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Risk Analysis of Bridge Team Management on Navigational Safety in the Mahakam River Fairway

Yunus Hans Cristian Sihotang, Dion Lebang, Sunarlia Limbong
Merchant Marine Polytechnic of Makassar, Indonesia
sihotangyunus123@gmail.com

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Abstract

Although navigational risk management has received considerable attention in maritime safety research, few studies have quantified collision and grounding risks in Indonesia's narrow river fairways using long-term incident records. This study analyzed the risk levels of collision and grounding incidents involving KM. Tonasa Line XIX in the Mahakam River Fairway and evaluated compliance with Bridge Resource Management (BRM) practices in maintaining navigational safety. A descriptive qualitative approach was employed, drawing on BRM theory, Human Factors Theory, Situational Awareness Theory, the International Regulations for Preventing Collisions at Sea 1972, and the International Safety Management Code. Data were collected through direct observation during sea practice, in-depth interviews with the Master and three Deck Officers, and a literature review. Risk quantification was conducted using the Formal Safety Assessment framework established in IMO MSC/Circ.1023 and based on 25 verified incidents recorded in the fairway between 2021 and 2026. The findings identified human error—including fatigue, miscommunication, and inappropriate decision-making—and environmental conditions, such as channel siltation, strong currents, and high traffic density, as the dominant risk drivers.

Based on the formula Risk Score = Likelihood × Consequence, collision incidents, comprising at least 17 cases, and grounding incidents, comprising at least eight cases, each received a score of 9 and were classified as high risk. The study concludes that BRM procedures are available on board but are not consistently implemented, particularly in relation to situational awareness, assertive communication, and fatigue management. These findings extend the literature on incident-history-based Formal Safety Assessment in confined waterways and provide practical implications for shipping companies, bridge officers, and waterway authorities seeking to strengthen navigational safety in the Mahakam River corridor. The study also provides a basis for future comparative research involving multiple vessels and river fairways.

Keywords: Bridge Resource Management; Collision and Grounding; Formal Safety Assessment; Navigational Risk; Narrow River Fairways

INTRODUCTION

Indonesia, as the world's largest archipelagic state, relies on sea transportation as the primary backbone of the movement of goods and people between its islands. Maritime safety, however, continues to face serious challenges, particularly in risk analysis, which plays a central role in accident prevention at sea (Wang et al., 2021). Hazard identification is the first step of this process, aiming to recognize every potential threat to the vessel, crew, cargo, and surrounding waters (Tao et al., 2024). In the Indonesian context, risk factors commonly stem from limited navigational equipment, miscommunication among watch officers, dynamically changing currents and weather, and errors in situational judgment. These conditions are especially prevalent in narrow channels, where a vessel's room to maneuver is limited, currents are strong, and safe distances between vessels are difficult to maintain. In waterways such as East Kalimantan's Mahakam River, grounding is the most frequent accident type, typically arising from a combination of internal factors inaccurate tidal and Under Keel Clearance (UKC) calculations, weak coordination among watch teams and external factors such as sedimentation-driven depth changes and squat effects in shallow water.(Li et al., 2023)

Within this context, the Convention on the International Regulations for Preventing Collisions at Sea (COLREG 1972), ratified by Indonesia through Presidential Decree No. 50 of 1979, functions as the principal legal instrument governing navigational conduct, including Rule 9 on Narrow Channels and Rule 8 on Action to Avoid Collision, alongside provisions on sound signaling, continuous lookout, and readiness of navigational equipment and documentation.

In field practice, weak implementation of these COLREG principles is frequently the root cause of narrow-channel accidents, particularly when bridge teams fail to identify hazards, maintain effective communication, and apply appropriate collision avoidance measures(Chauvin et al., 2013). The author's own sea-practice experience aboard KM. Tonasa Line XIX, a cement carrier owned by PT Pelayaran Tonasa Line, illustrates this concretely: the vessel experienced two incidents in the Mahakam River Fairway within a three-month span a collision with a coal barge under tow by TB Superstar on 20 December 2024, and a grounding near Buoy 6 on 24 February 2025. Neither incident resulted in serious structural damage, yet both revealed underlying weaknesses in hazard identification and bridge team coordination, which have consistently been identified as major contributors to maritime accidents (Qiao et al., 2020). Addressing such weaknesses requires a Bridge Resource Management (BRM) approach that optimizes the role of every bridge crew member, strengthens two-way communication, builds collective situational awareness, and improves strategic coordination among watch officers. Previous studies have demonstrated that effective bridge teamwork, communication, and human-factor management significantly improve navigational safety and reduce the likelihood of collisions and grounding incidents (Wang et al., 2021).

