Efforts and regulation developments of maritime environmental recovery based on ship accident and oil spill

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Abstract. Ship accidents are a matter that needs special attention. This paper aims to provide information about tanker accidents that cause oil spills at sea. The ship accidents in question are the Erika Ship and the Prestige Ship. The impact of this accident is an oil spill at sea that damages the ecosystem of both animals and plants. Overcoming the problem of oil spills at sea can be done in several ways, such as using chemical liquids, mechanical, in situ burning, and bioremediation. As a result of this incident, the European Union issued new regulations related to improving ship safety named Erika Package I, II, and III.

1. Introduction

Ships are a common means of transportation in the distribution of goods. One type of ship is a container ship. The advantage of this ship is the flexibility in its operation because it does not require loading and unloading cargo. Marine transportation is responsible for moving millions of dollars' worth of goods every day. Marine transportation includes commercial cargo-carrying vessels, such as trading vessels, and non-commercial cargo vessels, such as ferries and cruise ships. Ships are one of the modes of sea transportation used to transport goods. The goods transported are usually trade goods within the country or between countries. As a means of transportation, it is not immune from accidents. An incident, or sequence of incidents, resulting in any of the following that is directly connected to the operation of a marine vessel: material damage to a marine vessel; stranding, damage, or involvement in an accident; death or serious injury to a person [1–5].

The eight primary categories of marine catastrophes are as follows: foundered, fire (or explosion), contact, collision, war loss (or hostilities), oil leak, wrecked (i.e., stranded, grounding), foundered, ship hull (or equipment fail), and war loss (or hostilities) [6–10]. Preventing Accidents Assessing the likelihood of an incident is more crucial than handling one once it occurs. By avoiding the factors that can contribute to accidents, accidents can be avoided. It is possible to take preventive action while exercising the greatest caution and accountability. Avoid dangerous working circumstances, be prepared for emergencies, and notify your supervisor right once of any accidents, irregularities, or even minor equipment damage.

Ship accidents can occur with several causes such as weather factors, human error, and technical issues. It is undeniable that weather is one of the crucial factors in ship operations. Technology has developed rapidly, including navigation technology and weather forecasting. Weather-related accidents can occur when the ship's captain ignores reports of weather conditions along the ship's indicated route. Weather conditions that can cause accidents, such as rainstorms, hurricanes, high waves, or thick fog that can interfere with visibility.

Human error is also highlighted when a ship accident occurs. This factor accounts for the most significant cause of ship accidents. The negligence of the crew in the operation of the ship also needs to be considered. It is not uncommon for crew members to ignore the captain's directions to check certain parts, resulting in operational disruptions. Crews also need training on ship safety procedures so that in the event of an untoward event, they are prepared to handle it.

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Technical issues can also be a severe problem that can lead to ship accidents. Often, the maintenance process needs to be addressed due to several conditions. The condition that usually occurs is for operational cost savings. If the ship is never maintained, it will cause damage at a more significant cost than the maintenance cost.

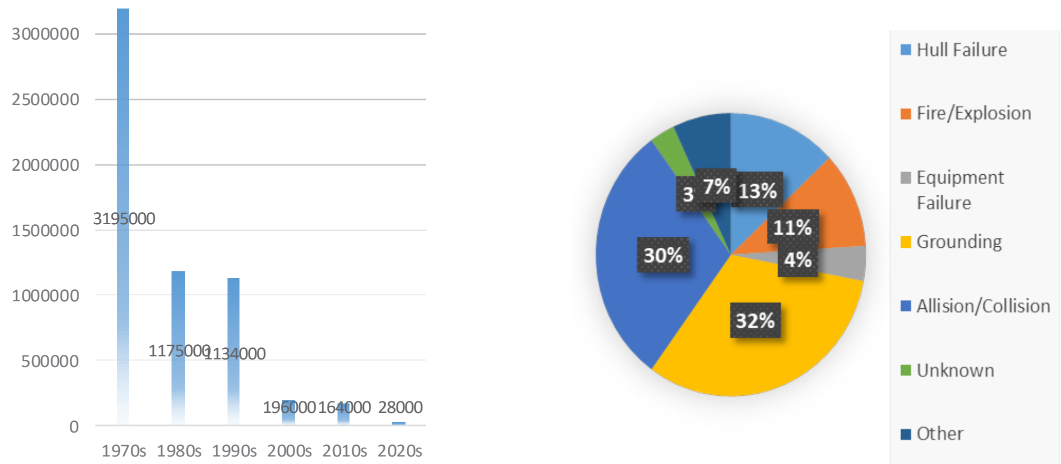

Fig. 1. Data on tanker ships between 1970 and 2023: (left image) annual quantity of split from tanker accident [11], and (right image) Classification of type accidents [12].

