Advanced and Sustainable Technologies
ASET
E-ISSN 2976-2294
Volume 5, No 2, September 2026 [201-222]

Determinants of Domestic Ferry Casualties in Langkawi: A Narrative and Integrative Review

Ting Siew Cheong[1], Chin Voon Thong[1], Si Ying Ooi[1], Keng Bin Loke[2], Mohd Saiful Izwaan Saadon[2], Lai Chuah[1]* and Nor Hasni Osman[1]

[1]School of Technology Management and Logistics, Universiti Utara Malaysia, Malaysia.
[2]Faculty of Maritime Studies, Universiti Malaysia Terengganu, Malaysia.

Received 8 May 2026, Revised 3 June 2026, Accepted 23 June 2026

ABSTRACT

Domestic ferry transportation plays a crucial role in supporting tourism, regional connectivity and economic development in Langkawi, Malaysia. Despite improvements in maritime safety regulations and operational standards, ferry casualties continue to occur, raising concerns regarding safety performance and operational risk management within high demand island transport corridors. Increasing passenger demand and operational pressures in tourism driven routes may challenge compliance with safety standards and expose ferry services to environmental and operational uncertainties. This narrative and integrative review synthesizes existing literature on the determinants of domestic ferry casualties, focusing on human factors, environmental conditions, mechanical failures, organizational influences and technical knowledge as potential determinants identified in the broader maritime safety literature. Accident causation is identified as multifactorial and dynamic, involving interactions between human limitations, environmental uncertainties and technical system vulnerabilities rather than isolated operational failures. Heinrich's domino theory, Bird's domino theory and Systems theory are applied to explain behavioral triggers, management control weaknesses and system level interactions influencing casualty occurrence. It provides important insights for policymakers, ferry operators and maritime authorities to enhance safety management, strengthen regulatory enforcement and improve operational resilience. The study also directly contributes to Sustainable Development Goal 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities and Communities) by promoting safe, resilient and sustainable domestic maritime operations.

Keywords: Domestic ferry, Maritime safety, Ferry casualties, Langkawi.

1. INTRODUCTION

In Malaysia, between 2018 and 2024, 351 vessel accidents were reported in Malaysian waterways [1], indicating that marine accidents continue to occur annually despite ongoing efforts to enhance safety standards and enforcement actions. This persistent pattern suggests that maritime safety challenges remain deeply embedded within operational, technical and environmental dimensions of the shipping sector, underscoring the need for more preventive safety strategies.

Langkawi is an island archipelago located in the Andaman Sea [2], situated off the west coast of mainland Malaysia and separated from the mainland by the Malacca Strait [3]. Langkawi, a district within the state of Kedah in northern Peninsular Malaysia, is one of Malaysia's most popular tourist destinations [4]. The tourism sector contributed significantly to Kedah's gross domestic

*Corresponding author: johnfatt2000@yahoo.com

product, with Langkawi's tourism industry by generating RM 1.7×10^9, representing 6.5% of the state's Gross Domestic Product in 2019 [5]. This economic dependency on tourism further emphasizes the importance of safe and reliable transportation systems, particularly ferry services which serve as a primary gateway to the island.

During the COVID-19 pandemic, the number of visitors to Langkawi declined sharply in 2020, with ferry passenger numbers falling from 2,206,498 to 1,199,155 [6]. By 2024, the total number of visitor arrivals recorded for Langkawi in the dataset reached 1,341,289. This recovery trend reflects the resurgence of tourism activities and indicates increasing pressure on ferry operations to accommodate growing passenger demand. Figure 1 illustrates the total arrivals of visitors at Langkawi and Pangkor Island between 2018 and 2024. The data showed that Langkawi consistently recorded nearly twice as many visitors as Pangkor Island throughout the period, highlighting its continued importance as a major domestic ferry destination in Malaysia. The sustained rebound in visitor flows also implies greater exposure of ferry operations to congestion, schedule pressure and service reliability demands, all of which may heighten operational risk if not properly managed.

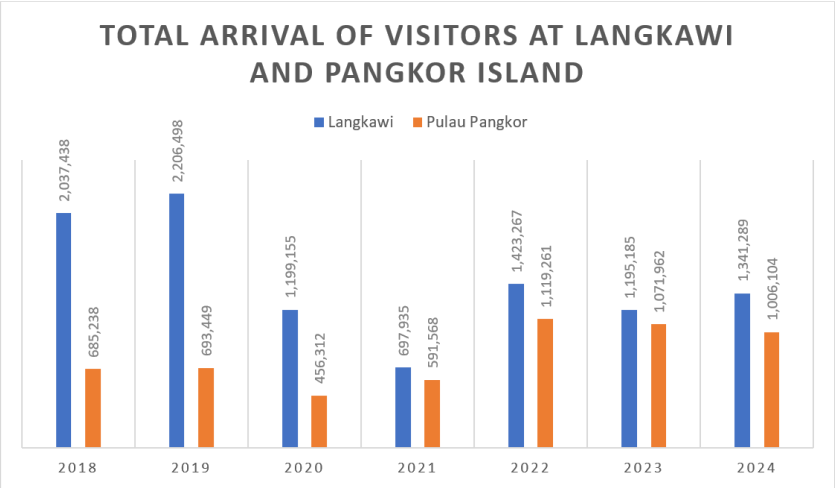

Figure 1: Total arrival of visitors to Langkawi and Pangkor Island [6].

Domestic ferry services played a key role in connecting Langkawi Island with mainland Malaysia. The total number of ferry casualties recorded in Langkawi was 28 cases between 2018 and 2024 [1]. Figure 2 showed that ferry casualties occurred every year during this period, indicating that safety issues persisted within Langkawi's domestic ferry operations. The recurring nature of these incidents suggests that existing safety measures may not be sufficiently effective in addressing underlying risk factors. One notable incident occurred on 11 May 2021, when the passenger ferry Starcity Express No. 6 experienced an engine room fire while en route to Langkawi, carrying 305 passengers on board, with all passengers reported safe [7]. Another significant incident occurred on 28 October 2022, when the passenger ferry Starcity Express No. 6 with 133 passengers ran aground near the Kuala Kedah estuary, requiring a rescue operation by the Malaysian Maritime Enforcement Agency [8]. These incidents highlight the potential severity of ferry accidents and the importance of effective emergency response and safety preparedness.

Under the International Convention for the Safety of Life at Sea (SOLAS), Chapter IX – Management for the Safe Operation of Ships, Regulation 4, document of compliance was a document issued to a company that conformed with the ISM Code's criteria [9]. There were 11 companies that held the Document of Compliance for passenger ships and high speed craft, indicating their capability to safely operate passenger vessels in Malaysia [10]. Compliance with

international standards does not fully eliminate operational risks particularly in dynamic and high demand ferry environments.