The maritime safety literature has examined several of these dimensions separately. Dominguez-Péry et al. (2021) provide a bibliometric review confirming that human error remains the dominant contributor to maritime accidents and call for research that moves beyond individual blame toward systemic analysis. (Sánchez-Beaskoetxea et al., 2021) distinguish active errors (direct operator actions) from latent errors (organizational and managerial conditions that quietly erode safety defenses), a distinction operationalized through the Human Factors Analysis and Classification System (HFACS). (Sharma et al., 2019) formalize situational awareness into three hierarchical levels perception, comprehension, and projection while (Chan et al., 2022) demonstrate that junior officers with underdeveloped situational awareness are disproportionately prone to maneuvering errors. (Kodak & Dal, 2024) apply root cause analysis to link BRM implementation directly to navigational safety outcomes, and (Muhammad Setyan Farros Wa Savero et al., 2025) conduct a comparable root cause analysis of a grounding incident in another Indonesian narrow river channel, the Kapuas River.

Collectively, these studies establish the conceptual and causal importance of human factors, situational awareness, and Bridge Resource Management (BRM) in isolated incidents or in general maritime operational contexts (Sharma et al., 2019); (Sánchez-Beaskoetxea et al., 2021). Previous research has demonstrated that deficiencies in human performance, communication, and situational awareness are among the leading contributors to maritime accidents and navigational errors (Chauvin et al., 2013); (Wang et al., 2021). However, what remains limited is empirical work that anchors risk scoring to a multi-year inventory of actual incidents in a specific narrow river fairway and couples this quantitative assessment with a structured comparison between intended BRM procedures and their actual implementation in operational practice. This is the research gap that the present study seeks to address.

The novelty of this study lies in combining a five-year historical incident inventory (25 verified cases in the Mahakam River Fairway, 2021–2026) with the IMO Formal Safety Assessment (FSA) scoring framework, and in using two firsthand-observed incidents aboard KM. Tonasa Line XIX as detailed case illustrations of where Bridge Resource Management (BRM) procedures diverge from actual bridge practice. The study is theoretically grounded in Bridge Resource Management (BRM) theory, Human Factor Theory, Situational Awareness Theory (Sharma et al., 2019), and contemporary studies on human error in maritime accidents (Sánchez-Beaskoetxea et al., 2021). The research also adopts the principles of the International Safety Management (ISM) Code, COLREG 1972, and ISO 31000:2018 as complementary frameworks for maritime risk management and safety assessment.

Building on this foundation, the study aims to analyze the risk level of grounding and collision incidents experienced by KM. Tonasa Line XIX in the Mahakam River Fairway, and to evaluate the compliance of Bridge Resource Management (BRM) implementation by the bridge team in maintaining navigational safety.

METHODS

This study employed a descriptive qualitative approach, aimed at describing, elaborating, and analyzing the research object in depth within its natural operational setting before drawing generalized conclusions.

A case study design was used, centered on KM. Tonasa Line XIX as it transited the Mahakam River Fairway. Three key concepts guided the research: risk analysis (a systematic, measurable, and continuous process of identifying, analyzing, evaluating, and controlling risk); bridge team coordination (collaborative activity among the master, watch officers, and navigation operators to ensure safe, efficient, and well-coordinated ship operation through clear communication and shared situational awareness); and navigational safety (the fulfillment of technical and operational requirements ensuring safe, reliable voyage execution, including seaworthiness, navigational equipment, and crew competence).

