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Research Article

Risk Assessment and Evaluation of Environmental Impacts in Hazardous Material Transportation: The Case of Kanal Istanbul

Vildan Bölükbaşı*[1], Can E. Balas[2] and Beril S. Akın[3]

[1] Gazi University, Graduate School of Natural And Applied Sciences, Ankara, Türkiye (*ORCID Number: 0000-0003-0691-2097)*

[2] Gazi University, Sea and Aquatic Sciences Application and Research Center, Ankara, Türkiye (*ORCID Number: 0000-0002-5994-0561)*

[3] Gazi University, Graduate School of Natural And Applied Sciences, Ankara, Türkiye (*ORCID Number: 0000-0003-0706-8764)*

Abstract

The Bosphorus is a geopolitically important water channel for Turkey and the world's maritime transportation. It is crucial for Turkey and all countries using the Turkish Straits to reduce pressure on the Bosphorus, minimize problems that might arise after a potential marine accident, and ensure the safety of navigation, life and the environment of the Bosphorus. The Canal Istanbul project is planned to be realized as an alternative sea route to the Bosphorus to reduce the ship traffic of the Bosphorus and reduce the risk of possible maritime accidents. It is of the utmost importance to take the necessary measures for environmental protection and navigation safety within scope of the Project to reduce the risk of possible marine accidents in the new channel that will be developed. This study has made risk assessments for preventing pollution that may arise from possible marine accidents for Canal by considering the factors, accident types, and spill amounts of marine accidents involving ships on international ships in the projected Canal Istanbul. In the studies, risk assessment was made by Monte Carlo Simulation, and the amount of spill that may occur in a marine accident was determined according to the type of accident. In addition, risk assessments were made for Canal Istanbul according to each type of accident using the ASSHTO method. As a result of the evaluations, the risky areas of the canal were determined, and it was seen that the amount of oil spillage might be high in fire and sinking accident types.

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Tehlikeli Madde Taşımacılığında Risk Değerlendirmesi ve Çevresel Etkilerin Değerlendirilmesi: Kanal İstanbul Örneği

Özet

İstanbul Boğazı jeopolitik açıdan hem Türkiye hem de Dünya deniz taşımacılığı için önemli bir su kanalıdır. Boğazlardaki güçlü akıntılar, keskin dönüşler ve değişken hava koşulları deniz ulaşımını son derece zorlaştırmaktadır. İstanbul Boğazı üzerindeki baskının azaltılması, muhtemel bir deniz kazası sonrasında yaşanabilecek olayların önlenmesi ve dolayısıyla İstanbul Boğazının seyir, can, mal ve çevre güvenliğinin sağlanması Türkiye'nin olduğu kadar Türk Boğazlarını kullanan tüm ülkeler için önemlidir. İstanbul Boğazı'nın gemi trafiğini azaltmak ve buna bağlı olarak meydana gelmesi olası deniz kazalarının riskini azaltmak için İstanbul Boğazı'na alternatif deniz yolu olarak Kanal İstanbul projesinin gerçekleştirilmesi planlanmaktadır. Söz konusu proje kapsamında, oluşturulacak yeni kanalda olası deniz kazalarının riskini en aza indirmek, çevre ve seyir güvenliği için gerekli önlemleri almak büyük önem taşımaktadır. Bu çalışma ile, projelendirilen Kanal İstanbul özelinde uluslararası sefer yapan gemilerin karıştığı deniz kazalarının faktörleri, kaza tipleri ve döküntü miktarları göz önüne alınarak Kanal İstanbul için olası deniz kazalarından kaynaklanabilecek kirliliğin önlenmesine ve korunmasına yönelik esasların belirlenmesinde kullanılabilecek risk değerlendirmeleri yapılmaya çalışılmıştır. Çalışmalarda Monte Carlo Benzeşimi ile risk değerlendirilmesi yapılarak kaza tipine göre deniz kazasında meydana gelebilecek döküntü miktarları belirlenmiştir. Yine, bu veriler ışığında Kanal İstanbul için ASSHTO metodu kullanılarak her bir kaza tipine göre risk değerlendirilmeleri yapılmıştır. Yapılan değerlendirmeler sonucunda kanalın riskli alanları belirlenerek yangın ve karaya oturma kaza tipinde petrol döküntü miktarlarının yüksek olabileceği görülmüştür.

Anahtar Kelimeler
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[1] Corresponding Author Email: vildanbolukbasi@hotmail.com

1. INTRODUCTION

Maritime transportation is one of world trade's most important and largest transportation sectors. It accounts for a significant portion of the maritime transportation of oil and dangerous cargoes worldwide and is of great economic value. More than 80% of the volume of international trade in goods is carried out by sea, which is even higher in most developing countries [1]. However, maritime transportation of oil and dangerous cargoes also carries significant risks. In the event of an accident, oil tankers or dangerous cargo vessels can cause environmental pollution and lead to ecological severe impacts [2]. Therefore, the maritime transportation sector has to adopt strict safety measures and procedures for the transportation of oil and dangerous cargoes. Accidents at sea can result in major environmental disasters, loss of life, and heavy economic losses. For example, suppose a tanker carrying 30000 tons of liquefied petroleum gas (LPG) is involved in an accident and explodes. In that case, it will generate 11 times more energy than the atomic bombs dropped on Hiroshima and Nagasaki. This means the extinction of all living things in an area of 400 km^2 [3]. Also, it is estimated that approximately 200,000 tons of oil spills have occurred in the Straits in ship accidents to date. Emergency response techniques and practices to mitigate the environmental impacts of marine accidents are also costly methods. The International Petroleum Industry Environmental Protection Association (IPIECA) states that the cost of cleaning a barrel of oil spilled into the sea varies between 700 and 3000 dollars [4].

The International Maritime Organization (IMO) continues its efforts to prevent possible accidents and losses before they occur by using various risk assessment methods instead of taking measures by taking lessons from disasters. However, because it is impossible to correct the damage caused by disasters to the ecosystem completely, and the damage costs are much higher than the costs of prevention activities, the importance of risk assessment studies has increased [5]. Nowadays, risk assessments are performed using fault tree analyses [6], multi-objective network flow models that allow routing strategies [7], and mathematical models [8] to determine oil tankers' grounding probability. Such analyses enable the determination of risk cost estimates in the transportation of petroleum products by sea, especially in taking necessary precautions [9]. Similarly, in the transportation of crude oil and petroleum products by sea, it is possible to conduct risk analyses according to the characteristics of the vessel transiting in the maritime zone to reduce the risk [10]. A risk analysis has been carried out by using the open FTA (Fault Tree Analysis) program for the collision, collision, grounding, and fire-explosion accidents occurring on oil tankers with the marine accident data registered in the GISIS (Global Integrated Shipping Information System) system organized by IMO between 1998-2010. According to the accident data, the high-risk accident types for oil tankers are collision, collision, grounding, and fire-explosion marine accidents. It is determined that the most significant factor in the occurrence of marine accidents is human error [11]. When the accidents in the UK are analyzed, it is stated that the decisions made during the design and operation of maritime activities are essential for risk assessment [12]. In order to examine collision and grounding accidents in maritime accidents in the Human Factors Analysis and Classification System (HFACS), the study was conducted with Chi-Square Independence Test, Simple Conformity, and Multi-conformity Analyses based on annual, monthly, watch hours, accident region, ship type, gross tonnage (GT), bridge crew according to the titles of the Rules of the Regulations for Preventing Collision at Sea (COLREG) revealed that there were decision errors and resource management deficiencies. [13].