In Langkawi, multiple ferry operators such as Langkawi Ferry Lines (LFL) provided the passenger ferry services from Kuala Perlis to Langkawi and Kuala Kedah to Langkawi [11]. The travel time from Kuala Perlis took approximately 80 min, a shorter time compared to Kuala Kedah which took about 105 min [12]. Passengers were able to choose their departure point based on convenience and accessibility. On 17 September 2024, nearly 4,000 passengers were affected when 10 ferry trips on the Langkawi–Kuala Kedah route were cancelled due to waves reaching approximately 5 m [13]. The following day, eight ferry trips on the same route were also cancelled because of continued high-wave conditions [14]. These disruptions illustrate the operational relevance of environmental conditions on ferry operations and highlight the vulnerability of ferry services to weather related risks.

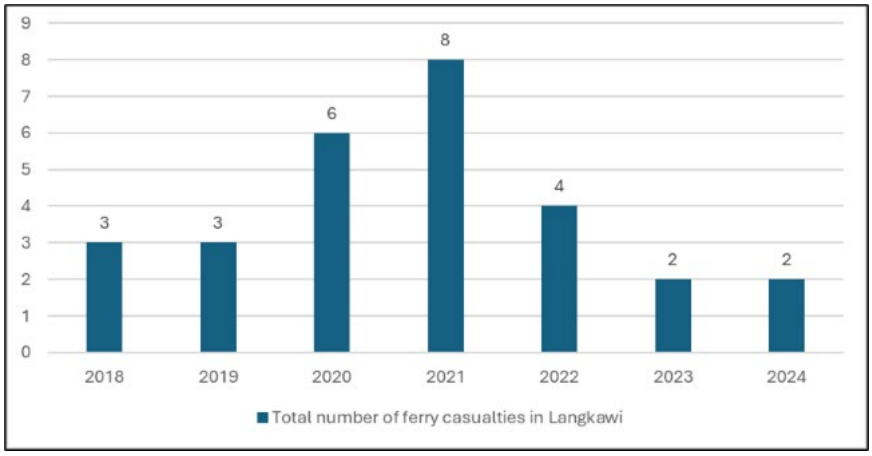

Figure 2: Total number of ferry casualties in Langkawi [1].

Previous studies have identified several contributing factors to ferry accidents. [15] stated that human error is a major cause of accidents, as the ability to identify risks and make sound decisions is crucial in minimizing accidents. [16] reported that 50% of accidents were at least partly caused by bad weather, dangerous waves, flooding from monsoons or unusually strong currents. [17] reported that marine accidents were linked to mechanical failures arising from inadequate maintenance practices by operators. [18] emphasized that a profit oriented mindset may lead to overloading, while [19] noted that vessels are sometimes overloaded up to three times their capacity, increasing instability.

Scholars [20] further explained that duplicated authorizations, weak enforcement and ineffective governmental supervision resulted in poor coordination and delayed responses in maritime disaster management, reflecting significant organizational shortcomings. This multicausal pattern highlights a critical operational vulnerability that threatens local socio-economic stability. Understanding these interactions is vital to achieving SDG 9, which targets the development of reliable, sustainable and resilient transport systems. Furthermore, identifying how these risk factors interact directly supports SDG 11 by enhancing maritime safety compliance and ensuring safe, accessible and disaster-resilient public transport connectivity for island communities.

Although many studies have examined ferry casualties in other countries, there has been insufficient empirical research on ferry casualties in Malaysia, especially on islands. Previous studies were conducted in Nigeria [17], UK [21], Indonesia [22] and global [16, 18, 23, 24]. No comprehensive review has specifically focused on Langkawi's domestic ferry operations. Langkawi represents a particularly relevant case study for island ferry operations because it combines high tourism-driven passenger demand, dense ferry traffic, exposure to dynamic

environmental conditions such as monsoons and tidal fluctuations. These characteristics are common to many island and archipelagic regions worldwide including Southeast Asia, the Caribbean and Mediterranean tourist destinations. By focusing on Langkawi, this review provides insights that are not only locally contextualized but also generalizable to other island ferry systems facing similar operational, environmental and regulatory challenges. Highlighting the potential relevance of human, mechanical, organizational, environmental and technical determinants to Langkawi's ferry operations thus offers lessons that may inform ferry safety management in comparable global contexts.

2. REVIEW APPROACH AND LITERATURE SELECTION

The review does not statistically test determinants or causal effects in Langkawi. This review adopts a narrative and integrative review approach rather than a systematic review or meta-analysis. This approach was considered appropriate because the objective of the study is to synthesize multidisciplinary evidence on domestic ferry casualties in Langkawi by integrating peer-reviewed maritime safety studies, accident causation theories, regulatory documents, official statistics and relevant incident reports. The review focused on previously published literature to capture recent developments in ferry safety, maritime casualty trends, environmental risks, safety governance and passenger vessel operations. Seminal works published before 2015 were also included where necessary to support foundational accident causation theories, regulatory context and the historical development of Langkawi ferry operations.

Relevant literature was identified through academic databases and search platforms including Scopus, Web of Science, ScienceDirect and Google Scholar. These sources were supplemented by official and institutional materials from organizations such as the International Maritime Organization, Malaysia Marine Department, Malaysian Maritime Enforcement Agency, Langkawi Development Authority, Maritime Institute of Malaysia and relevant Malaysian legal and regulatory documents. Search terms included combinations of "domestic ferry casualties", "ferry accident", "passenger vessel safety", "maritime accident causation", "human factors" ,"environmental condition", "mechanical failure", "organizational factors", "technical knowledge", "Langkawi ferry" and "Malaysia maritime safety".

Sources were included when they addressed ferry or passenger vessel casualties, maritime accident determinants, safety management, regulatory governance, environmental or weather-related operational risks, mechanical and technical failures or accident causation theories relevant to domestic ferry operations. The selected literature was organized thematically into human, environmental, mechanical, organizational and technical determinants and was interpreted using Heinrich's domino theory, Bird's domino theory and Systems theory to explain how these factors interact within a sociotechnical ferry safety system. The review does not statistically test these determinants or estimate their causal effects on ferry casualties in Langkawi. Instead, it identifies potential determinants reported in the broader maritime safety literature and evaluates their contextual relevance to Langkawi's domestic ferry operating environment.

A total of 87 sources were included in this review, comprising peer-reviewed journal articles, scholarly works, official documents, regulatory documents, government statistics, institutional materials, relevant news and industry sources.

3. GLOBAL MARITIME SAFETY AND MARITIME SAFETY IN MALAYSIA

Data from the Global Integrated Shipping Information System (GISIS) recorded 1,884 marine casualty cases between 2015 and 2019 and 1,227 cases between 2021 and 2024 [25]. Although the latter period contains fewer reported cases, the periods differ in duration and should not be interpreted as directly comparable five-year intervals. This declining trend suggests gradual improvements in global maritime safety performance. The continued occurrence of over a thousand cases highlights a critical reality. Maritime risks remain significant and persistent. These records cover very serious marine casualties, marine casualties and marine incidents, representing the full range of safety related events in maritime operations.