The spilling of different cargo is one effect of a ship accident. Oil, or ship fuel, is one of them. The annual amount of oil split from tanker accidents is displayed in Figure 1 and is taken from the ITOPF. According to insurers' figures, human error accounts for 80% of oil tanker accidents that result in pollution from oil spills at sea. Poorly executed manoeuvres, neglected maintenance, insufficient system checks, a lack of communication among crew members, exhaustion, or an insufficient reaction to a minor event that escalates into a large accident are examples of human errors [12].

2. Mechanic of collision and grounding

There is an increasing need to reduce collision and grounding rates. Collision and grounding have a significant impact on ship structures. Ship collision is an event when a ship collides with another object. These other objects include other ships, reefs, and harbours. Grounding is a condition when the bottom of the ship hits the seabed so that damage to the ship occurs. Collision and grounding require special attention because they can cause various material losses, casualties, and environmental damage due to pollution. The causes of this event vary, such as bad weather, human error, or technical errors on the ship [3].

The impact of collision and grounding on the ship itself varies. Minor accidents can include deformation of the hull or holes in the hull. When a collision occurs, the ship structure will absorb the kinetic energy of the collision. The kinetic energy is converted into internal energy. The process occurs briefly so the ship structure is deformed or possibly torn and ruptured. The deformation also depends on the design and material of the ship structure. When two ships clash on their sides, it is known as a side collision. These accidents can have various effects depending on the cargo being carried, the angle of impact, and the ship's speed. When a ship's bow collides with another object- a ship, a pier, or coral- it is called bow crushing. A ship's grounding occurs when its bottom touches an underwater object. The object typically strikes coral. When a ship collides, it will experience a large impact depending on several factors, such as speed and contact angle [13-16].

The ship has an extremely intricate structural design. Because of this, the flaws, harm, and manner in which structures are destroyed as a result of collision or grounding are also highly complicated. A ship can be thought of as an assembly of layered, welded structures, with stiffeners providing support for the horizontal bulkheads, deck, and bottom plating, which are composed of different plates [17]. Numerous tests were carried out to demonstrate the theory that, in the event of a collision, the ship's structure would absorb energy and cause the plate membrane and stiffeners to deform, the web frames to fold and crush, the horizontal decks to fold, cut, and crush, and the ship bottoms to cut [18-21]. When the ship is moving, there is kinetic energy. If the bottom of the ship hits a pointed rock, the kinetic energy will be spent by tearing the bottom of the ship. The friction between the ship and the rock, however, absorbs the kinetic energy if the boulder has a broader surface. In the meantime, the ship's hull may shatter in a moment if it grounds quickly. This suggests that the ship's induced sectional forces may surpass the ship's hull strength. The influence of collision and grounding studies can be separated into two categories: internal and external collision dynamics. The movement of the colliding ship and its interactions with its surroundings are connected to external collision dynamics. Internal collision dynamics, on the other hand, is concerned with the material damage that a collision causes to the ship's structure (see Figure 2).

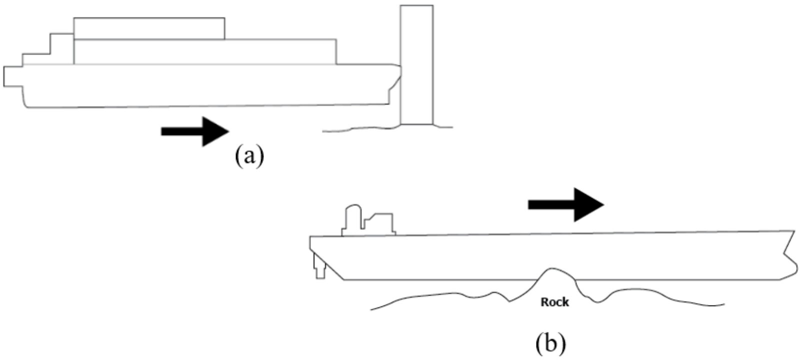

Fig. 2. Types of collision in ship accidents; bow crushing, side crushing, and grounding (ordered clockwise).

