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Hazard Identification and Risk Analysis System to Minimize Impacts of Shipping on Marine Environment

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Abstract: Sri Lanka has frequently dealt with shipwrecks because it is geographically located at the center of international shipping lanes. The X-Press Pearl shipwreck caused to the territorial sea can be identified as irreversible damage. To protect the marine system, the Marine Pollution Prevention Act was enacted. Collision of ships, internal technical failures, human errors, or weather effects is multiple causes responsible for marine accidents and incidents. To do safe and clean operations in the maritime industry is the role of the human factor. This research includes the significant impact of the X-Press Pearl maritime disaster on Sri Lanka's sensitive coastal environment, local communities, and the economy, identifying hazards, risk assessment, Disaster management cycle. There is uncertainty in marine environmental risks because of the complex factors and fuzzy mechanisms. Therefore, a new assessment technique is proposed based on a weighted Bayesian network (BN). This paper aims to offer hazard identification and risk analysis system to minimize the impacts of shipping on the marine environment. Therefore, in the end, some recommendations are highlighted to implement to prevent similar events shortly.

Index Terms: Hazard identification; marine pollution; risk assessment; X-press pearl incident

1 INTRODUCTION

The global shipping industry contributes millions of dollars' worth of goods every day. It supports the continuation of the trade in finished goods, goods and international products across various sectors. Therefore, maritime transport has become one of the leading modes of transport around the world. Sri Lanka also has four main sea-ports around the island, namely Colombo, Galle, Hambantota and Trincomalee. The Port of Colombo is ranked among the 50 best container ports in the world in terms of volume of containers handled.

Ship accidents are a significant factor when considering the history of sea ports. It causes a lot of pollution to the environment, such as ocean pollution, air pollution, impacts on biodiversity. Historically Sri Lanka has experienced relatively limited maritime disasters, but over a period of ten months, Sri Lanka suffered two major incidents, namely that of the MT New Diamond crude oil carrier in September 2020 and MV X-Press Pearl cargo vessel in May 2021. Both incidents were caused by fire aboard the ships. The MV X-Press Pearl is a Singapore-registered ship that caught fire on May 20 and has been on fire ever since (June 2, 2021, 19:30). The incident took place about 18 km off the coast of Colombo. The joint operation of the Sri Lankan and Indian naval forces continued to struggle to wipe out the flames on the 10th day. Following are the main hazardous materials inside the ship[1]:

- Bunker fuel oil spill (348 tons)
- Hazardous and noxious substances (81 were carrying dangerous goods including 25 tons of nitric acid, caustic sodic, methanol)
- There was 9,700 tons of potentially toxic epoxy resins on board
- 1,486 containers (1214 of which were loaded with an assortment of raw materials, hazardous chemicals, and finished products)
- Microplastics (nurdles or plastic pellets < 5mm)

- In total, there were 87 containers carrying several types of plastic pellets aboard the ship
- The overall quantity of plastic pellets is estimated at around 1,680 tons
- Macro plastics (5-50 mm)

The crew and respondents were tasked with controlling the fire, removing nitric acid, removing the ship, keeping the ship afloat, and managing cargo and fuel leaks. After the crew was evacuated, local authorities worked hard to contain the blaze.

It is reasonable to fear that the chemical spill has already caused untold damage to Sri Lanka's coastline, including the popular tourist resorts. Most of them are located in the coastal areas of Negombo and Kalutara. Also, the beaches in the area were covered with thick plastic and an oil slick appeared in the surrounding ocean. Our response time to disaster management is one of the crucial factors in preventing further damage.

2 X-PRESS PEARL INCIDENT BACKGROUND

International shipping carries hundreds of millions of containers each year. There are many kinds of causes for marine accidents. The leading causes are natural conditions, technical failures, cargo-related factors, road conditions, and human or personal faults. Natural conditions can be natural phenomena. Examples of natural phenomena are current, tidal flow, heavy winds, reduced visibility due to fog and heavy snow and rain, sea storms, darkness, Etc.[2]. Technical failures have occurred inside the ship. Some technical failures are corrosion, constructive damage, engine failure or other damage to the ship. Those issues were due to untimely maintenance and lack of ship services.

2.1 Technical effect

The hundreds to thousands of containers are lost at sea each year, and their contents are dumped into the ocean. When considering the X-press pearl vessel incident, the vessel with 1486 containers may have increased the amount of the lost container due to the catastrophic damage caused by the fire. The vessel's safety is as important as the safety of the crew, cargo, crew, equipment and environment. Therefore, the main factors to consider are the proper packing methods and techniques, stowage procedure, and recording the correct content with weight.

By May 11th, X-press pearl vessel crews had discovered that nitric acid was leaking from a container has loaded at Jebel Ali. They immediately called for both Hamad and Hazira ports to allow it to land. Nevertheless, permission was not granted[3]. According to X-Press Feeders, the request was denied "because there was no immediate availability of specialist facilities or expertise to deal with the leaking acid".

The vessel then set sail for Colombo[4]. The ship arrived in Colombo on May 19th and was anchored outside the harbor hoping for an anchor. However, the ship did not declare an emergency for the cargo acid leak. On May 20th, the ship's representatives requested that the container be returned to work. Port Master has been informed that Colombo is already content with the expertise to assist them as a maritime hub. The vessel then released the first fire report, and the crew extinguished it using its internal system[5]. The Sri Lanka navy assisted in dousing fire onboard MV X-press pearl, as shown in Figure 01[6].

Figure 01: Sri Lanka Navy assisted in dousing fire[6]

This disaster occurred during the southwest monsoon season, which lasts from May to September. In addition to heavy rainfall, strong southwesterly winds also cause rough sea conditions. That makes it harder to control situation.

The X-Press Pearl fire is believed to have been caused by a properly expressed but improperly or incorrectly packaged or stored nitric acid leak. Nitric acid is a toxic as well as corrosive, flammable liquid. The X-press Pearl was carrying 25 tons of Nitric acid[7].