The United Nations Office for Disaster Risk Reduction (UNDRR) defined a maritime casualty as a serious maritime event involving loss including fatalities, severe injuries or total vessel loss while a maritime accident referred to an unplanned occurrence during vessel operations that results in major consequences such as structural damage, personal injury, pollution, grounding or collision [26]. A maritime incident refers to an event that affects vessel safety during operations without leading to severe damage, loss of life or major environmental impact, typically involving low severity technical disruptions such as temporary engine malfunction [27]. This classification framework highlights that both accidents and incidents are critical indicators for evaluating maritime safety performance and risk exposure.

Global shipping activity further reflected the scale of maritime exposure. [28] reported that approximately 109,000 merchant vessels covering cargo and non-cargo ships of 100 gross tonnage and above were operating at the beginning of 2024. This fleet expansion reflected growth in global capacity, with an increase of 3.4% in 2023, up from 3.2% in 2022. Bulk carriers accounted for 42.7% of the fleet, followed by oil tankers (28.3%), container ships (14.0%), general cargo vessels (3.6%) and other vessel categories (11.5%). Ferries and passenger vessels represented 0.4% of the total fleet within the “other vessels” category. Despite representing a relatively small proportion of the global fleet, passenger ferries involve continuous human exposure and high passenger density thereby increasing the potential social consequences of accidents compared with cargo vessel incidents.

A previous study [29] reported approximately 3,310 marine shipping casualties and incidents worldwide in 2024, with machinery damage or failure accounting for the largest share viz. 1,860 cases. Collisions with other vessels accounted for 251 cases while fire related incidents contributed 250 cases. The same report recorded 7 vessel losses linked to extreme weather conditions during the year. Long term analysis of ferry accident records showed that many ferry related incidents arose from preventable conditions including human error, overcrowding, inadequate training and adverse weather, with increasing influence from climate variability [16]. This indicates that ferry casualties are typically multicausal and influenced by both operational and external environmental factors rather than a single isolated cause.

Maritime safety conditions in Malaysia reflected similar concerns. Between January and May 2025, 108 maritime incidents involved 251 individuals were recorded, resulting in 36 fatalities, 12 missing persons and 203 rescues [30]. Reports also showed that nearly 80% of the 226 maritime accidents recorded in Malaysia during 2024 involved individuals who were not wearing life jackets indicating weaknesses in safety compliance. Data from the Malaysian Maritime Enforcement Agency recorded 1,259 successful rescues, alongside 64 fatalities and 25 missing persons during the same period [30]. These statistics underscore the potential relevance of behavioural compliance and safety awareness to accident severity in Malaysia’s domestic maritime transport sector.

In Langkawi, ferry operations faced frequent disruption from environmental and tidal conditions. During the Chinese New Year period in 2025, low tide levels restricted ferry movement as

operations were only possible when water levels exceeded 1.4m, leading to reduced daytime services and suspension of evening operations despite full passenger demand [31]. On 28 July 2024, rough sea conditions resulted in the cancellation of 8 ferry services between Kuala Kedah and Langkawi over 2 days, leaving 1,926 passengers stranded [32]. These repeated service disruptions highlighted the sensitivity of domestic ferry operations to environmental and operational limitations.

Maritime safety governance operated within an established international legal framework. United Nations Convention on the Law of the Sea (UNCLOS) adopted in 1982 and entered into force in 1994, provided a comprehensive framework for ocean use, maritime activity and resource management. By early 2025, UNCLOS had been ratified by 170 parties including 169 States and the European Union [33]. Within the United Nations system, the International Maritime Organization (IMO) and International Labour Organization (ILO) fulfilled complementary regulatory functions covering maritime safety, environmental protection and labour conditions. IMO comprises 176 member States [34] while ILO consists of 187 member States and oversees 192 conventions, 5 protocols and 209 recommendations [35]. Malaysia had ratified 19 ILO conventions and 1 protocol including the Maritime Labour Convention (MLC) 2006 which sets minimum standards for seafarer welfare and working conditions [36]. These international regulatory instruments collectively establish the legal foundation for maritime safety governance by strengthening vessel operational standards, seafarer competency requirements and labour protection mechanisms across member States.

Malaysia had held IMO membership since 17 June 1971 and had served as a Council Member since 2005 [37]. Malaysia had ratified 31 international maritime conventions, consisting of 30 IMO instruments and 1 ILO convention [38]. This extensive level of treaty participation reflects Malaysia's strong institutional commitment to aligning national maritime practices with internationally recognized safety standards and regulatory expectations. Despite the presence of extensive international and national regulatory frameworks, maritime accidents particularly domestic ferry casualties, continue to occur, suggesting gaps in implementation, enforcement and operational practices. Although Malaysia's maritime safety framework is supported by international conventions, national legislation and vessel certification requirements, the effectiveness of these instruments depends largely on enforcement consistency and operational compliance. Regulatory frameworks may establish minimum safety standards, but weak enforcement can reduce their preventive value when inspection findings are not followed by timely corrective action, when operators treat certification as a procedural requirement rather than a continuous safety obligation or when crew and passengers do not comply with safety procedures during daily operations. In domestic ferry services, such compliance weaknesses may appear in several forms including delayed maintenance, inadequate monitoring of vessel seaworthiness, insufficient emergency preparedness, poor adherence to weather-related operational restrictions and limited reporting or analysis of minor incidents and near misses. These weaknesses create a gap between formal regulatory compliance and actual safety performance.

This enforcement–compliance gap is directly relevant to ferry casualty occurrence because domestic ferry operations take place in dynamic environments where high passenger demand, tight schedules, tidal constraints and adverse weather conditions can increase operational pressure. When regulatory oversight is weak or fragmented, operators may have greater opportunity to prioritize service continuity over preventive safety measures. As a result, hazards that should be controlled through inspection, reporting, training, maintenance and operational monitoring may remain unresolved until they escalate into casualties. Therefore, the continued occurrence of ferry casualties despite the existence of regulatory frameworks suggests that maritime safety should not be assessed only by the presence of laws, certificates, or institutional structures, but also by the quality of enforcement, inter-agency coordination and the extent to which safety requirements are embedded in everyday ferry operations.

Ensuring the safety of passengers at sea was a fundamental priority in maritime operations. Previous news reported by [39] highlighted a tragic incident in Malaysian waters in which 4 people lost their lives following a collision between a speedboat and a passenger boat. Such incidents emphasize the high human impact of maritime accidents and the need for stringent safety measures in passenger vessel operations.