The risk assessment of the marine accidents that occurred in the Bosphorus between 2004 and 2008 revealed that the most common type of vessel involved in accidents was general cargo/dry cargo (54.8%), and 69 (60%) of the ships involved in accidents were under

5000 GRT. This study has determined that small vessels are more likely to be involved in accidents [14]. When the accidents involving ships on international voyages in our coastal areas are examined, it is stated that there is a need to determine the factors that cause accidents and establish an infrastructure to minimize marine accidents by evaluating the relationships between these factors [15]. Most of the accidents in the Bosphorus have been caused by oil spills caused by tankers. Tanker accidents in the Bosphorus have caused severe pollution problems in the ecological sense as well as a serious problems in economic losses. Between 2000 and 2019, 520 marine accidents occurred in the Bosphorus [16]. It states that decisions made during the design and operation of maritime activities are essential for risk assessment. [17]. While accidents are expected to increase in large ship transits, the use of pilotage in Bosphorus transits reduces the probability of accidents. According to this result, regardless of the size of the ships, the necessity of pilotage service through the Bosphorus is emphasized more. [18]. In 2020, if we analyze the materials passing through the Bosphorus, it was determined that 13% of the ships carried dangerous goods, and half of them carried petroleum products. Again, when we look at the distribution of hazardous products depending on the IMDG code of the ships passing through the Bosphorus, 63.5% consists of flammable liquids, 10.6% toxic gases, and 9.4% corrosive substances [19].

In order to define the probability and risk of marine accidents in Turkey, a risk assessment model (MaRisk) was developed by the Monte Carlo method using the accident archives of the Undersecretariat of the Maritime Affairs Search and Rescue Department. As a result, it was found that the potential amount of spillage in accidents other than common and collision-type accidents in Turkey is between 50 tons and 100 tons per year [20]. It is stated that the increase in the number of ships carrying dangerous cargo and the amount of hazardous cargo carried through the Bosphorus is a severe threat to the safety of navigation, life, property, and the environment in the Bosphorus and it is pointed out that the traffic has exceeded the safe passage limit. Therefore, it is assessed that accidents in the Bosphorus may have severe consequences for the entire region, primarily for the city of Istanbul, and that the closure of the Straits to traffic in such an accident would adversely affect all countries benefiting from the Bosphorus, especially the Black Sea countries. [21-22-23-24].

Canal Istanbul Project has been designed with infrastructure and superstructures such as emergency berths, emergency response centers for the operation of the canal, canal entrance, exit structures, and ship traffic systems to reduce the Bosphorus's traffic and reduce the risk arising from possible ship accidents [19]. Therefore, the risk assessment of this project, which is in the planning stage, is important in determining the measures to be taken for potential accidents and emergency response methods.

With this study, risk assessments that can be used in determining the principles for the prevention and protection of pollution that may arise from possible marine accidents for Canal Istanbul have been tried to be made by taking into account the factors, accident types, and spill amounts of marine accidents involving ships on international voyages in the projected Canal Istanbul. The results obtained as a result of the study will form an important basis for the preparation of an emergency response plan for Canal Istanbul, which is in the planning stage, according to the amount and impact of oil spillage in case of a possible accident.

İstanbul Strait and Canal İstanbul Project

The Bosphorus is an important waterway connecting the continents of Asia and Europe and is also one of the world's most heavily trafficked areas [25]. The Bosphorus is the main trade route linking the Black Sea countries to the world markets and is also crucial for military security. The Bosphorus passes through the center of Istanbul, declared "the world's cultural heritage" by UNESCO, and through the city's most historic sites. In addition, the Bosphorus is recognized as one of the most crucial maritime transportation routes and one of the narrowest straits in the World [26]. The Bosphorus is also a critical energy corridor for the distribution of Caspian oil to the world market. Approximately 150 vessels pass through the Bosphorus every day. These vessels include container ships, oil tankers, dry cargo ships, passenger ships, and other commercial vessels. In addition, smaller vessels such as yachts and fishing boats also navigate the strait. While the number of ships/tankers passing through the Bosphorus was around 3,000 per year in the 1930s, when the Montreux Treaty was signed, which determined the system of passage through the straits, this number increased approximately six times to 24,000 30 years later. Further, it increased in the following years to 50,000 [16].

The amount of cargo and dangerous cargo transported through the Straits worldwide increases yearly. As a result, even if the number of ships remains at the same level, there has been a significant increase in the cargo carried and ship lengths. Similarly, according to the number of ships passing through the Bosphorus between 2006-2020 by ship type, the most common ship types are determined as general cargo ships, bulk cargo ships, and tankers, respectively [1]. Also, when the number of ships and tankers passing through the Bosphorus between 2006-2018 is analyzed, it is determined that the number of chemical tankers has increased in proportion to the decreasing number of ship passages. The Bosphorus has an annual safe passage capacity of 25,000 ships and has been hosting a traffic load 72% above its ability, with an average of 43,000 ship passages in recent years. According to the data of the last five years, ships wait for an average of 14.2 hours for each passage in the Bosphorus, and this period is expected to increase to 4-5 days in the coming years [37]. The number of ships and tankers passing through the İstanbul Strait is given in Figure 1.

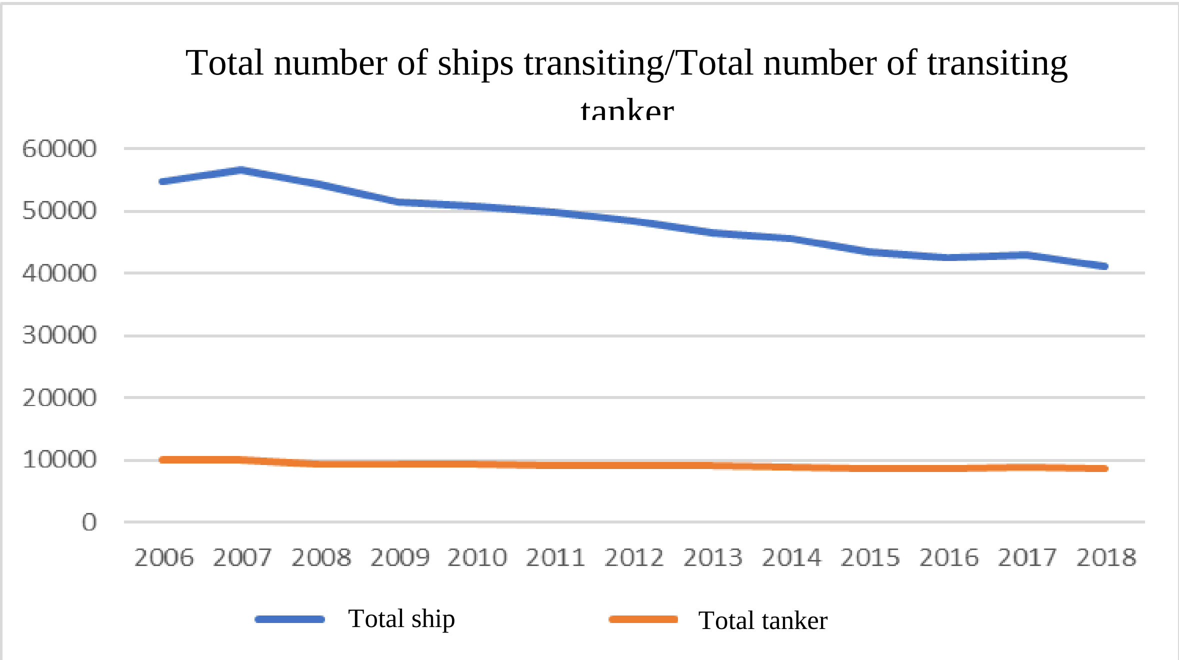


Figure.1. Number of Ships and Tankers Passing through the Bosphorus [16].

