INVESTIGATION OF GROUNDING ACCIDENTS IN THE BAY OF IZMIR WITH THE APPLICATION OF ROOT-CAUSE ANALYSIS

ALI CEMAL TOZ [*], CENK SAKAR [*] AND BURAK KOSEOGLU [*]

[*] Dokuz Eylul University Maritime Faculty
Tinaztepe Campus Buca, 35160, Izmir, Turkey
e-mail: ali.toz@deu.edu.tr, cenk.sakar@deu.edu.tr, burak.koseoglu@deu.edu.tr

Keywords: Bay of Izmir, Root-Cause Analysis, Grounding, Ship, FTA.

Abstract

City of Izmir as the third largest city of Turkey, is the opening gate of Anatolia to the world through Aegean Sea. The city with its great volume of cargo capacity plays crucial role both in international and domestic sea trade. The Port of Alsancak located at the inner part of the bay is the largest seaport of Aegean Region in terms of annual loading capacity. The main objective of this research is to find the root-causes of accidents that have resulted in the groundings in Bay of Izmir. To do this, the Root Cause Analysis methodology was carried out on the accidental data provided by Turkish Main Search and Rescue Coordination Center (TMSRCC). Between 2001 and 2016, a total of 24 ships grounded at the entrance of Yenikale due to shallow water conditions, which is regarded as the riskiest point in terms of groundings. In this study, the Fault Tree Analysis (FTA) method which is the one of the most preferred root cause analysis methods was used. As a result, it was found that equipment failures and geographical factors are the main reasons of grounding accidents in Bay of Izmir. In order to eliminate these causes, necessary precautions have been offered and suggestions for further studies have been made.

1 INTRODUCTION

Ship grounding can be defined as a contact of a ship hull with the ground [1]. Grounding of ship is a type of accident that can cause destructive secondary consequences such as sinking of the ship, fire/explosion and environmental pollution [2]. Groundings and fires on board are the dominant types of shipping accidents worldwide. Between 1990 and 2013, the second most important cause of ship accidents, which resulted in total loss, is grounding [3]. There are many reasons for the accidents resulting in the grounding of the ships. The main causes of these accidents are human error, equipment failure and heavy weather conditions [2,4,5,6]. In this study, it is aimed to determine the root causes of the ship accidents in Bay of Izmir, where groundings are frequently experienced.

2 LITERATURE REVIEW

In the literature, there are many studies investigating the root causes of ship accidents. [7] carried out a study through Fault Tree Analysis (FTA) method in order to find root causes of collision and grounding of oil tankers. Finally, the factors of "colreg violation and lack of communication" under human error origin have been found the root causes which have the great effects on collision and grounding accidents.

[8] aimed to investigate the potential risks causing accidents in passenger ships (Ro-Pax) and the role of human error in these incidents. In their study, Formal Safety Assessment (FSA) and FTA methods were used to identify hazards and their impact levels on related accidents. Finally, it was resulted that the human error has the highest contribution to the result in ship grounding and collision accidents. [9] used FTA method to investigate root causes of tanker accidents during loading and unloading operations in terminals. They concluded that "failure to comply with operating procedures" and "lack of knowledge" is the most important factors. [10] aimed to construct a fault tree model considering both fires and explosions in a dual fuel ship. [11] carried out a fault tree analysis on ship drift emergency of Three Georges Lock with the method of FTA. They concluded that heavy wave conditions, mechanical failures and improper loading have the highest effects on drifting situation. [12] developed a grounding and collision analysis toolbox (GRACAT) to analyze the probabilities of collisions and groundings in Southeast Texas Waterways. It was found that the probabilities of collisions increase with the increase of the traffic volume and groundings are much more likely to occur than vessel collisions in the area due to the current conditions. [13] used an approach concentrating FTA and event trees analysis (ETA) incorporating The Human Error Rate Prediction (THERP) data to quantify individual errors.

3 MATERIALS AND METHOD

In this study, the FTA method as one of the most commonly used risk assessment technique was carried out to investigate probability of root causes and their impact level on grounding accidents in Izmir Bay.