Certification systems were established to verify compliance with safety standards. A ship that carried more than 12 passengers was classified as a passenger ship [40]. All passenger ships operating within Malaysian waters shall carry a passenger certificate. Passenger ship safety certificate will be issued to a passenger ship that complies with the requirements for a period not exceeding 12 months after inspection and survey [40]. This periodic certification mechanism functions as a regulatory safeguard to ensure continued vessel seaworthiness, operational readiness and compliance with statutory passenger safety requirements. The inspection ensures that all ship components and equipment meet safety requirements and certificates may be withdrawn if the vessel is deemed unfit for operation. This regulatory mechanism serves as a critical control measure to prevent unsafe vessels from operating and to ensure passenger safety. International Association of Classification Societies (IACS), a non-governmental organization, played a crucial role in the global maritime industry. IACS leveraged its accumulated maritime knowledge and technology to promote maritime safety, safeguard the environment and establish unified rules to ensure that ships comply with consistent international standards [41]. IACS comprised 12 member classification societies, each of which cooperated in promoting technical standards for ship design, construction and management, supported global regulatory development and ensured professional integrity through the Quality System Certification Scheme [42]. In Malaysia, the government had authorized a total of 11 classification societies, with 9 members from the IACS, while 2 were non-IACS-recognized organizations [43].

Table 1: Classification societies authorized by Malaysia [43].

No.	Society Name	Founded	Country of Origin
IACS Members			
1	American Bureau of Shipping (ABS)	1862	USA
2	Bureau Veritas (BV)	1828	France
3	China Classification Society (CCS)	1956	China
4	Det Norske Veritas (DNV)	1864	Norway
5	Indian Register of Shipping (IRS)	1975	India
6	Korean Register of Shipping (KR)	1960	South Korea
7	Lloyd's Register (LR)	1760	UK
8	Nippon Kaiji Kyokai (ClassNK)	1899	Japan
9	Registro Italiano Navale (RINA)	1861	Italy
Non IACS Members			
10	Ship Classification Malaysia (SCM)	1994	Malaysia
11	MY Classification Sdn Bhd	2021	Malaysia

Within Malaysia, maritime safety oversight is supported by a network of federal and statutory bodies as shown in Figure 3, with the Ministry of Transport (MOT) serving as the principal authority responsible for policy formulation, regulation and international cooperation [44]. The Marine Department Malaysia (MMD) functions as the primary agency managing operational shipping matters while port authorities operate as independent statutory bodies overseeing port operations. The Maritime Institute of Malaysia (MIMA), established in 1993 as a company limited by guarantee under the Companies Act 1965, serves as Malaysia's national maritime policy research institute, providing policy research [45], advisory support and strategic analyses to government agencies, industry stakeholders and academia to strengthen maritime governance, planning, and implementation at the national, regional, and global levels. Although this multi

agency governance structure reflects a comprehensive institutional framework effective coordination and enforcement remain critical challenges.

While ferry operations were crucial for connectivity in Malaysia especially in Langkawi [46], studies on the factors influencing domestic ferry casualties remained limited. Existing research has largely focused on global or international contexts, with insufficient attention given to localized domestic ferry operations. This limitation indicates a significant research gap in understanding how contextual operational characteristics, tourism driven passenger demand and localized environmental conditions influence ferry casualty patterns within Malaysian island transport systems. This review addresses this gap by synthesizing existing literature on key determinants including human factors, environmental conditions, mechanical failures, organizational influences and technical knowledge within domestic ferry safety systems. By integrating international maritime safety perspectives with Malaysia specific operational contexts, this review provides a structured understanding of the interacting risk factors affecting domestic ferry casualties in Langkawi and supports the development of more informed safety management and policy improvement strategies.

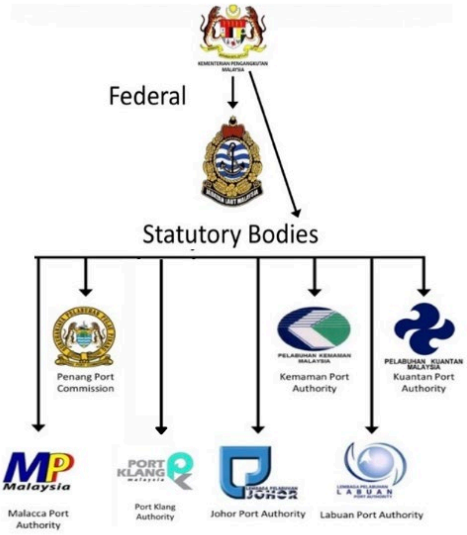

Figure 3: Federal and statutory bodies involved in Malaysia's maritime sector [47].

4. OVERVIEW OF DOMESTIC FERRY CASUALTIES

In maritime operations, the term "casualty" covered both serious accidents and less severe incidents that posed potential risks to vessel safety, crew members, passengers, and the marine environment [27]. This broad classification reflects the need for a comprehensive understanding of safety events across varying levels of severity within maritime operations. Although incidents and accidents differed in severity, both could generate harmful outcomes if left unaddressed. Accidents generally involved grave consequences such as fatalities, substantial structural damage, or total vessel loss, while incidents often involved near misses, minor injuries, or limited technical malfunctions [26]. Although marine casualties and marine incidents differ in severity and classification, both provide important information for maritime safety monitoring, investigation and prevention [48].

To provide a clearer overview of domestic ferry casualty occurrence in Langkawi, Table 2 summarizes the annual number of reported ferry casualty cases between 2018 and 2024. The data show that casualties occurred every year of the review period, indicating that ferry safety issues were persistent rather than isolated. The highest number of cases was recorded in 2021,

followed by 2020 and 2022. Although the number of reported cases declined in 2023 and 2024 [1], the continued occurrence of casualties indicates that ferry safety remained an operational concern and warrants consideration of potential operational, environmental, technical, and organizational contributing factors relevant to Langkawi's domestic ferry system.

Table 2: Annual distribution of domestic ferry casualties in Langkawi, 2018–2024 [1].

Year	2018	2019	2020	2021	2022	2023	2024
Number of ferry casualty cases	3	3	6	8	4	2	2

In Malaysia, maritime casualties involving ferry operations were formally reported using the KEM1 form issued by MMD [49]. KEM1 form required ferry operators to report all safety related events including incidents and accidents regardless of severity. Reportable incidents included non-fatal injuries, near miss occurrences, stranding, operational disruptions or minor equipment malfunctions while accidents typically involved serious injuries, fatalities or significant vessel damage [26]. This inclusive reporting mechanism ensures that even low severity events are captured, enabling early identification of safety risks and operational deficiencies. By categorizing both incidents and accidents as casualties, KEM1 reporting system ensured that all safety relevant events affecting ferry operations were formally documented and subjected to review.

This reporting approach supported systematic safety oversight by allowing maritime authorities to record, monitor and analyze occurrences that might compromise ferry safety. Such comprehensive data collection facilitated trend analysis, risk identification and evidence-based decision making in maritime safety management [27]. A minor collision that caused limited damage to a ferry but resulted in no injuries was still recorded as a casualty under the KEM1 framework [49]. Recognizing minor events as casualties encouraged the use of near misses as learning opportunities rather than insignificant occurrences. Treating minor and major events within a unified reporting system also supported the identification of recurring hazards within ferry operations [48].