Canal Istanbul Project, planned to be constructed in line with the stated requirements, is designed as a safe alternative waterway connecting the Black Sea to the Marmara Sea and the Mediterranean Sea by opening a canal along a route of approximately 45 km. The project in question is not only a transportation project. Still, it will be an integrated project that includes coastal facilities such as emergency berths, emergency response centers for the operation of the canal, canal entrance, and exit structures, infrastructure, superstructures such as ship traffic systems, and container ports (Figure 2).

Canal Istanbul is a water channel specially designed for the passage of ships as a waterway with a depth of 21 meters and a surface width of 360 meters. The canal width these ships can pass through is planned for a range of approximately 250-1,000 meters, depending on the berthing structures and maneuvering areas on the route [19].

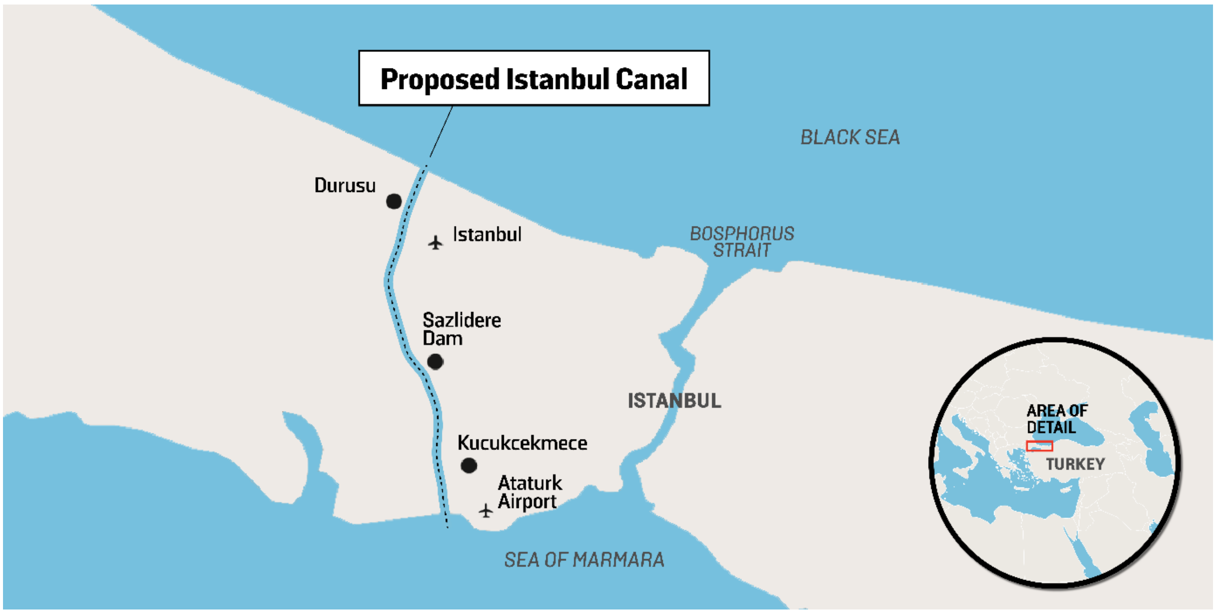


Figure 2. Canal Istanbul Project Route [19].

2. MATERIAL AND METHOD

Within the scope of the study, data on the type, size, and number of watercraft that can pass through the canal are accepted as the data determined throughout the Bosphorus. Within the scope of the planned project, scientific and technical studies for the area are ongoing. Therefore, risk assessments that may occur after the project's construction in question according to the determined technical principles have yet to be made. In this context, with this study, the maximum ship size that will be used in risk assessment and used as the most critical factor during the determination of the canal dimensions is the maximum ship size that is foreseen to pass through the canal, and in the studies carried out in this context, the maximum ship sizes for different ship categories were considered. It has been determined that the critical vessels affecting the channel design are fuel tankers and container ships.

In the studies conducted for the Bosphorus, it is estimated that the total number of vessel calls through the Bosphorus will increase from 43,781 in 2017 to 85,850 by 2070 [19]. When the number of ships passing through the Bosphorus is compared with other channels, it is determined to host the highest number of ships (Table 1). With the increasing trade and oil production in the Black Sea, it is clear that the increase in the number of ships passing through the Bosphorus and the increase in ship sizes will be inevitable (Table 1).

Table 1. Comparison of important channels in the world [28].

Channel Name	Length (m)	Depth (m)	Transit Duration (hours)	Width (m)	Annual Passage (2019)
Bosphorus	33	25-110	2	700-3600	41 112
Panama	81.3	12-14	9	150-300	13 785
Suez	193	11-24	12-15	220	18 880
Kiel	98.7	11	6.5-8	103-204	30 000
Canal Istanbul	45	20,75	3-4	275	69 000 (max.)

To reduce traffic and accident risks in Bosphorus, traffic flow will be gradually directed to Canal Istanbul, with 85% of container ships expected to be diverted into the Canal in 2070. The number of ships passing through the Bosphorus and Canal Istanbul hosts the highest number compared to other channels, as given in table 1. Therefore, it is planned to direct the traffic flow to the Canal by gradually transferring the ships passing through the Bosphorus to Canal Istanbul according to the years. For example, for container ships above a certain length, it is estimated that 5040 of the container ships estimated to pass through the Bosphorus in 2070 will pass through Canal Istanbul at a rate of 85% [19]. According to these estimates, it is estimated that 150-160 ships will pass through Canal Istanbul per day according to the evaluations made for four main ship categories [19]. Considering these rates, severe ship traffic is possible in Canal Istanbul.

Monte Carlo Simulation Model

Monte Carlo simulation is a statistical accident analysis method with several advantages over other processes in the literature for planning multi-unit coastal structures and determining risk scenarios. The most important of these advantages is that the uncertainties in accident occurrences can be statistically incorporated into the solution [29]. Its primary advantage is that it allows for the inclusion of uncertainties in accident occurrences in a statistically rigorous manner. Specifically, the model assigns random values to accident occurrence variables from various probability distributions through many repeated simulations, thereby generating a range of realistic accident probabilities for the channel [30]. The most probable accident scenarios are then identified, and necessary precautions are taken before they occur.

Within the scope of the study, statistical data for risk assessment were studied together with Monte Carlo Simulation, and the amount of spillage that may occur in case of a possible accident was determined according to each type of accident. For the accidents such as collision, collision, sitting, hard leaning, drifting in strong hydrographic and meteorological conditions, and similar accidents caused by the ships, the probabilities and severities of accidents as a result of ship maneuvers were determined by repeating the specified maneuvers 30 000 times with probability distributions modeled in the computer environment by Monte Carlo simulation, which is a quantitative method. Oracle Crystal Ball program was used for the Monte Carlo method.