When the bow strikes the side of the ship, it can cause the side structure of the ship to deform and even be destroyed. Damage to the stricken ship can include deformation of the hull, failure of the ship's transverse structure, and destruction of the deck and bottom. The affected plate can experience bending, shearing, and tension deformation. If the penetration is too great, the plate can break, causing leakage of liquids such as ship fuel. Damage to the plate can occur due to several factors, such as material type, structural arrangement, indenter shape, collision speed, and plate thickness. Metal beams have three major failure criteria. The first failure modes are tensile tearing failure, transverse shear failure, and energy density failure. Tensile tearing failure mode can occur when the maximum tensile strain is equal to the critical rupture strain of the material. Next is the transverse shear failure mode, which can occur when the beam is subjected to large transverse shear deformation in a narrow section. The beam will break when the total transverse shear displacement equals its critical value. The last criterion is the energy density failure mode, where damage to the rigid-plastic structure occurs when the absorption of plastic work per unit volume reaches a critical value. When the bulbous bow strikes the ship's side, the hull plate will stretch, and the stringer web will fold and crush. The collision causes deformation whose magnitude depends on the material properties. Energy dissipation in the structure is done in two ways: by bending in the plastic hinge lines and by plane stretching of the plate fields.

When the ship experiences collision and grounding, the ship's structure will absorb kinetic energy and convert it into internal energy. Several studies have formulated an empirical approach formula for calculating the energy absorbed by the structure. This equation has a similar concept where the amount of energy absorbed is directly proportional to the damage to the ship structure. Minorsky [22] made an empirical approach to twenty-six ship accident cases summarized in Equation 1.

$$E = 4.73R_T + 32.7 \quad (1)$$

Furthermore, this equation was refined by Woisin [23], who began to introduce the low-energy collision equation by including the effect of height of broken members and component thickness in Equation 2.

$$E = 4.71R_T + 0.5\sum(h.t_s^2) \quad (2)$$

Zhang [24] then conducted an empirical approach on energy absorption based on the damage mode in Equations 3 and 4.

$$E = 3.50\left(\frac{t}{d}\right)^{0.67} \quad (3)$$

$$E = 3.21\left(\frac{t}{l}\right)^{0.6} \quad (4)$$

Prabowo et al. [25] have conducted research on the crashworthiness assessment of thin-walled double-bottom tankers using the empirical formula and also numerically. This study uses various scenarios that can occur when the ship is grounded, namely raking and stranding. The results can be seen in Figures 3 and 4.

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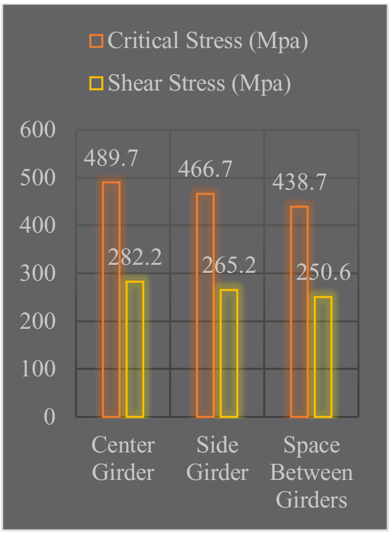

Fig. 3. Structural response and damage extent for the raking scenarios.

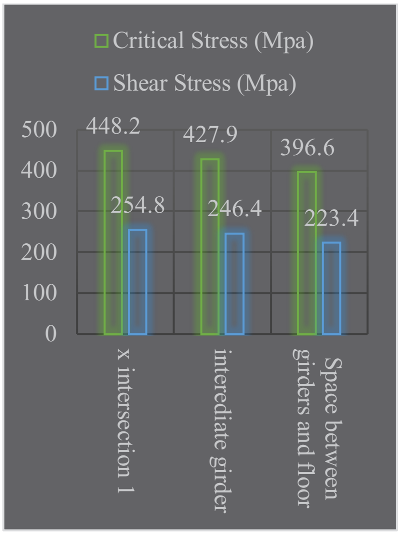

Fig. 4. Structural response and damage extent for the stranding scenarios.

