Work environment: vessel condition	The fishing boat is stable and safe for daily fishing operations.
Work environment: deck surfaces	The deck or working surface is not slippery during fishing activities.
Work environment: weather and sea exposure	Fishing activities are exposed to strong winds, waves, tides, or sudden weather changes.
Work environment: fishing gear condition	Fishing gear is in safe condition and does not create additional injury risk.
Work environment: on-board hazards	The boat has physical hazards that may increase the risk of falls, cuts, or being struck by equipment.

Table 3. Indicators of human and environmental risk measures

Construct	Items	Score Range	Risk Category	Cronbach's Alpha
Occupational safety behaviour	32	1–32	High risk = 1–16; Low risk = 17–32	0.889
Work environment	20	1–20	High risk = 1–10; Low risk = 11–20	0.846

Note: The high-risk and low-risk cut-offs are operational categories for field risk prioritisation. They should not be interpreted as clinically validated thresholds.

2.6 Multifactor risk modelling

Data were analysed using IBM SPSS Statistics. Descriptive statistics were used to summarise respondent characteristics and accident occurrence. For categorical predictors, the lower-risk category was coded as the reference group: low-risk safety behaviour, low-risk work environment, income above the benchmark, organisational membership, insurance coverage, work duration of 8 hours or less per day, work period of 5 years or less, age of 40 years or less, high education, and female gender. Missing data were minimal, below 2% across variables, and were handled using complete-case analysis. Initial screening was performed using chi-square tests and crude odds ratios with 95% confidence intervals. Variables with $p < 0.25$ in the bivariate analysis were entered into the multivariable logistic regression model, while age, education, and gender were also tested as a priori demographic controls because of their theoretical relevance. Backward elimination using the likelihood ratio criterion was applied to identify a parsimonious model, but the retained estimates were interpreted as adjusted associations rather than causal effects.

Because the design was cross-sectional, the analysis cannot establish whether unsafe behaviour, economic constraint, or environmental exposure preceded reported accident experience. The model-selection process therefore focused on identifying a practical risk-priority pattern rather than estimating causal effects. Age, education, gender, work duration, work period, insurance status, and fishermen's organisation membership were considered as theoretically relevant controls during model building. Variables not retained in the final parsimonious model should not be interpreted as unimportant for safety practice; rather, they did not improve the adjusted statistical model in this dataset. To reduce dependence on median-based categorisation, a robustness check was estimated using the original continuous scores for safety behaviour and work environment. Adjusted odds ratios with 95% confidence intervals were reported and interpreted as risk-priority indicators in line with risk management practice [21]. Multicollinearity was assessed using variance inflation factors, with all values below 2.0. Model fit was evaluated using the Hosmer-Lemeshow goodness-of-fit test, while explanatory capacity was reported using Nagelkerke R^2. An interaction term between safety behaviour and work environment was tested to assess whether environmental exposure modified the behavioural risk pathway, but it was not statistically significant and was not retained. With 150 accident events among 285 respondents, the number of events was considered sufficient for the final parsimonious model. Ethical approval was obtained from the Universitas Ibnu Sina Review Board on 12 October 2025 (approval number 112/X/LPPM/EC/2025). Written informed consent was obtained from all participants before data collection.

3. RESULTS AND DISCUSSION

3.1 Respondent profile and accident occurrence

Of the 285 traditional fishermen included in the analysis, 150 respondents (52.6%) reported at least one work accident during the previous 12 months. This figure should be read as a sample-level finding rather than a population prevalence, because respondents were recruited through incidental site-based sampling. It indicates that accident experience was common among the fishermen reached in this study, but it should not be generalised to all traditional fishermen in Batam City without caution. The respondent profile also reflects the safety vulnerability of the analysed sample. Most respondents were male (97.5%), aged over 40 years (58.6%), had low educational attainment (61.8%), and had worked as fishermen for more than five years (74.0%). A large proportion worked more than eight hours per day (63.9%), earned income at or below the Batam salary benchmark (66.3%), had no occupational insurance (71.6%), and were not members of a fishermen's organisation (60.0%). More than half of the respondents were classified as having high-risk safety behaviour (55.8%) and working in a high-risk environment (51.2%). Taken together, these characteristics suggest that reported accident experience in this setting was linked not only to exposure at sea, but also to limited organisational protection, weak insurance coverage, constrained economic capacity, and unsafe routine practices. Similar patterns have been reported in other Indonesian small-scale fishing communities [19]. The full distribution of respondent characteristics and reported accident occurrence is presented in Table 4.

