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Analysis of Collision Accidents in Maritime Transportation by FTA Method

Deniz Taşımacılığında Çatışma Kazalarının Hata Ağacı Analiz Yöntemi ile Analizi

Türk Denizcilik ve Deniz Bilimleri Dergisi

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ABSTRACT

The aim of this study is to determine the possible causes of collision accidents by using Fault Tree Analysis (FTA). In this study, we were able to examine the potential cause of collision accidents, then develop a fault tree model of the root causes of the accidents using the FTA approach, and finally provide the probability of basic event combinations leading the occurrence of accidents. A total of 62 collision accident reports providing detailed information about the causes of accidents were obtained by Marine Accident Investigation Branch (MAIB) between 2005 and 2020.The study found that most of the factors (E_1/Misuse of navigational tools, E_3/COLREG Rule-5 (Look-out)) that had the greatest effect on the collision were mainly due to the inadequacy to keep a safe navigation watch. For that reason, the findings of the study are very important in terms of determining the strategies to eliminate the risks for future accident prevention. For future studies, it should collect more accidents data on varying types of ships to improve their prediction performance, incorporate expert opinions with fuzzy evidence into the model to minimize uncertainties, and enhance model expressiveness. In addition, alternative risk assessment methods should be applied considering other types of vessels for better comparisons.

Keywords: Accident analysis, Collision, Fault Tree Analysis, Marine accident

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ÖZET

Bu çalışmanın amacı, hata ağacı analizi (FTA) kullanılarak çatışma kazalarının olası nedenlerini belirlemektir. Bu çalışmada, ilk olarak çatışma kazalarının olası nedenleri belirlendi, ikinci olarak, FTA yöntemi kullanılarak kazaların kök nedenlerine ait hata ağacı modeli oluşturuldu ve son olarak, kazaya neden olan temel olay kombinasyonlarının olasılığı hesaplanmıştır. Deniz Kazaları Araştırma Şubesi (MAIB) tarafından 2005-2020 yılları arasında kazaların kök nedenleri hakkında detaylı bilgi veren toplam 62 adet çarpışma kazası raporu alınmıştır. Çalışmanın sonucunda, gemilerin çatışma riski olasılığına en büyük etkiye sahip olan faktörlerin ((E_1/Seyir ekipmanlarının yanlış kullanımı, E_3/COLREG(Denizde Çatışmayı Önleme Tüzüğü) Kural-5 (Gözcülük)) esas olarak emniyetli bir seyir vardiyası tutma yetersizliğinden kaynaklandığı tespit edilmiştir. Bu nedenle, çalışmanın bulguları gelecekteki kazaların önlenmesi açısından riskleri ortadan kaldıracak stratejilerin belirlenmesi adına oldukça önemlidir. Gelecekteki çalışmalar için, tahmin performanslarını iyileştirmek adına çeşitli tipteki gemiler hakkında daha fazla kaza verisi toplanmalı, belirsizlikleri en aza indirgemek için uzman görüşlerini bulanık kanıtlarla modele dâhil edilmeli ve modelin anlamlılığı artırılmalıdır. Ayrıca daha iyi karşılaştırmalar için farklı gemi türleri de dikkate alınarak alternatif risk değerlendirme yöntemleri uygulanmalıdır.

Anahtar Kelimeler: Kaza analizi, Çatışma, Hata Ağacı Analizi, Deniz Kazaları

1. INTRODUCTION

Shipping plays an important role in representing more than 90% of global trade by huge cargo volumes cost-effectively, cleanly, and efficiently (Chen *et al*., 2019; UNCTAD, 2019). On the other hand, maritime transport is one of the hazardous industries because of entails a variety of accidents such as collision, grounding, fire etc. (IMO, 2019; Du *et al*., 2020). Marine accidents not only threaten the lives of crew members but also cause major economic losses and property destruction, thus causing severe negative impacts in coastal countries on the marine ecosystems (Chang *et al*., 2014; Chen *et al*., 2019). Despite significant attempts to ensure maritime safety through different systems, there is still an increase in the number of dangerous accidents that make safety and environmental concerns (Eliopoulou *et al*., 2016; Kececi and Arslan, 2017). As a result, maritime safety has become a growing concern.

According to AGCS (Allianz Global Corporate & Specialty) (2021) Safety and Shipping Review reports that 2,815 incidents in total including 41 total losses vessels over 100GT has occurred. The report shows that sinking and collision accidents are the most expensive cause of loss for insurers, accounting for 16% of the value of all damages - more than $ 1.5 billion. Data from European Maritime Safety Agency (EMSA) between 2014 to 2019 distribution of casualty events per cargo ship type report states that collisions represent 22.6% of all events, followed by contacts (18%) and loss of propulsion power (17%). Another report in 2020, 706 marine accidents were reported to the Japan Transport Safety Board (JSTB). The most frequent types of marine accidents in 2020 were collision (27.4%), grounding (22.8%), and contact (13.5%). Machinery and propulsion failure (76.6%) are leading factors to cause accidents. For this reason, the collision accidents are among the most frequent marine accidents, and ongoing attempts have been made to avoid this issue or minimize the consequences.

Analyzing marine accidents is one of the effective ways to reduce maritime safety risks (Fan *et al*., 2020). It is important to identify the reasons that contribute to the ship accidents in order to deter such accidents from happening in the future (Luo and Shin, 2019). Because accident risk avoidance is important not only for protecting human life and the environment, but also for mitigating financial costs (De Maya *et al*., 2020). The review on marine accident analysis clearly states that the current approaches have just targeted specific causes (human error, technical failure, etc.). However, the occurrence of marine accidents commonly depends upon different failures in a variety of safety barriers (Wang *et al*., 2021). For this reason, it is important research domain the determine causes of accidents for the purpose of improving safety and prevent future accidents. The principal focus of this paper is to present an analytical framework based on a fault tree analysis (FTA), which proposes interpreting the probability and importance of leading factors to ship collision accidents.