Oracle Crystal Ball is a program designed for forecasting, simulation, and optimization and can be used as an MS Excel add-on application. With this program, risks and uncertainties can be analyzed and used in future forecasts using historical data. The program, compatible with Monte Carlo simulation, contributes to more realistic projections and a better understanding of probabilities in risk assessment studies. Oracle Crystal Ball helps us make strategic decisions by accurately evaluating forecast uncertainties [31].

AASHTO Metod

Today, in maritime safety and risk assessment, the AASHTO method is used to examine the types and causes of accidents for specific regions or ports in fleet management studies that consider the maritime sector's accident risks. Accidents indicate maritime safety, especially the safety of ships, crew, and cargo. Classification of accidents and prevention of losses is important for the transportation sector as marine accidents are of great economic importance. Therefore, a classification tree method was applied to estimate the total ship loss cases. The resulting classification tree can be used for risk analysis studies. Causes of accidents include ships running aground, contacting the seabed, striking piers, rigs, platforms, or other external objects, colliding with other ships, catching fire, or suffering an explosion or further severe machinery damage [18-32].

Coastal structures, especially those over navigable waters such as bridges, are vulnerable to ship collisions. Bridges are important transportation links between separate coasts of human settlements. The assessment of the probability of accidents and failures is an important area of research, and there are many studies in the literature [33-34-35-36]. The probability of a ship deviating from its course (PA) is a value that occurs when it turns from its path. This may be due to human error, adverse weather conditions, or mechanical failure. The most accurate method to determine the PA is based on historical accident data and the number of ships passing through the waterway [32]. Method II uses historical accident data, assuming a relationship between the probability of vessel deviation and historical accident data. The method I is a semi-deterministic procedure, and Method II is a risk analysis procedure used for waterways. Therefore, Method II was used in our study.

The probability of a ship deviating from its course (PA) in the manmade channel can be estimated considering human error, adverse weather conditions, or mechanical failure. The most accurate method to determine the PA is based on past accident data and the number of vessels passing through the waterway [29]. Therefore, the sub-model uses past accident data to estimate the relationship between the probability of ship aberration. To find the probability of ship aberrancy (PA) in Canal Istanbul, Equation (1) is used as given by the "Guide Specifications and Commentary Vessel Collision Design of Highway Bridges [18-32]:

$$PA = BR\ (R_B)\ (R_C)\ (R_{XC})\ R_D) \qquad (1)$$

where; PA is the probability of deviance, BR *is* the aberrancy base rate, R_B is the correction factor for turning angle, R_C: is the correction factor for current acting parallel to the vessel path, and R_{XC}: is the correction factor for current acting perpendicular to vessel path, R_D: correction factor for vessel traffic density which is defined by low, medium and high density. The aberrancy base rate (BR) is a standard value. The value (BR) is 0.6×10^{-4} for ships and 1.2×10^{-4} for barges. The correction factor for current has been calculated using the average current of the risk zones. The correction factor (R_B) for the turning angle (θ) can be estimated for 3 regions [18-30]:

i. Straight Region: For a straight region:

$$R_B = 1.0 \qquad (2)$$

ii. Transition Region: For a transition region:

$$R_B = \left(1 + \frac{\theta}{90^o}\right) \tag{3}$$

iii. Turn/Bend Region: For a turn or bend region:

$$R_B = \left(1 + \frac{\theta}{45^o}\right) \tag{4}$$

The correction factor for current acting parallel to vessel path (R_C) can be computed by:

$$R_C = \left(1 + \frac{V_C}{10}\right) \tag{5}$$

where; V_C: current component parallel to vessel path (knots). The correction factor for current acting perpendicular to vessel path (R_{XC}) can be calculated as:

$$R_{XC} = (1 + V_{XC}) \tag{6}$$

where; V_{XC}: current component perpendicular to vessel path (knots) .

Risk Assessment

Within the scope of the study, past accident data were compiled from ITOPF (2019) databases and evaluated according to accident types and spill quantities [38]. Accident probability calculations were made using these data and vessel traffic information. While making the analysis calculations, it was defined as "Risk = Accident Probability x Accident Results." After determining the accident risk, the average amount of hazardous materials spilled per ship was calculated in tons/ship for each accident type. Thus, the accident probability of each type of accident (fire, spillage, explosion, etc.) was determined [20]. Again, using the marine accident data, the amount of leakage likely to spread per ship due to the accident was determined according to the incident type. Figure. 3. shows the Marine Accident Risk Assessment Flow Diagram.

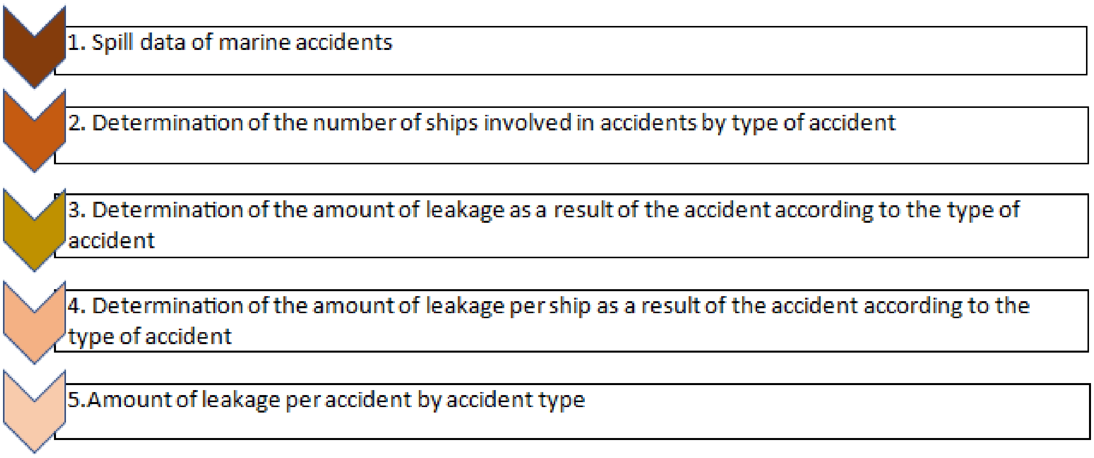


Fig. 3. Marine Accidents Risk Assessment Flow Diagram [20].

3. RESULT AND DISCUSSION

In order to realize an effective response to oil and chemical incidents in maritime, it is crucial to determine the risk assessment, estimate the probability of an oil spill based on the historical data of the current events and categorize the probabilities, estimate the importance of the potential consequences of the possible occurrence and categorizing these importance degrees, creating a risk matrix, evaluating various oil scenarios and determining the risk rating. In this context, for the risk assessment studies for Canal Istanbul, the canal was divided into 15 sections, considering the ship turning angles and shelter areas. Therefore, risk studies were calculated separately for each section. In the partitioning of the channel, ship turning angles were calculated as in Figure-4 and marked on the channel in the Netcad program. Figure-5 shows Canal Istanbul partitioning and ship turning angles.

