Assessment of ship collision risk based on the recorded accident cases: Structural damage and environmental recovery

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Abstract. Transportation is vital due to its capability to transport cargo and people massively. However, if maritime accidents take place, they may cause a significant impact not only on the economy and lives lost but also on the environment. This review paper provides a summary of research and reports on marine accidents, including the inclusion of ship type effects, types of accident events, and the accident consequences, especially to the marine environment. The paper covers global accident data, accident reports from various global accident investigation authorities, and the investigation results. Overall, this study aims to highlight the global tendency of marine accidents and how the accident affects the surrounding site's environmental condition. Additionally, the regulations and activities for environmental recovery are elaborated to tackle the damage caused by the ship accident. The contribution of this review is expected to provide a broader view of the maritime casualties and the effects on the marine environment and the regulations to overcome the damaged ecosystem.

1. Introduction

The rising demands for cargo transportation caused a significant growth of ships and influenced the emergence of various types of ships. However, this growth has caused new problems, such as increased ship accident probability with complex conditions and even scenarios. Studies have been conducted to observe the main factors of maritime casualties by analyzing the risk of maritime accidents from 2017 to 2021 [1]. The analysis used the Bayesian Network (BN) model to analyze the main factors affecting the risk of accidents or Risk Influential Factors (RIFs). The data collected in the study is based on the Global Integrated Shipping Information System (GISIS) and Lloyd's Register Fairplay (LRF) databases. The research by [1] concluded that the main factor affecting the risk of accidents is the type of ship, as shown in Figure 1. Based on Figure 1, it can be seen that ship accidents are influenced by various parameters such as the ship's central dimension, environmental conditions, management, and voyage conditions. The accident analysis is also challenging considering the various accident events including sinking, stranding, grounding, collision, capsizing, rollover, fire/explosion, engine damage, and other faults on the ship. Additionally, the various accident consequences make the safety assessment of marine accidents more complex. One of the significant consequences is environmental damage since it damages creatures' habitats and pollutes water and fish, which might be a source of food and jobs.

In the present paper, the discussion was focused on the casualty parameters, including the inclusion effect of ship types, variation of casualty events, and site distribution of the events, as well as the consequences to the environment and how to overcome environmental impacts. The literature review examined the relationship between ship types, accident risk, and accident consequences. Separately, past accident records were identified to analyze the ship accident's severe impact on the environment. Regulations on marine pollution were also reviewed to understand the appropriate procedure for tackling marine pollution.

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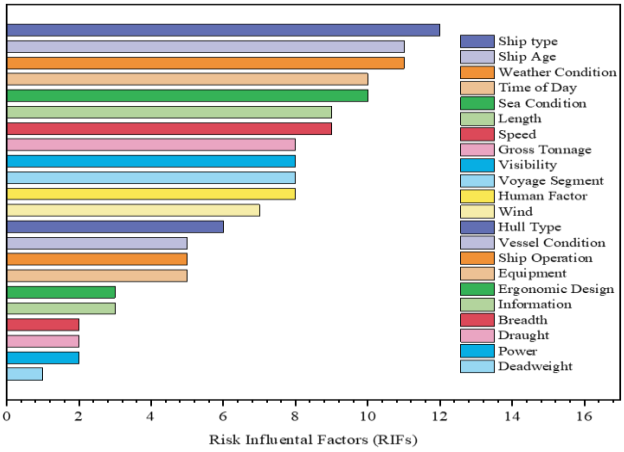


Fig. 1. The key factors affecting accident risk are redrawn from [1].

2. Maritime safety and security

Several studies have analyzed maritime accidents regarding ship type involvement, type of accidents, and the tendency of accident casualties. Studied global maritime accidents related to spatial patterns and characteristics based on accident report data that occurred from 2003 to 2018 [2]. The research indicates that general cargo vessels, bulk carriers, tankers, fishing vessels, and container ships are the primary types of vessels involved in maritime accidents, as illustrated in Figure 2 [2].