Within this concept, the aim of this study is to determine the factors associated with collision accident probability based on the Marine Accident Investigation Branch (MAIB) database using Fault Tree methodology. The rest of the paper depicts as follows. Section 2 describes the research gap based on literature review about marine accident severity, which is mostly dependent on FTA applications. An ordered Fault Tree analysis and the data for the study are introduced in Section 3. Section 4 presents the findings of the risk factors and analyses a total of 62 collision accidents between 2005 and 2020. The final section summarizes the study's conclusion and discussion.

2. LITERATURE REVIEW

Marine accidents have affected and changed the shipping industry from its origin, informing regulators, designers and operators that better action is needed to avoid similar consequences (Eliopoulou *et al*., 2016; De Maya and Kurt, 2020). Despite the maritime industry adopting new regulations and rules or a range of safety-enhancing measures, marine accidents remain a major concern (Zhang *et al*., 2021).

Many researchers have varying approaches and perspectives on the factors that influence marine accidents, but it is widely accepted that defining a root cause of accidents is a systematic research method influenced by many factors such as geographical factors, human factors, or any technological failure (Arslan *et al*., 2018; Chen *et al*., 2019). Lu and Tsai (2008) and Eliopoulou *et al*. (2013) state that the impact of the safety climate is leading root cause of crew fatality rate on container ship accidents. Yip *et al*. (2015) and Puisa *et al*. (2018) examined the passenger vessels collision accidents severity and the role of the broader socio-technical environment in accident causation. According to Wang and Yang (2018), the ship type and date of built were the most important factors affecting accident occurrence. Other significant findings from Zhang (2019) indicate that approximately 80% of collision and grounding accident causes include at least human failures or controversial judgments, and approximately 20% are subject to technical errors.

Maritime transportation entails a variety of risks because of the requirements of the profession, which might have serious implications (Zhang *et al*., 2021). In order to mitigate the risks on any operations onboard and improve maritime safety, Risk variables must be reduced to an acceptable level (Goerlandt and Montewka, 2015). The risk can be characterized as a function of the likelihood of a hazard/failure occurring and the severity of the consequences (Akyuz *et al*., 2020). One of the most effective ways to identify and reduce the hazards of marine transportation, as well as determine the most potential strategies to manage the risk, is to do a risk assessment (Zhang *et al*., 2016; Kuzu *et al*., 2019). Until now, research about ship collision risk management has concentrated on (a) empirical and (b) probabilistic risk analysis models (Zhang *et al*., 2021). Research on collision accidents primarily has used accident causality theory, statistical analysis, and methods to examine accident occurrence mechanisms and to determine contributing factors on the basis of accident statistical data and professional judgment (Zhang *et al*., 2019). Fault Tree Analysis (Antao and Soares, 2006; Ugurlu *et al*., 2015, Arslan *et al*., 2018), Bayesian Networks (Hänninen and Kujala, 2012; Chen *et al*., 2015; Wang and Yang, 2018; Aydın *et al*., 2021), Spatial analysis (Rong *et al*., 2021; Zhang *et al*., 2021) and Event Trees (Papanikolaou *et al*., 2007; Arici *et al*., 2020) methodologies are all common modeling tools for risk assessment of ship collision accidents. These methods are useful for determining the risk of a collision in a certain maritime area.

Antao and Soares (2006) investigated the possible dangers of accidents that may arise from

RoPax ships and the role of human error in accidents based on FTA methodology. Failure of radar and propulsion system is the highest probability contributions to the top event. Papanikolaou *et al*. (2007) conducted a fault tree and event tree accident analysis by determining the possibility of reasons that caused environmental pollution and economic losses in Aframax tanker accidents. Of these, navigational failure and failure of avoidance manoeuvring are the major reason of occurrence of collision accidents. Hänninen and Kujala (2012) proposed Bayesian Belief Networks methodology to analyze probability of the impact of human factors on ship collision accidents in the Gulf of Finland. Chen *et al*. (2015) suggested Bayesian Network and FTA analysis together to reveal the possibility of marine accidents based on traffic flow and historical data in Shenzhen waters. Failure of manoeuvring, human error and meteorological factors are the initial events of the risk of collision accidents. Ugurlu *et al*.'s (2015) paper on fault tree analysis of collision and grounding accidents discusses main causes of oil tanker accidents. Human failure, error of procedure and the lack of communication failure are the main reason of occurrence accidents between 1998 and 2010. Arslan *et al*. (2018) calculated the probability of three different accident type. Human error, lack of training and lack of skills failure are the highest contribution of probabilities. Guan *et al*. (2018) presented a fault tree model to analyze fire and explosion accident based on Chinese inland dual fuel ships. In general, the outcome of a collision accident (i.e. human life loss, property damage cost) is influenced by a number of factors, including the type of a ship, environmental conditions, accident periods, navigational stations, accident location, human mistake, and so on. The fault tree analysis method allows a deeper examination of the internal links between the top event in the system and all the basic events that caused the top event, and also has the advantage of allowing a better understanding of the system in light of the conditions that caused the accident. Based on the benefits listed below, this article applies the fault tree analysis method to determine the factors affecting ship collision accidents and identify the main factors that ultimately led to the accident (Arslan *et al*., 2018). Assessing and calculating the probability of ship collisions is of great importance as FTA methodology gives a cost-effective and practical way to risk mitigation.