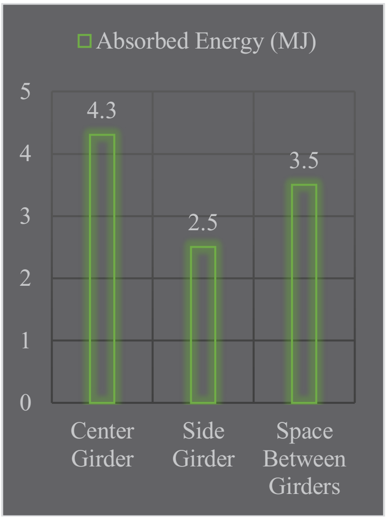

Fig. 5. Structural response and damage extent for the raking scenarios.

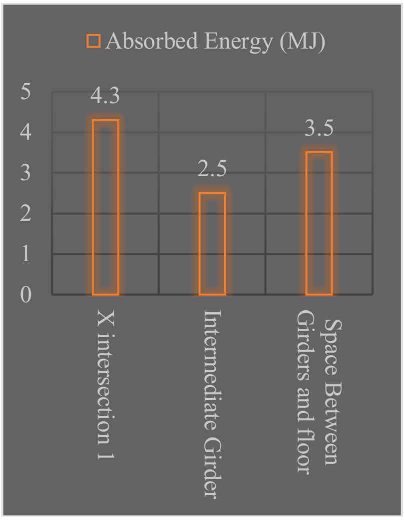

Fig. 6. Structural response and damage extent for the stranding scenarios.

3. Environmental damage after incidents

According to insurers' figures, human error accounts for 80% of oil tanker accidents that result in pollution from oil spills at sea. Human error can take many different forms, such as poorly executed manoeuvres, ignored maintenance, inadequate system checks, poor crew communication, exhaustion, or a poor reaction to a small event that grows into a large accident [12]. Marine transportation accidents have the side effect of pollution that impacts the environment and human health. There have been several major ship accidents throughout human civilization. Two of them are the MT Erika and MT Prestige ship incidents (see Figure 7).

The MT Erika incident occurred on December 12, 1999. MT Erika is a single-hull oil tanker that, at the time, was carrying 31,000 tons of heavy fuel oil. The cause of this accident was corrosion on the ship, which occurred due to poor ship maintenance. Poor ship maintenance results from the lack of transportation service tariffs, so some costs, including maintenance costs, need to be drastically reduced. In addition, structurally, the ship also underwent modifications so that it lost its balance. Modifications to the ship were made to the tank so that it suffered damage to tank 4. The oil spill caused by this accident had a serious environmental impact. Most of the ship's cargo spilled into the sea. Erika carried heavy fuel oil, which was composed of 60% vacuum distillation products, 30% heavy fuel oil, and 10% light fuel oil. Chemical dispersion could not be utilized to clean this oil since the viscosity at 10°C is equal to 20,000 cSt and the oil had to be heated during transport [11]. The clean-up process found waste oil amounting to between 190,000 and 200,000 tons. A tracing process was conducted to ascertain the extent of the oil spill found along

400 km of coastline. This impact continues to affect living creatures such as birds. Seventy-four thousand birds were exposed to oil and stranded along the Bay of Biscay. The process of environmental restoration takes a long time. The oil that stays in the sea for a long time becomes an emulsion that can increase its volume and viscosity, making it more difficult to clean.

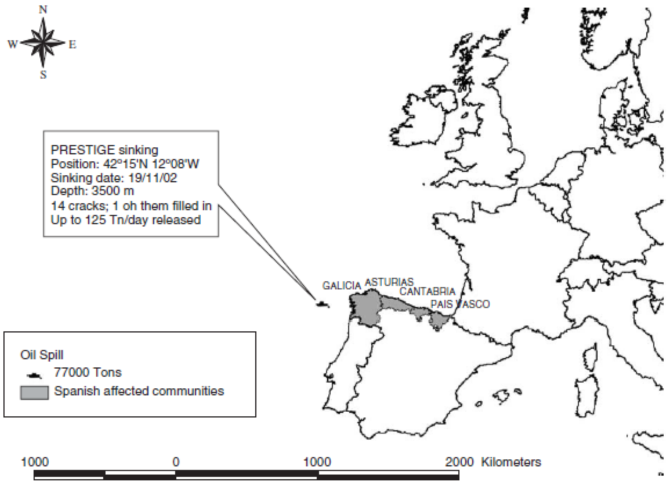

Fig. 7. Prestige ship oil spill accident site [26].