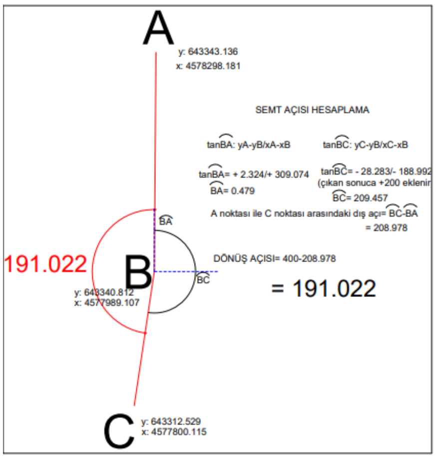


Figure.4. Canal Istanbul Ship Turning Angle Calculation.

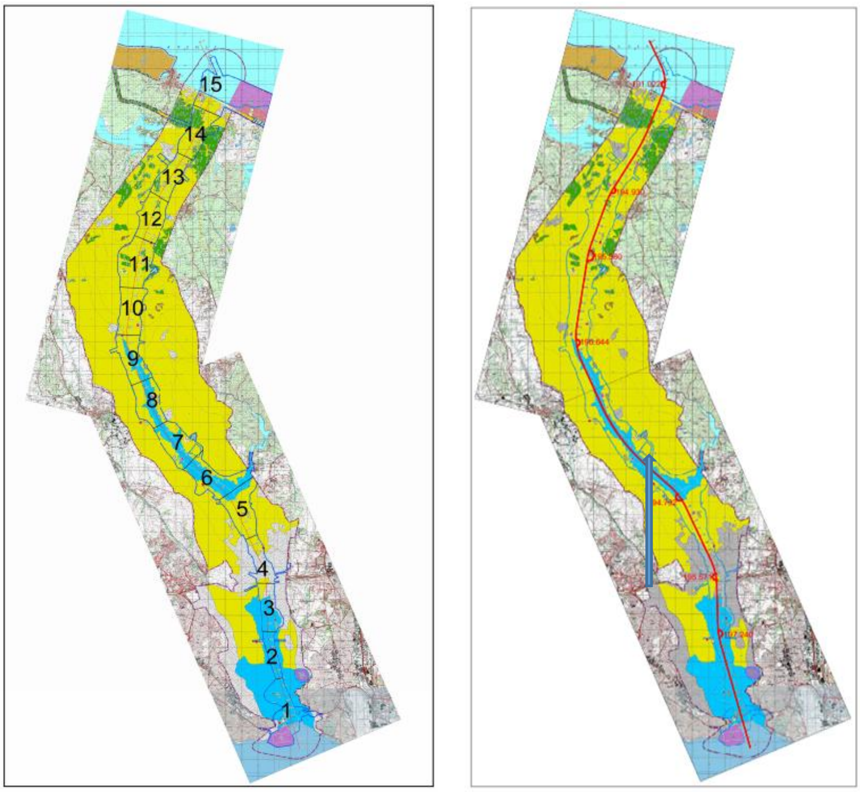


Figure.5. Canal Istanbul Ship Turning Angles and Canal Sectioning.

Correction factors for Canal Istanbul's turning angle were calculated separately for each region and accident type. First, the correction factor for the current was calculated using the average current of the regions and the angle between the current direction and the ship direction. The calculated average speed unit was converted to knots. According to the angle between the current direction and the ship direction, the current velocity perpendicular to the ship path and parallel to the ship path were determined. Then Rc, and Rxc values were calculated (Table 2). The correction factor for ship traffic density (RD) was classified into three groups low, medium, and high-density traffic. Since Canal Istanbul is expected to have heavy traffic, the correction factor for ship traffic density was taken as 1.60 for all regions.

Table.2. Canal Istanbul Probability Calculations.

Zones	BR	R_B	R_C	R_{XC}	R_D	PA
1	0,00006	1	1,097	1,009	1,60	1,06E-04
2	0,00006	1,38	1,097	1,009	1,60	1,66E-04
3	0,00006	1	1,097	1,009	1,60	1,06E-04
4	0,00006	1,34	1,097	1,009	1,60	1,42E-04
5	0,00006	1,33	1,097	1,009	1,60	1,41E-04
6	0,00006	1	1,097	1,009	1,60	1,06E-04
7	0,00006	1	1,097	1,009	1,60	1,06E-04
8	0,00006	1	1,097	1,009	1,60	1,06E-04
9	0,00006	1,37	1,097	1,009	1,60	1,45E-04
10	0,00006	1	1,097	1,009	1,60	1,06E-04
11	0,00006	1,35	1,097	1,009	1,60	1,43E-04
12	0,00006	1	1,097	1,009	1,60	1,06E-04
13	0,00006	1,33	1,097	1,009	1,60	1,41E-04
14	0,00006	1	1,097	1,009	1,60	1,06E-04
15	0,00006	1,25	1,097	1,009	1,60	1,33E-04

In the risk assessment of Canal Istanbul, calculations were made considering the conditions where the current is 1.0, 1.5, and 2.5 m/s. In addition, low (1 m/s) and high (2.5 m/s) conditions were studied in this context. Figure.5 shows that the current learned for Canal Istanbul is assumed to be 1 m/s, and Figure. 6 shows the results of the sinking-type accident where the current is considered as 2.5 m/s.

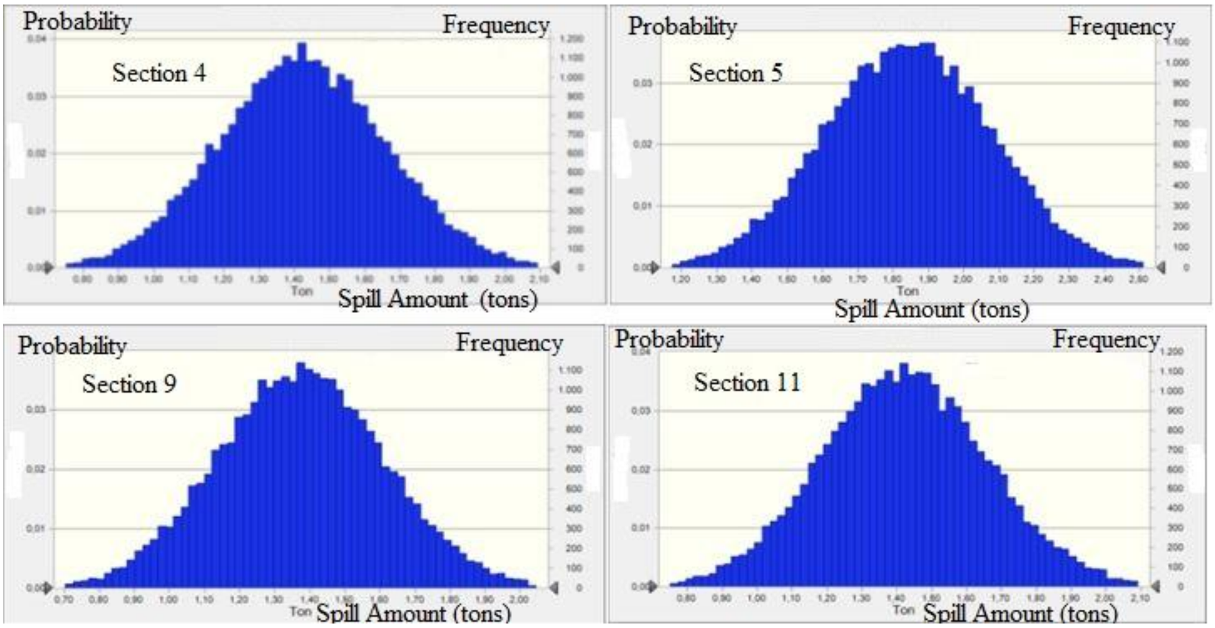


Figure.6. Simulation of the spill (tons) for sinking-type accidents at Canal Sections 4, 5, 9, and 11 for the average current speed of 1.0 m/s.