The unit of analysis was KM. Tonasa Line XIX itself, with four key informants purposively selected as the individuals directly responsible for bridge resource management: the Master (Officer A, 50 years) and three Deck Officers Chief Officer/Mualim I (Officer J, 53 years), Second Officer/Mualim II (Officer A, 25 years), and Third Officer/Mualim III (Officer S, 39 years). Informant identities are presented using role-based codes in accordance with research ethics principles, and participation in the interviews was voluntary.

Data were collected through field research, comprising in-depth interviews with the four officers using a semi-structured interview guide and direct observation conducted by the researcher as a human instrument during an onboard sea-practice placement in the Mahakam River Fairway, East Kalimantan (2024–2025), supplemented by library research drawing on academic literature, official incident reports (including from the Samarinda Port Authority/KSOP), and credible news media. Trustworthiness was supported through triangulation of interview, observation, and documentary data; the 25-incident inventory used for risk scoring was cross-verified against multiple independent sources per incident (see Table 1).

Data analysis combined two complementary techniques. Interview and observation data were analyzed using descriptive qualitative analysis, involving data reduction (filtering officers' statements to isolate content directly relevant to navigational constraints), data display (organizing findings narratively), and conclusion drawing. For risk quantification, the study applied the Formal Safety Assessment (FSA) framework of IMO MSC/Circ.1023, in which risk level is determined by multiplying two variables: the Likelihood (L) of an incident, calibrated objectively against the actual five-year incident frequency documented in the fairway (2021–2026), and the Consequence (C), assessed from the physical, operational, and safety severity of each incident type. Results were mapped onto a 3×3 risk matrix to classify risk as Low, Moderate, or High.

RESULTS

Research Object. PT Pelayaran Tonasa Line, headquartered in Biringkassi, Pangkajene and Kepulauan (Pangkep), South Sulawesi, is a shipping subsidiary within the distribution chain of PT Semen Tonasa, one of Indonesia's largest cement producers. The company operates under a documented ISM Code Safety Management System and conducts regular internal and external audits. KM. Tonasa Line XIX, built in 2015 by PT Dok dan Perkapalan Surabaya, is a Self-Propelled Barge (SPB) a barge-form hull fitted with its own propulsion, eliminating the need for tug assistance. The vessel has a length overall (LOA) of approximately 112.27 m, a breadth of 24 m, and a bulk cement carrying capacity of 8,000–8,200 tons, sailing at roughly 9 knots light and 5–7 knots when fully laden. For the past year, the vessel has serviced a fixed route to Samarinda, requiring regular transit through the Mahakam River Fairway a narrow, heavily trafficked waterway characterized by variable depth from ongoing sedimentation, a strong tidal influence on Under Keel Clearance, powerful ebb currents, dense commercial and barge traffic, and sharp bends that demand high maneuvering skill and collective situational awareness.

Collision Incident (20 December 2024). KM. Tonasa Line XIX departed Biringkassi on voyage 031 with 25 crew, anchoring at Muara Pegah before entering the fairway the next morning under a One Hour Notice procedure. After the pilot boarded around 06:00 WITA, the vessel proceeded at 5–6 knots against an ebb current. Roughly an hour later, near the East Kerbau Bend (Tikungan Kerbau Timur), the vessel encountered TB Superstar towing a coal barge outbound. The pilot detected the tug via AIS and agreed on a starboard-to-starboard passing while hugging the left bank; however, the narrow channel, sharp bend, and strengthening current caused the barge to lose control and strike the vessel's starboard side at low relative speed (≈3.2 knots), resulting only in minor scuffing with no breach or structural damage. Despite an adequately staffed bridge (Master, Pilot, Chief Officer, Chief Engineer, helmsman, and a cadet), the incident exposed delayed AIS-based identification, underused radar, ineffective communication between the watch officer and Master regarding channel traffic, imprecise decisions on safe distance and speed adjustment, and restricted visibility at the bend caused by nipa palm vegetation.

