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On the Grounding of Ships Determination of Risk Factors with Fault Tree Analysis (FTA)

Gemilerin Karaya Oturması ile ilgili Risk Faktörlerinin Hata Ağacı Analizi (FTA) ile Belirlenmesi

Araştırma Makalesi / Research Article

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Özet:
Küresel ticarete konu olan malların taşınmasında şüphesiz deniz taşımacılığı ilk sırada gelmektedir. Deniz taşımacılığı ölçek ekonomisi açısından düşünüldüğünde diğer taşıma türlerine göre avantajlı olmasına rağmen doğası gereği içerisinde pek çok risk barındırmaktadır. Bu riskler can, mal ve çevre güvenliğini tehdit etmektedir. İnsan hatası, makine arızası, çevresel koşullar gibi başlıca sebepler nedeniyle çeşitli gemi kazaları yaşanmaktadır. Yaşanan kazalar gemi ve yük ile ilgili hasar ve kayıplara neden olabileceği gibi çevre kirliliği, personelin yaralanması ve ölümüne de sebep olabilmektedir. Başlıca kaza türleri, çatma, karaya oturma, yangın/patlama, makine arızası, batma/yan yatma, sürüklenme olarak sınıflandırılabilir. Raporlar incelendiğinde bu kaza türleri arasında ilk sırada çatma, ikinci sırada ise karaya oturma gelmektedir. Çalışma kapsamında, ilk olarak Avrupa Deniz Emniyet Ajansı (European Marititme Safety Agency (EMSA)), Ulaştırma Denizcilik ve Haberleşme Bakanlığı (UDHB), Japon Transport Safety Board (JTSB), Bahama Maritime Authority (BMA) raporları ve literatür incelenerek içerik analizi yapılmıştır. Sonraki aşamada elde edilen göstergelere Hata Ağacı Analizi (Fault Tree Analysis (FTA)) yöntemi uygulanarak kök sebeplere inilmiştir. FTA sonucunda kök sebeplerin başında insan hatası, meteorolojik koşullar ve makine arızasının geldiği görülmüştür. Çalışmanın sonucunda karaya oturma kaza türünde risk faktörleri sınıflandırılmış ve istatiksel olarak değerlendirilmiştir.

Anahtar Kelimeler: Denizyolu Taşımacılığı, Gemi Kazaları, Karaya Oturma, Risk Faktörleri.

Abstract:

Maritime transport undoubtedly comes first in the transport of goods subject to global trade. Despite the advantages of maritime transport in terms of economies of scale, the inherent nature of this mode of transportation introduces a number of risks. Such risks have the potential to endanger human life, property, and the environment. A variety of maritime accidents can be attributed to a number of factors, including human error, mechanical failure and environmental conditions. Such incidents may result in damage and losses pertaining to the vessel and cargo, in addition to environmental contamination, injury, and even death of personnel. The principal categories of maritime accidents can be classified as follows: collisions, groundings, fires and explosions, machinery failure, sinking or shearing, and drifting. A review of the available data reveals that collisions represent the most common type of accident, followed by groundings. In the initial phase of the study, the European Maritime Safety Agency (EMSA), the Ministry of Transport, Maritime Affairs and Communications, the Japan Transport Safety Board (JTSB), and the Bahama Maritime Authority (BMA) reports and literature were subjected to analysis through content analysis. In the subsequent phase, the Fault Tree Analysis (FTA) methodology was employed to examine the identified indicators and ascertain the underlying root causes. The FTA revealed that human error, meteorological conditions and machinery failure were the primary root causes. The study yielded a categorisation and statistical evaluation of the risk factors associated with grounding accidents.

Keywords: Maritime Transportation, Ship Accidents, Grounding, Risk Factors.

1. Introduction

When sea transport is evaluated among other transport methods, it is the most preferred type of transport in world trade due to its advantages such as carrying more cargo at one time and tonnes/mile. The global commercial goods transportation sector plays a pivotal role in facilitating the efficient intercontinental movement of bulk solids and raw material products (Efecan, 2023). In addition, 90% of the transport needs of people in order to meet their needs are provided by sea (Usluer, 2022; Arıcan and Ünal, 2023). During this transport activity, the operational processes of ships involve a number of risks when meteorological conditions, ship material condition and crew's knowledge level, i.e. human influence, are added (Özbağ, Arıcan and Aydın, 2023). These risks pose a serious threat to human life, property, and the environment (Arıcan, Arslan and Ünal, 2023). If the risks, which are tried to be categorised under various main headings, come together, an accident is inevitable. For this reason, safety takes the first place in the maritime sector in order to avoid undesirable consequences. Efforts to ensure safety can be achieved by correctly identifying the risks and analysing them with appropriate methods. In order to reduce the risks, when approached from an inductive point of view, a ship crew working as a team becomes an important factor. Ship owner, master, crew members, harbour personnel are part of this team and they should take measures to reduce risk factors. Implementation of planned maintenance to the existing systems/devices on board in a timely manner, familiarisation of the personnel with emergency conditions, preparation of navigation plans taking into account meteorological conditions may be among the measures to be taken considering the maritime accidents experienced.