3.1. FTA method

Fault Tree Analysis (FTA) is deductive risk analysis in which an undesired event is analyzed using Boolean approach to integrate a series of sub events. The FTA method is utilized both for qualitative and a quantitative purpose. Qualitatively it is used to identify the individual scenarios that lead to the top event, while quantitatively the probability of each factor is determined. The main determinants of a Fault Tree are composed by the top event, primary events, intermediate events and logic gates [8]. A simple fault tree is shown in Figure 1.

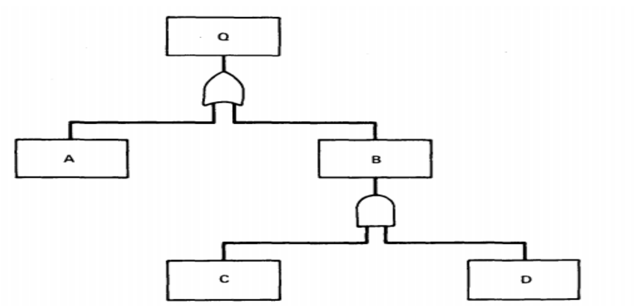


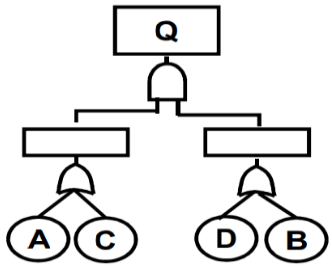
Figure 1: A simple fault tree design
Source: [14]

In this figure, “Q output” is illustrated as a top event. “A” is illustrated as a primary event. “B” is illustrated as an intermediate event. If all of the input faults happen, “And gate” is used between inputs and output. If least one of the input faults happens, “Or Gate” is used between inputs and output [14].

3.1.1 Qualitative analysis

The aim of qualitative analysis is to construct minimum cut sets (MCSs) which are combinations of the smallest number of basic events of the fault tree. The classic fault tree is mathematically represented by a set of Boolean equations as shown below.

Algebraic representation is:
Q = (A∪C) ∩ (D∪B) ∪ or gate ∩ and gate
which can be re-written as:
Q = (A∩D) ∪ (A∩B) ∪ (C∩D) ∪ (C∩B)
Q = (A•D) + (A•B) + (C •D) + (C•B)
which is a listing of Groupings ...each of which is a Cut Set
AD AB CD BC



3.1.2 Quantitative analysis

The quantitative fault tree analysis represents a calculation of the top event probability, equal to the failure probability of the corresponding load. The total contribution and probability values for these root causes were calculated by using the following formulas [9]:

$$TCAC = \frac{1}{RC_1} + \frac{1}{RC_2} + ... + \frac{1}{RCn} \quad (1)$$

TCAC: Total Contribution of Accident Cause
RC_1: A total Number of Root Causes in Ship Accident 1

$$PVAC = \frac{TCAC}{SN \times TY} \quad (2)$$

PVAC: Probability Value of Accident Cause
SN: Ship Number
TY: Total Year

The total contribution rates and probabilities of root causes according to the above formulation are shown in Table 1.

Table 1: Accident causes and frequency of their occurrence

No	Accident Cause	Frequency	Total Contribution	Probability
1	Steering Failure	3	3	8.33E-03
2	Violation of Rules	2	2	5.56E-03
3	Autopilot Failure	1	1	2.78E-03
4	Engine Failure	2	2	5.56E-03

5	Bad Weather Conditions	2	2	5.56E-03
6	Collision Avoidance Maneuvering	2	2	5.56E-03
7	Fatigue	1	1	2.78E-03
8	Alcohol Abuse	2	3/2	4.17E-03
9	Lack of BRM	2	2	5.56E-03
10	Shallow Water Conditions	2	2	5.56E-03
11	Inappropriate Voyage Planning	2	2	5.56E-03
12	Generator Failure	2	2	5.56E-03
13	Lack of attention	1	1	2.78E-03

A total of 13 root causes in 24 grounding accidents between 2001 and 2016 has been determined with the analysis of accident reports provided by Turkish Main Search and Rescue Coordination Center (TMSRCC). In addition, some data not included in the accident reports are provided from the marine pilots working in Izmir Bay.