From a Malaysian legal perspective, the MSO 1952 contains provisions relating to shipping and maritime casualties. Section 306I defines 'maritime casualty' specifically within the context of Part VA concerning pollution from ships, while the broader provisions on shipping casualties are addressed under the Ordinance's casualty inquiry framework [50]. This ordinance defined a maritime casualty as any occurrence that threatened the safety of a vessel, its passengers or crew, encompassing both accidents and incidents. The definition extended beyond events involving immediate loss of life or severe damage to include technical failures, navigational errors and adverse environmental conditions that had the potential to develop into more serious accidents if not addressed. Section 306I emphasized the importance of recognizing incidents as integral components of maritime casualties, encouraging early investigation and corrective action [50]. This approach aligns with modern risk management principles that prioritize prevention and early intervention over reactive responses.

This national framework was consistent with international maritime safety standards that emphasized the systematic documentation and analysis of near misses and minor incidents alongside major accidents [48]. Such events often signalled underlying weaknesses in vessel maintenance, crew competence, operational procedures or environmental risk management and therefore provided valuable warning signs for safety improvement.

The KEM1 reporting system and MSO 1952 Section 306I provided a structured framework for understanding and managing domestic ferry casualties in Langkawi. Incidents that did not result in fatalities or substantial damage were treated with equal importance as they offered valuable insights into potential operational risks [27]. Through consistent reporting, investigation and

analysis, maritime authorities were able to strengthen safety regulations, implement preventive measures and enhance the overall safety performance of domestic ferry operations.

The effectiveness of this reporting framework depends on the quality, completeness, timeliness, and consistency of the information submitted. Under-reporting of minor incidents and near misses, insufficient details on contributing factors, or inconsistent classification of events may reduce the reliability of casualty analysis and hinder the identification of recurring safety risks. Although Malaysia's KEM1 and MSO 1952 framework provides a strong foundation for casualty reporting, further improvements could be achieved through greater data standardization, digital reporting systems, enhanced near-miss reporting, and wider dissemination of safety lessons learned. Consistent with international best practices, casualty reporting should serve not only as an administrative requirement but also as a mechanism for continuous safety improvement and accident prevention.

From an operational perspective, the recurring occurrence of domestic ferry casualties in Langkawi highlights the importance of risk-based safety management. Casualty records should be used to support targeted inspections, enhanced monitoring, and regular assessments of vessel readiness, crew competency, and emergency preparedness. In addition, strengthening route-specific operational controls, weather monitoring, pre-departure inspections, and emergency response procedures can help reduce operational risks and support a more proactive, evidence-based, and preventive ferry safety system.

5. OVERVIEW OF DOMESTIC FERRY IN LANGKAWI

Langkawi's domestic ferry and maritime operations operate under the Kedah Port Rules 1984, which provide the legal and administrative framework for port and ferry activities in the state of Kedah. Under this arrangement, ferry terminals such as Terminal Ferry Penumpang Kuah (approximately 6.3066° N, 99.8508° E; 6°18′23.8″ N, 99°51′02.9″ E) functioned within the regulatory scope of Kedah's port governance structure. MMD was responsible for vessel registration, seaworthiness certification, safety inspections, crew competency requirements and compliance with national and international maritime safety conventions. This centralized regulatory framework ensures standardization in ferry operations. Despite ensuring standardization in ferry operations, this centralized regulatory framework may limit local operational flexibility in responding to dynamic challenges.

This governance structure reflected a regulated and standardized operational environment in which organizational decisions related to ferry operations were largely shaped by established government policies and statutory regulations rather than discretionary port level management. While such a framework strengthens regulatory compliance, it may also contribute to gaps in adaptive risk management particularly in high demand and weather sensitive ferry operations. This governance structure provides contextual background for considering the potential relevance of organizational factors to domestic ferry safety in Langkawi. The present review does not establish the direct influence or magnitude of organizational factors on casualty occurrence.

As shown in Figure 5, ferry operations in Langkawi began in 1961 with the establishment of Langkawi Ferry Services Sdn Bhd, which connected the island to Kuala Perlis [51]. This route became the earliest and remained the busiest ferry route serving Langkawi. The declaration of Langkawi as a duty free island in 1987 stimulated tourism and trade, leading to the expansion of ferry services through the entry of new operators such as Samavest Tours & Travel Sdn Bhd and Ekspres Bahagia (Langkawi) Sdn Bhd during the late 1980s and early 1990s [52]. This period marked the beginning of rapid growth in ferry demand driven by tourism development. The expansion of ferry connectivity during this phase supported greater passenger mobility and may

also have increased operational exposure associated with higher service frequency and vessel utilization.

The 1990s and early 2000s marked a period of diversification in ferry operators and routes with Wantas Shipping (Langkawi) Sdn Bhd joining the market [53], followed by Rowvest Langkawi Sdn Bhd in 2000 [54] and JMV Ferry Services Sdn Bhd in 2003 [55]. This period coincided with the establishment of the Langkawi International Maritime and Aerospace Exhibition which further enhanced Langkawi's profile as a maritime destination [56]. The expansion of operators increased service capacity and may also have contributed to greater operational complexity and competition within the ferry sector.

Between 2013 and 2018, the island witnessed the entry of RORO and cargo service providers such as Langkawi RORO Ferry Services Sdn Bhd [57], Langkawi Auto Express Services Sdn Bhd [58] and Dibuk Cargo Services Sdn Bhd [59], supporting both passenger and freight transportation. The post 2017 period witnessed further modernization with operators such as Goldhill Reward Sdn Bhd and Dragon Start Shipping Sdn Bhd expanding RORO services between Kuala Kedah and Langkawi [60]. This diversification reflects the transition of Langkawi's ferry system into an integrated maritime transport network supporting both tourism and logistics.

