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THE EVALUATION OF THE MARINE RISKS BASED ON THE FORMAL SAFETY ASSESSMENT

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ABSTRACT

The paper seeks to present how the methodology, known as formal safety assessment (FSA), manages to identify and verify potential marine hazards by using risk analysis while providing ways to control these hazards in a cost-effective way. This methodology supposes a prior analysis of available data on maritime accidents. Risk assessment is based on the identification of the major causes that would lead to the occurrence of the accident, the probability of their occurrence, and the consequences resulting from the occurrence of the event. Based on the consequences and the probability of the occurrence of the event, the level of risk is determined, depending on which the most effective control and risk reduction options are adopted. Risks are ranked based on ALARP acceptability criteria.

Keywords: FSA, risk assessment, risk control options, ALARP.

1. INTRODUCTION

Maritime transport has an important contribution to the development of the world economy, with the percentage of international trade by sea being approximately 80%. According to the United Nations Conference on Trade and Development [1], in 2020 the volume of maritime transport was 10.65 billion tons, registering a decrease of 3.8% compared to 2019. In order for the functioning of the maritime sector to be carried out in optimal parameters, it is necessary to take into account a number of factors that can lead to maritime accidents: extreme weather events, age of ships, human errors, navigational obstacles, complex technology, improper use of equipment, reduced visibility, etc. [2]. In order to prevent the occurrence of maritime accidents, considerable efforts have been made to improve the safety of navigation and the efficiency of traffic. In this sense, many international organizations and institutions, such as the International Maritime Organization (IMO), and the Intergovernmental Oceanographic Commission (IOC), have developed procedures, conventions, protocols, guidelines, regulations, rules, and international standards, regarding safety at sea, prevention, and control of marine pollution and navigation efficiency.

One of the objectives pursued by research in the maritime industry is the identification of the risks of maritime accidents and the assessment of the probability and consequences of their occurrence. In the literature, there are a number of methodologies for the assessment of maritime risks that take into account the prediction of the occurrence of accidents and their severity, the risk of failure or collision of the ship, and a number of other dangers that can result in the loss of human lives, as well as ecological disasters. In 1997, Kaplan defined risk as consisting of three elements: scenario, probability, and consequences [3]. However, in practice, when we discuss the stakeholders and the risk reduction measures, the understanding of the risk varies, and for this, the existence of some agreed and shared regulations is necessary. Therefore, in the maritime industry, an appropriate risk management methodology would allow the users of this industry to understand the concept of risk management and develop their management capacity so that to finally reach its integration into the functions of the maritime industry [4].

Starting from the risk of ship loss as a result of various causes, Bowen, (2020) showed that in the period 1750–1813, the annual rate of their loss was below 5%, and the main causes were destruction, collapse, and enemy actions [5]. This rate has been gradually reduced, reaching around 0.1% in recent years. This reduction in maritime accidents is mainly due to technical and technological changes in recent years [6]. Thus, Yang et al., (2019) emphasized that a major contribution to navigation safety was made by developments in the design of ships and satellite navigation systems, as well as the automatic identification system (AIS). Regarding these AIS systems, the authors are of the opinion that they offer today high-frequency models, real-time positioning of the ships, and in combination with databases, open the way to the era of digitization in the naval industry [7].

According to EMSA (2019), even if the rate of maritime accidents has decreased significantly in recent years, they still occur [8]. One of the causes of these accidents is accidental oil spills, which, although they have a low frequency, can be a real disaster for the marine environment ([9]; [10]; [11]).

One of the major concerns of the states of the world is marine pollution as a result of oil spills. That is why, both at the national level and at the regional level, appropriate measures are needed to facilitate obtaining a timely and coordinated response to limit the negative consequences of these accidental spills. Severe marine pollution accidentally produced by ships carrying petroleum products occurs as a result of oil spills of > 700 tons [12].