The critical review on collision accident analysis clearly shows that the current methods have targeted certain aspects such as human error, mechanical or technical failure. However, the occurrence of collision accidents commonly depends upon various causes in different parts of safety and navigational obstacles. To focus on this topic, the FTA methodology was used to reveal the probability calculations of causes of ship collision accidents and the main factors affecting them.

3. MATERIALS AND METHODS

FTA is a powerful risk assessment tool that identifies the root causes of top event (Antao and Soares, 2006; Khakzad *et al*., 2011; Arslan *et al*., 2018). It is an inferential and visual technique that is widely used to measure the failure probability of accidents evaluated using Boolean logic. (Ugurlu *et al*., 2015). The basic components of a fault tree can be classified as the top event, primary events, intermediate events, and logical gates (Zhou *et al*., 2017). Figure 1 is presented as a basic fault tree.

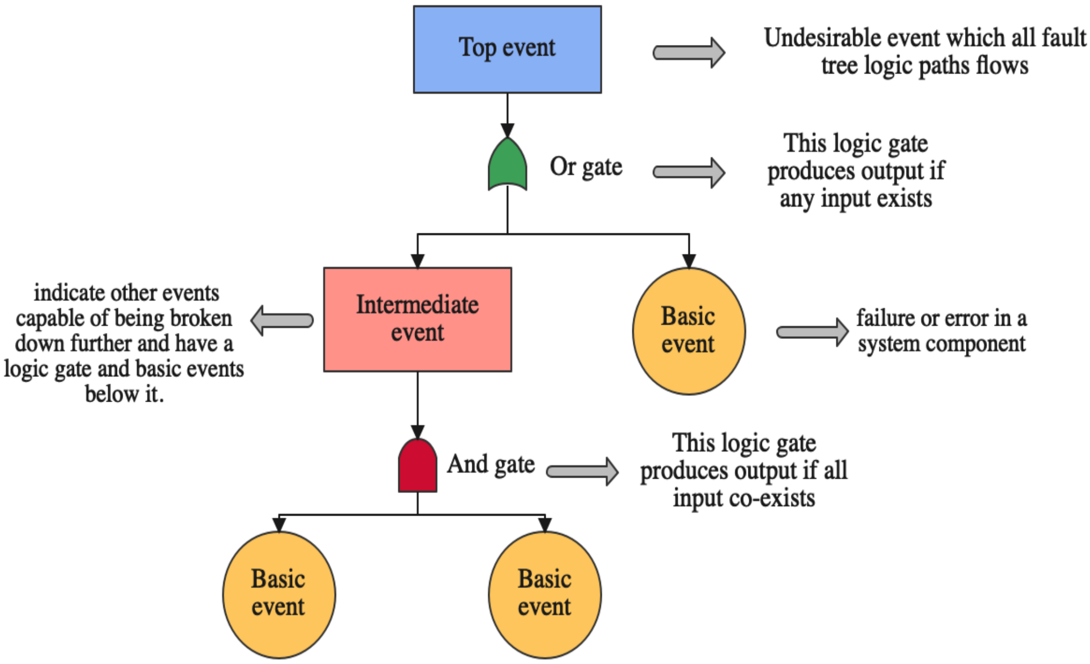

Figure 1. Basic Fault Tree Analysis

The probability of top event is closely related to the basic event failure probability causes in minimal cut sets. To do this, the intermediate event ("AND" or "OR" logic gates) probabilities are determined, beginning at the root of the tree, and progressing until the probability of top event is achieved (Ruijters and Stoelinga, 2015). For an "AND" and "OR" logic gate event, the following equation can be used for the probability of occurrence of a top event (Eq.1 and Eq. 2). Where $\varphi(x)$ represents the top event used to describe the complex system of undesired event; and x_i are basic events of i. "OR" logic gate occurs when at least one input factor occurs, "AND" logic gate occurs when both input factors occur (Zhang *et al*., 2019).

$$\varphi(x) = \sum_{i=1}^{n} x_i = \{x_1 + x_2 + \ldots + x_n\} \quad (1)$$
$$\varphi(x) = \coprod_{i=1}^{n} x_i = \{x_1 \times x_2 \times \ldots \times x_n\} \quad (2)$$

To perform a fault tree, the Open FTA program, which is known a fault tree analysis (FTA) program, has been used for determining the probability of causes in collision accidents. The Open FTA program is in charge of qualitative fault tree analysis to establish minimal cut sets and quantitative fault tree analysis, which includes a Monte Carlo simulation (FSC, 2005).

A total of 62 collision accident reports providing detailed information about the causes of accidents were obtained by Marine Accident Investigation Branch (MAIB) between 2005 and 2020. The MAIB database is responsible for carrying out investigations of all vessels' accidents to determine the causes of accidents at sea and take attempts for improving international co-operation in marine accident investigations (MAIB, 2021).

In this study, the FTA involves two phases: qualitative and quantitative steps. The qualitative step was used in the first part to categorize the accident causes, decide the probability values, and create a logical relationship between the reasons. The second part, the quantitative step, has calculated the minimal cut sets, analyzed the accident occurrence combinations, and presented the importance degree of the basic events causing the accident occurrence (Antao and Soares, 2006; Ruijters and Stoelinga, 2015; Ugurlu *et al*., 2015). To achieve this, a graphic was drawn using the Open FTA, a tool used for fault tree analysis, to explore the relationship between the causes both qualitatively and quantitatively. The main factors that cause collision were classified with reference to the DNV/GL–Marine Systematic Cause Analysis Technique. Initially, the root causes were determined and grouped according to the accident reports received by MAIB, and then the failure probabilities of each case were evaluated with the following equations (Ugurlu *et al.*, 2015):

$$\mathrm{TCAC} = \frac{1}{\mathrm{RC}_1} + \frac{1}{\mathrm{RC}_2} + \cdots + \frac{1}{\mathrm{RC}_n} \quad (3)$$

Where TCAC indicates the total contribution value of cause, and RC1 represents the total number of root causes for the accident of the ship no.1. Also, failure probability of each basic event is calculated by:

$$\mathrm{PVAC} = \frac{\mathrm{TCAC}}{\mathrm{SN} \times \mathrm{TY}} \quad (4)$$

Where PVAC indicates the probability value of the accident cause, SN indicates the number of ships, and TY indicates the total year.