In this study, researches and studies have been carried out on the accident type of grounding of ships. In this context, it is aimed to contribute to the literature in terms of determining the cause of the accident by making error types and analyses. As a result of the determined error rates, it is aimed to draw the attention of the maritime sector to reduce the causes of accidents. Based on the random sampling method, 20 types of grounding accidents were analysed. The reason for choosing this sampling method is to evaluate the types of grounding accidents unconditionally and concretely without depending on a specific geography and ship type. With random sampling, 20 accident reports were analysed without being bound to a specific year and geography. Fault tree analyses were performed with the causes of the accidents. With the fault tree method, the fault types obtained from the accident reports were determined and analysed with mathematical methods. The fault tree analysis method was determined for this study because it contains qualitative and quantitative methods. In the maritime sector, the fault tree method has been used in many subjects such as the analysis of injuries in port operations (Kuzu, Yunus and Arslan, 2018), another accident analysis, the analysis of accidents in tanker terminals (Arslan, Zorba and Stevak, 2017). It is a method used effectively in risk analysis and determination of error rates. The error rates were determined after the examined accident reports and fault tree analysis. It is aimed to draw attention to the problem areas and to provide solutions to the literature and the maritime sector within the scope of the determined error rates.

Marine accidents are defined as death, injury or man overboard, damage or loss of the ship, sinking, grounding, collision and environmental pollution caused by ships (UDHB, 2014). There are international institutions, national organisations and forums to investigate maritime accidents. Some of these organisations include “The Marine Accident Investigators' International Forum (MAIIF)”, which aims to increase maritime safety by reducing environmental pollution as a result of the evaluation of experiences and ideas. As another organisation, “The International Maritime Organisation (IMO)”, which dates back to 1948 and was established by the United Nations, plays an important role in the prevention of marine pollution and the supervision of the maritime sector. “The European Maritime Safety Agency (EMSA)”, an institution of the European Union, aims to reduce the risk of marine accidents, marine pollution from ships and loss of human life at sea (Kuleyin and Aytekin, 2015).

Within the scope of the analysis of ship accidents by years, the accident analysis report published by EMSA in 2023 was examined. When the accidents between 2014 and 2023 are analysed, it is seen that 2022 is a positive year in terms of reducing most of the accident indicators. Accident indicators consist of lost ships, deaths and injuries after the incidents. A total of 2510 marine casualties and incidents were reported in 2022. In the current situation, it is seen that 182 maritime accidents have decreased compared to 2021 and 84 compared to 2020. Between 2014 and 2022, a total of 23814 incidents were reported and the annual average number of incidents was determined as 2646. For this reason, 2022 was a year in which both the average number of accidents/incidents and marine incidents decreased. In 2022, the number of vessels involved in 2701 accidents and incidents decreased by 212 vessels compared to 2021 and 94 vessels compared to 2020. In 2022, 6 ships were lost, 524 ships were damaged, 180 ships were deemed unfit to proceed, 603 ships required shore assistance, 330 ships required towing, 17 ships were abandoned and 296 Search and Rescue (SAR) operations were conducted. When all these figures are compared to previous years, it is seen that ship accidents have decreased. There has been a significant decrease in the number of reported pollution since 2019. In 2022, total pollution was reduced, with fewer emissions released into the air and a significant reduction in pollution from cargo (EMSA, 2023).

Considering the stages of the voyage in which marine casualties or accidents occurred, the lowest average was ‘Departure’ with 8.3%, while the highest average was observed during navigation with 44%. The situations in which the ship was not underway, anchored or in harbour took place after the accidents during navigation with a rate of 21.4%. The distribution of the accidents according to years and in which situation they occurred are given in Figure 1.

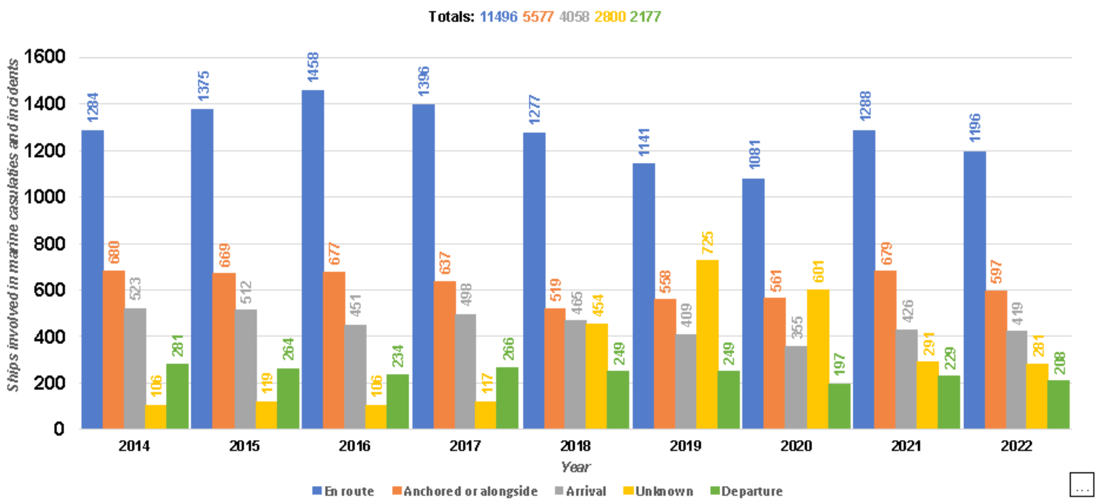


Figure 1. Maritime Accidents and Incidents by Segments of the Navigation Phase (EMSA, 2023).