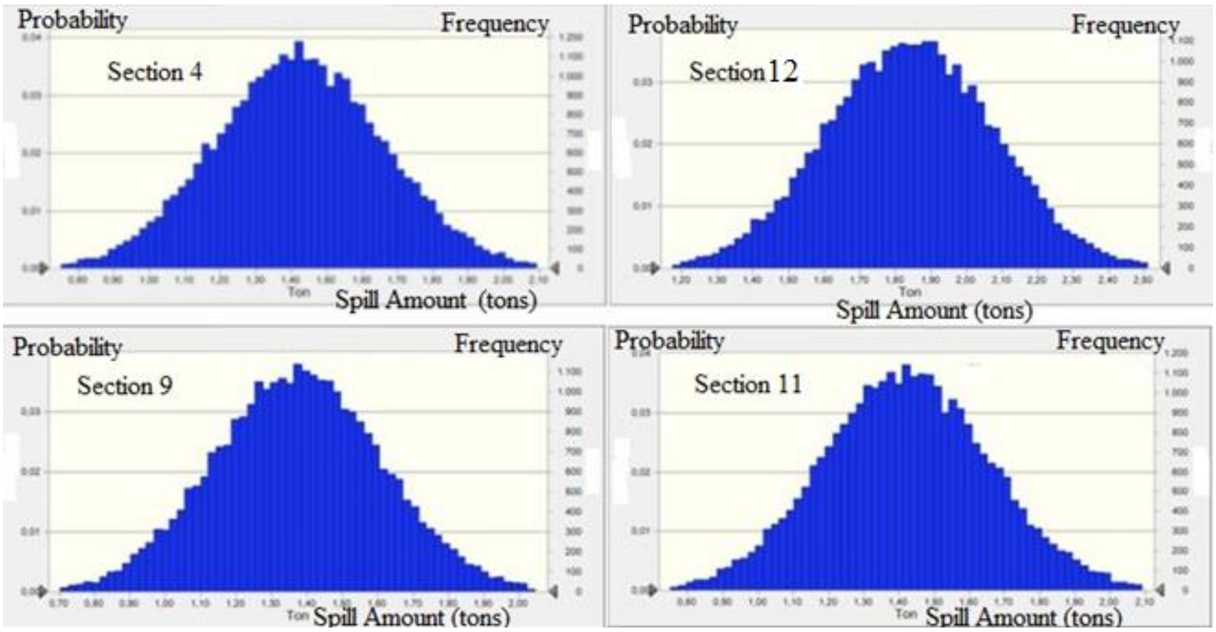


Figure.7. Simulation of the spill (tons) for sinking-type accidents at Canal Sections 9, 5, 13, and 11 for the average current speed of 1.5 m/s.

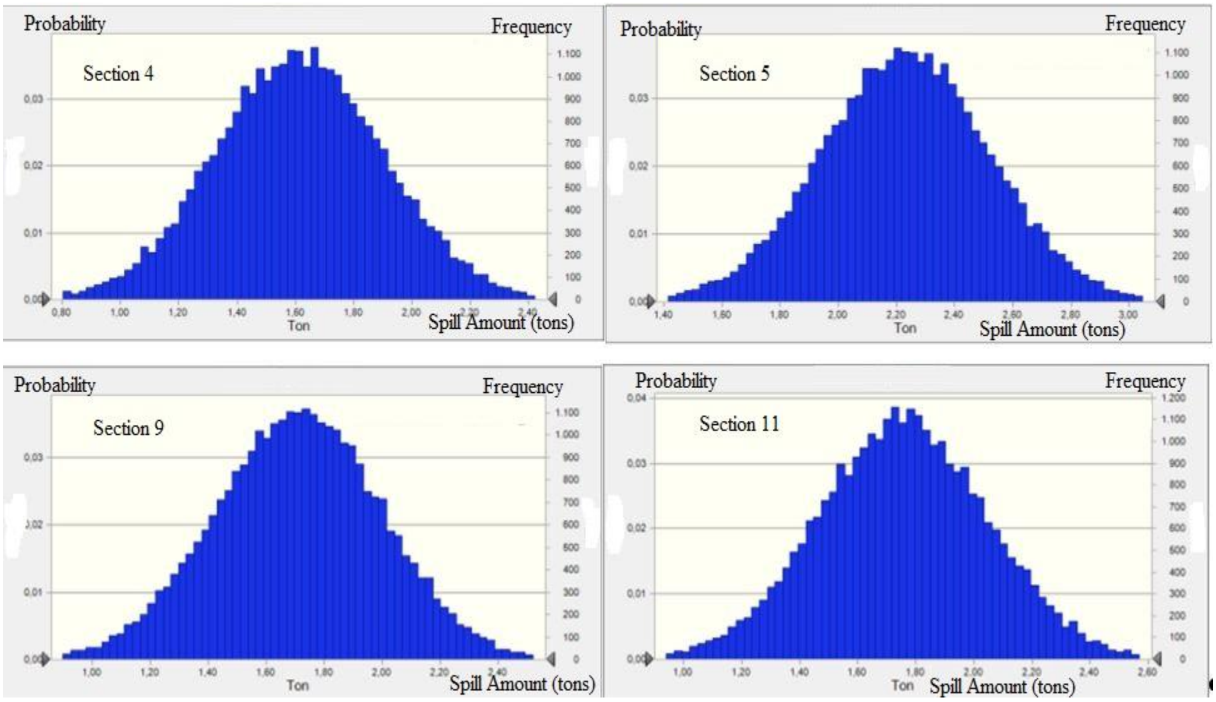
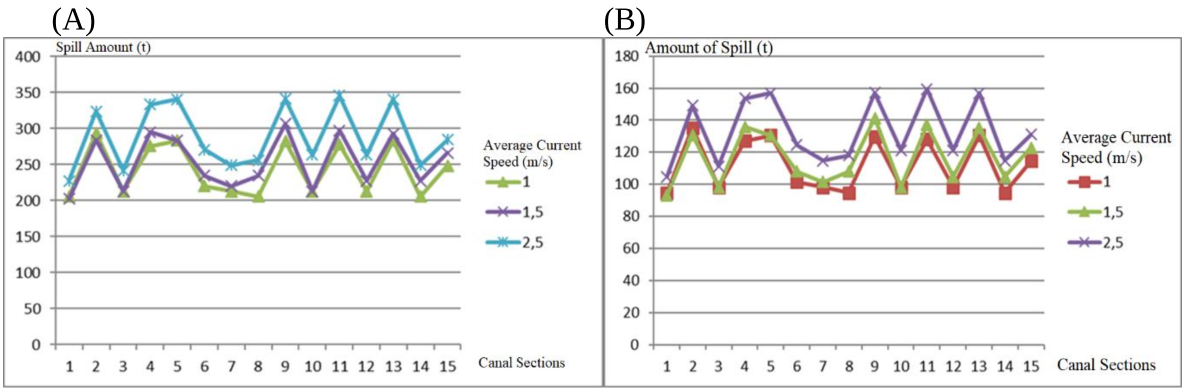


Figure.8. Simulation of the spill (tons) for sinking-type accidents at Canal Sections 4., 9., 5, and 11 for the average current speed of 2.5 m/s.