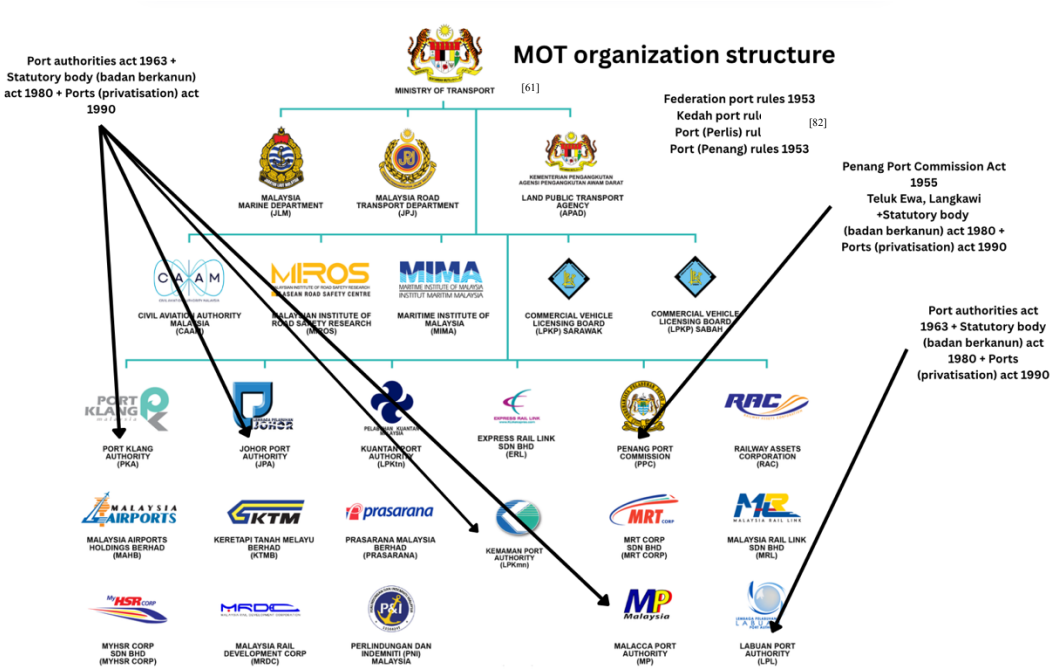

Figure 4: MOT organization structure [61].

In recent years, the industry continued to grow with the entry of Wantas RORO Sdn Bhd in 2022 [62], Langkawi Kedah RORO Sdn Bhd between 2023 and 2024 [63] and Sani Ferry Sdn Bhd in 2024 [64]. Their entry into the market highlighted Langkawi's increasing ferry capacity and connectivity. The continuous expansion of operators indicates strong market demand but also raises concerns regarding coordination, safety standard consistency and operational oversight.
This long-term evolution demonstrated the transformation of Langkawi's ferry system from a small scale passenger service into a comprehensive maritime network that now supported tourism, logistics and regional mobility. Expansion of ferry, RORO and barge operators reflected Langkawi's economic growth, strategic maritime location and dependence on safe and efficient ferry transport for both residents and visitors.

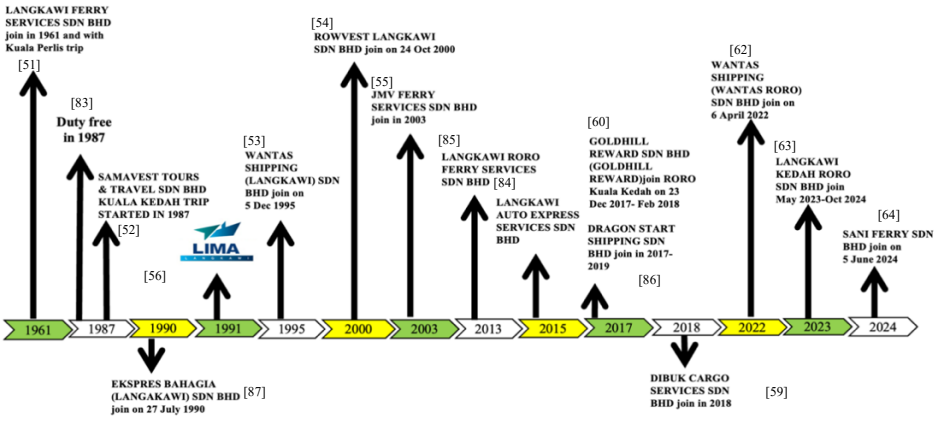

Figure 5: Evolution of Langkawi's ferry, RORO and barge services: A historical milestone flowchart.

6. THEORETICAL PERSPECTIVES ON DOMESTIC FERRY CASUALTIES

Heinrich's domino theory provided one of the earliest and most widely applied conceptual frameworks for explaining accident causation in transportation and industrial safety systems, offering a structured explanation of how domestic ferry casualties occur through a sequential chain of preventable factors [65]. Within maritime safety research, the theory remains relevant because it enables the identification of causal pathways linking human behavior, technical deficiencies and operational hazards to accident outcomes in passenger vessel operations.

Domestic ferry casualties are conceptually aligned with Heinrich's view that accidents and injuries do not occur randomly but develop progressively from underlying causes to unsafe acts, accidents and eventual injury. Human factors, mechanical failures and technical knowledge correspond directly to Heinrich's domino elements particularly the fault of person, unsafe act and mechanical or physical hazard stages. This structured causal sequence provides a practical analytical basis for identifying intervention points where safety controls can be introduced before accident escalation occurs.

Heinrich's domino theory explained accidents as a sequential chain of five interrelated factors: ancestry and social environment; fault of the person; unsafe act and/or mechanical or physical hazard; accident and injury. Each factor was connected to the next, forming a continuous sequence in which the failure of one element increased the likelihood of subsequent events. This theory demonstrated that accidents developed progressively rather than occurring randomly.

The first factor, ancestry and social environment, highlighted how personal traits and social influences shaped an individual's attitude toward safety. The 2nd factor, fault of the person, referred to personal deficiencies such as lack of knowledge, inattention or negligence. The 3rd factor, unsafe act or mechanical hazard, represented immediate causes of accidents, including unsafe behaviour or defective equipment. The 4th factor referred to the accident itself, while the 5th factor represented injury. These stages collectively illustrate how accidents evolve progressively rather than occurring suddenly.

The scholar [65] emphasized that accidents followed a predictable sequence of causes and could be prevented by removing one of the dominoes. The unsafe act or mechanical hazard was identified as the most critical stage. This highlights that controlling unsafe behaviour and mechanical risks can effectively interrupt the chain of accidents and prevent casualties. Empirical studies supported the relevance of Heinrich's domino theory. [66] applied the theory in construction safety, while [67] and [68] demonstrated its applicability in industrial and maritime

contexts. These studies confirm the theory's robustness and adaptability across different sectors, reinforcing its suitability for analysing domestic ferry casualties.

Supporting theoretical perspectives are further provided by Systems theory and Bird's domino theory, which strengthen the explanation of environmental and organizational determinants influencing ferry casualties. The integration of these complementary frameworks enables a multidimensional interpretation of accident causation by combining behavioral, managerial and system-level perspectives within maritime safety analysis.

Bird's domino theory [69] extended Heinrich's model by emphasizing management responsibility and lack of control as the root cause of accidents. Bird's model describes the sequence as lack of control, basic causes, immediate causes, incident and loss.

The first domino, lack of control, represents deficiencies in management functions such as planning, organizing, leading and controlling. This highlights that ineffective management systems can initiate accident sequences even before unsafe acts occur. The 2nd domino, basic cause, included personal and job-related factors such as lack of skills, poor supervision and inadequate work standards. The 3rd domino, immediate cause, referred to unsafe acts and unsafe conditions, while the 4th and 5th dominoes represented the incident and resulting loss.

Bird's domino theory emphasized that unsafe acts were often symptoms of deeper organizational failures rather than isolated individual errors. This perspective is particularly relevant in ferry operations where issues such as overloading, inadequate maintenance and weak enforcement often originate from management decisions. Bird's model complemented Heinrich's theory by identifying organizational control as the root cause of accidents, making it highly relevant for explaining the organizational determinant of ferry casualties in Langkawi.