Grounding Incident (24 February 2025). After anchoring overnight at Muara Mahakam, the vessel entered the fairway around 05:40 WITA following pre-departure tidal calculations that indicated adequate water conditions. While transiting at approximately 6 knots amid heavy morning traffic, the vessel's speed suddenly dropped from 6 to 0 knots near Buoy 6 a location known for its relatively shallow depth. Attempts to move the vessel ahead and astern initially failed. With the tide table indicating a still-rising tide, the Master and Pilot elected to wait roughly 25 minutes before instructing a staged engine increase (dead slow ahead, half ahead, full ahead), which successfully refloated the vessel to continue toward Samarinda.

Interview Findings. All four officers identified similar preparatory requirements before entering the fairway: aligning entry timing with tidal conditions, keeping all off-duty officers and engineers on standby, maintaining an alert helmsman, keeping deck crew ready fore and aft, sustaining clear internal and external communication, reducing speed in high-risk zones, and coordinating closely with the pilot. Regarding causation, the Master cited unavoidable shallow depths at low tide, uncontrolled speed in congested traffic, poor mutual understanding on channel-space sharing between passing vessels, and engine or steering trouble. The Chief Officer emphasized the fairway's narrow, shallow geometry that pushes vessels toward the channel's center axis, combined with poor coordination and insufficient passing distance between vessels. The Second Officer detailed pre-entry equipment checks (AIS, VHF radio, echo sounder, whistle, radar, and manually corrected charts, given the absence of ECDIS on board) and post-incident procedures (multi-point sounding after grounding; alarm, engine stop, position plotting, and tank-integrity checks after collision), and identified external factors (strong tidal currents, poor visibility from heavy rain or fog, small boats crossing the channel) and internal factors (weak radio communication, human error). The Third Officer stressed navigational-aid readiness checks before each watch and identified recurring causes including strong currents combined with variable depth, inattentive watchkeeping, suboptimal inter-vessel communication, and reduced visibility from fog or heavy rain.

Observation Findings. Direct observation corroborated the interview findings across three factors. First, human error: the narrow fairway sharply limits maneuvering room, amplifying the consequences of hydrodynamic effects such as strong currents, shallow water, bank effect, squat, and high traffic density; recurring error patterns included inaccurate tidal calculations, disregard of echo sounder and radar readings, poor VHF communication, flawed decision-making, and ineffective COLREG application in congested waters. Second, technical factors: echo sounder inaccuracy was a recurring issue, with the instrument still displaying residual depth readings even after the vessel had fully grounded, producing a misleading perception for the bridge team. Third, environmental factors: the fairway's shallow, dynamically shifting bed driven by tidal action and continuous sedimentation combined with nipa palm vegetation obstructing visibility at sharp bends, substantially elevates collision risk if not carefully accounted for in voyage planning.

Following the study's methodological approach, risk identification was grounded in actual incidents documented in the Mahakam River Fairway over the past five years (2021–2026), consistent with ISO 31000:2018's emphasis on historical data as a basis for hazard identification and with the IMO FSA requirement to inventory actual incidents prior to risk assessment. Drawing on academic literature, KSOP Samarinda reports, credible media coverage, and primary observational data, 25 documented navigational accidents were identified in the fairway, as shown in Table 1.

Table 1. Documented Navigational Accidents in the Mahakam River Fairway (2021–2026)

No	Date	Vessel(s)/Parties Involved	Type	Description	Source
1	Aug 30, 2021	TB JKW Mahakam 2 & barge Intan Kelana 13	Collision	Struck Mahakam I Bridge pylon; pillar scratched and dented	Wikipedia, 2025
2	2021	MT. Tameda Maru 03	Grounding	Grounded entering the fairway; cargo exceeded safe draft	Sabang S.B., Poltekpel Surabaya, 2024
3	Mar 28, 2022	GT 19, Dolphin 11, 15 & 18 (four barges)	Collision	Struck Mahakam I Bridge pylon	Wikipedia, 2025
4	2022	LCT Total III	Grounding	Grounded near Buoy 14–16	Siahaan et al., Jurnal Maritim, 2022
5	Dec 23, 2022	TB Mitra Anugrah I & coal barge	Collision	Current-driven barge struck Mahakam Bridge pylon	Detik.com, 2022
6	Jul 27, 2023	MV. Tanto Luas	Grounding	First grounding of this vessel	Firman et al., JURRITEK, 2025
7	Aug 2023	Several merchant vessels & barges	Grounding	Prolonged dry season; multiple vessels grounded upstream	TribunKaltim, 2023
8	Sep 15, 2023	MV. Tanto Luas	Grounding	Second grounding of the same vessel	Firman et al., JURRITEK, 2025
9	Nov 25, 2023	MV. Tanto Luas	Grounding	Third grounding of the same vessel	Firman et al., JURRITEK, 2025
10	Jan 24, 2024	MV. Tanto Luas	Grounding	Fourth grounding; miscommunication with TB Kalimas II	Firman et al., JURRITEK, 2025