Due to the long-term impact of oil spills, which varies from oil tank damage to oil loss, and environmental pollution, today special attention is paid to examining the consequences of oil tank accidents ([13]; [14]). In order to reduce the frequency of these accidents, new methods of forecasting, identification, monitoring, and reduction of these risks are considered by developing quantitative methods for determining the probability and consequences of accidents [6].

Due to the pollution of the marine environment and major economic losses as a result of oil tanker accidents, the interested parties in the transportation of crude oil (ship and cargo owners and carriers) pay increased attention to the risk of oil transportation. They are interested in the identification and assessment of risk in the transportation of petroleum products, as well as the framework for the assessment of petroleum accidents [15]. A framework for risk analysis of maritime transport systems was proposed by Goerlandt and Montewka (2015) [14]. For the probabilistic quantification of the risk, the authors created a Bayesian Network (BN) model that was used as a proactive tool for evaluating the occurrence of spills in different areas.

The paper aims to present a five-step methodology, developed by the IMO, for increasing safety at sea and reducing the number of oil spills, using risk analysis.

2. RESEARCH METHODOLOGY

To assess safety in the maritime industry, so as to ensure that actions are taken before a disaster occurs, the IMO has developed a methodology to identify and verify potential marine hazards, known as Formal Safety Assessment (FSA), which provides ways to control these hazards in a cost-effective way [16]. The FSA carries out a balanced, structured, and systematic process oriented towards the assessment of risks in maritime transport activity, by evaluating the costs and benefits related to various risk reduction options with the aim of addressing disasters before they occur [17]. The method is carried out in five steps (identification of hazards, assessment of risk factors, adoption of risk control options, cost-benefit analysis to measure the profitability of risk control options, and recommending actions to decision-makers) and covers all aspects of a complete analysis of the security, while also suggesting appropriate security measures against potential threats [18]. By applying this methodology, the author seeks to find answers to several questions: What are the relevant dangers in the case of oil spills? What are the causes, effects, and severity of oil spills? What is the probability of the occurrence of a situation of interest? How can the situation be improved through various preventive risk control options? How can the costs and benefits associated with each preventive option be calculated? The FSA hazard analysis method is based on a series of available reports, issued by institutions such as the IMO, the European Union Commission, and the European Maritime Safety Agency, on existing event databases, on maritime accident statistics, being a proactive tool in what concerns the identification of risks and the development of scenarios ([19]; [20]). The results obtained by applying this method depend on the availability of data and the expertise of the analysts in making rational judgments.

Step 1 Hazard identification

The identification of dangers involves the identification of situations that would lead to severe environmental pollution. A hazard is considered to be a situation that causes damage to the environment, people, property, or businesses, regardless of the probability of the occurrence of such an event. The purpose of identifying these hazards is to create a complete list of the most relevant accidents, followed by their description and the establishment of the areas where these accidents occur. In the case of environmental pollution due to massive oil spills from ships, the risk analysis focuses on those hazards that can generate the loss of tank integrity. As a result of an accident resulting in the loss of the ship's integrity, the following situations may occur: the ship capsizes due to loss of stability, the ship breaks due to structural damage, or the ship remains afloat after suffering some damage.

Other dangers identified in the databases are ship collisions with various obstacles, shipwrecks, and explosions [17].

For an effective assessment of the hazards that could cause environmental pollution, they must be ranked. This first stage is necessary to understand if the identified hazards are major or minor.

According to ITOPF (International Tanker Owners Pollution Federation) statistics, in the period (2010-2021), 19 accidents with massive oil spills of over 700 tons have occurred, as a result of oil tanker accidents, which means a massive reduction of over 90% compared to 1970 when the number of these accidents has been 245 (Table 1) [11].