Systems theory explained that accidents resulted from interactions among multiple components within a system, including human, technical, organizational and environmental elements [70]. Unlike linear models, Systems theory provides a dynamic and holistic perspective, recognizing that failures often arise from complex interdependencies. In ferry operations, environmental conditions such as weather, sea state and visibility functioned as external subsystems that continuously interacted with internal components such as crew performance, vessel condition and management practices. Disruptions in any component may lead to system imbalance and increase the likelihood of accidents.

Systems theory consisted of several core elements, including inputs, processes, outputs, feedback and environment. Input referred to resources such as crew, equipment and environmental conditions, while processes involved operational activities. Outputs represented outcomes such as safe operations or accidents and feedback allowed for system improvement. A strong feedback mechanism is essential for learning from past incidents and enhancing safety performance. The environment represented external conditions beyond operational control, such as weather and sea conditions, which significantly influenced ferry safety. Subsystems within the ferry system were interdependent, meaning that failure in one component could trigger system wide failure.

The integration of Heinrich's domino theory, Bird's domino theory and Systems theory provides a comprehensive and multidimensional framework for understanding domestic ferry casualties. Heinrich's theory explains the sequential nature of accidents, Bird's theory highlights the role of management and organizational control, while Systems theory captures the interaction of multiple factors within a complex operational environment. This combined theoretical approach enables a more holistic analysis of ferry safety, supporting the identification of critical intervention points across human, technical, organizational and environmental dimensions.

7. POTENTIAL DETERMINANTS RELEVANT TO DOMESTIC FERRY CASUALTIES IN LANGKAWI

While this review aims to analyze potential determinants relevant to domestic ferry casualties in Langkawi, it is important to note that specific quantitative data for environmental, human, mechanical, organizational or technical factors are not publicly available for this region. Consequently, the discussion is based on a narrative synthesis of available literature, official reports and international studies. Where applicable, we contextualize findings to Langkawi by considering operational, environmental and regulatory characteristics typical of the island's ferry system, without introducing unsupported numerical estimates. This approach allows the manuscript to provide analytical and practical insights into potential determinants of ferry casualties in Langkawi while acknowledging the limitations imposed by the lack of local empirical data. Table 3 presents a synthesis matrix of potential determinants relevant to domestic ferry casualties, summarizing the principal factors and supporting studies across human, environmental, mechanical, organizational and technical categories.

Table 3: Synthesis Matrix of Ferry Casualty Determinants.

Determinant	Key Factors	Source / Study
Human	Crew fatigue, decision-making errors, inadequate training	[17, 23]
Environmental	Weather conditions, tides, monsoon storms	[16, 17]
Mechanical	Inadequate maintenance	[17]
Organizational	Management challenge	[18]
Technical	Navigational challenge, technical failures	[18]

7.1 Influencing Domestic Ferry Casualties

Domestic ferry casualties refer to any occurrence involving a passenger ferry operating within national waters that resulted in fatalities, injuries or situations where the vessel was abandoned, not under command, stranded or materially damaged [50]. In this review, domestic ferry casualties are conceptualized as a multidimensional safety outcome potentially associated with interactions among operational, environmental, technical and organizational determinants rather than a single isolated failure event. This conceptual perspective recognizes that the reviewed literature commonly associates ferry casualties with multiple contributing factors rather than with a single isolated cause.

As summarized in Table 2, Langkawi recorded 28 domestic ferry casualty cases between 2018 and 2024. The annual pattern shows that casualties occurred throughout the review period, with the highest number recorded in 2021, followed by 2020 and 2022. This quantitative pattern indicates that ferry casualties in Langkawi were not isolated events but recurring safety occurrences within a high-demand island transport system. Although the number of reported cases declined in 2023 and 2024, the continued occurrence of casualties indicates the need to examine the potential relevance of human, environmental, mechanical, organizational and technical determinants on ferry safety performance.

Such casualties remained a serious concern for many maritime nations particularly in regions where ferries served as a vital mode of transportation connecting islands, coastal areas and rural communities. Previous studies indicated that ferry casualties were more prevalent in developing countries and were often associated with high numbers of fatalities and significant property losses [16]. Ferry casualties also disrupted transport services and economic activities by affecting mobility and trade routes. In tourism-dependent regions such as Langkawi, ferry disruptions may negatively impact tourism flows, local businesses and regional economic stability while weakening public confidence in maritime transport reliability.

Despite advances in vessel design and navigation technology, ferry casualties continued to occur, reflecting ongoing challenges in operational safety and management effectiveness [22]. This suggests that technological improvements alone are insufficient without effective management of human, organizational and environmental factors. Understanding potential contributing factors relevant to domestic ferry casualties therefore requires an integrated sociotechnical perspective that considers interactions among crew performance, environmental conditions, maintenance practices and safety governance structures. Such understanding is essential for improving safety performance and guiding preventive measures by maritime authorities and ferry operators.

7.2 Human

Human factors were widely recognized as major contributors to maritime and ferry casualties. These factors include poor decision making, fatigue, lack of situational awareness, inadequate communication and insufficient technical knowledge, all of which have been associated in the reviewed literature with reduced crew performance and unsafe practices within time sensitive navigation environments and high passenger density ferry operations.

A previous study [15] identified fatigue from long working hours, weak communication and limited technical competence as significant contributors to ferry casualties. [22] further classified human factors into individual, group and organizational dimensions, reporting that they accounted for approximately 28.8% of overall shipping safety issues. [17] found that 44.9% of ferry accidents in Nigeria were directly linked to human error, highlighting the global relevance of human performance in maritime safety across both developing and advanced maritime transport systems.

Within ferry operations, unsafe behaviour, poor teamwork and weak compliance with safety procedures increased human related risks, while continuous training, effective communication and strong adherence to safety standards remained key measures for reducing human error and mitigating domestic ferry casualties [71]. Operational stress, time pressure and environmental uncertainty further influence human performance, potentially impairing judgment and decision making during critical situations.

Human factors played a crucial role in determining safety performance in ferry operations as they involved individual behaviours, attitudes, mental states and decision making processes that have been associated with accident occurrence [18]. Unsafe behaviours such as poor communication, fatigue, negligence and non-compliance with procedures could lead to navigation errors, improper equipment handling and delayed emergency responses [72]. The importance of human factors was supported by [66], who applied Heinrich's domino theory and identified unsafe acts as immediate causes of accidents. This highlights that human error often serves as the initiating trigger within accident sequences and frequently interacts with technical limitations and environmental stressors rather than operating independently.

7.3 Environmental Condition

Environmental conditions referred to the external natural and physical surroundings that affected ferry operations and safety [73]. [17] reported that 33.7% of ferry accidents were attributed to environmental factors, while [24] highlighted the role of adverse weather and poor visibility. These conditions included weather patterns, submerged objects and tidal variations which directly influenced navigation and vessel performance [8]. Environmental conditions are considered in this review as a potential determinant relevant to ferry casualties, particularly in monsoon-influenced maritime regions such as the Malacca Strait and Andaman Sea surrounding Langkawi.