3.2 Study Site

Bay of Izmir as one of the most important waterway for the oceangoing vessels carrying huge amount of cargo to the Alsancak Port as a seaport integrated with commerce and industry. The Bay is surrounded with the city of Izmir that plays an important role in maritime transportation [15]. Location and depth characteristics of Bay of Izmir as study area are shown in Fig. 2.

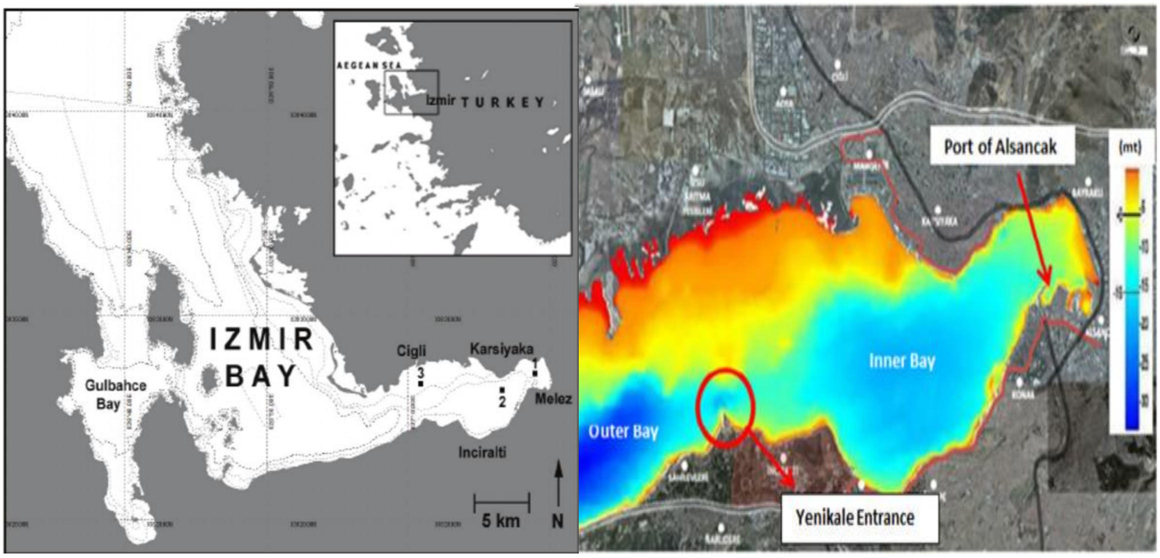


Figure 2: Study area map: bay of Izmir, Turkey.
Source: [15]

As clearly understood from the table that shallow water conditions due to alluvium accumulation by Gediz River at Yenikale entrance have negative effects on navigation safety of ships entering and leaving the bay [15]. Therefore, Yenikale Entrance where grounding accidents frequently occur is the riskiest point of Izmir Bay.

3.3 Findings and Results

In this study, the grounding accidents in Izmir Bay were considered for evaluation. A total of 24 events caused by 13 factors were determined. Initially the fault tree including main, intermediate and root causes was constructed then, the probabilities of sub-events and their impact level were calculated with the application of Open FTA software. The details of the accidents are shown in Table 2.