The results obtained using the ASSHTO method for Canal Istanbul were again run in Oracle Crystal Ball program for each section. The comparisons of the spill quantities in the Canal Sections of Canal Istanbul for the Sinking / Collapse / Collision and Fire / Explosion Accident Types are given in Figure 9.



(C) (D)

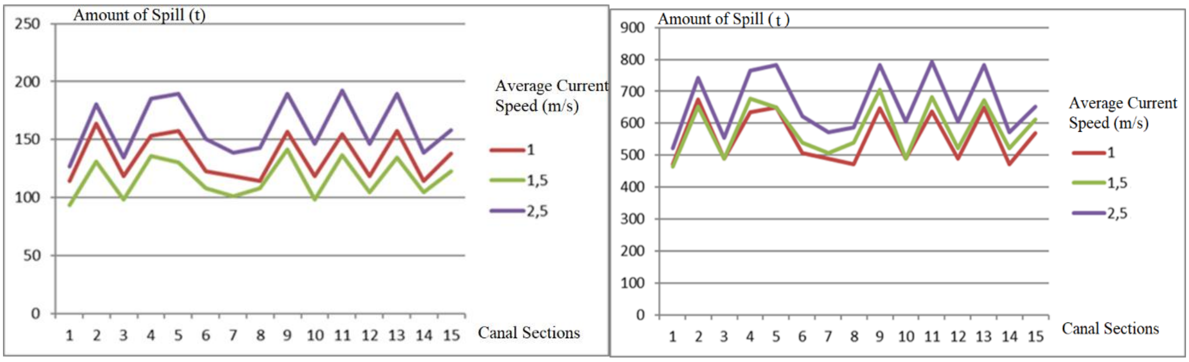


Figure.9. Comparison of Spill Amounts in Channel Sections for (A) Sinking Accident (B) Collision Accident; (C) Grounding Accident Type (D) Fire Accident Type.

The study analyses environmental conditions along the canal and conducts individual risk evaluations for each part of the channel. The study reveals that fire and sinking accidents may result in larger spills than other probable accident categories. When both the canal sectionalization studies and the canal as a whole are evaluated, it is estimated that the amount of spillage may be higher than the possible accident types of fire and sinking accident types, as seen in Figure 9. The study also evaluates the likelihood of collision-type accidents in Canal Istanbul and finds it to be lower than in Bosphorus due to the prohibition of mutual ferry and yacht crossings. As the channel would function in a unidirectional manner, the possibility of collision-type events is relatively low, according to risk assessment studies done for this study. In addition, the study analyses the risk locations along the canal for different sorts of accidents based on ship turning angles along the ship passage route along the canal.

The study identifies the 2nd, 4th, 5th, 9th, and 13th canal sections as high-risk areas for sinking accidents, the 4th, 5th, 9th, and 11th sections for collision accidents, the 2nd, 4th, 5th and 13th sections for collision-type accidents, the 4th, 5th, 9th, and 11th sections for grounding-type accidents, and the 2nd, 4th, 5th, 9th, and 11th sections for fire accidents. In these risk assessment studies, different current speeds are considered separately, and as can be seen in Figure 6, Figure 7 and Figure 8, it is estimated that the degree of risk and the amount of spill in the channel will increase in parallel with the current speed. Therefore, again with this study, it is seen in Figure 12 that if there is a fire accident type, it will negatively affect the environment.

The study notes that a daily average of 150 ships passing in the Canal of Istanbul is anticipated to be intense. Thus, the study recommends the addition of emergency ports in sections with high risk, particularly Sections 2, 4, 5, 9, 11, and 13. Despite the implementation of Vessel Traffic Services (VTS) in the Canal, the study concludes that it would be difficult to intervene in the event of a potential accident under poor weather conditions due to the length and volume of the Canal. Some wind, wave, current and visibility thresholds cause navigation restrictions. As a result of the navigation simulation study and ship flow simulation studies, navigation thresholds for Canal Istanbul have been determined. However, it would be appropriate to evaluate these threshold values in according to all the data obtained from the accidents in the Bosphorus. In this context, it would be fair to prepare them by considering the ship types that are expected to pass the most, and the ship types that are involved in the most accidents according to historical data.

Within the Canal Preliminary Projects scope, emergency mooring areas have been planned approximately every 4.5 km along the Canal to allow the damaged vessel to wait or get out of traffic in case of engine failure, fire, or other accidents. As these areas are located on the shores, they are designed so that inoperable ships can wait outside the navigation channel, and navigation will not be interrupted. The ship can be towed to be repaired [25]. In case of possible marine accidents, it will be towed to emergency mooring areas within the Canal. However, this planning should be planned according to potential risky areas, and ship transits and ship mooring areas should be designed accordingly.

The Canal Istanbul project has substantial obstacles, including heavy ship traffic and a dense population along the coast. In addition, around 20% of passing vessels are tankers, cargo ships transporting risky cargo, LNG, or LPG. Therefore, good navigation management, risk assessment, and emergency response are essential for the canal's safe and efficient operation. This necessitates the construction of emergency response zones, the appraisal of navigation limits relative to Bosphorus incidents, and the design of ship transits and mooring sites to identify potential risk zones.

Overall, this study provides valuable insights into the potential accidents and risks associated with Canal Istanbul and suggests measures to mitigate these risks. This study's results can improve Canal Istanbul's management to ensure its safe and sustainable operation. fire and sinking are considered the most crucial potential accident types. Due to the difference in environmental factors along the canal, risk assessment studies were evaluated by MCS for each section. It is estimated that the amount of spill may be higher in fire and sinking accident types compared to possible accident types, both when channel segmentation studies are considered and when evaluated as a whole. To mitigate the risks, emergency mooring basins are planned approximately in every section so that when the ship encounters danger, she can be towed for repair and exit the navigation channel without interrupting the navigation in the channel. Each emergency mooring basin has a total berthing length of 450 m and can accommodate one design ship and two tugboats. The anchorage basins of tugboats can accommodate six tugs.

4. CONCLUSİON

In this research, which is a risk assessment for the planned Canal Istanbul project, the risky areas of the canal were determined, and it was determined that the amount of oil spills in the type of fire and sinking accidents could be high. Looking at the future ship passage estimates in Canal Istanbul, ship traffic is expected to be intense, with an average of 150 ship passages per day. When evaluated in this context, it would be appropriate to add emergency response areas in addition to the shelter areas in the 2nd, 4th, 5th, 9th, 11th, and 13th sections where the risk is likely to be high. Although the traffic regularization system is applied in the channel, it is estimated that intervention in case of an accident in times of high weather conditions and high currents will be difficult due to the length of the channel and vessel traffic. For this reason, it is imperative to have emergency response areas and a separate plan and center for the channel to intervene in marine accidents in these high-risk sections effectively.

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5. REFERENCES

1. UNCTAD,2021; United Nations Conference on Trade and Development, Review of Martime Transport, Ankara, Türkiye.
2. Globalization, Transport and the Environment, Transportation Research Part D: Transport and Environment, 2017.