2. Risk Factors in Maritime Transport

Although maritime transport has a lower accident rate compared to other transport methods, the risky activities in this method can cause irreparable loss of life and property. Marine accidents can be generally classified as collision, grounding, fire and flooding. Due to the fact that maritime transport is more preferred today, a field of research and law called Collision Law has been established in order to reduce the risks to the environment, ships and cargoes due to intensified maritime traffic (Gürel, 2022). According to Article 1286 of the Turkish Commercial Code, collision is divided into two types as direct or indirect collision. Direct collision is defined as the collision of two or more ships, while indirect collision is classified as the damage to another ship or its personnel as a result of the ship's manoeuvring or being in the harbour, not obeying the navigation rules. According to the two different types of collision, post-accident sanctions vary. Collision is a situation where a ship collides with another ship, a floating object on the sea surface or a fixed object. Collision accidents may occur due to electronic or mechanical failures in ship systems and devices, non-compliance with international rules, human error due to lack of knowledge or inexperience, and adverse weather conditions (MEB, 2015).

The type of grounding accident is the situation where the ship contacts the heel or sits on the seabed and loses its mobility due to the main reasons such as incorrect hull calculation of the distance from the water cut line to the keel, incorrect navigation plan or entering shallow waters. As a result of grounding, the ship may encounter situations such as tearing of the hull under the water cut, perforation of the balance tanks and the ship may become unusable.

With the formation of oxygen, flammable material and temperature environment, a fire environment is formed in ships (Bilgili, 2005). Although the formation of fires as a result of gas accumulation is mostly observed due to the compartmentalised structure, today, with the widespread use of electric vehicles, fires caused by electric vehicles are increasing, especially on Ro-Ro ships. Since the cooling and intervention of battery cells is not sufficient in the ship environment, such fires have been increasing in the maritime sector in recent years and it has been observed that the destructive effect is quite high. The European Union and the International Maritime Organisation continue to work on new regulations and sanctions on this issue (Özkan, 2023).

Capsizing is the situation where water is taken into the decks of the ship from the pierced hull or balance tanks after the damage to the keel lines of the ships or hard grounding. In severe weather conditions, even if there is no damage to the hull, capsizing occurs as a result of the decks remaining in water.

3. Method

In the study, the reports of organisations such as UDHB, JTSB, BMA on ship accidents were examined and a content analysis was conducted by taking into account the accidents resulting in grounding. Content analysis is a qualitative research method that enables the analysis of many materials such as texts, articles, thesis studies, sample accidents/incidents within the scope of rules in order to reach measurable, objective and verifiable information (Metin and Ünal, 2022). Content analysis, which is one of the qualitative research methods among the reliable methods, saves time for researchers and reaches simple results as a result of the analysis (Karakurt and Özay, 2022). With the content analysis method, after the accidents were analysed in depth, the way in which they examined the integrity of the event was examined. In this way, the analysed data were evaluated and the reasons that would affect the occurrence of the incident were classified. In this context, the universe of the study consisted of accidents related to grounding between 2010-2024. Within this universe, 20 grounding accidents were selected by random sampling. In the context of research and study, a collection of elements and units selected by a specific method and representing the general subject is referred to as a sample (Ural and Kılıç, 2021). In the next stage, 'Fault Tree Analaysis (FTA)' method, which provides the opportunity to utilise qualitative and quantitative data from risk assessment methods, was used. Fault tree method (FTA) was preferred because it is suitable for the subject of the study and the measures taken for the occurrence or non-occurrence of the situation considered as a peak event can be analysed in detail.

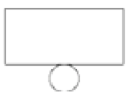
3.1. Fault Tree Analysis (FTA)

Fault Tree Analysis is a type of analysis in which qualitative and quantitative methods are used. There are various stages in creating and calculating the fault tree for the analysis (Erdoğan and Erarslan, 2021). Fault tree analysis method is an effective method to ensure system security. It is an effective method in terms of finding the probability of an undesirable situation occurring in the current situation and the root causes that cause this situation. The fault tree analysis method is a risk analysis method in which the root causes that cause adverse events to occur are presented graphically by combining various sequential and parallel events (Ak and Zorluer, 2022). It can be considered as a comprehensive visualisation of the deductive method.

The risk analysis method, which was developed by various communication companies in 1962 and later developed by Boeing as a qualitative and quantitative analysis technique, became widespread after 1970 and has become the most preferred method today. The fault tree method, which is shaped by logical diagrams, shows the relationship between system failures. The process, which starts by considering a faulty situation, accidents or an undesirable situation as the main event, examines the different components of the problem by considering them as the main event (Erdoğan and Erarslan, 2021; Özkılıç, 2005).

In fault tree risk analysis, after the problem, problem or event to be solved is determined, the peak event should be determined. The peak event refers to undesirable situations in the system. The causes that may cause or be thought to cause these situations are associated with both the peak event and each other and a fault tree is created with the logic gates used in the fault tree method. If there are sub-causes of the causes associated with the peak events, the fault tree structure is expanded by adding logic gates. The event subject handled in the fault tree, that is, the basic events that may cause the peak event, are determined and added to the tree structure. A basic event is an event that occurs without any other cause other than itself. The tree is completed by identifying all basic events involving risk. In the fault tree, calculations are started from the bottom and proceed upwards. The main connection gate is mostly made using AND and OR gates. All other gates are special cases of AND and OR gates. The connection gates used in the fault tree method are shown in Tables 1 and 2 (Ak and Zorluer, 2022). In this study, fault tree risk analysis method is preferred because it provides simple methods for understanding the faults and facilitates the solution, it is effective in improving the understanding of the problem due to the cause and effect relationship, and it saves resources and time because it is easily adaptable to continuous updates.

Table 1. Gates and Symbols Used in Fault Tree Risk Analysis Method (Ak and Zorluer, 2022; Vesely, Dugan, Fragola, Minarick and Railsback, 2002).