Table 2: Details of groundings in Izmir Bay

No	Shıp Type	GRT	Flag State	Accident Cause	Accident Type
1	Dry Cargo	1923	Turkey	Violation of Rules	Grounding
2	Dry Cargo	4951	Turkey	Violation of Rules	Grounding
3	General Cargo	2584	St. Vincent	Autopilot Failure	Grounding
4	Dry Cargo	5044	Gibraltar	Engine Failure	Grounding
5	Dry Cargo	20276	Greece	Heavy Weather Conditıons	Grounding
6	Container	42336	Germany	Collision Avoidance Maneuvering	Grounding
7	Dry Cargo	2457	Georgia	Fatigue	Grounding
8	Container	20624	Malta	Alcohol Abuse	Grounding
9	Dry Cargo	2457	Comoros	Lack of BRM	Grounding
10	Ro-Ro	33825	Italy	Engine Failure	Grounding
11	Container	23897	Germany	Generator Failure	Grounding
12	Dry Cargo	1972	D. Republıc	Steerıng Gear Failure	Grounding
13	Dry Cargo	2457	Cambodıa	Alcohol Abuse	Grounding
14	Dry Cargo	986	Turkey	Steering Failure	Grounding
15	Container	10282	Turkey	Lack of BRM	Grounding
16	Container	24836	England	Collision Avoidance Maneuvering	Grounding
17	Dry Cargo	15698	Panama	Steering Gear Failure	Grounding
18	Container	15859	Liberia	Heavy weather Conditions	Grounding
19	Dry Cargo	1042	Syria	Shallow Water Conditions	Grounding
20	Dry Cargo	489	Turkey	Inappropriate voyage	Grounding
21	General Cargo	708	Tonga	Lack of Attention	Grounding
22	Dry Cargo	1198	Cambodia	Inappropriate Voyage Planning	Grounding
23	Dry Cargo	16382	Greece	Shallow Water Conditions	Grounding
24	Dry Cargo	768	Denmark	Generator Failure	Grounding

It is seen that a large part of the vessels are foreign flagged and small tonnage. The ship accidents were tested with Monte Carlo Simulation using Open FTA program. Contribution ratios and importance levels for each root cause were obtained. A total of 89 failure modes from 13 initial events were found for grounding accidents. The values for these data are given in Table 2.

Table 3: Monte carlo simulation initial event contribution rates for grounding accidents

No	Initial Event	Failure Contribution	Importance Level	Percentage Rate (%)
1	X11 (Rudder Failure)	7.834666E-003	13.48	13.85
2	X12 (Shallow Water Conditions	5.591208E-003	9.62	9.88
3	X4 (Lack of BRM)	5.416846E-003	9.32	9.57
4	X13 (Heavy Weather Conditions)	5.352914E-003	9.21	9.46
5	X1 (Collision Avoidance Maneuvering)	5.318041E-003	9.15	9.40
6	X8 (Engine Failure)	5.259921E-003	9.05	9.30
7	X10 (Generator Failure)	5.207612E-003	8.96	9.20
8	X6 (Alcohol Abuse)	3.940581E-003	6.78	6.96
9	X3 (Inappropriate Voyage Planning)	2.592182E-003	4.46	4.58
10	X2 (Violation of Rules)	2.563121E-003	4.41	4.53
11	X5 (Lack of Attention)	2.528249E-003	4.35	4.47
12	X9 (Autopilot Failure)	2.493377E-003	4.29	4.41
13	X7 (Fatigue)	2.487565E-003	4.28	4.40

As understood from the table that X11 which is named as “Rudder Failure” is the most important factor and has the biggest contribution in grounding accidents. “Lack of BRM” and “Shallow Water Conditions” are the second and the third important factors in accidents. It is also seen that accidents caused by equipment faults frequently occur.

In addition, although the bay is located in a natural protected area, bad weather conditions nevertheless caused grounding. Again the results show that the effect of human error on accidents is lower than the others. Besides, many boats engaged in fishing in the area and their captains who do not know the rules of Colreg cause the ships to ground. As well as other types of boats causing accidents due to lack of information on restricted passage conditions for ships.

Alcohol abuse is the other root cause of grounding accidents. This cause was not provided by the accident reports. This data was obtained from interviews with pilot masters. Especially this cause is the main factor of grounding accidents of river type vessels called as volgo-balt.