No	Date	Vessel(s)/Parties Involved	Type	Description	Source
11	Jan 28, 2024	MV Spil Renata & barge Soluna 20	Collision	Collision at Buoy 8, Muara Pegah; both vessels heavily damaged	Kaltim Post, 2024
12	Jun 5, 2024	LCT Delta AA5 & klotok KM Palopo 02	Collision	Collision at Kutai Lama; one crew member missing	UpdateIKN, 2024
13	Dec 20, 2024	KM. Tonasa Line XIX & TB Superstar	Collision	Barge struck starboard side; minor scuffing (Research Case)	Primary data, 2024
14	Dec 23, 2024	Barge M80-1302 & TB KD 2018	Collision	Struck the 6th pylon of Mahulu Bridge	Ocean Week, 2026
15	Jan 4, 2025	TB Bloro 7 & TB Raja Laksana 166	Collision	Two coal barges struck Mahulu Bridge	Ocean Week, 2026
16	Feb 16, 2025	TB MTS 28 & barge Indosukses 28	Collision	Timber barge struck Mahakam I Bridge; pylons 2 & 3 damaged	Wikipedia, 2025
17	Feb 24, 2025	KM. Tonasa Line XIX	Grounding	Grounded at Buoy 6; faulty echo sounder reading; refloated after 25 min (Research Case)	Primary data, 2025
18	Apr 26, 2025	Barge BG Azamara 3035	Collision	Towline parted; barge drifted and struck Mahakam I Bridge	Liputan6, 2025
19	Oct 22, 2025	TB Serasi 14 & fishing boat	Collision	Collision in Teluk Lerong; fishermen survived	Kompas.com, 2025
20	Dec 23, 2025	Coal barge	Collision	Struck the fender of Mahulu Bridge	Kompas TV, 2025
21	Jan 4, 2026	TB Bloro 7 & TB Raja Laksana 166	Collision	Struck Mahulu Bridge again (<2 weeks after previous incident)	Ocean Week, 2026
22	Jan 25, 2026	TB Atlantik Star 23 & TB Marina 1631	Collision	Mooring line parted; drifting pontoon struck Mahulu Bridge	KSOP/PopNews, 2026
23	Mar 8, 2026	SPOB fuel-carrying tanker	Collision	Struck Mahakam I Bridge pylon (24th recorded bridge-strike)	Koran Nusantara, 2026
24	Mar 30, 2026	Medium-sized barge	Collision	Adrift barge struck a floating house; went viral on social media	Sekolapedia, 2026
25	May 13, 2026	KM Meratus Konawe & KM Spil Ratna	Collision	Two container ships collided at the "Kuda Mati" channel; 8 containers fell overboard	Indo Maritim, 2026

Source : Observation Result, 2025

Of the 25 identified incidents, collision was the dominant type (≥17 cases, average ≥3.4 occurrences/year), followed by grounding (≥8 cases, average ≥1.6 occurrences/year), empirically confirming that both incident types are structurally recurring risks rather than sporadic events.

Likelihood and Consequence were then assessed against the criteria in Table 2, following IMO FSA and ISO 31000:2018 principles.