Event Symbols	
	Basic (Simple) Event: A basic event that does not require development

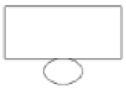
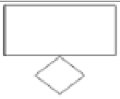
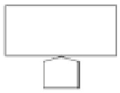
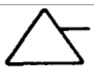
	Situational Event: The existence of specific conditions and constraints that pertain to the utilisation of logic gates (in conjunction with 'preempt' and 'prioritise and' gates).
	Undeveloped Event: An event that cannot be developed further due to an inadequate outcome or a lack of available information.
	External Event: Event expected to occur
Gate Symbols	
	AND - Output fault occurs if all of the input faults occur
	OR - Output fault occurs if at least one of the input faults occurs
	Combination Gate: An output error will occur if n of the input errors occur.

Table 2. Gates and Symbols Used in Fault Tree Risk Analysis Method (Ak and Zorluer, 2022; Vesely et al., 2002).

Gate Symbols	
	EXCLUSIVE OR - Output fault occurs if exactly one of the input faults occurs
	PRIORITY AND - Output fault occurs if all of the input faults occur in a specific sequence (the sequence is represented by a CONDITIONING EVENT drawn to the right of the gate}
	INHIBIT - Output fault occurs if the (single} input fault occurs in the presence of an enabling condition (the enabling condition is represented by a CONDITIONING EVENT drawn to the right of the gate}
Transfer Symbols	
	TRANSFER IN - Indicates that the tree is developed further at the occurrence of the corresponding TRANSFER OUT (e.g., on another page)
	TRANSFER OUT - Indicates that this portion of the tree must be attached at the corresponding TRANSFER IN

Firstly, the problem area that will replace the main event is determined. In this way, the factors causing the main event are limited and the main branches of the fault tree are started to be formed. The fault tree is created using the gate and event symbols used in Tables 1 and 2. Then, the probability calculation of the tree created by using 'Booleon Mathematics', which gives the fault tree the feature of being quantitative, is calculated within the scope of statistical data. The values calculated as a result of this mathematical method are classified and the results are evaluated. Possible problem areas and deficiencies or weaknesses of related events are determined. In general, by statistically determining the problem areas of the main event in this way, the effective cause of the occurrence of the main event is determined and it is ensured to focus on the solution of this problem. The frequently used rules of Booleon Mathematics are given in the table (Ak and Zorluer, 2022).

Table 3. Booleon Mathematics Rules (Ak and Zorluer, 2022).

Define	Rule
Commutative Rule	1a. X•Y = Y•X 1b. X+Y = Y+X
Associative Rule	2a. X•(Y•Z) = (X•Y)•Z 2b. X+(Y+Z) = (X+Y)+Z
Distributive Rule	3a. X•(Y+Z) = X•Y+X•Z X•(Y+Z) = X•Y+X•Z 3b. X+Y•Z = (X+Y)•(X+Z)
Idempotent Rule	4a. X•X = X 4b. X+X = X
Absorption Rule	5a. X•(X+Y) = X 5b. X+X•Y = X
De'Morgan's theorem	6a. (X•Y)' = X'+Y' 6b. (X+Y)' = X'•Y'

When using the AND gate, the data of the events in which it is used are written horizontally in the matrices created and the data are multiplied with each other and transferred to the upper gate. When the OR gate is used, the calculation is made with the result of the sum of the subevents in the use of the gate and the data is written vertically to the matrix in the part where this gate is used. An example fault tree application is shown in Figure 2.

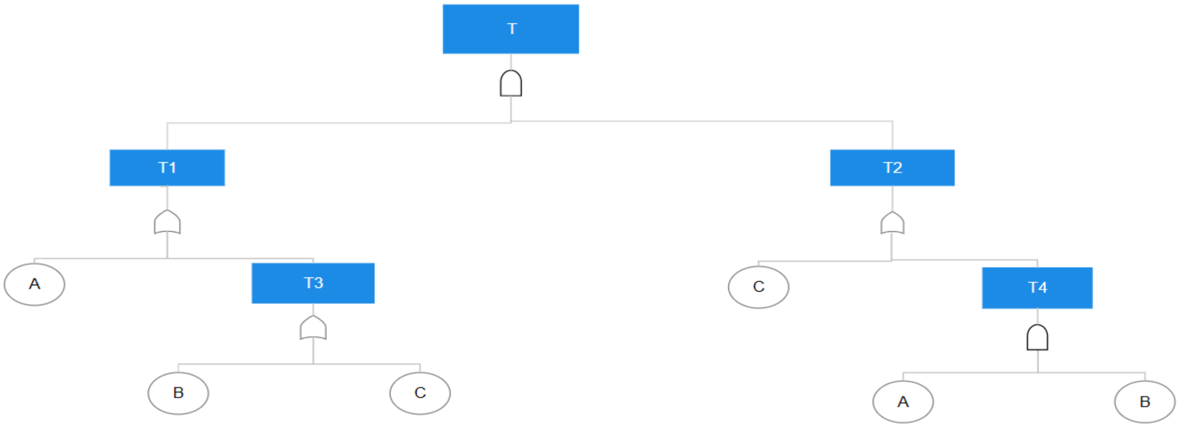


Figure 2. Example Fault Tree Application.

T4 = A . B (1)
T3= B+C (2)
T1 = A + T3 = A + (B + C) (3)
T2 = C + T4 = C + (A . B) (4)
T = T1 + T2 = (A + B + C). [C + (A . B)] (5)
T= (A + B + C) . C + (A + B + C) (6)
T = A . C + B . C + C + A . B + A . B + C . A . B (7)

T=C+A.B (8)

The calculations made within the scope of the sample fault tree study are indicated with relations. As a result of the calculations, relation number 8 is obtained. In this context, the finalised reduced fault tree view is shown in Figure 3.