2.2 Being prepared for impacts

To manage the disaster, the National Oil Spill Contingency Plan (NOSCP) has activated by the Marine Environment Protection Authority (MEPA). Also, collaborated with the Sri Lanka Armed Forces, technical government departments, local authorities and other key stakeholders[8]. On June 4, the United Nations (UN) Resident Coordinator in Sri Lanka received an official request from the Ministry of Foreign Affairs for technical assistance. Also, on June 10, the Executive Director of the United Nations Environment Program (UNEP) received a similar request. In response to these requests and coordination with the UN Resident Coordinator, the UNEP / OCHA ((UN) Office for the Coordination of Humanitarian Affairs) Joint Environmental Unit mobilized a team. That team consisted of four experts to advise the Government of Sri Lanka primarily on[8]:

- Design and implement an environmental assessment
- Prevent, minimize and respond to incident risks
- Strengthen national capabilities to deal with future maritime disasters

Moreover, the joint Environment Unit included two oil/chemical and marine litter experts for the four-member team deployed. One expert is from France's Centre of Documentation, Research and Experimentation on Accidental Water Pollution (CEDRE). And the other expert from the Italian National Institute for Environmental Protection and Research (ISPRA).

Specialists are mobilized through the Director-General of the European Commission for the European Civil Protection and Humanitarian Aid Operations / Emergency Response Coordinating Center (DG ECHO / ERCC). An environmental assessment specialist led the United Nations Environment Program Resilience to Disasters team. Also, the Conflicts Global Support Branch was in Sri Lanka from 16th to 30th of June. Marine Environment Protection Authority has done excellent services. They had organized consultation meetings with members of the Environmental Damage Assessment committee.

Furthermore, facilitated site visits to the shipwreck and impacted shoreline sites. In addition, UN team members received continuous feedback from their headquarters and network (regarding technical issues encountered during the operation)[8].

2.3 Vessel rescue operation

On 21st May, the fire intensified, complicating and challenging for everyone[9]. The crew and respondents were tasked with controlling the fire, removing nitric acid, keeping the ship afloat, and managing cargo and fuel leaks. Also, this happened during the curfew and the COVID-19 epidemic, which restricted movement due to the seasonal southwest monsoon.

At 4 pm on May 20th, the ship began to emit yellow and brown smoke, as shown in Figure 02[10]. Then the incident Management Team (IMT) was activated and immediately held its first meeting. The team comprised MEPA Sri Lanka Port Authority (SLPA), Navy and Coast guards.

Figure 02: Emission of yellow and brown smoke from the vessel[10]

On May 21st, four IMT representatives visited the ship. Then, a fire was reported in the deck. The shipping company was ordered to take remedial action, to which he responded by sending a rope operated by a rescue company, SMIT. The next day, explosions were heard in the warehouse, and the ship caught fire. On May 24th, while the situation was still under control, rescue crews boarded the vessel to contain the blaze. At about noon, the whole ship was engulfed in flames the next day. Several containers were reported to have fallen into the sea.

2.4 Launch of activities to rescues the vessel

Several Sri Lanka and Indian Coast Guard fire brigade boats were deployed to douse the fire. A 'boundary cooling' technique is applied initially with foam. However, when the foam ran out replacing it with water. Dry chemical powders are also dropped over the vessel to extinguish the fire, as shown in Figure 03[11].

Figure 03: Dry chemical powders are also dropped over the vessel[11]

At the same time, IMT activated its NOSCP and mobilized 15 stakeholders with oil spill response assets (boom, absorber, Etc.) to be ready. The fire situation will be under control by May 31st. It has been decided to tow the boat to a refugee destination west of NM 50 off the coast to minimize the impact on other maritime shipping and the coastal environment. Four saviors boarded the ship and inspected it on June 1st.On June 2nd, after the MV X-Press was towed nearly Nautical Mile (NM) 1, the ship's rear sank about 17km off the coast of Colombo and 8km off the coast. The front part is floating, and the bridge is above the water. Despite all the efforts made to rescue the vessel, as Figure 04[3], [12], [13], the vessel's bow, which was initially buoyant, continued to sink.

Figure 04: Launched activities to rescue the vessel[3], [12], [13]

Finally, on June 17th, it sank utterly to a depth of about 21 meters on the seabed. Figure 05[14] shows that only the upper forecast deck and the crane are visible at the last minute.

Figure 05: The moment the X-press pearl vessel sinks[14], [15]

2.5 Actions taken to minimize the impact

- A series of dedicated meetings were successively organized with each relevant expert thematic working group. Bilateral meetings were held exclusively with the groups responsible for conducting the following thematic evaluations[8]:
    - Identifying the root cause of the incident, chemicals and oil assessment
    - Environmental effects
    - Air pollution
    - Water and seashore
    - Aquatic resources
    - Biodiversity
    - Socio-economic impacts (tourism)
    - Damage and economic valuation
- Necessary steps were taken to protect the sensitive coastal environment, especially the Negombo Lagoon and other estuaries and entrances.
- Sri Lankan authorities have banned fishing in the area around the wreckage. There were specific regulations that the mortarium should be maintained for fishing until the debris and containers were removed and the seabed checked for contamination.
- The MEPA has activated the NOSCP to deal with the incident as the mandatory body for dealing with marine pollution in Sri Lanka[8].
- The MEPA also implements organizational procedures to clean up plastic pellet contamination.
- The International Owners Pollution Federation (ITOPF) and Oil Spill Response Limited (OSRL) provide significant technical assistance to MEPA in designing and implementing coastal cleanup operations on behalf of the ship owner and the P&I Society (Marine Insurance)[8].
- Dry chemical powders are also dropped over the vessel to extinguish the fire.
- Sri Lanka navy assisted in dousing fire onboard MV X-press pearl.