To begin, review MAIB investigation reports from ship collision accidents to determine the fault tree's top event and any relevant contributing events. To finish the diagram, build the basic fault tree diagram and double-check the logical linkages between the underlying events. After the fault tree has been formed, one of the most critical steps in Fault Tree application is to explore all of the basic event combinations, which is both a necessary and sufficient condition for the top event to occur. Minimal Cut Sets are the name for these combinations (MCS) (Antao and Soares, 2006; Ugurlu *et al*., 2015). To compute the probability of a ship collision, the fault tree must first be described using Boolean algebra, which is then simplified to obtain minimal cut sets (Chen *et al*., 2015). The bottom-up and top-down algorithms are two basic aspects for determining minimal cut sets. Each gate is represented as a Boolean expression of basic events and/or other gates in this way (Ruijters and Stoelinga, 2015). Finally, using the recommended solutions for ship collision accidents, calculate and analyze the fault tree's minimal cut sets as well as the structural importance of the underlying events, to find the major causes of the accident. Figure 2 depicts the overall research structure and methodology.

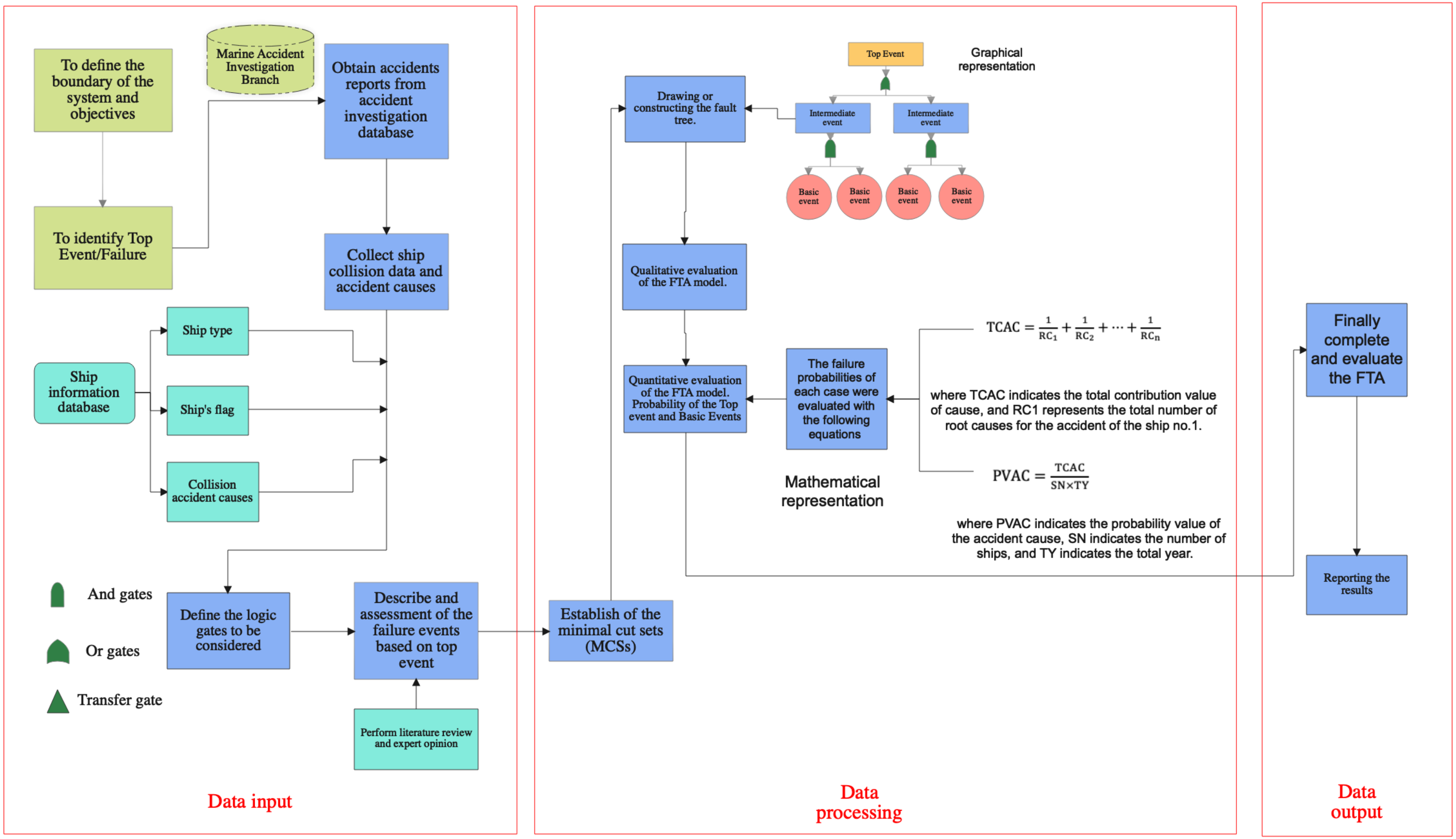

Figure 2. The flow chart of FTA

3.1. Dataset

The limitations of the study are that ships under 100 GRT (Gross tonnage) are not included in the dataset and the root causes are not clearly stated in the accident reports examined. A total of 17 ship collision accident reports are not included in the data set. A total of 62 ship accidents that resulted in collision between 2005 and 2020 were investigated.