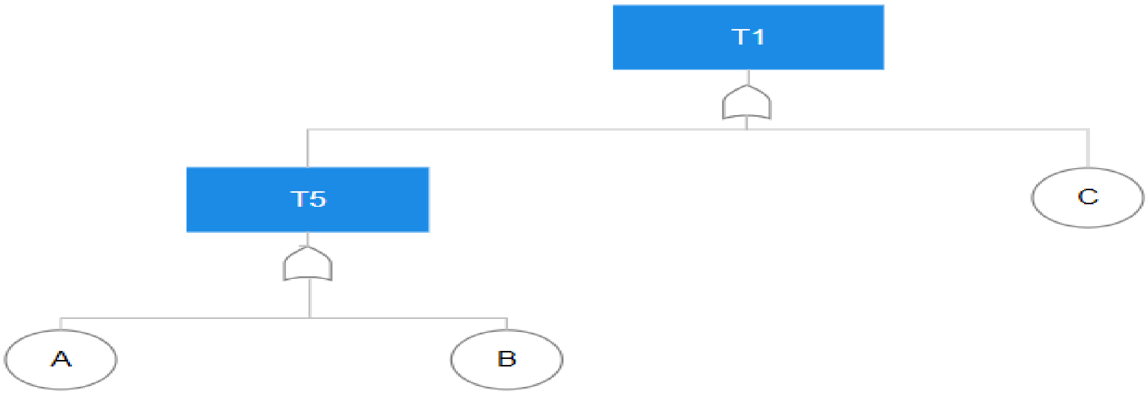


Figure 3. Reduced Fault Tree

4. Application

In the study, the data obtained through content analysis regarding grounding, which is one of the most prevalent types of maritime accidents, was organized and presented in tabular form. Ship names and information were not given in the table, instead "Ship-1, Ship-2, ..." were used. Accidents that resulted in grounding of ships due to various reasons were analysed and content analysis was conducted on Ship-1(UDHB, 2011), Ship-2 (UDHB, 2016), Ship-3 (UDHB, 2015), Ship-4 (UDHB, 2011), Ship-5 (UDHB, 2016), Ship-6 (JTSB, 2015), Ship-7 (JTSB, 2017), Ship-8 (JTSB, 2017), Ship-9 (JTSB, 2018), Ship-10 (JTSB, 2021), Ship-11 (JTSB, 2022), Ship-12 (JTSB, 2023), Ship-13 (JTSB, 2024), Ship-14 (BMA, 2017), Ship-15 (BMA, 2018), Ship-16 (DTO, 2017), Ship-17 (URL-2, 2015), Ship-18 (URL-1, 2024), Ship-19 (URL-3, 2023) and Ship-20 (UDHB, 2017). Within the scope of the analysis, information about the accident date, ship condition, personnel injuries and losses, environmental pollution and type of failure are given in Table 4.

Table 4. Analysis of the Accidents Investigated in the Study.

Ship Name	Accident Date/ Ship Condition	Personnel Injuries and Losses	Environmental Pollution	Type of Failure
Ship-1	2011/ Anchored	-	-	Meteorological Conditions
Ship-2	2015/ Underway	-	-	Meteorological Conditions
Ship-3	2012/ Underway	2 Dead	-	Meteorological Conditions

		1 Injured		
Ship-4	2010/ Anchored	1 Dead	-	Meteorological Conditions
Ship-5	2014/ Underway	-	-	Human Error
Ship-6	2014/ Underway	-	-	Human Error
Ship-7	2016/ Underway	-	-	Human Error
Ship-8	2017/ Underway	-	-	Engine Failure/Meteorolog-ical Conditions
Ship-9	2017/ Underway	-	-	Engine Failure/Meteorolog-ical Conditions
Ship-10	2019/ Underway	-	-	Human Error
Ship-11	2020/ Underway	1 Injured	-	Engine Failure/Meteorolog-ical Conditions
Ship-12	2020/ Underway	-	-	Human Error
Ship-13	2023/ Underway	-	-	Meteorological Conditions
Ship-14	2017/ Underway	-	-	Human Error
Ship-15	2018/ Underway	-	-	Human Error
Ship-16	2015/ Underway	-	-	Human Error
Ship-17	2015/ Anchored	-	-	Meteorological Conditions
Ship-18	2024/ Underway	-	-	Engine Failure
Ship-19	2023/ Underway	-	-	Engine Failure
Ship-20	2017 Underway	-	-	Human Error

4.1. Fault Tree Analysis Application

As a result of the accident reports analysed and the literature research, the fault tree diagram formed by the main and intermediate causes of grounding of the ships is shown in Figure 8.

The main factors causing accidents were determined as human error, deficiencies in deck equipment, environmental factors and technical failures. Each main factor was analysed and calculated and the probability values are presented in Table 6. In the analyses, the probability of occurrence of each intermediate factor affects the probability of occurrence of the main factors. Among all ship accidents, since the causal factors of grounding accidents are different in each case and they are a series of causes that affect each other, a way of calculating the probability by dividing a factor causing grounding by the total number of cases was not preferred (Erdoğan and Erarslan, 2021). In this study, the probabilities of the intermediate factors were determined with the Probability Scale shown in Table 5, which is preferred as a reliable method and has been proven to be usable in various scientific studies. At the same time, according to the Japanese Transport Safety Board (JTSB) data, it was determined that 33 of the 99 marine accidents reported in the first 3 months of 2024 were of the grounding type (JTSB, 2024). In this context, calculations were made by taking into account the values specified in the probability scale since various factors are effective in this type of accident.