The next incident was the MT Prestige accident on November 13, 2002. The vessel carried 77,000 tons of oil from Ventspils, Latvia, to Gibraltar. The cause of this accident was the rupture of the hull due to wave action. The specific causes were structural fatigue, corrosion, and stress from patching new plates over old plates. The waves caused leaks in three tanks on the starboard wing and two on the starboard aft side of the ship. The leaks resulted in the ship losing balance, characterized by the ship tilting to the right. This incident resulted in pollution in the form of an oil spill along the coast of Spain and France. Over 80% of the oil cargo carried was spilled into the sea. The sunken wreck still releases about 125 tons of oil every day. An estimate is that 87,594 alcids were killed by the Prestige oil spill disaster off Galicia. Of these, 48% were Common Murres, 28% were Atlantic Puffins, and 23% were Razorbills [27]. The structure of the coastal food web may have been impacted by the oil spill, which would have led to the temporal variations in prey availability that are seen in the shag diet. From the mouth of the River Miño (Spain) to the English Channel (France), 3000 kilometers of shoreline were impacted by the slick. The shores of Spain, France, and Portugal were included in the slick cleanup efforts [28].

In addition to its obvious effects on birds and beaches, oil pollution also impacts marine life. Fish use some areas as spawning or nursery grounds, and coastal communities and wildlife populations are harvesting grounds. Even if it is only for a brief period, oiling marine and coastal habitats may substantially negatively influence fish stocks, migratory birds, and nearby communities that depend on fishing and tourism. Before the effects of oil and some of the chemicals used to clean up spills are fully felt, more than 20 years may pass. Oil sticks to the feathers of seabirds and is extremely toxic to fish and shellfish. When even trace amounts of oil are on the ocean's surface, bird mortality rates can become very high. If oil gets on a bird's feathers, it will not be able to control its body temperature and will freeze to death. Moreover, ingesting any quantity of oil through food or water can be lethal on its own or cause anemia, reduced fertility, and other health problems. The long lifespans and low reproduction rates of many seabird species mean that populations will take some time to recover from periods of significant adult mortality.

4. Technical efforts for ecosystem recovery

Many efforts are being made to improve the environment. Environmental damage caused by marine accidents needs special attention. Over time, there have been technological developments in dealing with oil leaks. Some detailed information about the type of oil leak is needed to consider which method to use. When there is an oil spill at sea, every moment is precious, especially at the beginning of a leak. To get accurate information about oil spill properties with Synthetic Aperture Radar (SAR) launched to satellites. The Erika's cargo was a mixture of 10% of light fuel oil, 30% of heavy fuel oil, and 60% of vacuum distillation products. After the accident, many questions arose as to how to deal with the oil spill and Several French Laboratories took oil samples from the incident and began to identify which methods were suitable.

The first clean-up was carried out on December 15, 1999, but was postponed due to bad weather. It was resumed four days later using several vessels. These vessels deployed 30-meter booms and attempted to clean up the oil using Transec 250 skimmers. The Transect 250 skimmer is a type of equipment used to clean up oil spills with the ability to contain the spill and pump oil to other vessels. In addition to using booms, the clean-up effort at this incident was with a pump. This pumping process is to move the oil in the sea to a holding tank that will be transported by other ships. The clean-up lasted for three months, and it was able to clean up 10,000 tons of oil.

Furthermore, in the Prestige ship accident, the clean-up process was also carried out on a large scale. This operation used ships from Spain and several other neighbouring countries. This process experienced several obstacles, mainly related to the weather. In addition, the vessels used did not have heating equipment, so they could not dispose of the oil that had been collected. Fishing boats also contributed to the clean-up process. This is because oil spills also impact the fishing ban process. Prestige ships carry heavy oil, so there are limited options for clean-up. The spilled oil can spread to the sea very quickly. The best measure that can be taken is shoreline protection. However, not only that, the part of the oil that belongs to light crude oil can be given a chemical dispersant so that the oil can be broken down.

There are several methods to deal with oil spills, namely [29]: (1) chemical treatment (dispersants, emulsion breakers); (2) in situ burning; (3) mechanical recovery (booms, skimmers, oil-water separators, adsorbents; and (4) bioremediation.