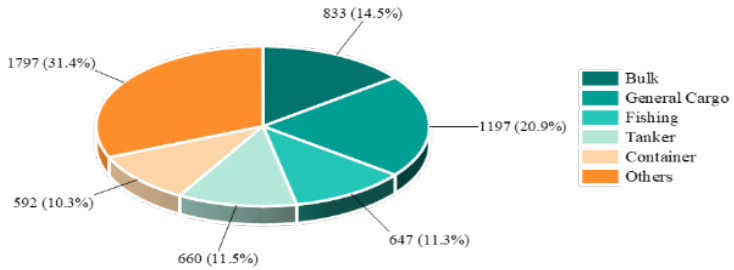


Fig. 2. Distribution of all global maritime accident data by ship type, redrawn from [2].

In the study [2], they categorized ship accidents according to both the vessel type and the accident location. The mapping is categorized into six maritime zones: East Asia, Southeast Asia, and Oceania; Europe with the UK as the focal point; the Asia-Europe-Africa Region encompassing the Mediterranean Sea; North America and South America; and Southwest Africa. As illustrated in Figure 3, general cargo ships exhibit the highest accident rates in three regions (East Asia, Europe with the UK as the focal point, and the Asia-Europe-Africa Region surrounding the Mediterranean Sea). Conversely, bulk carriers are the predominant vessels involved in maritime accidents in Southeast Asia and Oceania, North America, as well as South America and Southwest Africa.

On the other hand, a statistical analysis of marine accident data and AIS data in Norwegian waters has also been conducted [3]. The study aimed to identify conditions associated with navigation-related accidents (groundings and collisions). The findings showed "typical" differences in accidents between vessel categories. A chi-square test was also done to determine if some types of vessels had relatively high rates of navigation-related accidents compared to other groups. As seen in Figure 4, the chi-square test shows that cargo ship types have relatively higher navigation accidents than other ship types, where as many as 69.2% of accidents on cargo ships are navigation accidents. Meanwhile, other types of vessels, such as fishing vessels and passenger vessels, experienced navigation accidents of 66.5% and 44.3%, respectively. The study concluded that the type of vessel is one of the factors that can increase the occurrence of navigation-related accidents such as grounding and collision.

Furthermore, security issues are related to criminal activities such as pirating, armed robbery, and terrorism. Annual reports on acts of piracy and armed robbery against ships by the International Maritime Organization (IMO) stated that there were 229 incidents in 2020, 172 incidents in 2021, and 131 incidents in 2022 [4]. The distribution of pirating

activities is listed in Figure 5. From the figure, it can be seen that the Malacca Strait has the highest number of recorded activities. Unlike safety issues, which mainly impact the ship's structural integrity, security issues are more related to the loss of cargo and injury of the crew.