Table 5. Probability Scale (Ak and Zorluer, 2022).

Probability	**Frequency of Realisation**
1 in 10 cases	Very Often
1 in 100 cases	Often
1 in 1000 cases	Sparse
1 in 10000 cases	Very Little
1 in 100000 cases	Rarely
1 in 1000000 cases	Very Rarely

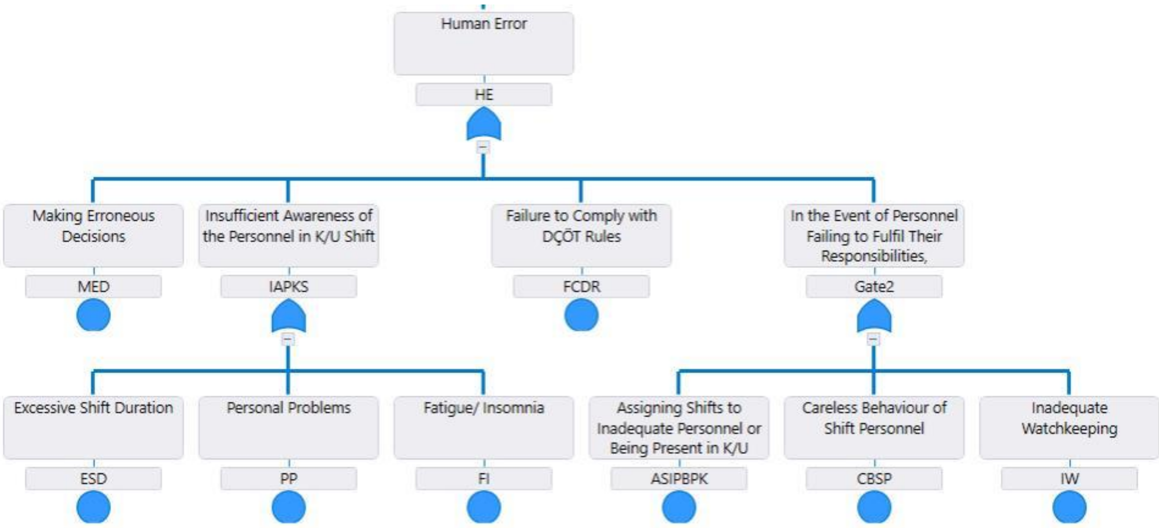
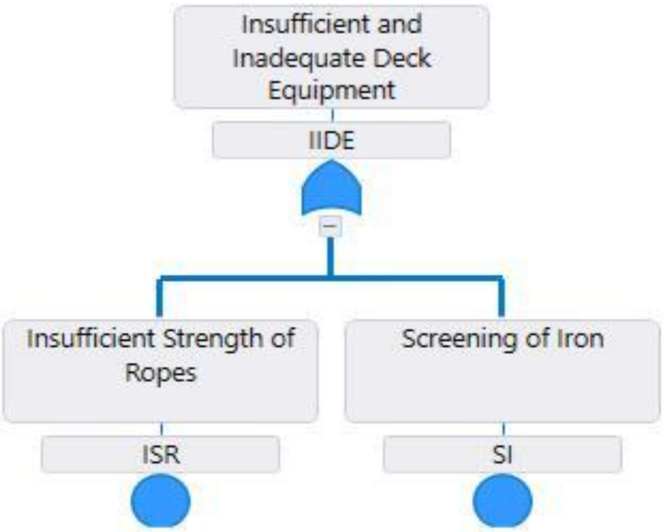


Figure 4. Fault Tree Human Error Cross Section.

Human error is a very powerful criterion in grounding accidents. The fault tree template created under this main heading is shown in Figure 4. Basically, accidents occur as a result of wrong decisions and practices, due to reasons such as lack of information and carelessness. In the aftermath of accidents in particular, the human impact is emphasised in order to determine the causes of the incident. In particular, human activities such as the intensity of the shift duration, the operations carried out during the shift change, the captain's instructions in the night log are the first elements to be examined after the accident. Secondly, one of the conclusions that can be drawn from the reports analysed is that accidents occur as a result of incorrect decisions and operations when personnel who are still in their probationary period or have little experience are given more responsibility than their position allows. This problem is based on the lack of knowledge or the lack of knowledge of the area of application of the knowledge due to the lack of navigation experience. Looking at the criterion of human error as a cause of accidents, it can be seen that it is generally due to a lack of responsible behaviour. In this context, the intermediate factors of the main factor of human error have been determined by considering this situation.

Figure 5. Failure Tree for Deck Equipment Cross Section.

In the context of the accident reports examined, the cross section of the fault tree under the main cause of deficiencies in deck equipment is shown in Figure 5.