According to the 62 accident reports examined, the distribution of ships damaged as a result of the collision by ship types is shown in figure 3. Since ship to ship risks are taken into account in the accident reports collected from MAIB, the data set in the figure was interpreted statistically on 124 data.

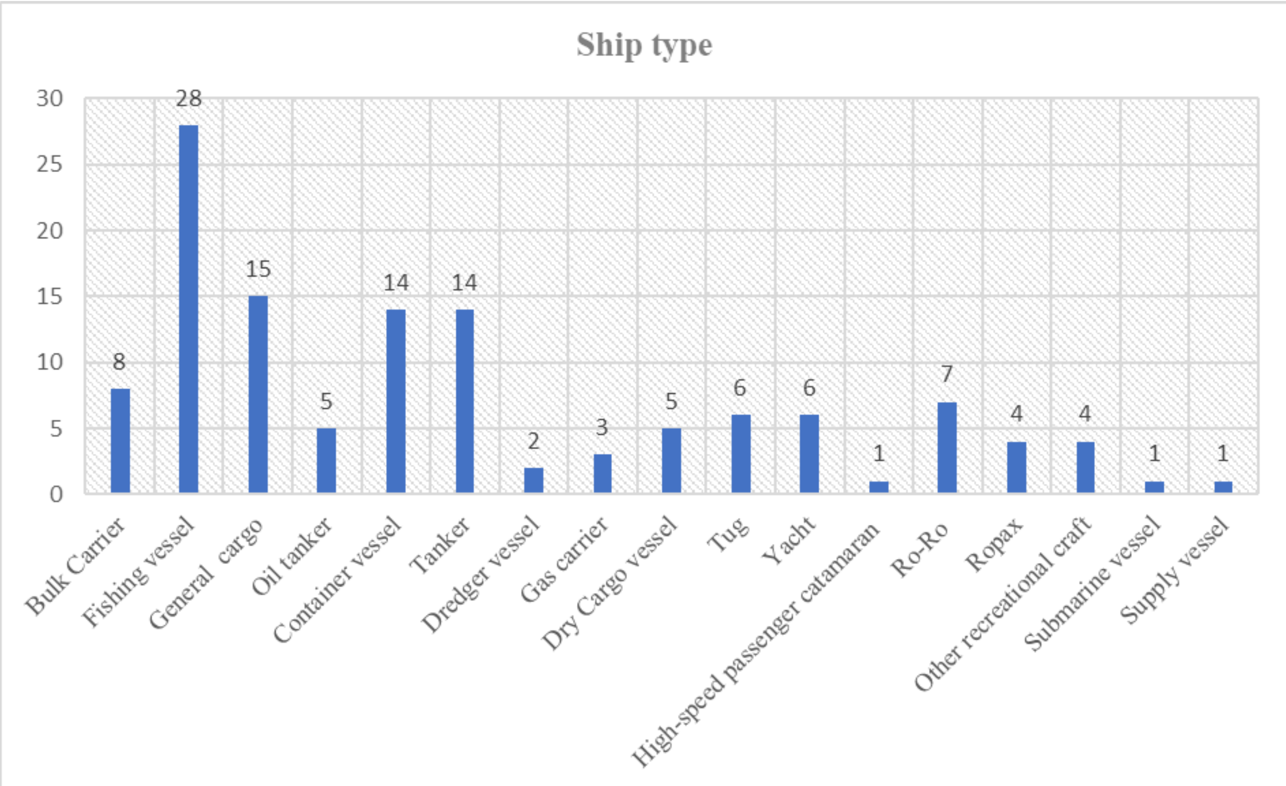

Figure 3. Distribution of collision accidents by ship type

As seen in Figure 3, fishing vessels have the highest accident rate (22.6%), followed by general cargo vessel (12.1%) and container vessels (11.3%). Distribution of collision accidents by ship flag is shown in Figure 4.

As shown in Figure 4., it is observed that the most frequent ship flag on collision accident is United Kingdom (51.6%) and Panama (6.5%). When the flags of the ships that caused the collision accidents were examined, it was determined that they had the flag convenience (FOC) status.