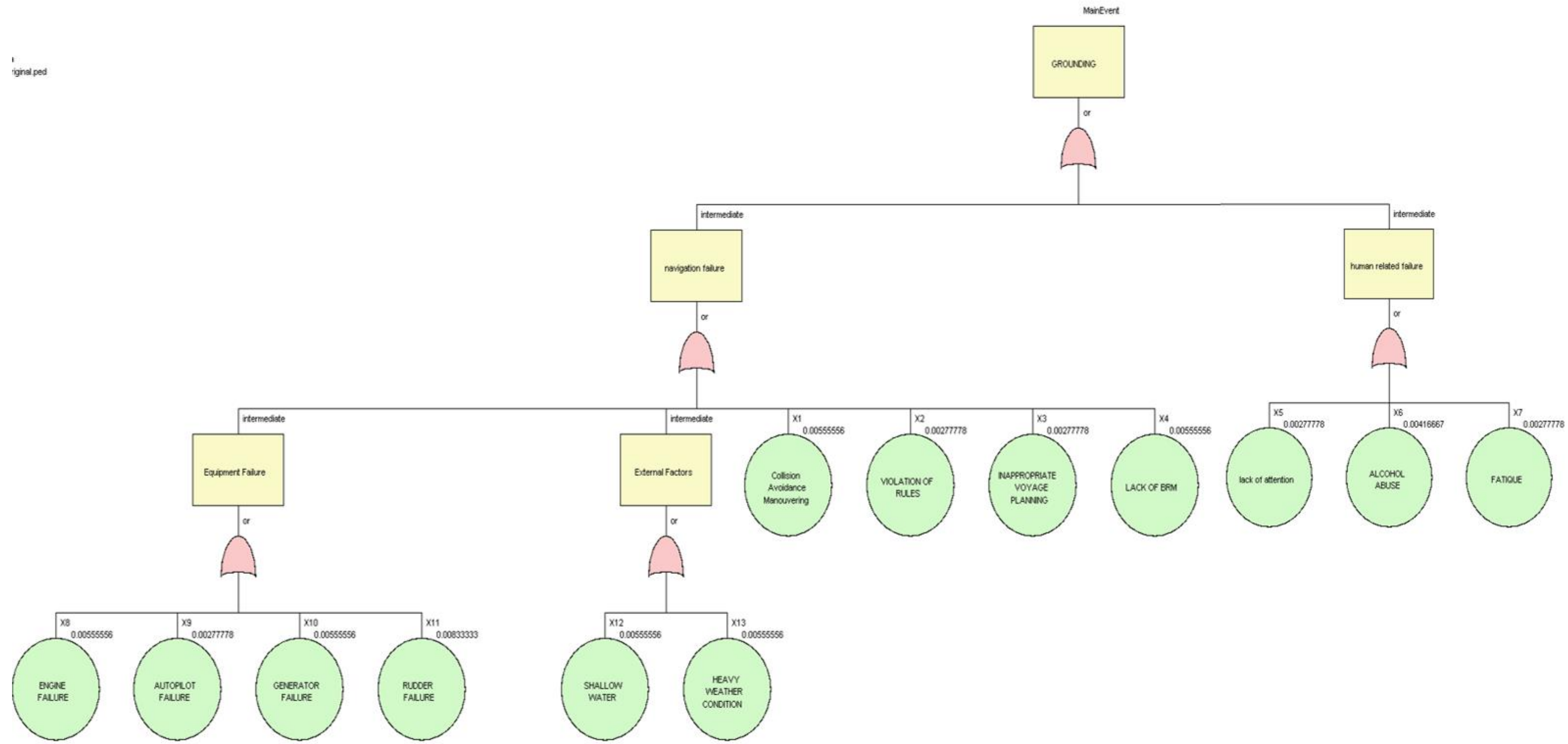


Figure 3: Fault tree for grounding accidents

CONCLUSIONS

In this study, a total of 24 grounding accidents in the Bay of Izmir between 2001 and 2016 have been investigated. It has been resulted that ship accidents, which result in grounding due to geographical constraints of the region, are frequently experienced. Therefore, it is aimed to determine the precautions that should be taken in order to prevent these accidents from happening again.

In this study, it is seen that the most important factor in the accidents is the rudder failure under equipment fault. Although these failures seem to be caused by malfunctions on their own, it is known that the inadequate maintenance measures may also cause this fault. In both cases, regular maintenance operations should be carried out and inspections should be conducted by authorities.