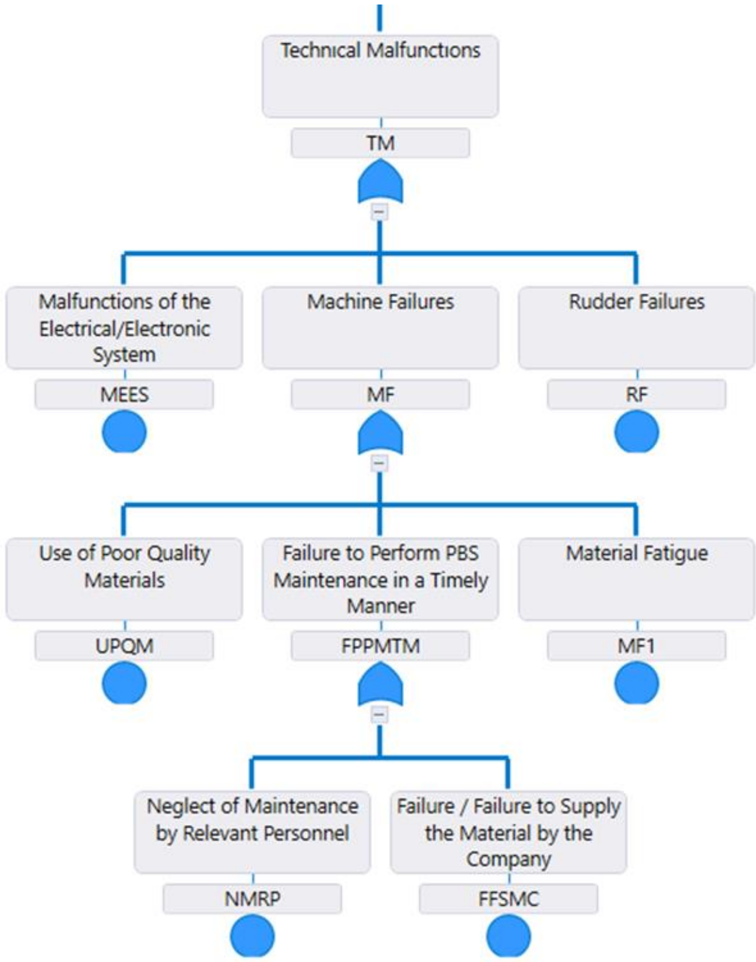


Figure 6. Fault Tree Technical Failures Cross Section.

Apart from grounding, technical failures are one of the causes of accidents in all conditions. The fault tree diagram created under the main heading of technical failures is shown in figure 6. Apart from grounding, technical failures during navigation may prevent the ship from completing the navigation safely. For this reason, technical failures can be considered the most risky type of failure for ship safety after human error. While such accidents can occur for many reasons, human error is indirectly effective for reasons such as failure to implement Planned Maintenance Systems (PMS), use of poor quality materials and use of faulty materials. It is believed that the rate of technical failures can be reduced by carrying out repairs on time and using more innovative products instead of end-of-life materials.

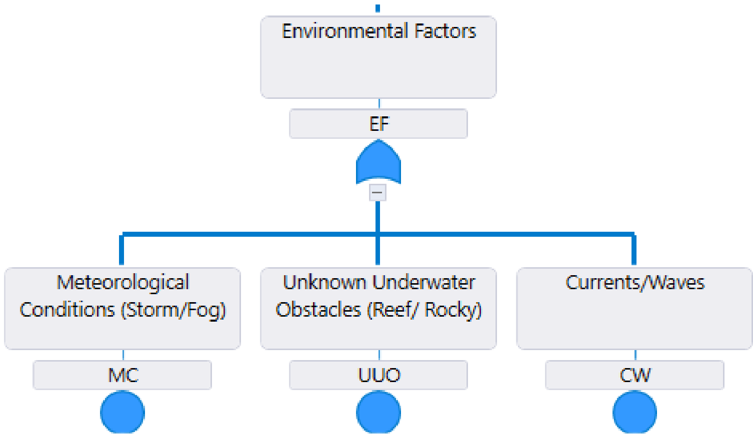


Figure 7. Fault Tree Environmental Factors Cross Section

The fault tree diagram for the environmental factors involved in ship groundings is shown in Figure 7. From the accident reports examined, it was found that meteorological events, under-water obstructions and unpredictable currents cause grounding type accidents.

The grounding of ships was analysed by constructing a fault tree with 4 main sections in the accident type. From the accident reports examined and the literature review, it was found that the majority of accidents are due to human error. The general view of the fault tree generated by the root cause analysis is shown in Figure 8. The analysis was calculated using "Booleon Mathematics" and as a result the probabilities of the main sections were determined. As a result of the analysis, the probability values are presented in Table 6 and it is determined that human error is more effective than other sections. This is followed by the probability of the technical failure criterion, which plays the second most effective role in accidents. In addition to the accident events, the causes of the accident events in the maritime history were also effective in determining the criteria of the analyses made by dividing into 4 main branches in the accident type of grounding of ships. In future studies, it is expected that the tree can be further developed in the problem areas of human error and technical failures, which are more likely to occur than other intermediate sections.

Table 6. Probability Values Obtained as A Result of Fault Tree Analysis.

Main Cross Section Event	Probability
Human Error	0,008
Deck Equipment	0,002
Technical Failures	0,006
Environmental Factors	0,003

Crewing with experienced personnel or with personnel who have received good training can ensure safer navigation. From a technical point of view, it is important to carry out timely maintenance of the ship's machinery and to carry out surveys such as hull inspections, including points that cannot be overlooked. Whether classified as a collision or a grounding, the Prestige is an example of a major accident and environmental pollution caused by technical negligence combined with meteorological conditions. At the same time, it was a turning point in the maritime industry, where groundbreaking decisions were taken and implemented. The fault tree for ship groundings is shown in Figure 8 with its main factors and sub-causes as a whole.