Table 2. Likelihood and Consequence Assessment Criteria

Score	Likelihood Criteria	Score	Consequence Criteria
3 (High)	≥5 occurrences in 5 years (2021–2026); average ≥1/year, recurring consistently	3 (High)	Physical contact with hull/structure or infrastructure; grounding with keel pressure; potential structural damage and risk to personnel
2 (Moderate)	2–4 occurrences in 5 years; average 0.4–0.8/year	2 (Moderate)	Operational disruption or schedule delay without direct structural contact
1 (Low)	≤1 occurrence or none observed in 5 years; theoretical potential only	1 (Low)	No operational disruption and no structural contact

Table 3. Risk Matrix (3×3)

L \ C	1 – Low	2 – Moderate	3 – High
3 – High	3 – Moderate	6 – High	9 – High
2 – Moderate	2 – Low	4 – Moderate	6 – High
1 – Low	1 – Low	2 – Low	3 – Moderate

Table 4. Risk Assessment Results

No	Incident Type	Verified Cases (2021–2026)	L	C	L×C	Risk Level
1	Collision (ship-to-ship, ship-to-bridge, or uncontrolled drifting vessel)	≥17 cases (avg. ≥3.4/yr)	3	3	9	High
2	Grounding (siltation, strong currents, inaccurate UKC, echo sounder misreading)	≥8 cases (avg. ≥1.6/yr)	3	3	9	High

As shown in Table 4, both collision and grounding scored the maximum value of 9, placing them in the High-Risk category requiring immediate mitigation under the applied framework.

One notable anomaly emerged within the incident inventory: MV. Tanto Luas grounded four separate times within a six-month span (27 July 2023, 15 September 2023, 25 November 2023, and 24 January 2024; Table 1, rows 6, 8–10). This concentration of repeat groundings on a single vessel rather than a spread of isolated incidents across many different vessels diverges from the general pattern of one-off occurrences seen elsewhere in the inventory. It is reported factually here as an anomaly relevant to the research focus; its possible causes and implications for fleet-level risk exposure are addressed in the Discussion section.

Risk quantification in this study followed the IMO Formal Safety Assessment formula, in which risk level is the product of Likelihood and Consequence:

$$\text{Risk Score} = L \times C \qquad (1)$$

where L denotes Likelihood (scored 1–3, calibrated to five-year incident frequency) and C denotes Consequence (scored 1–3, based on physical/operational severity), as detailed in Table 2. Applying Equation (1) to the data in Table 1 produced the scores reported in Table 4.

DISCUSSION

Triangulating interview, observation, and incident data reveals that barriers to bridge team coordination in the Mahakam River Fairway stem from three interlocking dimensions. In the human resource dimension, crew fatigue from extended working hours reduces watch officers' alertness and response speed, while ineffective communication internally between watch officers and externally via VHF, frequently degraded by radio-frequency "doubling" from congested traffic, repeatedly prevented timely transmission of other vessels' positions and maneuvering intentions, delaying the Master's decision-making. These findings are consistent with previous studies highlighting fatigue, communication failures, and human-factor interactions as critical contributors to maritime operational risk (Moreno et al., 2023); (Singh et al., 2023). In the technical-operational dimension, the echo sounder's inaccurate reading during the 24 February 2025 grounding, combined with the absence of an Electronic Chart Display and Information System (ECDIS) requiring reliance on manually corrected paper charts, meant the hydro-oceanographic data available to the bridge team could lag behind actual fairway conditions. Furthermore, bridge usability limitations and poor integration of navigational information may further reduce navigators' ability to maintain safe operations under dynamic conditions (Danielsen et al., 2022). In the environmental dimension, rapidly shifting currents, sedimentation-driven depth variation, and nipa-palm-obscured sharp bends confronted a bridge team whose communication and response capacity was not yet fully trained to handle these compounding factors simultaneously. These three dimensions converge on a single interpretation: the weak, inconsistent implementation of Bridge Resource Management, rather than the absence of BRM procedures themselves, underlies both incidents (Röttger & Krey, 2021).