3 DIVISION AFFECTED BY THE INCIDENT

Oil spills into the ocean, the effects of plastics and micro-plastics, and chemical reactions to marine life can all be caused by this incident. It reported that many residents nearby coastal areas started to collect potentially hazardous materials that output from the vessel[16]. The sever and irreversible damage done to Sri Lanka's marine and coastal ecosystems and wildlife by the MV X-press Pearl has affected many sectors[2].

3.1 Environmental impact

The ship carried a stockpile of hazardous chemicals, including nitric acid, ethanol, dust urea, grilled urea, and dense polyethene. In addition to these toxic substances, mixed waste or other substances can also cause pollution[13]. Chemical release due to shipwreck poses a severe threat to the ocean and coastal ecosystem[2]. Garbage and debris sourced from vessels is a recognized key contributor to marine pollution[17]. It is reported that a large number of plastics of various sizes and conditions have been washed ashore (Figure 06)[18], [19]. Specifically, the arrivals coming directly from the wreck and lost containers are composed of[8]:

i) Various types of plastic pellets
    - Linear Low-Density Polyethylene (LLDPE)
    - Low-Density Polyethylene (LDPE)

- High-Density Polyethylene (HDPE)

ii) Burnt plastic fragments of various sizes (micro < 5mm to macro > 5mm)
iii) Other debris and cargo
iv) foam and sludge of unknown composition.

Figure 06: Cleaning the plastics pallets which have been washed ashore[18], [19]

However, experts' research indicates that only a portion of the spilt petals has reached the Sri Lankan coast and that many of the petals are still in the sea. Buried plastic pollution is also caused by high wave energy and sand movement, most notably in Sarakkuwa beach, where the UN team observed layers of plastic pollution embedded in several dozen centimetres of sand.

According to the Department of Wildlife Conservation (DWC), 251 dead turtles had been washed ashore by July 17 after the incident. Moreover, the daily collection of corpses continued. Moreover, 33 marine mammals - 28 dolphins and five whales - were washed ashore after the incident[8]. Some of the animals affected by this incident are shown in Figure 07[20]–[23].

Figure 07: Animals affected by the incident[20]–[23]

Other ecologically sensitive areas affected by the incident include mangroves and turtle nesting sites, especially in the Negombo Lagoon. Because oil is difficult to evaporate, seawater oil can form a dangerous oil film with severe consequences.

Massive fires and explosions on the ship caused significant air pollution. Winds from the west and southwest also contributed to the rapid spread of air pollution. The smoke from the fire spread over several kilometers for about ten days and severely impacted the event.

3.2 Social impact

Oil pollution results in photosynthesis inhibition. They are also reducing the dissolved oxygen content. In addition, it leads to destroys biological and physiological functions. All of these factors contribute to the gradual decline of marine fish stocks. There are nearly 200,000 fishing families on the island. Nearly 30,000 fishing families in the Gampaha District are affected by this incident[24]. Oil in the oceans is easily attached to fishnets, reducing the efficiency of net equipment, increasing the difficulty of cleaning, increasing the cost of fishing, and incurring significant economic losses. Moreover, Sri Lankan consumers were affected by the shortage of food such as fish, prawns, crabs, Etc.[8].

Marine oil pollution directly or indirectly affects human health, including anaesthesia and suffocation, dermatitis, chemical pneumonia, and other health hazards. Inhaling large amounts of diesel oil droplets in the short term can cause chemical pneumonia[13]. Marine pollution leads to soil destruction, and the ultimate direct harm to humans is through the entry of toxic toxins into crops, especially groundwater, into the food chain.

The nearest district to the scene, Gampaha, has been hit hardest by many debris stranded along the coast. The plastic pellets are concentrated around a 5km stretch of coastline north of Colombo, the hub of the Sarakkuwa coast. However, the situation along the southern coast in the Matara and Galle districts is significantly different. The plastic pellets did not come directly from the wreckage but from a single container stranded more than 100km south and stranded on an island off the coast[8]. Containers lost due to the incident are shown in Figure 08[25].

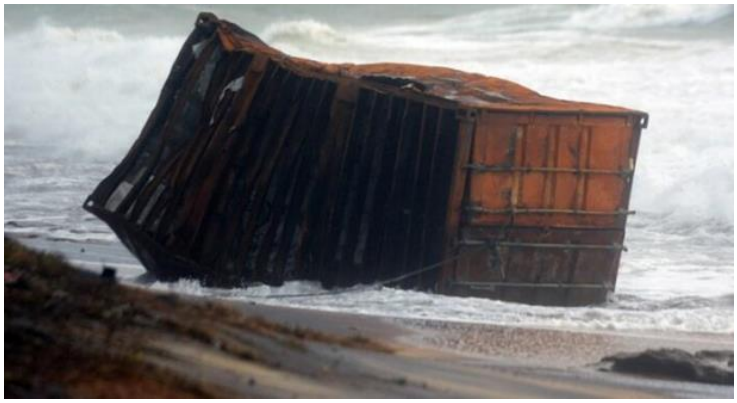

Figure 08: Containers lost due to the incident[25]

3.2 Economic impact

The wrecked X-press Pearl ship is easily linked to beach pollution. As a result, it spoils the fun of the beach attractions with the image of a seaside town. Coral reefs are an important breeding and breeding ground for fish, lobsters, prawns, crabs, and marine aquarium fish. Also, many birds died due to the sea oil coating. The poor quality of the water causes a large number of organisms to die. All these impacts destroy tourism resources and affect the economy. In addition, fishing in the high-yielding Negombo Lagoon, where aquaculture is practiced, has also been suspended. This phenomenon occurred in shallow water (<25m) with high bio diversities such as reefs and soft-bottom habitats. There are no significant sea grasslands other than the Negombo Lagoon area. The entire coastline near the disaster is economically essential for fishing and tourism[8].

Lost containers whose location is unknown poses a naval risk. Containers may be swept down to sea level and collide with merchant ships. The presence of debris in rich fishing grounds also affects the livelihood of the local fishing community. Therefore, the Sri Lankan authorities had banned fishing in the area around the wreckage, which directly affected the economy[8].