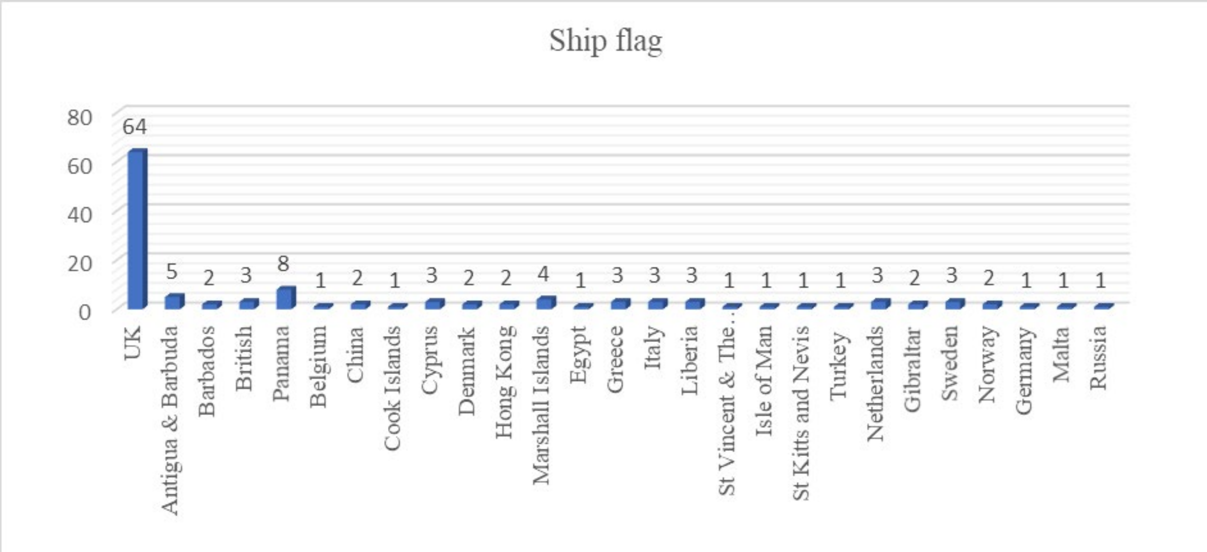

Figure 4. Distribution of collision accidents by ship flag

3.2. Findings

According to the analysis results, collision accidents (X_0-TE/ 0.00033) may occur due to either sub-standard acts or practice (X_1/0.0534) and sub-standard conditions (X_2/0.0061) as indicated in Figure 5. Sub-standard act and practices consist of intermediate causes of failure to follow the procedure (X_3/0.0283), communication failure (X_4/0.0084), and navigation failure (X_5/0.0176), while sub-standard conditions factor is affected by equipment failure (X_6/0.0027) and adverse conditions (X_7/0.0034) factors.

The Violation of COLREG (X_8/0.0158), among the other factors (SMS failure (E_2/0.0044) and misuse of navigational tools (E_1/0.0084)), is the factor that has a dominant influence on the variable of failure to follow the procedure. Also, communication failure may occur due to poor communication (E_8/0.0037), lack of bridge resource management (BRM) (E_9/0.0040) or language barrier (E_{10}/0.0007). Lack of competence is affected by the soft skills (X_{10}/0.0091), including a lack of decision making (E_{15}/0.0007) and situational awareness (X_{12}/0.0084), and hard skills (X_{11}/0.0073) influenced by a lack of knowledge (E_{12}/0.0047), lack of familiarization (E_{13}/0.0013), and lack of training (E_{14}/0.0013). Equipment failure is influenced by the operational failure of critical equipment such as main engine failure (E_{18}/0.0007), tugboat failure (E_{19}/0.0010), and navigational aids failure (E_{20}/0.0010). An adverse condition represents the severe conditions such as extreme sea conditions (E_{21}/0.0027), and heavy traffic (E_{22}/0.0007). Also, on the other hand, navigation failure consists of blind sector (E_{11}/ 0.0013) and lack of competence (X_9/0.0163).

In the view of detailed analysis, the occurrence probability risk of collision accident is found is 3.30E-04 (0.03%). The probability of the top event is computed by utilizing Boolean algebra to apply values to the probabilities of basic events until the top event is achieved. Since the minimal cut sets in the FTA is a set of basic events whose occurrence enables that the top events occur, they must be analyzed and discussed. Table 1 shows the probability distribution calculation of the events in the system. Accordingly, the top event is strongly affected by basic event-1 E1 (Misuse of navigational tools) which has the highest occurrence probability in the system. Following the accident description, FTA was built to explore the root causes of the collision accidents as shown in Figure 5.

Calculating the contribution degree of the basic events that cause accidents is another noteworthy result gained by FTA. A basic event contribution analysis was conducted for this aim performed by

the Open FTA program. According to the analysis results, E1-Misuse of navigational tools (13.8%) and E16-Fatigue (12.71%) have the largest share in the occurrence of collision accidents contribution factors.
A quantitative analysis was used to identify the minimal cut sets for the collision fault tree using Boolean algebra. 85 minimal cut sets were identified as a result of the study. Table 2 represents top ten minimal cut sets combinations. According to the findings, the combinations including extreme sea conditions and misuse of navigational tools are the minimum cut sets when collision accidents are at their highest level. Furthermore, it is seen that fatigue, COLREG Rule-5 (Look out) and Lack of knowledge combinations with extreme sea conditions basic events have a great influence on the occurrence of collision accidents.

Table 1. Probabilities of the components and their contribution on the accident occurrence

EVENT NAME	EVENT NOMENCLATURE	DESCRIPTION	FAILURE PROBABILITY	TOTAL CONTRIBUTION
Top Event	T_E	COLLISION	0.00033	
Intermediate event-1	X_1	Sub-standard act and practice	0.0534	
Intermediate event-2	X_2	Sub-standard conditions	0.0061	
Intermediate event-3	X_3	Failure to follow procedure	0.0283	
Intermediate event-4	X_4	Communication failure	0.0084	
Intermediate event-5	X_5	Failure to navigation	0.0176	
Intermediate event-6	X_6	Equipment failure	0.0027	
Intermediate event-7	X_7	Adverse conditions	0.0034	
Intermediate event-8	X_8	Violation of COLREG (Collision regulation at sea)	0.0158	
Intermediate event-9	X_9	Lack of competence	0.0163	
Intermediate event-10	X_{10}	Soft skills	0.0091	
Intermediate event-11	X_{11}	Hard skills	0.0073	
Intermediate event-12	X_{12}	Situational awareness	0.0084	
Basic Event-1	E_1	Misuse of navigational tools	0.0084	0.1381
Basic Event-2	E_2	SMS failure	0.0044	0.0719
Basic Event-3	E_3	COLREG Rule-5 (Look-out)	0.0074	0.1215
Basic Event-4	E_4	COLREG Rule-6 (Safe speed)	0.0027	0.0442
Basic Event-5	E_5	COLREG Rule-8 (Action to avoid collision)	0.0044	0.0719
Basic Event-6	E_6	COLREG Rule- 22 (Visibility of lights)	0.0010	0.0166
Basic Event-7	E_7	COLREG Rule-35 (Sound signal in restricted visibility)	0.0003	0.0056
Basic Event-8	E_8	Poor communication	0.0037	0.0608
Basic Event-9	E_9	Lack of Bridge Resource Management (BRM)	0.0040	0.0663
Basic Event-10	E_{10}	Language barrier	0.0007	0.0110