Table 4. Distribution of respondent characteristics and reported work accidents

Characteristic	Category	n	%
Age	≤40 years	118	41.4
	>40 years	167	58.6
Education	Low (≤junior high)	176	61.8
	High (≥senior high)	109	38.2
Gender	Male	278	97.5
	Female	7	2.5
Work duration	>8 hours/day	182	63.9
	≤8 hours/day	103	36.1
Work period	>5 years	211	74.0
	≤5 years	74	26.0
Income	≤salary benchmark	189	66.3
	>salary benchmark	96	33.7
Fishermen's organisation	Not member	171	60.0
	Member	114	40.0
Insurance	No	204	71.6
	Yes	81	28.4
Safety behaviour	High risk	159	55.8
	Low risk	126	44.2
Work environment	High risk	146	51.2
	Low risk	139	48.8
Work accident	Yes	150	52.6
	No	135	47.4

3.2 Bivariate risk screening

The initial screening in Table 5 shows that occupational safety behaviour, work environment, income, work duration, fishermen's organisation, insurance, and work period met the entry criterion for multivariable modelling. Occupational safety behaviour produced the strongest crude association with work accident experience, followed by work environment and income. Age, education, and gender were not statistically significant in the bivariate analysis; however, as stated in the analytical strategy, they were tested as a priori demographic controls and were not retained in the final model because they did not improve model fit.

3.3 Multifactor risk model

After backward elimination, the final multivariable model retained three predictors: occupational safety behaviour, income relative to the Batam salary benchmark, and work environment. The model demonstrated acceptable fit based on the Hosmer-Lemeshow test ($\chi^2 = 4.21$, df = 7, $p = 0.755$), with a Nagelkerke R^2 of 0.482, indicating that the retained variables explained a meaningful proportion of variation in reported work accident experience within this sample. Multicollinearity was not evident, as all VIF values were below 2.0. High-risk occupational safety behaviour showed the strongest adjusted association with reported accident experience (AOR = 18.851). This result suggests that unsafe routines, including inconsistent PPE use, weak pre-departure checks, unsafe gear handling, and poor emergency readiness, are important operational points for prevention, but it should not be read as proof that unsafe behaviour alone caused the accidents. Income at or below the salary benchmark was also associated with reported accident experience (AOR = 4.368), suggesting that economic constraint may reduce fishermen's practical capacity to invest in protective equipment, vessel maintenance, and safer work decisions. A high-risk work environment was likewise associated with accident experience (AOR = 4.203), indicating that physical exposure, including vessel, deck, weather, and sea-condition hazards, remains relevant after accounting for behaviour and income.

To reduce information loss from median-based categorisation, a robustness check was estimated using the original continuous scores for occupational safety behaviour and work environment. The continuous-score model produced the same substantive direction as the categorical model; lower safety-behaviour scores remained the strongest signal in the model (adjusted log-odds coefficient = -0.21, $p < 0.001$). The model-building process also considered age, education, gender, work duration, work period, insurance status, and fishermen's organisation membership as theoretically relevant controls. Their exclusion from the final parsimonious model should not be interpreted as evidence that they are unimportant for safety practice; rather, they did not improve the adjusted statistical model in this dataset. Given the cross-sectional design and self-reported measures, the large AOR for safety behaviour should be interpreted as a risk-priority signal rather than a causal effect estimate [26]. The estimate may also be affected by recall bias, common-method bias, reverse interpretation, or conceptual proximity between reported safety routines and accident experience. The final model is presented in Table 6, and the additional robustness and control checks are summarised in Table 7 as model-stability information rather than additional causal estimates.

Table 7 summarises the robustness and control checks used to examine whether the main interpretation depended only on the median-based categorical specification. These checks are presented as model-stability information and should not be interpreted as additional causal estimates.

Table 5. Initial risk screening: bivariate associations between candidate predictors and work accident experience