Furthermore, public panic over the consumption of "polluted fish" has been exacerbated by a significant increase in turtle and dolphin deaths led to the economic impact. As a result, sales and consumption of seafood across the country declined.

The UN team presented the MEPA with a series of advisory notes during the mission. It is content with their observations and recommendations. The main recommendations focused primarily on minimizing the identified significant risks are[8]:

- The oil layer leaving the debris may cause the bunker oil to release suddenly
- Planning coastal oil spill responses
- Preparation of a detailed plan for the removal of lost debris and containers at sea
- Beach cleaning strategy
- Refer environmental assessment to critical hotspots to assist in emergency decision making

4 MITIGATE DISASTERS

Rules and regulations are essential to reduce the disaster's effect. The Prevention of Marine Pollution Act No. 35 of 2008 is the existing law on marine pollution in Sri Lanka[2].

4.1 Environmental protection

The central concept of environmental issues is the Polluter Pays Principle (PPP). It states that the person or authority involved in polluting the environment should be held responsible for the cost of the damage. The principle of preventive measures and precaution is fundamental[2]. When considering the X-press pearl disaster, a caretaker ship circled the X-Press Pearl 24 hours a day, monitored the wreck for an oil spill to reduce the environmental effect[8].

The main fishing grounds near the most affected areas were partially protected by booms along the two input access roads to the Negombo Lagoon. It is estimated that about 80% of the plastic pollution caused by

this boom can be prevented from entering the lagoon. Moreover, to mitigate disasters caused by oil spills, the Marine Environment Protection Authority (MEPA) immediately has activated the National Oil Spill Contingency Plan (NOSCP). By the time the UN team visited, these booms had been eliminated. The two main methods had used to separate plastic contaminants from sand are[8]:

- Manual sieving – Applied under dry sand conditions, time-consuming, cost-effective
- Flotation in seawater – Used for wet or coarse sand, more effective, reduced the volume of sand collected

4.2 Social security

Although the risks are well identified, the lack of scientific evidence to assess seafood health risks has led to uncertainty and suspicion. Many test results have been considered to assess chemical contamination levels. The main concerns are seafood safety within the no-fishing zone and seafood security outside the no-fishing zone. All the test results and recorded data are most important. Those data are essential to:

- Assist in making critical decisions regarding the maintenance
- Adjustment or lifting of the fishing ban
- To educate and assure the general public about the safety of seafood consumption

Arriving in bulk with nurdles mixed with other debris was initially hauled by hand using large crates and heavy equipment, as shown in Figure 09[26]. As the cleaning progressed, the number of nurdles continuously decreased, and sand increased. Significant amounts of bags contain large amounts of sand, and in some cases, it has been observed that it can reach up to 80%.

Figure 09: Cleaning up the stock of nerds that arrived[26]

It has received technical and financial assistance from international partners to effectively address maritime disasters and strengthen its capacity to protect maritime health, fisheries resources and global trade.

4.3 Economic protection

While governments play a crucial role in all disasters that have been experienced in the past. Governments also play a vital role in disaster preparedness and response. As an island, developing the economic strength of the fishing industry is an essential part of Sri Lanka. However, it is estimated that the livelihoods of 20,000 fishing families have been disrupted due to the disaster. In addition, many others who depend on affiliate fishing, from net manufacturers to boat owners, are also affected to varying degrees. Therefore, fishermen demand SLR 3,000-4,000 (USD 15-20) per day. Chemical pollution and debris from the incident have created the following direct risks to the fisheries sector[8]:

- Seafood safety
- Damage to fishing gear and other assets
- Risk to fisherman from debris at sea

To decrease all these economic problems, the government activated many rules and regulations according to the Marine pollution prevention Act No.35 of 2008. The Coast Conservation and Coastal Management Act can be implicitly identified as a particular act that includes maritime and criminal liability provisions for offences committed under that Act[27]. Backroom, finance, technology, communications These are support services that assist in conducting, initiating and implementing disaster management, relief and development programs. Humanitarian activities are part of a continuous improvement cycle that requires measurement. It is already packed in Sri Lankans.

There is no better beach than the Negombo Lagoon area. Emphasizes the commitment of states to protect and conserve the marine environment, including measures to reduce and control marine pollution[27]:

- Global and regional cooperation of states to prevent maritime pollution
- Technical support
- Monitoring and Environmental Assessment
- International law and national law
- Enforcement
- Protection / safeguard
- Liability and accountability
- Sovereign immunity
- Obligations under other Conventions

5 HAZARD IDENTIFICATION

Maritime accidents, incidents, or marine casualties can be considered unsuitable conditions involving shipping activities[28]. Maritime accidents, mishaps, and near-misses are examples of a marine incident. An unintended incident with negative consequences (injury, death, economic loss, environmental harm, and property loss) is called an accident[8].

There are four types of accidents, according to the Maritime Accident Investigation Bureau (MAIB) report in 2019[29]. They are[27], [30]:

- Very serious accidents (the total loss of a ship, the loss of lives, or significant pollution)
- Serious maritime accidents (from the following outcomes. (a) the boat cannot proceed due to substantial engine immobility, substantial accommodation damage, severe structural damage. (b) Pollution, (c) Dragging or breakdown that necessitates coastal assistance)
- Less serious maritime accident (is a description of any maritime accident that is very serious or serious)
- Marine incidents (occurrence or sequence that happened directly related to the action of an endangered ship)

5.1 Why it has commonly happened

Another study discovered that the primary causes of major accidents are high-level organizations, such as organizational influence and insecure oversight[28]. The Human Factor Analysis and Classification System (HFACS) classified these accidents as severe and less serious. Statistical studies have lately indicated that the principal cause of most marine accidents is human error[8]. The human errors that contribute to marine pollution are resulting in oil spills, waste sludge spills, oil spills, or bunker accidents[29].