Table 1. Probabilities of the components and their contribution on the accident occurrence (continued)

Basic Event-17	E_{17}	Alcohol abuse	0.0007	0.0110
Basic Event-18	E_{18}	Main engine failure	0.0007	0.0110
Basic Event-19	E_{19}	Tugboat failure	0.0010	0.0166
Basic Event-20	E_{20}	Navigational aids failure	0.0010	0.0166
Basic Event-21	E_{21}	Extreme sea conditions	0.0027	0.0442
Basic Event-22	E_{22}	Heavy traffic	0.0007	0.0110
Basic Event-11	E_{11}	Blind sector	0.0013	0.0220
Basic Event-12	E_{12}	Lack of knowledge	0.0047	0.0773
Basic Event-13	E_{13}	Lack of familiarization	0.0013	0.0220
Basic Event-14	E_{14}	Lack of training	0.0013	0.0220
Basic Event-15	E_{15}	Lack of decision making	0.0007	0.0110
Basic Event-16	E_{16}	Fatique	0.0077	0.1271

Table 2. Top ten minimal cut sets combinations

Minimal cut sets combination	**Basic Events**	**Probability values**
Minimal cut set-04	E_1*E_{21}	2.6800E-05
Minimal cut set-79	E_{16}*E_{21}	2.0790E-05
Minimal cut set-14	E_3*E_{21}	1.9980E-05
Minimal cut set-59	E_{12}*E_{21}	1.2690E-05
Minimal cut set-09	E_2* E_{21}	1.1880E-05
Minimal cut set-24	E_5* E_{21}	1.1880E-05
Minimal cut set-44	E_9* E_{21}	1.0800E-05
Minimal cut set-39	E_8* E_{21}	9.9900E-06
Minimal cut set-02	E_1*E_{19}	8.4000E-06
Minimal cut set-03	E_1*E_{20}	8.4000E-06