Table 1 Number of oil spills/year [11]

Year	7-700 Tonnes	>700 Tonnes
1970s	543	245
Average	54.3	24.5
2010	5	4
2011	4	1
2012	7	0
2013	5	3
2014	4	1
2015	6	2
2016	4	1
2017	4	2
2018	4	3
2019	2	1
2020	4	0
2021	5	1
Total	54	19
Average	4.5	1.6

In the analysis of maritime accidents, it is important to determine the causes of their production and the relationships between these causes. There is a multitude of causes of accidents at sea (severe weather conditions, gas emissions from tanks, water depth, visibility, high traffic density, navigational obstacles, human error, ship damage), which can lead, separately or in combination, to major oil spills ([15]; [20]). According to statistical data, most accidents are due to severe hydrometeorological conditions and human errors [18]. The causes of oil spill greater than 7 tonnes, according to ITOPF (2021), were grouped as follows [11]: grounding, collision, equipment failure, fire/explosion, hull failure, and other, unknown (Fig. 1).

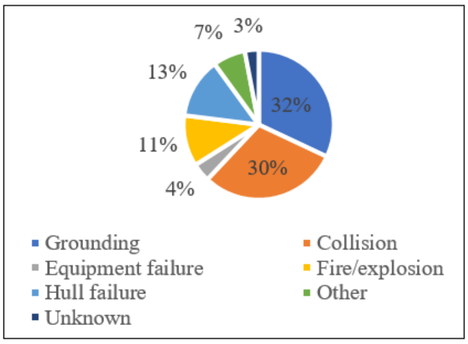

Fig. 1 Causes of tanker spills in the period 1970-2021 (processed from [11])

The identification of hazards based on the historical records of spills existing in the databases, which contain the types of accidents and their consequences, does not allow to obtain information on the causes of their production. The most used techniques for identifying marine hazards are numerical methods (Fault Tree Analysis-FTA and Event Tree Analysis-ETA) and what-if techniques (SWIFT) [21].

The purpose of risk assessment is to establish the level of risk acceptability according to risk standards and criteria, after which the need to implement risk reduction measures is suggested. It involves evaluating the probability of the occurrence of the event, its consequences, and its severity and can be qualitative or quantitative. If R is the level of risk, P is the probability and Q is the consequence, then the level of risk is determined by the relationship:

$$R = P \times Q \quad (1)$$

According to ITOPF statistics, the frequency of marine disasters decreased in the mid-80s, and after 2012 they became very rare [11] (Fig. 2). The reduction of oil spills is due, on the one hand, to the efforts of the shipping industry and, on the other hand, to governments (through the IMO).

The risks of oil spills can be intolerable (involve serious consequences, which can lead to a catastrophic state, loss of human life, or major financial losses), tolerable (can be tolerated/accepted to ensure benefits), and acceptable (insignificant). Intolerable risks are eliminated or reduced until they become tolerable or acceptable, while tolerable risks must be periodically reviewed to ensure their maintenance at this level [22].

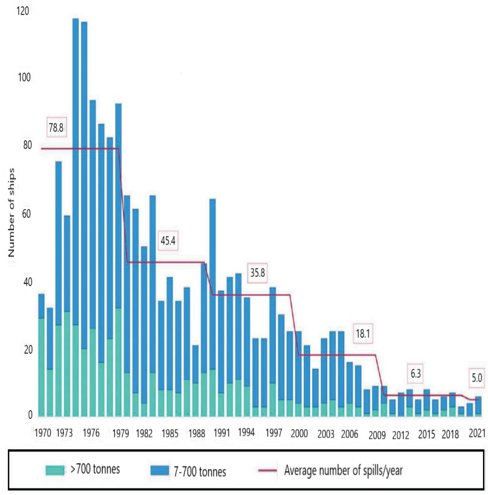

Fig. 2 Number of tanker spills from 1970-2021 (from [11])

The probability of occurrence of dangerous events can be approached qualitatively/quantitatively and can be frequent (the accident is likely to occur several times per year), reasonably probable to frequent (the accident is likely to occur once per year), reasonably probable (the accident is likely to occur once per 5 years), reasonably probable to remote (the accident is likely to occur once per 10 years), remote (the accident is likely to occur once per 15 years), remote to extremely remote (the accident is likely to occur once per 20 years) and extremely remote to extremely improbable (the accident is likely to occur once in a lifetime) ([17]; [18]). A qualitative approach requires the experience and judgment of experts, while a quantitative approach is based on historical reports, national and international databases, and accident statistics.