5.2 Environment hazards – A ship

Design/construction and equipment of floating craft; cargo; offshore petroleum exploitation are the environmental hazards involving maritime transport. Pollution coming from the hold, cargo tanks, main engine room, fuel tanks, ballast tanks, drilling equipment, sanitary facilities, staff facilities and utility rooms are treated as the source of pollution of a ship[27]. Also, ship-generated pollution can be categorized by considering its characteristics and origin. Types of ship-source pollution are oil, harmful substances, sewage, garbage and harmful emissions. Pollution can also be categorized as operational pollution and preventable pollution. Operational pollutions are discharges and emissions arising from the regular operation, accidental pollution resulting from unexpected situations (running aground, fire, collision). Illegal activity and accidental emissions exceeding standards are some examples of preventable pollution[1], [28]. The most dangerous pollutants generated by seagoing vessels are Oily waste and oil derivative waste.

Maritime transport safety relies on multiple factors. Some of them are the technical condition of a ship, lifesaving and rescue appliances, the presence of means to control and address risks, professionalism of the crew, means of communication, or the ability to respond in emergencies. Relating to the shipping design and equipment and safety management, safety methods are guaranteed to maintain an acceptable level of risk of maritime accidents and minimize their adverse environment[31].

6 RISK ASSESSMENT

Maritime transportation is cost-effective because it transports bulk goods, petroleum products, food supplies, manufactured goods, containerized cargo, etc., over long distances[30]. According to an IMO (International Maritime Organization) document, tankers, general cargo ships, bulk carriers, passenger ships, containerships, and fishing vessels are the classifications of maritime vessels. The IMO issued international safety codes and regulations for the shipping safety regime[32].

Independent classification societies are given the rules for the construction of the ship. Marine safety regulations have grown. But, if an accident occurs, the rules get revised. However, it has been less

effective[31]. Because of this, the shipping industry has developed more formal safety assessments. Piracy, narrow waterways, inclement weather conditions, vessel collisions, natural disasters (tsunamis, earthquakes, etc.), and dangerous, uncharted waterways are some kinds of threats that can be dangerous for maritime transportation. The industry has followed international maritime regulations and improved the safety and security of the industry[33].

Due to changing traffic patterns, different traffic rules, and environmental conditions (such as visibility and wind), constantly evolve maritime port situations. Figure 10 shows the Framework for maritime risk assessment and risk reduction interventions[30].

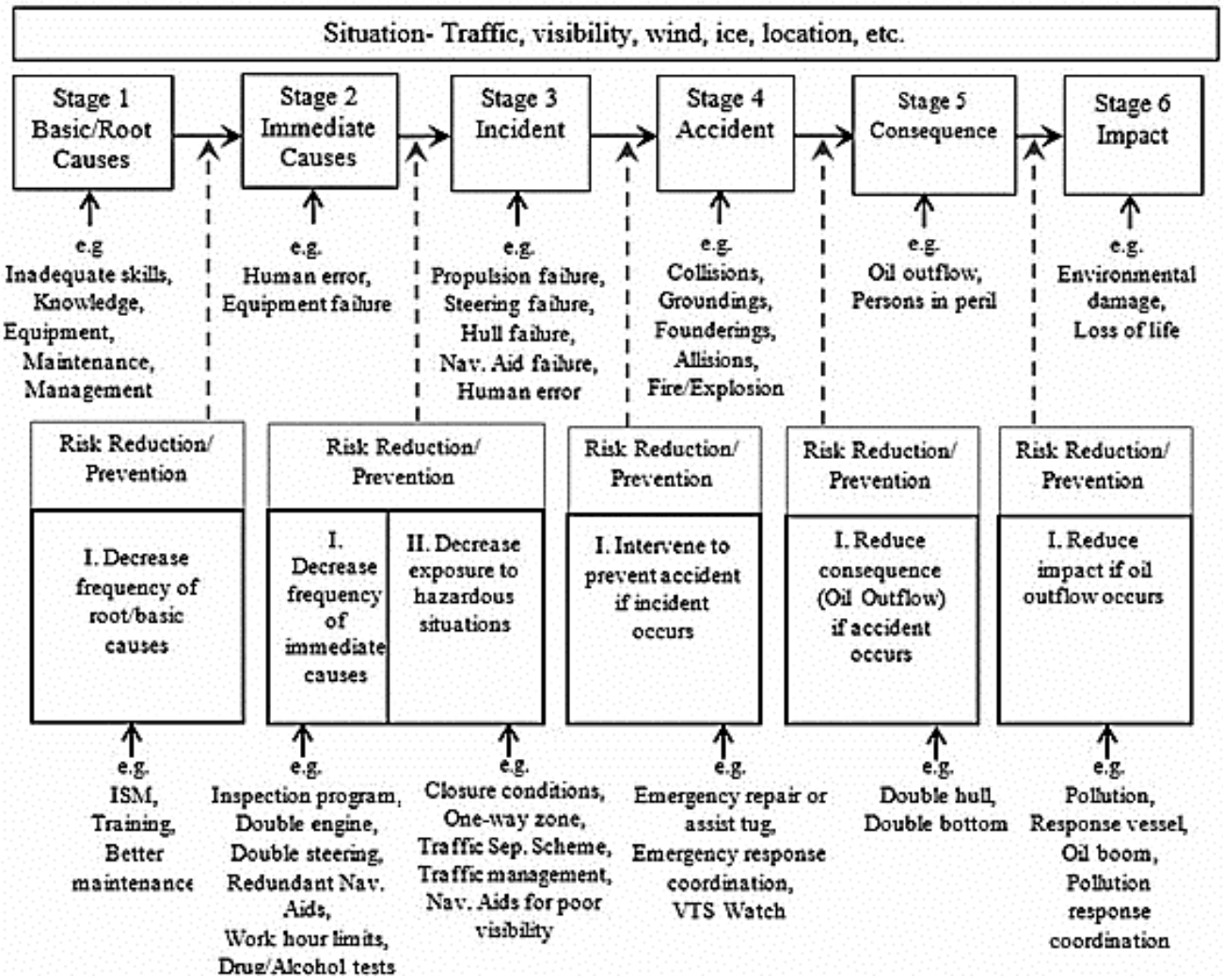

Figure 10: Framework for maritime risk assessment and risk reduction interventions[30]

6.1 Marine environmental risk identification

To establish the risk assessment system, meteorological and oceanic factors that pose potential threats to ship navigation, infrastructure, and personnel safety are extracted from the basis of risk identification[28]. Risk assessment helps in decision-making. The information generated through risk assessment help impacted parties understand the decisions' factors. The steps of the risk assessment are[8], [30]:

- Hazard identification
- Frequency assessment
- Consequence assessment and finally
- Risk evaluation

6.2 Disaster management cycle

Disaster management is described as a process composed of several stages. The following phases are shown in Figure 11[27].