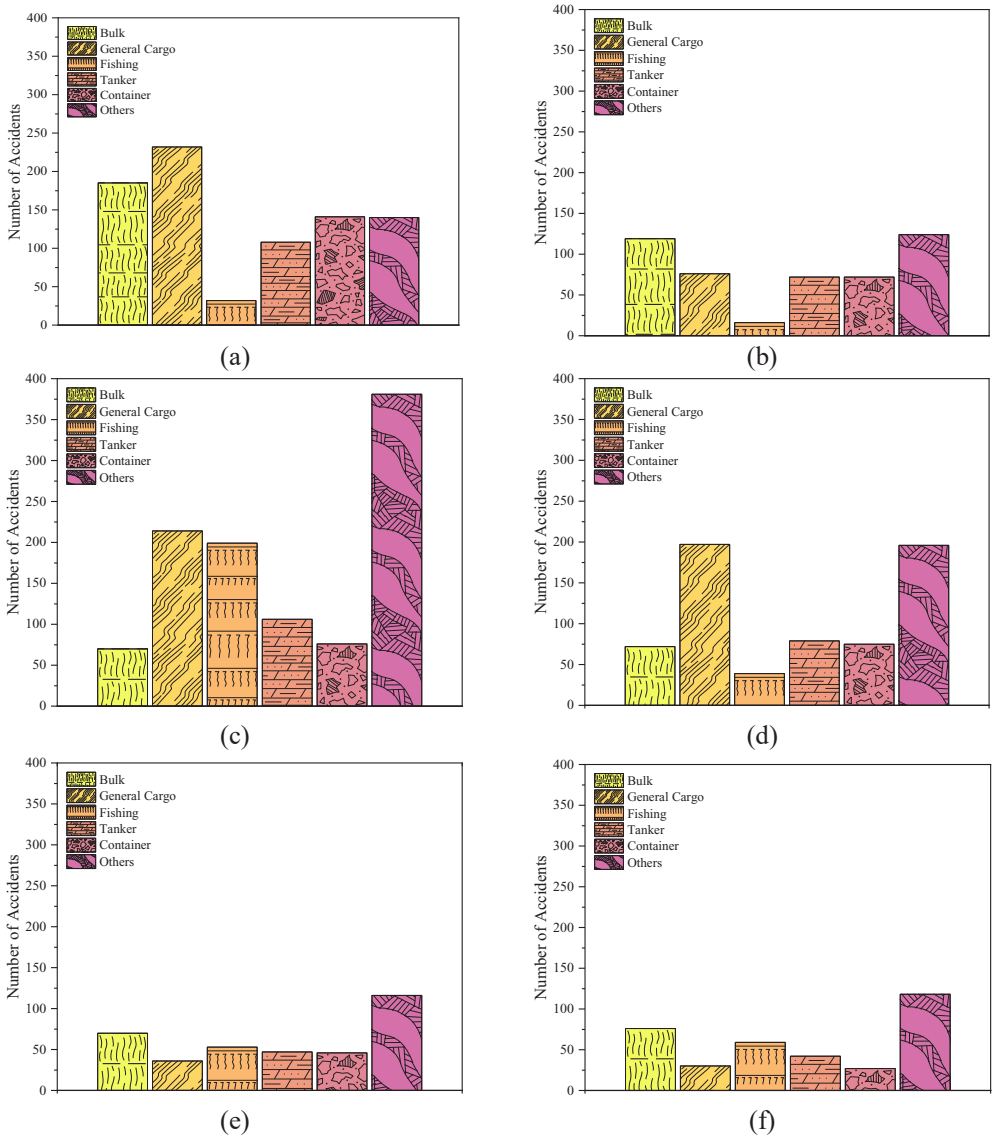


Fig. 3. Distribution of marine accidents by vessel type in (a) The East Asian region comprising China and Japan, (b) Southeast Asia alongside Oceania, (c) Europe with the United Kingdom as its focal point, (d) The region spanning Asia, Europe, and Africa with the Mediterranean Sea at its heart, (e) North America, and (f) South America along with Southwest Africa, redrawn from [2].

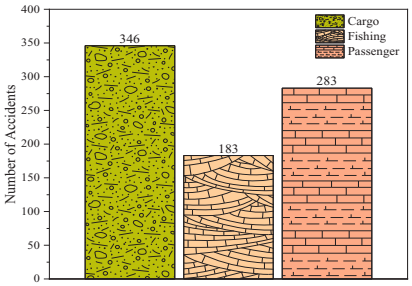


Fig. 4. Navigation accident data based on ship type, redrawn from [3].

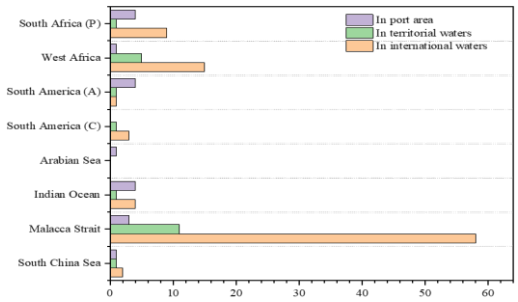


Fig. 5. Regional analysis report of piracy and armed robbery, redrawn from [4].