3. Akten, N., 2004. The Bosphorus: Growth of Oil Shipping and Marine Casualties in The Turkish Straits and Their İmplacations for the Environment, Marine Safety and Environmental Protection Seminar Proceedings, 134-144, İstanbul.
4. Talınlı, I., Sarioz, K., Yamanturk, R., 2003. "Assessment of Environmental Damage in the Sea of Marmara due to Oil Spill From Volganeft-248" 6th International Conference on the Mediterranean Coastal Environment MEDCOST 03, October 2003, Ravenna, Italy.
5. Bayar, N., 2010. İstanbul Boğazı'nda Deniz Trafik Güvenliğinin Risk Tabanlı Bulanık-AHP ve FMEA Yönetemleri ile İncelenmesi, Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, Gemi İnşaatı ve Gemi Makineleri Mühendisliği Anabilim Dalı, Doktora Tezi, İstanbul.
6. Amrozowicz MD. Quantitative Risk of Oil Tanker Groundings. Master's Thesis,1996. MA: Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge.
7. Lakovou ET., 2001. An Interactive Multi-Objective Model For The Strategic Maritime Transportation Of Petroleum Products: Risk Analysis And Routing. Safety Science; 39(1–2):19–29.
8. Kuroda K, Kita H, Kono S., 1982. Mathematical Model of Ship Collision Probability. Memoirs of the Faculty of Engineering, Kyoto University, 44(1):135–157.
9. Dougligeris C, Iakovou E, Yudhbir L., 1997. Maritime Route Risk Analysis for Hazardous Materials Transportation. Proceedings of the 8th IFAC/IFIP/IFORS, Transportation Systems, Chania, Greece ; 2:563–568.
10. Van Dorp,J.R., J.R. Merrick, 2011. On a risk management analysis of oil spill risk using maritime transportation system simulation, Ann. Oper. Res. 249–277.
11. Uğurlu, Ö., 2011. Petrol Tankerlerinde Meydana Gelen Deniz Kazalarının Risk Analizi. Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü, Trabzon.
12. Wang, J. 2006. Maritime risk assessment and its current status. Quality and Reliability Engineering International, Vol.22, 3–19.
13. Yıldırım, U., 2016. Deniz Kazalarının İnsan Faktörleri Analiz ve Sınıflandırma Sistemi (HFACS) ile İncelenmesi, Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü, Trabzon.
14. E. Asyalı and T.Kızkapan, "Türkiye Kiyilarinda 2004-2008 Yillarinda Uluslararasi Sefer Yapan Gemilerin Kariştiği Deniz Kazalarinin Analizi", Dokuz Eylül Üniversitesi Denizcilik Fakültesi Dergisi, C:4, S:2, 2012,İzmir.
15. Kızkapan, T.,2010. Kıyı Alanlarında Gemi Emniyet Yönetimi ve Deniz Kazaları Analizi. Dokuz Eylül Üniversitesi Sosyal Bilimler Enstitüsü, İzmir.
16. Ministry of Transport and Infrastructure of Türkiye, 2020. Turkish Straits Ship Passage Statistics Türkiye.
17. J. Wang, 2006. Maritime Risk Assessment and its Current Status. Quality and Reliability Engineering International, Vol.22:3–19.
18. Küçükosmanoğlu, A., 2012. Marıtıme Accıdents Forecast Model For Bosphorus, Mıddle East Technıcal Unıversıty School Of Natural And Applıed Scıences,Ankara.
19. Ulaştırma ve Altyapı Bakanlığı Altyapı Yatırımları Genel Müdürlüğü, 2020. "Kanal İstanbul Çevresel Etki Değerlendirmesi Raporu (Kanal İstanbul Nihai ÇED Raporu)", Kanal İstanbul Nihai ÇED Dosyası,Ankara.
20. Küçükosmanoğlu Alp, 2008, "Sızıntı Miktarının Deniz Kazaları Risk Modeli (Marisk) ile Araştırılması", Doktora Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü Kazaların Çevresel ve Teknik Araştırması, Ankara.

21. Ece, N.J., 2005. İstanbul Boğazı'ndaki Deniz Kazalarının Seyir Ve Çevre Güvenliği Açısından Analizi Ve Zararsız Geçiş Koşullarında Değerlendirilmesi. Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara.
22. Arslan, Ö.; Turan, O., 2009. Analytical Investigation of Marine Causalities at the Strait of Istanbul with SWOT-AHP method. Marit. Policy Manag., 36, 131–145.
23. Or, I.; Kahraman, 2002. I. A Simulation study of the accident risk in the Istanbul Channel. Int. J. Emerg. Manag. , 1, 110–124.
24. Ulusçu, Ö.S.; Özba¸s, B.; Altıok, T.; ˙Ilhan, O.; Özhan, A.A., 2009. Risk Analysis of the Vessel Traffic in the Strait of Istanbul. Risk Anal., 29, 1454–1471.
25. Volkan Aydogdu, Cemil Yurtoren, Jin-Soo Park and Young-Soo Park, 2012. A Study on Local Traffic Management to Improve Marine Traffic Safety in the Istanbul Strait, The Journal of Navigation , Volume 65 , Issue 1 , pp. 99 – 112, 2021
26. Chamber of Shipping, Istanbul & Marmara, Aegean, Mediterranean and Black Sea Region, Maritime Sector Reports, http://www.denizticaretodasi.org.tr/en-en/pages/Sector-Report.aspx.
27. The Turkish Straits: A Key Transit Route for Energy Flows," 2017. International Energy Agency, Türkiye.
28. Yılmaz, E.H. K.,Kanal İstanbul'un Hukuksal Açıdan Dört Büyük Kanal İle Karşılaştırmalı Analizi, Journal of International Studies, Cilt:4, Volume:4, Number:1.
29. Balas, C.E., Balas, L., Williams A.T., 2006. "Discussion: Risk assessment of revetments by Monte Carlo simulation", Proceedings Of The Institution Of Civil Engineers-Maritime Engineering, 159(2), 81-84 .
30. Balas, C.E. and Balas, L., 2002. "Risk Assesment of some Revetments in Southwest Wales, United Kingdom", ASCE Journal of Waterway, Port, Coastal and Ocean Engineering, American Society of Civil Engineers, 128(5), 216-223.
31. https://www.oracle.com
32. AASHTO,2009. American Association of State Highway and Transportation Officials, "Guide Specifications and Commentary Vessel Collision Design of Highway Bridges", Second Ed., USA.
33. Ole Damgaard Larsen, 1993. Ship collision with bridges: the interaction between vessel traffic and Bridge Structures. International Association for Bridge and Structural Engineering (IABSE), Switzerland .
34. Kristiansen, S. , 2005. Maritime transportation. Safety management and risk analysis, Elsevier.
35. SHAO Xu-dong, ZHAN Xue-fang, LIAO Chao-hua, YAN Ban-fu and LIU Jun-ke, 2007. Risk Assessment for Collision Protection of Existing Bridge-View from Collision and Replacement of Sunshine Skyway Bridge.
36. Dimitris X. Kokotos and Yiannis G. Smirlis, 2005. A Classification Tree Application to Predict Total Ship Loss. Journal of Transportation and Statistics, U.S. Department of Transportation Research and Innovative Technology Administration Bureau of Transportation Statistics. Volume 8 Number 2.
37. http://www.ubak.gov.tr/BLSM_WIYS/DTGM/tr/Kitaplar/20161116_165220_64032_1_64480.pdf
38. https://www.itopf.org/knowledge-resources/data-statistics/statistics/