Figure 11: Disaster management cycle(Law Proceedings, 2021)

Mitigation – The mitigation and readiness phases are heavily influenced by developmental factors of the disaster management cycle(Law Proceedings, 2021). A lack of emergency preparedness and Inappropriate development procedures can lead to increased disaster susceptibility. The goals of a development-oriented disaster management method are, reduce hazards, prevent disasters, and prepare for emergencies. The development of public policies and strategies that either modify disaster causes or minimize disaster consequences on people, property, and infrastructure are entailed in the mitigation phase and the entire disaster management cycle(Anselain & Thomas, 2021). Disaster management cycle is shown in Figure 12 (Law Proceedings, 2021).

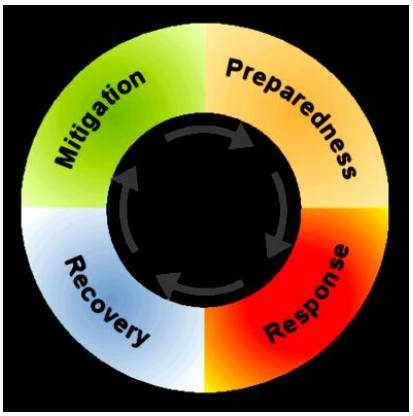

Fig.12. Disaster management cycle[27]

Preparation – It involves planning how to respond. Preparation is used as a warning system used to alert people. Also, it consists of the training given to establish a faster reaction to evacuate in such an event. Planning evacuation routes, identifying safe refuge sites, and the military response to a disaster are other involvements of preparedness[27].

Response – To provide immediate assistance to maintain life, support the morale of the affected population and improve health are the aim of emergency response. The response has two main objectives; they are consecutive and constitute two sub-phases[30].

i. By activating the ‘‘silent network’’ or ‘‘temporary networks,’’ respond immediately.
ii. Restores in the shortest time possible the essential services. The restore sub-phase is the delivery of goods to the highest possible number of beneficiaries.

The common objectives of responders are Saving and protecting human life, relieving suffering, Containing the emergency – limiting its escalation or spread and mitigating its impacts, Protecting the health and safety of responding personnel, Safeguarding the environment[27].

And also, protecting property as far as reasonably practicable, Maintaining or restoring critical activities, maintaining regular services at an appropriate level, Providing the public and businesses with warnings, advice, and information are the common objectives of responders. There are different types of responders. Some of them are Rescue, Relocation, Provision Food and Water, Provision Emergency Health Care, Prevention of Disease and Disability, Repairing Vital Services, e.g., Telecommunications, Transport and Provision Temporary Shelter[1].

Recovery – The complete restoration of all services and local infrastructure, permanent construction or replacement of severely damaged physical structures, and the revitalization of the economy (including agriculture) are known as recovery. This period includes the phases of rehabilitation and reconstruction, Rehabilitation and reconstruction are the phases of recovery. It aims to reestablish the population's living conditions affected by the disaster and promote the changes needed to risk reduction of future disasters.

Each stage has two supply chain principles: agility and leanness when transitioning between the steps[34]. When an unpredictable demand is combined with short lead times, the ability to respond to unexpected changes is usually defined as agility. When demand is relatively stable and predictable, doing more and better with more minor is leanness.

6.3 Maritime environment risk assessment - the role of the human factor

Marine environment risk assessment has yet to be discussed the role of the human factor. At this point, Human error play's a crucial role. The SLIM and Fuzzy sets are employed to present a risk-based approach[29], [32].

6.4 Ballast Water Treatment (BWT) system onboard ship

BWT system may reduce stress on the ship's hull, improve propulsion, and be an essential element of ships to stabilize vessels at sea. However, invasive species may cause severe ecological and health problems, recognized as one of the most significant problems for the maritime environment and ecology. Notably, most treatment systems generate disinfection by-products (DBPs) in varying amounts by using oxidative substances for ballast water treatment[32]. It has harmful effects on the marine ecosystem and human health. Because of that, Ballast Water Treatment is risky for crew life onboard ships and marine ecology.

6.5 Fuzzy sets

Zadeh (1965) introduced the fuzzy theory for extending the traditional notation of sets to solve uncertainty in decision-making. Fuzzy sets can solve imprecision in the judgments of experts in decision-making[32]. To transform the idea of decision-makers into helpful information, used linguistic values. Where can state experts' knowledge in natural language (such as high, medium, or low) can be applied this theory[1], [35].

6.6 Weighted BN-based risk assessment model

Between the marine environmental risk and factors have a nonlinear and fuzzy relationship. Therefore, expression, fusion, and reasoning of multisource uncertain environmental information can be defined as risk assessment. With the development of artificial intelligence, several machines and deep learning algorithms have been applied to deal with complex uncertainties and nonlinear modelling problems. BN is well suited for the risk assessment of marine environments along the Maritime Silk Road[35].

There is a new risk assessment model called the weighted BN-based model. Compared with traditional risk assessment models, it can be an intuitive expression, prior knowledge combination, multisource information fusion, and uncertainty processing. It is suitable for marine environmental risk assessment. Also, the experimental results show that it widens the modelling technology of risk assessment.