Examining the collision through a BRM lens shows that foundational procedures were followed the pilot boarded, core personnel were on the bridge, and VHF communication established a starboard-to-starboard passing agreement yet four implementation gaps emerged: (1) situational awareness radar was underused to track the barge behind the blind bend, and the passing agreement was not collectively re-evaluated as the current strengthened; (2) communication the passing agreement was one-directional with no re-confirmation as conditions changed, and internal officer-to-Master communication about evolving traffic was inadequate; (3) decision-making no real-time speed or maneuver adjustment was made despite predictable current strengthening; and (4) teamwork no cross-check of the pilot's tactical decision occurred, and AIS, radar, visual, and radio information were not integrated into a shared risk assessment before passing.

The grounding incident shows a parallel pattern. Initial safety steps were completed (One Hour Notice, pilot boarding, pre-departure tidal calculation), yet the same four gap categories appear: (1) situational awareness the echo sounder's erroneous reading was never cross-verified against a second source, reflecting a single point of monitoring inconsistent with BRM's redundancy principle; (2) communication no officer raised a clarifying concern about depth near the known-hazardous Buoy 6 before the incident, indicating underdeveloped assertive communication; (3) decision-making the pre-departure tidal estimate was not validated against real-time data before the fairway was entered; and (4) teamwork manual sounding by the crew was performed only after grounding rather than proactively before entering the critical area.

Read together with the risk assessment in Table 4, these gap patterns explain why both incident types scored the maximum value of 9: the high Consequence score reflects the fairway's inherently confined, current-affected geometry, while the high Likelihood score reflects how consistently these same four BRM gaps recur across the 25-incident inventory rather than appearing as one-off lapses. The repeat-grounding anomaly of MV. Tanto Luas (Discussion point 3 above) reinforces this interpretation: four groundings on one vessel within six months suggest that the underlying gap is not confined to KM. Tonasa Line XIX alone but reflects a broader, fairway-level vulnerability in how bridge teams operating this corridor manage situational awareness and cross-verification under the same environmental pressures.

These findings align closely with (Sharma et al., 2019) three-level situational awareness framework: the failure to detect the barge's position early via radar reflects a Level 1 (perception) deficit; the imprecise interpretation of tidal data before the grounding reflects a Level 2 (comprehension) deficit; and the delayed adjustment of speed and maneuvering plan at the sharp bend reflects a Level 3 (projection) deficit. The findings also corroborate (Sánchez-Beaskoetxea et al., 2021) distinction between active and latent error: underused radar during the collision constitutes an active error a direct, in-the-moment operator lapse while the apparent absence of a structured pre-entry navigational briefing and regular BRM refresher training reflects a latent, organizational-level error that quietly weakened the team's safety margin. This is consistent with (Dominguez-Péry et al., 2021) broader argument that maritime human error is rarely attributable to individual carelessness alone but instead emerges from the interaction of people, technology, and organizational systems a pattern also implicit in (Kodak & Dal, 2024) root cause linkage between BRM implementation quality and navigational safety outcomes. The recurrence of grounding as a structural risk in another Indonesian narrow river channel, as documented by (Muhammad Setyan Farros Wa Savero et al., 2025) in their root cause analysis of a grounding incident in the Kapuas River, further suggests that the vulnerabilities identified here are not unique to the Mahakam River but may reflect a broader pattern affecting Indonesia's narrow inland shipping fairways more generally an inference that future comparative research could usefully test.

Theoretically, this study contributes an incident-history-anchored application of the IMO Formal Safety Assessment (FSA) framework to a confined Indonesian river fairway, an operational context that remains comparatively underexamined relative to open-sea or port-approach risk studies, while extending the Bridge Resource Management (BRM) and situational-awareness literature with a paired qualitative gap analysis and quantitative risk score. This contribution complements recent studies emphasizing the importance of non-technical skills, structured BRM training, and operational learning in improving navigational safety and decision-making on the bridge (Campaniço Cavaleiro et al., 2020); (Fjeld & Tvedt, 2020).