Consequences of marine oil spill accidents are loss of life/serious injury, loss of property, and environmental damage. The criterion used to evaluate the consequences on the environment is considered to be the socio-economic vulnerability of the environment through its exposure to oil. These consequences can be global (the accident produces multiple fatalities and oil spill size > 10,000 tonnes), catastrophic (the accident produces multiple fatalities and oil spill size between 1,000-10,000 tonnes), severe (the accident causes a single fatality of multiple severity injuries and oil spill size between 100-1,000 tonnes), significant (the accident causes multiple/severe injuries and oil spill size between 10-100 tonnes) minor (the accident causes single injuries and oil spill size between 1-10 tonnes) and slight (the accident causes minor injuries and oil spill size < 1 tonne) [17]. In evaluating these consequences on the ecosystems, it is necessary to take into account the multitude of organisms that compose them and the different sensitivities to the oil. Among the factors that determine the nature and duration of damage (the type and quantity of oil, weather conditions, and characteristics of the affected area), the most important is the type of oil. Due to the high viscosity of crude oil and fuel oil, they are very persistent in the marine environment, leading to widespread contamination of coastal resources [12].

The types of accidents identified based on the analysis of historical data and the performed scenarios allow the statistical determination of the probability of the occurrence of the event and its consequences. By evaluating the levels of the two elements, the level of risk can be established (equation 1). The obtained risks are compared to obtain a ranking of them based on the ALARP acceptability criteria. Decision-making for new safety measures/improvement of existing ones is based on the order of prioritization of risks. Due to the multiple consequences and factors that influence the severity of these oil spills, assessing the total risk using a single criterion is difficult. Therefore, if the loss of human life exceeded 10^{-3}/person per year, the risk is considered unacceptable, a situation also valid for the case where other risk components are high, even if the level of marine risk is lower. According to Det Norske Veritas (2001), the risk cannot be described as "acceptable" even if the loss of life is 10^{-6} or less because this only applies to the total risk [16]. In situations where other consequences of risks are unknown, their weight is calculated for the risk assessment, which leads to the application of the acceptability criteria for the combined risk. As an alternative solution, the risk to life, property risk, and environmental pollution risk can be calculated separately, which are then verified on the basis of separate acceptability criteria. Defining the level of acceptability of marine risks depends on the experience and judgment of experts. For a good understanding of how to evaluate marine risks, a risk matrix is used (Table 2). Table 2 presents: Green color - Acceptable only with ALARP actions considered; Yellow color - Acceptable by using the ALARP principle and considering further investigations; Red color - Not acceptable-risk reducing measures required.

Table 2. Risk Matrix

Likelihood / Consequence	Extremely improbable	Extremely remote	Remote	Reasonable probable	Frequent
Catastrophic					
Severe					
Significant					
Minor					

Source: original

Within the risk matrix, depending on the risks generated, the probability of occurrence, and the consequences, the risks can be classified into: "unacceptable", "tolerable" and "acceptable in broad terms".
Unacceptable risks, if any, are reduced to a level where they become tolerable or acceptable or must be eliminated. Risk reduction is done by applying measures where the benefit obtained from risk reduction compensates the cost associated with risk reduction, and is considered to be reduced at least below that level at which it is "As Low As Reasonably Practicable", i.e. it is ALARP (Fig. 3).