The dispersant method consists of two parts: a surfactant and a solvent. When the dispersant material is dissolved into the spilled oil, undispersed oil droplets will form due to reduced interfacial tension between the oil and water. This method is effective when used on viscous oil types. Dispersants are detergent-like products sprayed onto oil slicks to remove oil from the sea surface and disperse it into the water column at very low concentrations. This accelerates oil degradation by natural processes and eliminates or significantly reduces the impact on sensitive shorelines and habitats [30].

The use of various living organisms, such as bacteria, fungi, and plants, to clean up or reduce environmental pollution is known as bioremediation. These living organisms can decompose or combine different harmful chemical compounds found in different places, such as water, soil, or air. This makes it possible to create a healthier and safer environment for humans and other living things around. Bioremediation is known to be the safest and most appropriate remediation method because it can restore the environment to almost its natural state [31]. Bioremediation can be done in situ or ex situ. When there is no way out to evacuate the oil, it is done in situ by adding some genetically modified microorganisms. The ex-situ method is done to prevent the spread of pollution contamination. In situ, bioremediation is a good option for dealing with oil spills [32].

5. Development of environmental safety regulation

The European Union actively worked to improve maritime transportation safety laws following the tragic Erika accident, releasing the Erika I and II Packages in March and December 2000. The Helsinki Declaration on the Safety of Navigation and Emergency Capacity in the Baltic Sea Area was agreed upon and signed by the Baltic countries on September 10, 2001. In response to the tragedies of "Erika" and "Prestige," the European Union passed three legislation packages known as "Erika I," "Erika II," and "Erika III" in order to raise safety standards in marine transportation [33]. In the Erika I Package of March 21, 2000, the European Commission proposed immediate and future more complex action measures. The measures are as follows:

- By 2015, the latest, replace single-hull tankers with double-hull or similar designs.
- Tightening of ship inspections in European ports.

Additionally, the Erika II package of December 6, 2000, included the following measures: preparing financial compensation for victims of oil spills in European waters up to a maximum of €1,000 million through the IOPC Funds; strengthening the monitoring of maritime traffic in European waters by establishing a system that allows a Lisbon-based European Maritime Safety Agency to detect the location of ships in real time.

ARIKA In terms of the reasoning behind ship collisions, it is plausible to predict that many involved ships—not only tankers—would be better able to withstand collisions if they were double-hulled [34]. The catastrophe involving the Prestige ship served as the catalyst for updating maritime safety standards. These rules are found in the Third Maritime Safety Package (MSP3) and the Hazardous and Noxious Substances by Sea Convention, which was signed in 1996. Increased vessel utilization of European ports and member state compliance with international maritime norms on these vessels are the main goals of the March 2009 Erika III package.

- Seriously monitoring vessels that dock at European ports - Prohibiting ships from sailing if their specifications are substandard
- Ship owners must take out insurance in case of environmental damage.
- Introduction of a traffic monitoring system, especially for ships traveling long distances.
- Selection of shelters for ships in distress.

- Revision of the compensation mechanism for passenger losses in the event of a marine accident.

Following the Prestige shipwreck, the following updates were proposed by the commission:

- Prohibiting fuel transportation by single-hull vessels because sinking can cause the most damage.
- Refuse single-hull tankers from entering European ports after 2010 instead of 2015.

This legislation aims to strengthen the regulatory framework available to manage the repercussions of an accident should it occur again, with a focus on the affected parties, and to prevent another disaster in European seas [35]. Six directives and two regulations [36] have addressed seven subjects with these goals in mind.

6. Conclusions

This paper aims to explain ship accidents that cause oil spills. The case examples reviewed are the Erika and Prestige ship accidents. Both events resulted in oil spills that polluted the environment. The impact of the Erika ship accident caused severe environmental impacts. The spilled oil has polluted the ocean and disturbed the marine ecosystem. Various efforts have been made to overcome the oil spill. There are several ways to overcome pollution, such as chemical methods by dissolving chemicals, mechanical use nets, in situ burning, and bioremediation. The Erika and Prestige ship accidents led the European Union to issue new regulations. This new regulation aims to improve safety in the field of sea transportation. This regulation is named Erika I and II Packages and then followed by Erika III since the Prestige Ship incident. All of these regulations require ship owners to replace ship equipment to comply with new safety standards to prevent similar incidents from happening again.

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