Especially due to the limited maneuvering area in the region, it is impossible for the vessels in emergency to make grounding avoidance maneuvers. In this context, some precautions both for geographical limitations and other factors should be taken in order to prevent grounding accidents. For short term solution it is suggested to carry out a dredging operations in order to extend of the maneuvering area for safety of navigation. On a long-term basis, some precautions can be taken for the Gediz Delta, which causes the bay to be shallow.

In addition, pilotage service area should be extended to include risky areas. For example, pilot embarkation station can be transferred to the outer region of the bay. Besides, the Vessel Traffic Services (VTS), established in 2016 and fully operational in 2018, is expected to play an important role to prevent future accidents. The VTS will also be an actor in terms of controlling of the maritime traffic in the region at the same time.

The most important limitations of the study are the insufficient and incomplete data of the accident reports provided. A more comprehensive study can be carried using reports with more detailed information. In this study, FTA was used as a risk assessment method. Different methods can be used in future studies for better solutions.

REFERENCES

[1] Mazaheri, A. and others. Modeling the risk of ship grounding—a literature review from a risk management perspective. In: *Journal of maritime affairs WMU* [online]. 2013. 12. [viewed date 15 May 2018]. Available from: http://dx.doi.org/10.1007/s13437-013-0056-3.

[2] Akten, N. Shipping accidents: a serious threat form marine environment. In: *Journal of the Black sea/Mediterranean environment.* 2006. 12 (3). 269–304.

[3] Primorac, B. and Parunov, J. *Review of statistical data on ship accidents*. In: *Maritime technology and engineering*. Lisbon, Portugal. 2016.

[4] Acar, U. and others. Collisions and groundings – major causes of accidents at sea. Marifuture papers. 2008. 48–51. [viewed date 12 May 2018]. Available from: http://www.marifuture.org/Publications/Papers.aspx.
[5] Kılıç, A. and Sanal, H. T. Çanakkale boğazi'nda karaya oturmayla sonuçlanan gemi kazaları. In: Journal of *Balıkesir Üniversitesi Fen Bilimleri Enstitüsü*. 2016. 17(2). 38-50.

[6] Papanikolaou, A. and others. Casualty analysis of Aframax tankers. In: *J. Engineering for the Maritime Environment*. 2007. 221(2). 47–65.

[7] Ugurlu, O. and others. Analysis of grounding accidents caused by human error. In: *Journal of marine sciences*. 2015. 23(5). 748-760.

[8] Antão, P. and Soares, C. Fault-tree models of accident scenarios of Ro-Pax vessels. In: *Int J. Auto. Comput*. 2006. 3. 107.

[9] Arslan, O. and others. Fault tree analysis of tanker accidents during loading and unloading operations at the tanker terminals. In: *Journal of eta maritime science*. 2018. 6. 3-16.

[10] Guan, Y. and others. Fault tree analysis of fire and explosion accidents for dual fuel (diesel/natural gas) ship engine rooms. In: *Journal of marine. sci. appl.* 2016. 15. 331.

[11] Tang, L. and Guobin, Wu. Fault tree analysis on ship drift emergency of three Georges lock. In: *Proceedings of IEEE*. 2009. pp. 4244-4639.

[12] Wu, X. and others. Probability analysis of vessel collisions and groundings in southeast texas waterways. In: *Transportation research record: journal of the transportation research board*. 2014. 44-53.

[13] Amrozowicz, M. D. and others. A probabilistic analysis of tanker groundings. In: *The seventh international offshore and polar engineering conference*. International Society of Offshore and Polar Engineers. 1997.

[14] Vesely, W. E. and Roberts, N. H. Fault tree handbook. United States Nuclear Regulatory Commision. 1981.

[15] Toz, A. C. and Koseoglu, B. Trajectory prediction of oil spill with Pisces 2 around Bay of Izmir, Turkey. In: *Marine pollution bulletin*. 2018. 126. 215-227.