3. Risk of ship structure damage

The factors that cause shipping accidents are complex. In general, ship accidents can be categorized into ship failures and crew accidents. The causes of ship failure include sinking, stranding, grounding, collision, capsizing, rollover, fire/explosion, engine damage, or other faults on the ship. Crew accidents include accidents due to slips and falls on board during the voyage, operation of hatches and winches and other machinery, exposure to hazardous substances, and other accidents that result in the loss of crew members at sea [5]. This part discusses the accident risk for the three most extensive sea transportation modes (oil tanker, cargo carrier, and passenger carrier as presented in Figure 6).

Fig. 6. Structural damages due to collision experienced by passenger carrier [6].

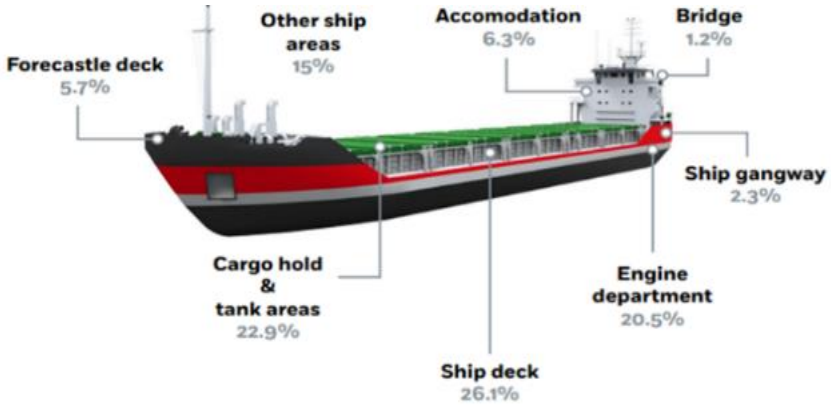


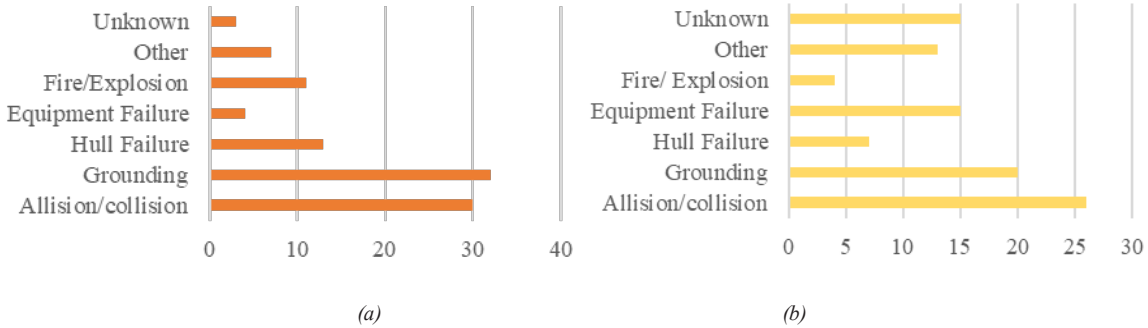
Fig. 7. Main places of occurrence with person(s) on board cargo ships for 2011-2018 [10].

In crude oil tankers, in terms of accident events, such as collision, fire/explosion, grounding, hull/machinery damage, and war/hostilities losses accounted for 23.1%, 9.6%, 0.44%, 45.5%, and 00.77% of all accidents, respectively. From the data, the greatest danger in tanker accidents is the risk of hull/engine damage [7]. Hull damage can occur while the ship is sailing or during port operations, which may influence the ship's structural safety. Faults in the ship's equipment (such as cylinders, crankshafts, and superchargers of marine main engines) cause a ship to fail to operate normally [8]. General cargo ships have the highest frequency of collision accidents. In general, vessels that have a more significant