Adverse weather such as strong currents and poor visibility could affect human decision making, equipment reliability and organizational response [74]. [16] further reported that hazardous weather was a major contributor to fatalities and ship losses. Increasing climate variability and unpredictable sea conditions may further intensify environmental risks, potentially making ferry operations more vulnerable to sudden disruptions and safety challenges, especially during peak tourism seasons when higher service frequency may increase operational exposure.

From the perspective of Systems theory [70], environmental conditions acted as an external subsystem interacting with human, technical and organizational components. Imbalance among these components may lead to system failure and increase the likelihood of ferry casualties, highlighting the importance of integrating real-time environmental monitoring and adaptive operational decision support within ferry safety management systems.

7.4 Mechanical Failures

Mechanical failures referred to the breakdown or malfunction of machinery or components that prevented safe vessel operation [75]. These included failures in engines, propulsion systems, steering mechanisms and safety equipment [76]. [77] highlighted that poor maintenance and delayed repairs contributed to machinery breakdowns, while [17] reported that 17.9% of ferry accidents were linked to mechanical failures.

Mechanical failures were often caused by inadequate maintenance practices, including neglected inspections and delayed replacement of worn components. Such deficiencies may compromise vessel seaworthiness and increase operational risk, particularly under challenging environmental conditions. From Heinrich's domino theory, mechanical failures represented the stage of mechanical or physical hazard [65]. When combined with human error and inadequate technical knowledge, these failures may escalate into major accidents. Improving maintenance culture, inspection routines and technical oversight through predictive maintenance systems and condition based monitoring technologies may help reduce mechanical risks relevant to ferry operations in Langkawi.

7.5 Organizational

Organizational factors referred to management structures, safety governance and operational control systems influencing ferry operations [71]. Effective resource allocation, maintenance planning and enforcement of safety procedures were critical for safe operations [78]. Poor communication between management and crew could weaken situational awareness, especially under high risk conditions [71].

Organizational shortcomings often acted as indirect contributors by shaping unsafe working environments rather than immediate causes of accidents [78]. [66] explained that weak management control formed the first domino in Bird's domino theory. [69]emphasized that lack of control led to unsafe conditions and increased accident risks.

In ferry operations, organizational issues such as overloading, cost cutting in maintenance and inadequate training programs may increase operational risks. Strengthening safety governance, management accountability and organizational culture together with effective regulatory coordination between maritime authorities, ferry operators and port management institutions may contribute to reducing ferry safety risks and strengthening preventive safety management. From an organizational perspective, weak enforcement and poor operational compliance may transform regulatory requirements into passive administrative procedures rather than active safety controls. In ferry operations, this may weaken the effectiveness of maintenance planning, crew competency management, passenger safety enforcement, and incident reporting. Therefore, organizational determinants are closely linked to the regulatory environment because ineffective

coordination between authorities, operators and port management can allow unsafe practices to persist and increase the likelihood of ferry casualties.

7.6 Technical Knowledge

Technical knowledge referred to the crew's ability to operate navigation systems, machinery and safety equipment effectively [79]. Strong technical competence enabled early detection of system failures and supported preventive maintenance [80]. Continuous training aligned with STCW standards may support operational reliability and strengthen compliance with international passenger vessel safety requirements.

Technical knowledge was particularly important during emergencies where accurate decision making and system handling were required [71]. [81] emphasized that many maritime accidents resulted from inadequate technical understanding rather than mechanical failure alone. Insufficient technical knowledge may lead to delayed responses, incorrect system handling and escalation of minor faults into major accidents. Although technical knowledge alone might not directly prevent casualties, it played a critical supporting role in enhancing operational safety when combined with effective management and favourable environmental conditions [16]. Within a sociotechnical maritime safety framework, technical competency can be considered an important supporting factor that may strengthen the effectiveness of safety procedures, maintenance practices and emergency preparedness in domestic ferry operations.

8. CONCLUSION

Maritime transportation plays an essential role in supporting economic activities, tourism, and regional connectivity, particularly in island destinations such as Langkawi, where domestic ferry services act as a key transport link between the mainland and the island's tourism-dependent economy. Despite improvements in maritime safety regulations and operational standards, ferry-related safety incidents remain a persistent concern, highlighting the gap between regulatory compliance and actual operational safety performance. This review synthesised literature on maritime safety and identified human factors, environmental conditions, mechanical failures, organizational practices, and technical knowledge as potential determinants relevant to domestic ferry safety outcomes, including the Langkawi operating context. Among these, environmental conditions appear particularly relevant to the Langkawi context, given monsoon variability, tidal constraints, and dynamic coastal weather systems. Overall, the reviewed literature suggests that ferry casualties may be understood not as isolated events but as system-level outcomes associated with interactions among environmental, human, technical, and organizational factors. The integration of Heinrich's Domino Theory and Systems Theory further suggests that ferry casualty occurrence reflects both behavioural sequences and broader system interactions. This highlights the importance of combining human-focused interventions with system-level safety management approaches to improve ferry safety performance. Although Malaysia's maritime safety framework includes structured reporting systems and regulations such as MSO 1952 aligned with IMO standards, implementation effectiveness remains a key challenge. Strengthening safety culture, maintenance governance, and real-time operational decision-making may be particularly relevant on high-demand ferry routes such as Langkawi. Effective management of ferry safety requires coordinated efforts among policymakers, maritime authorities, and operators, including improved risk monitoring, stronger enforcement, better maintenance practices, and continuous crew competency development supported by integrated governance. The determinants discussed in this review should be interpreted as potential factors relevant to Langkawi rather than as locally verified causal predictors of ferry casualty occurrence. As such, the findings are mainly qualitative and based on narrative synthesis, and are most applicable to similar island ferry contexts. Future research should explore digital navigation systems, predictive maintenance, climate-adaptive scheduling, and competency-based training.

Comparative studies across multiple locations are also recommended to determine whether the identified determinants reflect local conditions or broader regional patterns.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the School of Technology Management and Logistics, Universiti Utara Malaysia, for its institutional support and assistance in completing this review.

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Author contributions statement: Conceptualization, Ting Siew Cheong; Methodology, Ting Siew Cheong, Chin Voon Thong, Si Ying Ooi & Keng Bin Loke; Formal Analysis, Mohd Saiful Izwaan Saadon, Lai Chuah & Nor Hasni Osman; Investigation, Ting Siew Cheong & Chin Voon Thong; Writing & Editing, Ting Siew Cheong, Mohd Saiful Izwaan Saadon, Lai Chuah and Nor Hasni Osman.

Data Availability Statement: No new dataset was generated for this narrative and integrative review. All information analysed in this study was obtained from the published literature, official documents, publicly available statistics, and other sources cited in the manuscript.