To build a network structure, select the nodes, and identify the probability distributions of network nodes are the two aspects of the modelling process. A research[35] identified three primary modelling methods as following.

[1] Subjective manual construction

The causal relationships among nodes are determined based on expert knowledge, and the probability distributions are subjectively assigned to the nodes in the network. This is a straightforward method but subjective.

[2] Objective automatic construction

This modelling method, the technical limitation of the statistical model, makes the network's rationality questionable. It ignores the knowledge fusion ability of the BN (Bayesian Network). Also, it avoids subjective experience.

[3] Combination construction

This modelling method is widely recognized as an effective way to optimize the BN. Node selection, data process, structural learning, weighted parameter learning, and probabilistic reasoning are included in this modelling. Technical route of the weighted BN diagram is shown in Figure 13[35].

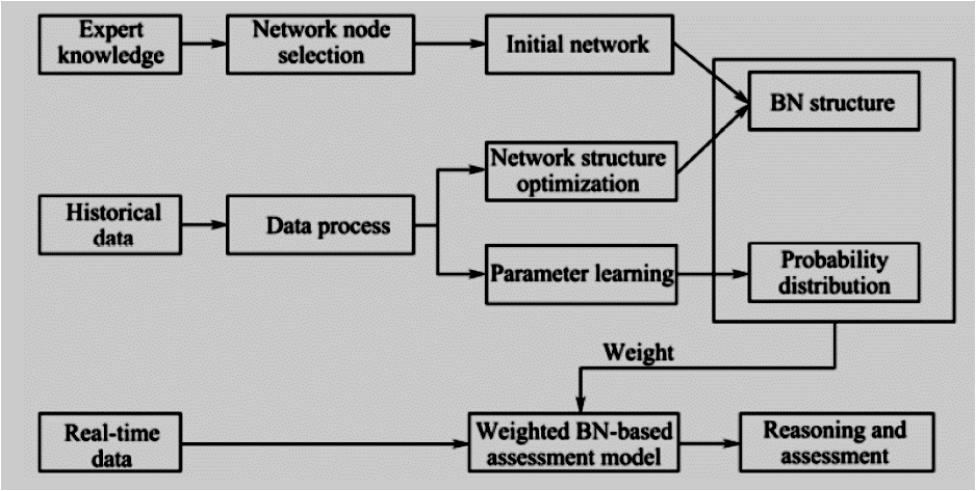

Figure 13: Technical route of the weighted BN[35]

7 ACTIONS TAKEN BY OTHER COUNTRIES

International Maritime Organization (IMO) is the international body available to develop and implement the regulations and recommendations to avoid marine disasters and cooperate with countries[16]. The leading international convention that safeguards the marine environment against ship pollution is the MARPOL 73/78 Convention. MARPOL is included in six separate Annexes for the technical requirements[33].

- Annex I – Prevention of Pollution by Oil (oil from operational measures as well as from accidental discharges).
- Annex II – Control of Pollution by Noxious Liquid Substances in Bulk
- Annex III – Prevention of Pollution by Harmful Substances Carried in Sea in Packaged Form
- Annex IV – Prevention of Pollution by Sewage from Ships (sewage discharge into the sea is prohibited).
- Annex V – Prevention of Pollution by Garbage from Ships (complete ban imposed on the disposal into the sea of all forms of plastics).
- Annex VI – Prevention of Air Pollution from Ships (Sets limits on Sulphur oxide and nitrogen oxide emissions from ship exhausts)

As shown in Figure 14, over 170 countries are with the MARPOL agreement[16].

Figure 14: Over 170 countries are with the MARPOL agreement, given with the green color[16]

8 RECOMMENDATIONS

- To avoid future incidents, create a risk analysis body to evaluate the previous incident with the possible root causes.
- To simulate the root causes of those accidents, it is vital to operate chemical safety and hazard investigation board and analyze the possible root causes to prevent similar kinds of future accidents.
- To avoid future accidents, shipping routes monitoring is essential for international authorities to be updated knowledge of cargo those ships are carrying, any leakages or damages, any sick or infected on board.
- For eliminating causes of accidents and incidents, Interest and active participation of all concerned are essential factors. For a successful and effective response, prompt reporting is the primary importance of accidents.
- Once any hazard is identified, the nearest coastal authority should immediately avoid and control that.
- To avoid severe accidents in the future, should report minor consequences, incidents and near misses. Responsible authorities have analyzed Near misses and should be informed to all countries in the shipping route to be aware and ready.
- To minimize the impact of oil spillage hazardous accidents, should develop oil-absorbing techniques. As an example, by using human hair, can be designed an oil-absorbing mat. It has zero cost, and it is a lipophilic material that can repel water but actively absorbs oil.
- To minimize exhaust emissions, many shipping companies use low Sulphur fuels. By increasing the potential ability of a fire (not biofuel), blended low Sulphur fuels will reduce the fuel's flashpoint. However, it will not be suitable for old ships to achieve the targets. Many cargo ships have been operating with exhaust gas capturing technology to avoid the low Sulphur fuel risk. Therefore, before entering the territorial waterways, authorities have to check their fuel type.
- Authorities should check the registered body of the cargo ship, goods on board, safety and health standards on board to avoid fire and accidents, owner of the vessel, insurance policy, and the insurance conditions. And also, should check the goods on board, quality of the ship manufactured year and the present state of the operating standards.
- Mitigating and eliminating risks from the incident.
- Oil Spill Surveillance and Recovery - Specific actions include: Should maintain boats and helicopters for daily surveillance to monitor oil discharge. To obtain a more accurate projection of its trajectory and fate (i.e. where and when the oil may wash ashore), should reinforce modelling of the oil spill trajectory. As soon as weather and sea conditions allow, should deploy two current buster systems to recover the oil slick and sheen. Should be inspected the vessel fuel tanks.

8.1 Methods of oil spill removal

The factors that affect an oil spill nature and duration are:

- Size and type of oil spill.
- Its behavior in the marine environment.
- Environmental conditions and physical characteristics.
- Location and time of the fall.
- The biological composition of the affected environment.
- The ecological significance of the constituent species and their susceptibility to oil pollution.