Variable	Category	Accident n (%)	Crude OR (95% CI)	p-Value
Occupational safety behaviour	High risk	126 (79.2)	12.34 (6.94–21.96)	<0.001
	Low risk	24 (19.0)	Ref.	
Work environment	High risk	104 (71.2)	5.42 (3.27–8.99)	<0.001
	Low risk	46 (33.1)	Ref.	
Income	≤benchmark	121 (64.0)	4.74 (2.78–8.07)	<0.001
	>benchmark	29 (30.2)	Ref.	
Work duration	>8 h/day	112 (61.5)	2.46 (1.50–4.04)	<0.001
	≤8 h/day	38 (36.9)	Ref.	
Fishermen's organisation	Not member	104 (60.8)	2.39 (1.46–3.91)	0.001
	Member	46 (40.4)	Ref.	
Insurance	No	124 (60.8)	3.27 (1.89–5.66)	<0.001
	Yes	26 (32.1)	Ref.	
Work period	>5 years	117 (55.5)	1.59 (0.94–2.69)	0.083
	≤5 years	33 (44.6)	Ref.	
Age	>40 years	92 (55.1)	1.27 (0.79–2.04)	0.330
	≤40 years	58 (49.2)	Ref.	
Education	Low	97 (55.1)	1.30 (0.80–2.10)	0.292
	High	53 (48.6)	Ref.	

Table 6. Final multifactor logistic regression model of work accident risk

Variable	B (SE)	AOR	95% CI	*p*-Value
High-risk occupational safety behaviour	2.937 (0.371)	18.851	9.103 to 39.037	<0.001
Income ≤ salary benchmark	1.474 (0.406)	4.368	1.970 to 9.689	<0.001
High-risk work environment	1.435 (0.408)	4.203	1.895 to 9.325	<0.001
Constant	-2.812 (0.421)	0.060	Not applicable	<0.001

Table 7. Compact summary of robustness and control checks

Check	Evidence and Interpretation
Continuous-score robustness	The original continuous scores produced the same substantive direction as the categorical model; lower safety-behaviour scores remained the strongest signal ($B = -0.21$, $p < 0.001$). This supports the use of categorical high-risk and low-risk groups for field risk prioritisation, not as clinical thresholds.
Control-variable check	Age, education, gender, work duration, work period, insurance status, and fishermen's organisation membership were considered during model building. Their non-retention means that they did not improve the adjusted model in this dataset, not that they are irrelevant for safety practice.
Model parsimony	The final model retained three variables with 150 accident events among 285 respondents. This event-to-predictor balance supports a parsimonious risk-priority model and reduces the risk of overfitting. The estimates remain interpreted as associations, not causal effects.

3.4 Risk priority interpretation and risk treatment

The three retained predictors were then translated into a risk-priority framework. Ranking was based on three considerations: strength of adjusted association with reported accident experience, feasibility of control in informal small-scale fisheries, and relevance to safety engineering principles. Each priority was linked to a risk-treatment strategy, understood as a planned set of actions to reduce or modify risk in line with the ISO 31000 risk management process [21]. The resulting framework is presented in Table 8.

Within the hierarchy of controls, elimination and substitution are difficult to apply in traditional fisheries because the work is inherently maritime and the vessel is also the production tool. Risk treatment therefore needs to concentrate on controls that are realistic for small boats and informal work settings. Administrative controls and PPE address the most immediate behavioural risks. Structural and institutional measures expand fishermen's safety capacity by improving access to equipment, insurance, and maintenance resources. Low-cost engineering and operational controls reduce exposure at the vessel, deck, landing-site, and weather-decision levels. The point is not to choose one layer over another, but to align them so that safe practice becomes technically possible and economically feasible.

Figure 1 should be read as a conceptual risk-control framework, not as a tested mediation model. Safety capacity refers to the practical ability of fishermen to work safely under informal maritime conditions, including access to PPE, vessel maintenance, communication tools, weather information, and the economic room to delay departure when conditions are unsafe. This framework provides the basis for linking each risk domain to the risk-treatment controls summarised in Table 8.

Table 8. Risk priority and risk-treatment implications

Priority	Risk Factor	AOR	Safety Engineering Interpretation	Recommended Risk-Treatment Control
1	High-risk occupational safety behaviour	18.851	Immediate human-factor risk involving unsafe routines and weak protective behaviour	Administrative controls and PPE: routine safety checklist, mandatory PPE use, pre-departure vessel inspection, behaviour-based safety training
2	Income ≤ salary benchmark	4.368	Resource constraint that limits safety capacity and reduces access to protective resources	Structural and institutional controls: subsidised safety equipment, cooperative procurement schemes, access to occupational insurance, livelihood support
3	High-risk work environment	4.203	Physical and operational exposure related to vessel, deck, weather, and sea-condition hazards	Low-cost engineering and operational controls: weather-based departure control, vessel safety checks, anti-slip deck treatment, safer landing infrastructure, standardised gear maintenance