number of port visits or have a higher level of voyage frequency, general cargo (21.7%), container ships (20.3%), and bulk carriers (20.3%), represent nearly 60% of the vessels involved in collisions [9]. The primary location of technical failures on cargo ships was the deck, with a percentage of (31.8%), followed by cargo hold and tank areas (22.9%) and the engine department (20.5%), as shown in Figure 7. For the passenger ships (cruise ships and ferries), with the object of studying ocean cruises, inland waterways, and harbor/dinner cruises, mentioned that accidents on ocean cruise ship types tend to result in more severe injuries compared to inland waterway and harbor/dinner cruise.
Accident damage costs per ton of ship for cruise ships are $207 and $62 higher for explosion and grounding accidents, respectively, compared to other cruise ship accidents [11]. Besides that, in an analysis of individual ferry accidents, [12, 13] concluded that fire/explosion hazards had a higher risk impact on injury than material/equipment and grounding accidents.

4. Environmental casualties due to marine accidents

Environmental casualties due to marine accidents are mainly caused by oil spills, either cargo or machinery oil. In this chapter, several oil spill cases are reported based on several ship types' accidents. In general, the tanker has the highest probability of oil spill as a consequence of marine accidents. Tanker accidents can cause hefty losses in marine damage due to the spillage of tanker vessels, such as oil and hazardous materials that can damage the marine ecosystem.
The oil tanker accident which caused the tanker spill is shown in Figure 8. According to statistics released by the International Tanker Owners Pollution Federation (ITOPF), by 2022, there were three large spills (>700 tons capacity) and four medium spills (7-700 tons capacity). Two of the large spills occurred in Asia and one in Africa. Moderate spills occurred in North America, Asia, and Africa. On average, the tanker spill in a decade reached nearly six spills (>7 tons capacity). Based on the accident data regarding tankers from 1970 until 2022, it was found that the most significant risk of accidents occurring on tankers, which have the highest consequences for marine pollution, was caused by collisions and groundings [14].



(a) *(b)*

Fig. 8. Causes of Tanker Spills 1970-2022, wirh risk of accidents for tanker spill capacity (%) (a) > 700 tonnes, and (b) 7-700 tonnes, data from [14].

Several marine accidents that pollute the environment include accidents that occurred on bulk carrier 'Fedra' at Europa Point, Gibraltar, On October 10, 2008, which caused an oil spill. The incident was due to the dangerous condition of the main engine, inadequate maintenance standards, and a shortage of spare parts. Although there were no fatalities or serious injuries among Fedra personnel, the vessel was declared a Constructive Total Loss and dismantled due to severe damage. Environmental impacts covered the Gibraltar and Spanish coastlines, necessitating a Level III pollution response involving both authorities. This incident highlights the importance of robust maritime safety measures and thorough response protocols [15].
Another accident causing an oil spill is the grounding case that occurred on October 5, 2011, when the container ship "Rena" was grounded on Astrolabe Reef in the Bay of Plenty, New Zealand, highlighting the complexities and dangers in maritime navigation. The accident was caused by inaccurate calculations of ocean currents, causing deviations from the planned route and threatening the safety of navigation. The impacts involved economic losses, environmental damage with 200 tons of heavy fuel oil spilled, total loss of the vessel, and damage to local reefs. This incident emphasized the need for improved safety management and compliance in the maritime industry [16].Fire accidents may also cause oil spills. For example, on the evening of March 30, 2018, a fire incident in Balikpapan Bay began when the Panamanian bulk carrier Ever Judger collided with and dragged a Pertamina crude oil pipeline, creating a large fire on the morning of March 31, 2018 (see Figure 9). The investigation concluded that the oil spill was caused by negligence in Bridge Resource Management (BRM) and a lack of adequate emergency response from the Ever Judger vessel. The impacts included air pollution felt by residents due to the smell of burning oil and contamination of

more than 7,000 kiloliters of crude oil in a 13,000-hectare marine environment. LAPAN observations showed a shift of oil toward the Makassar Strait, impacting Balikpapan and Penajam districts. Despite mitigation efforts, prolonged environmental consequences persisted, impacting marine habitats and the livelihoods of local communities [17].