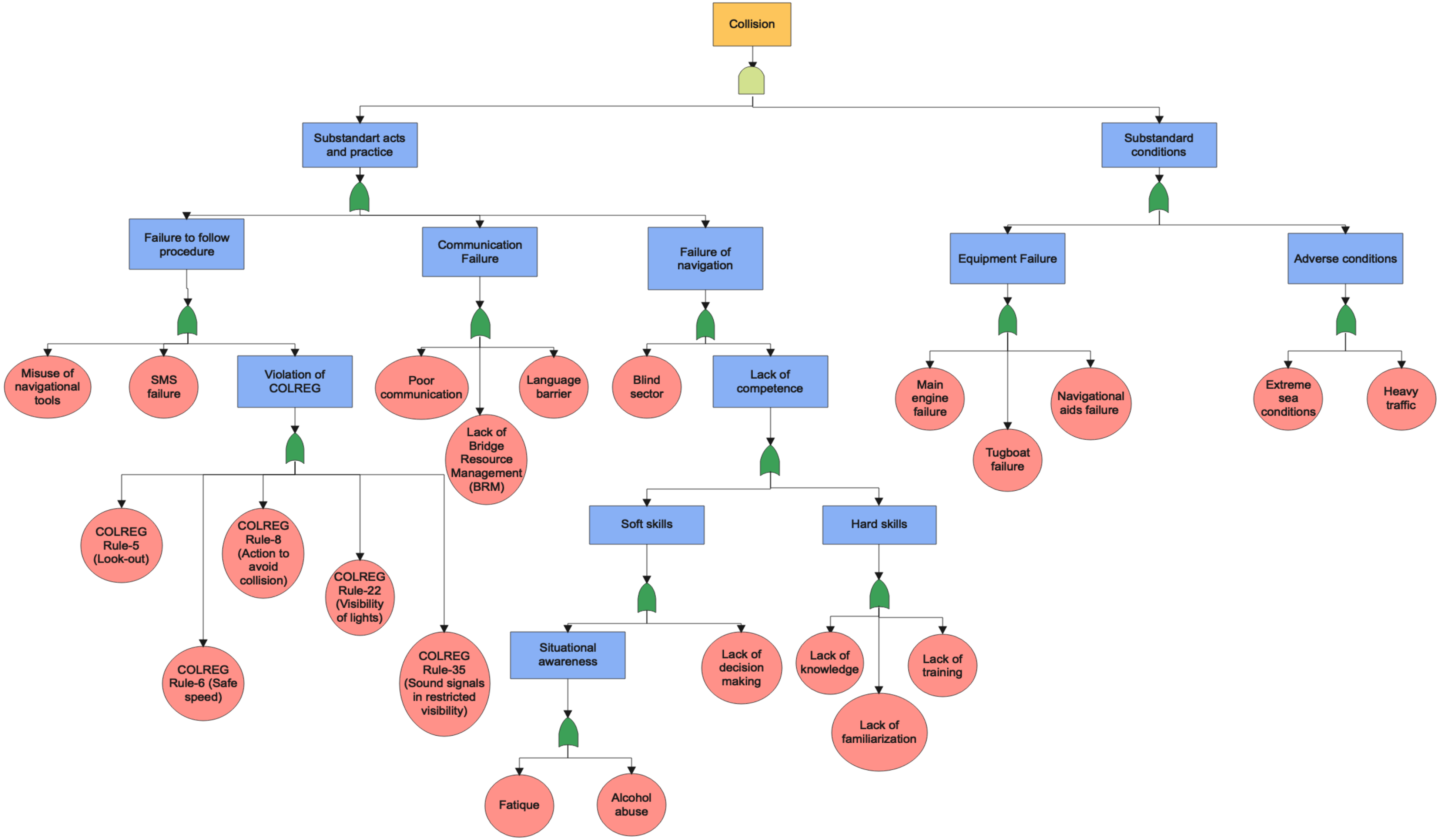

Figure 5. Fault tree of collision accidents

4. DISCUSSIONS

- Our study reveals that the factors associated to safety of navigation (misuse of navigational tools and violation of COLREG Rule-5 (Look out)), which are primarily caused by human error, have the highest impact on collision accidents.
- The findings of the study also show that sub-standard acts and practices including controllable parameters, primarily based on the knowledge, skills, and abilities of the crew, have a much greater impact on collision than sub-standard conditions. In addition, failure of equipment such as tugboat failure, navigational aids, and the main engine are secondary factors responsible for collisions.
- Along with other studies (Antao and Soares, 2006; Ugurlu *et al*., 2015; Chen *et al*., 2015; Akyuz *et al*., 2020) on collision accidents, this study makes a significant contribution to the relevant literature.
- Previous studies (Antao and Soares, 2006; Kum and Sahin, 2015; Ugurlu *et al*., 2015; Chen *et al*., 2015) found human factor to be the most important factor in collision. Parallel to these studies, our study found that navigation based factors which is caused primarily by human error played a crucial role; this result agrees with those of similar risk assessment studies.

This study used a FTA methodology to conduct a risk assessment of collision accidents. Our method is useful for estimating the probability of collision accidents but needs improvement. For example, future studies should (1) collect more data on the collision of ships of all sizes, (2) apply other risk assessment methodologies, (3) gather opinions of experts to minimize the uncertainties of the tree, and (4) consider other types of accidents in other marine regions.

5. CONCLUSIONS

Collision accidents, which account for the majority of very-serious marine accidents, have a catastrophic impact on human life and the environment. Consequently, it is essential to determine the major risks and their level of effect on the accident in order to stop future disasters. To achieve this, FTA was applied to explore the causes of collision accidents and their impact level on the incident occurrence. The findings of the research indicate that sub-standard acts and practice including drivable factors based primarily on crew operational knowledge, expertise and proficiency have a much greater impact on the collision than sub-standard conditions.

The study found that most of the factors (E1/Misuse of navigational tools, E3/COLREG Rule-5 (Look-out)) that had the greatest effect on the collision were mainly due to the inadequacy to keep a safe navigation watch. Thus, the crews' level of proficiency needs to be assessed at regular periods and, if required, the crew should participate in a refreshment course to strengthen their professional skills. In addition to COLREG in Rule 5, The lookout is an essential and vital member of the bridge crew. Many accidents could have been avoided if a well-trained lookout had been onboard. STCW 95 requires that a separate dedicated lookout be retained on the bridge in addition to the watchkeeper at all times throughout the hours of darkness and in busy marine regions when underway. Vessel owners, operators, and masters are responsible for ensuring that personnel involved in the navigation of vessels have a thorough awareness of navigational practices and the COLREGs.

It is the responsibility of policymakers to develop effective navigational safety methods with the goal of reducing human life loss and property damage costs in the event of an accident. Given the limited resources and budgets available, policymakers must prioritize safety practices. This can be accomplished with the help of a thorough grasp of the contributing elements that influence the outcome of a ship collision. Periodic BRM training and communications, the deployment of additional manpower, and regular bridge navigation exercises utilizing simulators are all possible risk reduction strategies. Internal and external information transfer, appropriate usage of marine English, and COLREG should all be part of such safety measures.

Furthermore, fatigue management, one of the other highest basic events, is a very important issue because of the devastating symptoms of

seafarers as poor judgments, slow reactions, poor memory, impaired vision are some of the signs. Fatigue risk management plans must be considered with the purpose of taking a proactive approach to prevention and management and decreasing the risk of fatigue-related accidents. A fatigue risk management plan should guarantee that fatigue information is included in a seafarer's health and safety orientation, that continuing education is incorporated into subsequent refresher training, and that crewmembers are kept informed through routine, weekly or monthly briefing of related topics.
This study makes a significant contribution to the existing literature by examining the subject from a various perspective. This research, in addition to adding to current knowledge, provides essential information to ship operators, allowing them to recognize the hazards associated with the crew's professional competency. As a result, the study's findings are critical in identifying strategies for reducing risks and preventing future accidents.

AUTHORSHIP CONTRIBUTION STATEMENT

Ali Cemal TÖZ: Conceptualization, Methodology, Validation, Formal Analysis, Writing - Original Draft, Software, Visualization, Supervision.
Müge BÜBER: Methodology, Validation, Formal Analysis, Writing - Original Draft, Writing-Review and Editing, Software, Visualization, Supervision.
Burak KÖSEOĞLU: Conceptualization, Writing - Original Draft, Resources, Visualization, Supervision.
Cenk ŞAKAR: Conceptualization, Writing - Original Draft, Resources, Visualization, Supervision.

CONFLICT OF INTERESTS

The author(s) declare that for this article they have no actual, potential or perceived conflict of interests.

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No ethics committee permissions is required for this study

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