Practically, the findings support several concrete measures for the shipping company and bridge teams: strengthening BRM implementation through a concise, plain-language navigational guide specific to the Mahakam River Fairway identifying known hazard points such as shallow buoy areas and sharp bends; regular Master-led training on narrow-channel procedures, emergency handling, and navigational equipment use; mandatory pre-entry navigational briefings covering current, tidal, depth, and traffic conditions; a near-miss and incident reporting system operating under a just-culture principle; a routine inspection and calibration schedule for radar, AIS, echo sounder, and VHF equipment, with paper charts kept current against the latest Notices to Mariners; and fairway-entry scheduling that consistently accounts for tidal conditions to preserve adequate Under Keel Clearance, particularly under full-load conditions. These recommendations are consistent with recent research highlighting the effectiveness of maritime resource management training and robust near-miss reporting systems in strengthening organizational safety culture and reducing accident recurrence (Praetorius et al., 2020); (Hasanspahić et al., 2020).

For waterway authorities such as KSOP Samarinda, the findings support continued strengthening of traffic scheduling (Sispro) enforcement and Master-Pilot Exchange practices, alongside periodic updates to hydro-oceanographic charting given the fairway's dynamic sedimentation.

This study is limited by its single-vessel case study design, which constrains the generalizability of the BRM gap analysis beyond KM. Tonasa Line XIX. Of the 25 incidents underpinning the risk score, only two were directly observed by the researcher; the remaining 23 were compiled from secondary sources official reports and credible media which may carry documentation or reporting limitations. The qualitative interview sample was also limited to four informants from a single vessel, and the Likelihood/Consequence scoring, while anchored to historical frequency, still involved a degree of researcher judgment in categorization. Future research is encouraged to replicate this incident-history-based FSA approach across multiple vessels and operators transiting the Mahakam corridor, ideally validated through an expert-elicitation panel to reduce single-researcher scoring subjectivity; to conduct comparative studies against other Indonesian narrow-channel river fairways (e.g., the Kapuas, Musi, or Barito Rivers); and to apply HFACS-based coding to a larger incident sample for a more granular decomposition of active versus latent causal factors.

CONCLUSION

This study finds that KM. Tonasa Line XIX faces a high level of navigational risk when transiting the Mahakam River Fairway, evidenced directly by the vessel's own collision (20 December 2024) and grounding (24 February 2025) incidents. Anchoring risk assessment to a five-year inventory of 25 documented fairway incidents (2021–2026) confirms that both collision (≥17 cases, average ≥3.4/year) and grounding (≥8 cases, average ≥1.6/year) fall into the High-Risk category, each scoring 9 on the IMO FSA Likelihood × Consequence matrix indicating that these are not isolated events but structurally recurring risks with a consistent causal pattern: barges losing control under strong currents, shallow buoy-area depths, sharp-bend currents, and inter-party miscommunication. The central finding is that Bridge Resource Management exists procedurally and structurally aboard KM. Tonasa Line XIX, yet has not been implemented optimally; the gap between intended and actual BRM practice particularly in communication, situational awareness, and fatigue management is the principal driver behind both incidents.

This study contributes to the maritime safety literature by demonstrating that anchoring IMO Formal Safety Assessment (FSA) Likelihood scoring to a verifiable, multi-year local incident record rather than relying solely on subjective expert judgment offers a replicable, evidence-based model for risk assessment in other confined Indonesian waterways. This approach is consistent with recent studies advocating data-driven and dynamic risk assessment methods that integrate historical accident records, operational conditions, and human factors to improve the accuracy of maritime safety analysis (Özaydın et al., 2022); (Merrick et al., 2022). Furthermore, the study extends Bridge Resource Management (BRM) and situational-awareness theory into a concrete narrow-river-fairway case by linking qualitative gap analysis directly to quantitative risk scores, thereby providing a practical framework for translating bridge-team performance into measurable operational risk (Chan et al., 2022); (Bowo et al., 2021).

Building on the limitations identified above, future research should: (1) replicate the incident-history-based FSA approach with expert-panel validation across multiple vessels and operators in the Mahakam corridor; (2) conduct comparative risk studies across other Indonesian narrow-channel fairways; (3) apply longitudinal monitoring to assess how targeted BRM training interventions affect incident frequency over time; and (4) integrate

HFACS-based coding for a deeper analysis of latent organizational causes underlying recurring narrow-channel accidents.

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