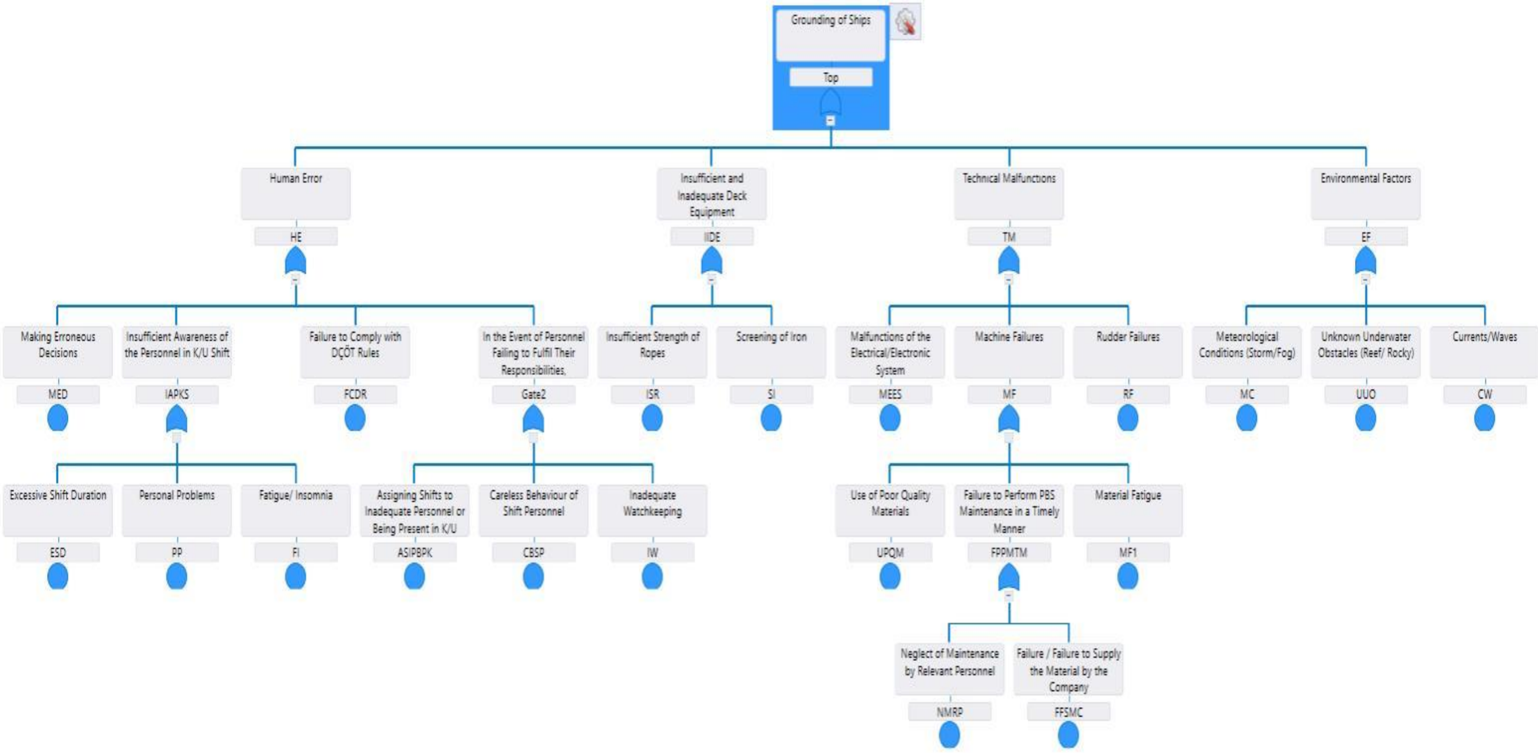


Figure 8. Fault Tree Analysis of Ship Grounding Accident Types.

5. Discussion and Conclusion

Within the scope of the study, ship grounding accidents between 2010 and 2024 were analysed. As a result of the examination of 20 accidents, 6 incidents were classified as meteorological conditions, 9 incidents as human error, 2 incidents as machinery failure and 3 incidents as both meteorological and machinery failure. It is seen that grounding is the leading type of marine accidents examined by EMSA and many other international organisations. When the accident reports were analysed and as a result of the cause analysis application used in the fault tree application, four root causes were found. It has been evaluated that the most common root causes are human error, drifting of ships, machinery failures and meteorological conditions. Among the root causes, it was determined that accidents occurred mostly due to the carelessness, inexperience, lack of awareness and wrong decisions of the personnel. For these reasons, human error is considered as the first factor causing grounding accidents. The second most common situation is the accidents caused by adverse meteorological conditions. Within the scope of the analysed reports, the inability of the vessels to withstand the waves caused some accidents. This situation suggests that the necessary maintenance and controls of the ships were not carried out on time. In this context, it can be considered that human error is partially involved in meteorological reasons. In addition, not having enough information about the geographical area to be navigated or not taking timely action caused such accidents. In the reports, it was observed that groundings caused by machinery malfunctions were frequently experienced. Especially in more risky areas such as narrow canals and straits, it was determined that machinery failure occurred one after another and as a result, the vessels ran aground. Since the fault tree method proceeds with a deductive point of view, the tree integrity was formed by searching for causality with the root causes determined. It is one of the important outputs of the study that this type of accident, in which the human factor is very effective, is one of the most common types of accidents, although the rate of serious injury accidents is low.

The fault tree model obtained as a result of the study allows better analysis of accidents and visualisation of the causes as a whole. The fault tree method with its deductive method and causality is very convenient in accident analysis studies. The impact of ship accidents in the maritime sector is quite large in every sense. For this reason, it is a necessity to evaluate ship accidents with various analysis methods, to determine the missing and critical points and to produce solutions. For this reason, examining different types of accidents and conducting new studies that will contribute to the safe operation of ships by using different risk analysis methods will contribute to the sector and the literature.

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