Oil removal techniques are categorized into four groups. They are chemical, mechanical, biological, and physicochemical methods.

a) Chemical methods

Due to the potential to alter the physicochemical properties of the oil, different types of chemical reagents are used to treat oil spills. These agents' activities are based on different effects. They are decreasing the spreading of an oil spill, eliminating the outflow, and enhancing removal efficiency by other cleaning processes like mechanical methods or adsorption. To treat oil spills, used most frequently used four chemical agents. Table 1 shows more detail about the chemical agents.

Table 1: Chemical agents

Dispersants	Solidifiers	Herders	Elasticity agents
Can use It on marine oil spillages where there are strong winds.	Considerable solidification can be achieved in rough seas.	Can drive the spilt oil slicks to the desired location or push oil slicks together.	Enhance the efficiency of oil removal by mechanical methods by improving visco-elastic properties of spilt oil.
Break down the oil slicks into fine droplets.	Change the physical state of a spilt substance from liquid to solid.	They are effective for thin oil slicks.	It is effective for very light oils (such as gasoline, diesel, kerosene etc.).
Promote the dilution of oil in water.	They are effective for thin slicks.	Reduces the stickiness of oil to objects.	Enhance the efficiency of oil spill removal by skimming.
They are effective for light oils.	Lower efficiency.		Can use it in a sensitive environment.
Not practical for heavy or weathered oil.	Solidified oil recovery is sometimes complicated because skimming equipment, pumps, and separators are constructed to handle liquids.		

b) Mechanical methods

It is also called the physical method. These methods are commonly used in aquatic environments and act as barriers. Without changing the chemical and biological properties of spilt oil, one can use these methods to prevent the spread of oil spills. Also, they will not cause secondary pollution to aquatic life and are appropriate for thick oil spills. Avoiding the diffusion of spilt oil can further control the spreading of an oil spill. The most commonly used Mechanical oil spill treatment methods are booms, barriers, skimmers, vacuuming. Table 2 shows more details about the mechanical oil spill treatment methods.

Table 2. Mechanical oil spill treatment methods

Booms	Skimmers
They are floating barriers designed to prevent spilt oil from spreading before using skimmers or separators.	They are used after booms limit the oil containing area.
Environmentally friendly method.	Water and oil's density difference and adhesive properties accelerate the skimming process.
Application is complex in extreme weather conditions.	Can reuse the recovered oil.
	Efficiency is highly dependent upon conditions at sea.

c) Biological methods

Bioremediation is known as the most common and most preferred biological method. When compared with other methods, it is a cost-effective and green method. But It requires quite an extended period. Bioaugmentation and bio stimulation are the two categories of bioremediation. Microorganisms (mostly Bacteria like; Pseudomonas, Alcanivorax sp. Fungi like; Aspergillus sp., Amorphoteca sp.) play a significant role in bioremediation.

d) Physicochemical methods

Many physicochemical methods have been used to remove pollutants from aqueous solutions in recent years. Sorption is the most advantageous method among the physicochemical techniques. Can consider this process as comprising both adsorption and absorption. Sorption is a cost-effective, accessible, promising, and simple method for removing pollutants. In most cases, can be recovered contaminants. Because of the ability to attract molecules on their surface and an excellent specific surface area, sorption is related to porous materials. There are mainly four types of Sorption. Table 3 shows more details about four types of Sorption.

Table 3: Four types of Sorption

Sorption by natural organics	Sorption by inorganic minerals	Sorption by synthetic sorbents	Sorption by biochar
Cost-effective.	Easy availability.	It consists of better oleophilic and hydrophobic properties.	It can be produced from biomass feedstocks.
Biodegradable.	Cost-effective.	Not readily biodegradable.	Will not cause secondary environmental pollution.
Easy to utilize.	Nonbiodegradable.		Cost-effective.
Sorption capacities of raw natural organics are low.	Sorption capacities are low compared to natural organics and synthetic sorbents.		Harmful contaminants in biomass may accumulate in biochar under some pyrolysis conditions.

8.1 Recommendations for an Unprecedented Nurdle Spill

i. Sightings of nurdles to safely inform clean-up efforts to educate and empower citizen scientists.
ii. To better gauge long-term threats from the wreck, create an account for the cargo initially onboard the vessel.
iii. After a spill, clean-ups for urgency continue. For that, minimize the removal of natural organic matter from the beaches and revise response efforts to account for any variability of spilt nurdles.
iv. To assess nurdle samples physical and chemical properties, fate, and transport in the ocean and toxicity to aquatic life, locally led research should be encouraged.
v. To avoid the plastic pollution stemming from the spill across multiple field sites and time points, prepare a robust baseline and compare it to recent pre-spill reports of microplastic corruption.

9 CONCLUSION

Maritime transportation is cost-effective because it transports bulk goods, petroleum products, food supplies, manufactured goods, containerized cargo, etc., over long distances. According to an IMO (International Maritime Organization) document, tankers, general cargo ships, bulk carriers, passenger ships, containerships, and fishing vessels are the classifications of maritime vessels. Design/construction and equipment of floating craft; cargo; offshore petroleum exploitation are the environmental hazards involving naval transport. There is a challenge to reduce the waste on the marine environment for citizens and governments:

- Industry including the maritime shipping industry (comprising building, registration, operation, and ship recycling).
- International organizations, committees, decision-makers, and regulatory bodies.
- Worldwide NGOs and researchers.

Hazard identification may involve working backwards to identify how this harm could occur and establishing those agents that may cause damage. This risk assessment can predict how long it would take to know the accident and evaluate the time available to set up countermeasures. This review highlighted the mainly significant impact on Sri Lanka's sensitive coastal environment, local communities and the economy by X-Press Pearl incident and Propose hazard identification and risk analysis system to minimize the effects of the marine environment. Some recommendations are highlighted to implement to prevent

similar events shortly.

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