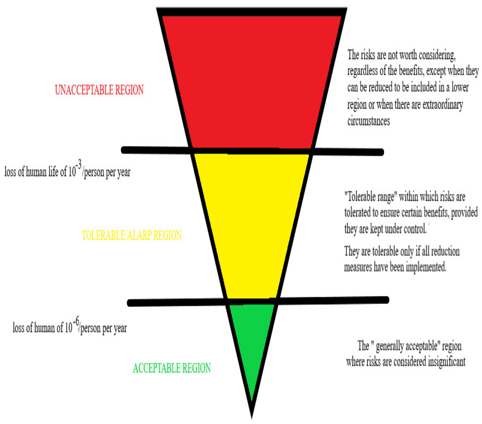

Fig. 3 ALARP acceptability criteria (processed from [23])

This means that the risk must be taken to the area of negligible risks so that reducing it further is "not worth the cost". Therefore, the risk reduction measures that are implemented are applied until no further risk reduction is possible without a significant expenditure that is disproportionate compared to the value of the risk reduction that has been achieved.
The risk assessment is uncertain, due to the sources used:
- an uncertain future regarding the adaptation of routes to sensitive areas, the structure of the ship, and the training of the crew;
- human errors that can lead to a wrong interpretation of information;
- missing historical data.

Step 3 Risk reduction/control options
The purpose of this stage is to establish which areas require control, identify risk control measures and evaluate their effectiveness through cost-benefit analysis and the grouping of risk control options that become practical regulatory options [24]. In this stage, the potential threats are analyzed and options are offered to control the identified risks, to prevent and reduce them, with the aim of improving safety in the transportation of petroleum products. After establishing the level of risk and the main causes of high-risk events, the proposed risk control options help analysts understand how the risks can be eliminated or reduced. In this way, well-founded decisions are made, contributing to reducing the probability (preventive options), but also the consequences (mitigation and control options) of oil spills in the future. It is necessary to identify the most appropriate and effective options so that the risks are reduced to a level where they become "reasonably practicable".

Step 4 Cost-benefit analysis
The purpose of the cost-benefit analysis is to compare the benefits and costs associated with the previously identified options. The evaluation of each risk reduction option is important to be made from the perspective of the benefits that can be obtained and the costs of their implementation, but also from the perspective of their contribution to risk reduction. Through this method, the monetary equivalent of each benefit associated with a risk control option can be determined, as well as comparisons of benefits over time. The use of the annual discount rate allows the reduction of large differences in future periods to

almost negligible differences in the current period. This allows the analyst to calculate the interest loss (gain) over time to determine the net present value (NPV) of each benefit. Risk reduction options have varying degrees of effectiveness, meaning that the cost of an option (costs of operation, training, inspection, and certification) can be very disproportionate compared to the benefits (number of deaths, number of victims, injuries, environmental damage) that would be obtained. After analyzing all the options, it is decided on the options that must be selected and implemented. When a control option achieves a cost-benefit ratio of less than 1, the option may constitute a viable strategy.

Step 5 Making decisions

The results obtained from the analysis of risk prevention and reduction options are used as a basis for recommendations made to decision-making and regulatory bodies, with the aim of bringing the risk to the lowest possible level. This first involves comparing and ranking risk control options based on costs and related benefits, but also establishing those risk control options that keep risks as low as possible. Also, in order for safety at sea to increase and the main causes of identified risks to be eliminated and accidents to be minimized, the recommendations for decision-making bodies must take into account the areas where legislation/regulations should be revised or developed.

3. CONCLUSIONS

Risk assessment in the case of accidents resulting in massive oil spills is a priority issue for environmental protection. The main causes that generate massive oil spills are severe weather conditions, gas emissions from tanks, water depth, visibility, high traffic density, navigational obstacles, human error, and ship damage. The frequency of marine accidents has decreased significantly in 2021, by more than 90 percent compared to the 1970s, from an average number of spills per year of approximately 79 in 1970 to an average number of spills per year of 5 in 2021. Using the matrix of risk, depending on the risks generated, the probability of occurrence, and the consequences, the risks are classified into: "unacceptable", "tolerable" and "generally acceptable" according to the ALARP principle. The cost-benefit analysis allows the comparison of risk control options, in order to select the best risk prevention and reduction options, which are recommended to decision-making and regulatory bodies in the field.

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