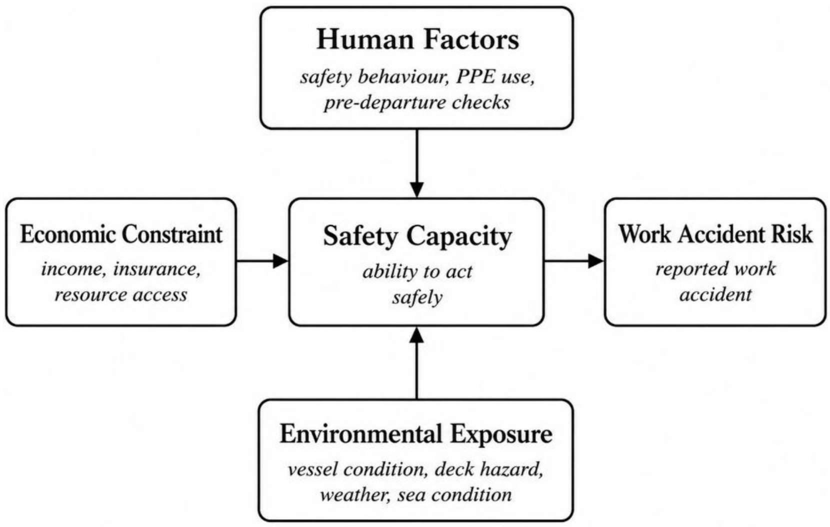

Figure 1. Multifactor risk framework of work accidents in traditional fisheries

3.5 Human factors as the main risk-control point

Occupational safety behaviour was the most immediate risk-control point in the model, but this result should not be read as a claim that accidents are caused simply by careless fishermen. In small-scale fisheries, decisions to wear PPE, inspect vessels before departure, delay trips during poor weather, or prepare communication tools are shaped by peer norms, time pressure, available resources, and the economic cost of not fishing [8, 24, 25]. Unsafe routines may therefore represent practical adaptations to informal work settings where written procedures are absent and daily decisions depend largely on experience-based judgement [27]. This interpretation is consistent with recent evidence showing that human elements are frequently identified in fishing-vessel accident analyses, particularly in small vessels that resemble the boats used in the study area [8]. Multifactor injury studies also show that individual safety practice cannot be separated from the situational and environmental conditions in which it occurs [4, 9]. Behaviour-based safety intervention should therefore move beyond awareness campaigns. Fishermen need operational tools that fit the size, cost structure, and daily routine of small vessels, including departure checklists, minimum PPE packages, gear inspection routines, and basic emergency communication preparation. The strong adjusted association for safety behaviour (AOR = 18.851) indicates that this domain should be prioritised in administrative controls and PPE programmes, but such interventions will only work if fishermen have the practical resources needed to act safely [28].

3.6 Environmental risk and operational exposure

The work environment remained significantly associated with reported accident experience after adjustment for safety behaviour and income (AOR = 4.203), indicating that physical and operational hazards are not secondary issues in traditional fisheries. Unstable decks, slippery surfaces, manual gear handling, wind and wave exposure, limited on-board safety features, and sudden weather changes create a hazard field in which even a minor unsafe act may be followed by injury. These conditions are typical of small-scale fishing operations in tropical archipelagic waters, where vessels are rarely equipped with engineered fall protection or standardised emergency equipment [29, 30]. Evidence from comparable Southeast Asian fishing contexts also identifies weather conditions, vessel characteristics, and on-board hazards as recurring contributors to occupational injury [12]. In this setting, environmental risk control cannot depend on expensive fleet redesign. More realistic measures include accessible pre-departure weather information, anti-slip deck treatment, minimum buoyancy and communication requirements, routine vessel checks, safer landing points, and standardised fishing gear maintenance. Marine weather governance is particularly important because the way weather information is delivered, trusted, and used can shape the level of exposure fishermen accept before going to sea [13]. These measures do not replace behavioural controls, but they reduce the hazard level within which safety behaviour must operate.

3.7 Economic constraint as a safety capacity factor

Income at or below the Batam salary benchmark was independently associated with a higher likelihood of reported work accident experience (AOR = 4.368), but this result should not be treated as a simple socio-economic association. In traditional fisheries, income is closely related to safety capacity, including the ability to buy PPE, repair vessels, replace damaged gear, pay for communication tools, maintain insurance, and absorb income loss when a trip must be postponed. Evidence from other fishing fleets shows that skippers often weigh physical danger against expected economic return when deciding whether to go to sea [16]. This risk-reward calculation is especially relevant when fishing income is unstable and household livelihood depends on daily catch. The finding is also consistent with studies of small-scale fishing vulnerability and informal work systems, where economic vulnerability can narrow safety margins and make it harder for workers to avoid suboptimal conditions [3, 31, 32]. In Batam's traditional fisheries, the large share of respondents with income below the benchmark and without insurance indicates that many fishermen have limited room to prioritise safety. Accident prevention strategies that rely only on individual responsibility are therefore unlikely to succeed. Subsidised safety equipment, cooperative procurement, occupational insurance access, and livelihood support are needed to make safer behaviour practically and economically possible.