(a) (b)

Fig. 9. Oil spill accident at Balikpapan Bay: (a) aerial photographs depicting the oil spill, and (b) Oil dispersant spraying [17].

5. Regulations for ecosystem recovery

The environmental casualties due to oil spills as consequences of ship accidents might be catastrophic since it might be harmful both for marine culture and human beings. Oil spills originating from international tankers entail the unintentional discharge of oil from sizable ships ferrying oil through global waters. Examining the trend in oil tanker spills over time as presented in Figure 10, it becomes evident that heightened awareness regarding the perils of such incidents has led to a decrease in their occurrence across international waters [18-25].

Table 1. Regulations on marine pollution [26].

Regulation	Adoption year	Purpose
International Convention for the Prevention of Pollution from Ships	1973	They are providing the appropriate measurement for preventing marine pollution and reducing the severity of environmental damage when marine accidents occur. This regulation also widely manages ship activities, which may trigger the hazards of marine pollution.
International Convention on Oil Pollution Preparedness, Response, and Co-operation (OPRC)	1990	Guidance on preparedness to address oil spill pollution, adequate response measures to tackle the oil spill, and establishment of international co-operation and coordination to deal with the oil spill.
International Convention on Civil Liability for Oil Pollution Damage (CLC)	1969	They ensure the compensation fulfillment of the affected local communities or citizens affected by marine pollution and the limitation of the compensation.
International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND)	1971	They are establishing the opportunity to raise the international fund for the compensation for oil pollution damage which aims to help the ship owner relieving form the compensation burden and providing additional compensation to the victims.
International Convention on Civil Liability for Bunker Oil Pollution Damage (BUNKER)	2001	It is establishing a framework to ensure prompt compensation to the victims who suffer from oil spills carried as fuel in the bunkers.

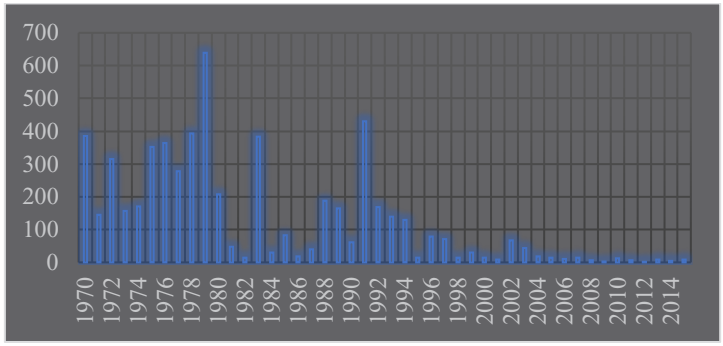


Fig. 10. The quantity of oil spilled by international tankers between 1970 and 2015 [18].

The International Maritime Organization (IMO) has adopted and proposed several regulations on marine pollution, as listed in Table 1. The regulations are aimed at preventing marine pollution, appropriate countermeasures if the marine ecosystem is damaged, and civil liability.

6. Conclusions

The present paper provides an understanding of parameters significantly influencing the risk of maritime accidents, brief reports on global shipping accidents having significant consequences on the marine environment, and evaluates the regulations on marine ecosystem recovery due to oil spills. Thus, this review provides a valuable reference for investigations and analyses related to maritime safety in maintaining the sustainability and integrity of the marine ecosystem. Based on the study from reported accident data, it was found that three ships that often have accidents include cargo ships, bulk carriers, and fishing vessels, concluding that the type of ship is one of the factors that affect the occurrence of ship accidents, where each ship has its risks and consequences according to the characteristics of the ship. Additionally, environmental damage due to oil spills is one of the significant consequences of marine accidents, which not only destroy water quality and may cause health issues but also economically affect the residents. To deal with the occurrence of marine ecosystem damage due to oil spills, the International Maritime Organization has adopted the International Convention on Oil Pollution, Preparedness, Response and Co-operation (OPRC) as a response measure.

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