3.8 Practical implications for safety risk management

The findings support a layered risk-management approach for small-scale fisheries, consistent with the hierarchy of controls and the risk-treatment stage of ISO 31000 [21]. The first layer should target routine behaviour through departure checklists, PPE use, gear inspection, and basic emergency readiness. The second layer should expand safety capacity through subsidised equipment, insurance access, cooperative purchasing, and institutional support. The third layer should reduce environmental exposure through weather-based departure decisions, anti-slip surfaces, minimum vessel safety checks, safer landing infrastructure, and basic communication systems. These layers must work as a connected system because behavioural rules will have little effect if fishermen cannot afford PPE, while improved equipment will not be sufficient if weather information does not reach fishermen in time or is not trusted in daily decision-making. The persistence of high injury rates in fishing and aquaculture across different national settings reinforces the need for risk-treatment strategies grounded in the realities of small-scale fisheries rather than copied from industrial fleet models [18]. For implementation, the results should be translated into routine landing-site briefings, simple safety reminders, task-rest scheduling, and group-based communication through fishermen's organisations. Workload-oriented safety design can support task and rest arrangements [24]. In archipelagic settings such as Batam, safety planning also needs to consider port access, inter-island movement, and the coordination of equipment and emergency support [20]. Therefore, practical intervention should prioritise low-cost and locally manageable actions, including minimum PPE packages, pre-departure safety checks, shared weather information, emergency contact procedures, and cooperative mechanisms for equipment maintenance, so that the recommendations remain closely aligned with the study's empirical findings and do not extend beyond the evidence provided by the accident-risk model.

3.9 Limitations

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design limits causal interpretation; therefore, the results should be understood as adjusted associations and risk-priority patterns rather than evidence of direct causal effects. Second, work accident experience was self-reported and was not verified through medical records, insurance claims, or administrative accident reports. This may introduce recall bias, particularly for minor incidents that respondents may forget or underreport. Third, the outcome was binary and did not distinguish accident type, severity, recurrence, medical treatment, or workdays lost. This limits the practical meaning of the term work accident and prevents more precise prioritisation by accident severity. Fourth, predictors and outcomes were collected in the same interview, so common-method bias remains possible. Although the study applied procedural safeguards, including rotating construct blocks and using behaviour-anchored response formats, some inflation of associations cannot be fully ruled out [26]. Fifth, the absence of a complete individual-level sampling frame required incidental site-based sampling. As a result, the sample should not be treated as statistically representative of all traditional fishermen in Batam City. Sixth, the study did not include trip-level and vessel-level variables such as fishing frequency, travel distance, vessel size, engine capacity, actual weather conditions, fishing gear type, and time at sea. Future research should use longitudinal or repeated-trip designs, develop more complete fishermen registries, distinguish minor and severe accidents, and integrate vessel-level and trip-level data to refine the socio-technical risk framework proposed in this study.

4. CONCLUSIONS

This study provides a field-based socio-technical assessment of factors associated with self-reported work accident experience among traditional fishermen in Batam City, Indonesia. Within the analysed sample, high-risk occupational safety behaviour showed the strongest adjusted association with reported accident experience (AOR = 18.851), followed by income at or below the salary benchmark (AOR = 4.368) and a high-risk work environment (AOR = 4.203). These findings suggest that accident prevention in traditional fisheries should not be framed only as a matter of individual compliance or environmental exposure. Instead, reported accident experience appears to be linked with a combination of daily work routines, economic capacity, and physical exposure. Behavioural safety practices are the most immediate point of intervention, but they will have limited effect without access to protective equipment, vessel maintenance, communication tools, insurance, and reliable weather-based decision support. The risk-priority framework developed in this study converts statistical associations into a layered risk-treatment strategy based on the hierarchy of controls. Because the study used cross-sectional, self-reported data and incidental site-based sampling, the findings should be interpreted as analytic evidence from the study sample rather than as causal or population-representative estimates. This perspective contributes to safety and security engineering by offering a practical framework for designing low-cost, layered safety interventions and by showing how field accident data can be organised around human factors, environmental exposure, and economic constraints.

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