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Ship-to-ship tanker transfer operations and risk analysis: Probabilistic approach

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Abstract

In recent years, there has been an increase in ship-to-ship cargo transfer operations at sea. In contrast to routine port berthing manoeuvrings, the berthing manoeuvrings of ship-to-ship tanker transfer operations, where the ships are in motion and under open sea conditions, contain many risks, unlike conventional port berthing manoeuvrings. Due to the recent history of ship-to-ship transfer operations, academic studies and risk assessments are limited to only a few studies conducted in recent years. For this reason, the purpose of this study is to perform the probabilistic risk analysis of underway ship-to-ship transfer operations berthing manoeuvring by using fault tree analysis so the risks and relationships between the risks that caused the collision accident were tried to be determined. Based on the findings, in order not to encounter unsafe situations during manoeuvres, weather reports of the transfer zone should be constantly monitored.

Keywords: Berthing, manoeuvring, risk analysis, sea, STS;

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1. Introduction

All bulk liquid cargo transfers made to one ship by docking with another ship while cruising offshore, at anchor or attached to a dock or buoy are evaluated within the ship-to-ship tanker transfer operation [1]. Tanker transfer operations from ship to ship can be performed while the ships are cruising on the sea, as well as can be done on the iron so that one of the ships can be moored. In addition, double banking is considered a ship-to-ship transfer operation in cases where one of the ships is connected to the dock and another ship is docked on the remaining yard on the seaside [1].

Large water-inflected vessels, especially in recent years where the number of crude oil on yard ships can dock and port numbers increase with depth due to lack of high water without approaching the harbour, on the ship-to-ship cargo transfer operations have increased in number [2]. The main advantage of ship-to-ship tanker transfer operations is the enormous time savings and therefore financial gain due to the fact that ships do not need to dock at the port [3]. It is expected that ship-to-ship transfer operations and the geographical transfer areas specific to these operations will increase significantly in the coming years [4].

The cruise ships manoeuvre in that approach. The required safety distance between the ships to manoeuvre the ship is relative to each other by adjusting the position of the binding which can be seen as a conflict avoidance manoeuvre. The most common ship to ship (STS) accident is the collision accident that occurs when ships approach each other during berthing manoeuvres [5].

In navigational berthing manoeuvres, one of the ships that is subject to operation, which is usually a ship with a large tonnage, moves along a fixed route at a low speed. Local weather, sea conditions and specific experiences related to the region are taken into account at the stage of determining the route to be followed. After that, the ship that will manoeuvre, usually a small tonnage ship, moves by taking the stern shoulder level from the large ship to dock and changes its course so that it parallels the large ship at a suitable distance, in light of the conditions in the region and with experience. A small manoeuvring ship, with the appropriate rudder and machine controls, appropriately reduces the horizontal and vertical distance between itself and a large ship. At this stage, the deceleration rates of the ships are equalised. When they become parallel, the ships are connected in such a way that the connection alignments of the manifolds correspond to each other. As an example, we can schematise this manoeuvre as shown in Figure 1 [6].

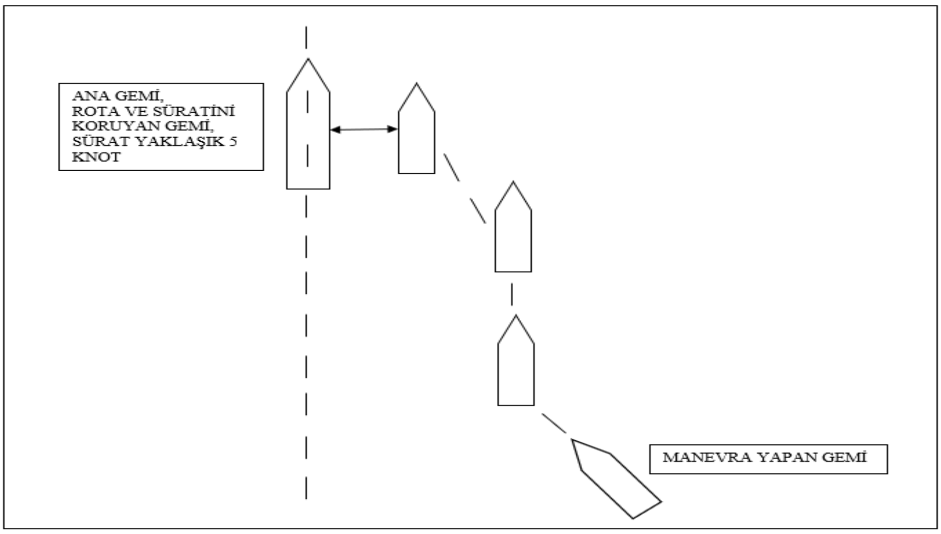

Figure 1. Stages of berthing manoeuvres in which the ships cruise

1.1. Literature review

The 'Ship-to-Ship Transfer Guide for Petroleum, Chemicals and Liquefied Gases', published by industry pioneers OCIMF, CDI, ICS and SIGTTO, is currently considered the most important guide for ship-to-ship tanker transfer operations. This guide, which was first published in 1975, was updated in the following years and has already been used as the main source in previous studies published on tanker transfer operations from ship to ship with the last printed version in 2013.

When previous studies have been investigated concerning ship-to-ship tanker transfer operations, very comprehensive literature has not been found due to the recent past. It has been observed that the research that has been started recently, with the fact that the prevalence of STS operations has started to increase, has been carried out within the last 15-year time frame. The literature between 2005 and 2020 was reviewed, when the majority of studies in the sea ship-to-ship transfer operations for oil tanker ship and cargo handling operations were conducted on studies granted safely.

1.2. Purpose of the study

Studies aimed at detecting the hydrodynamic effects that occur between ships, during ship-to-ship tanker transfer operations, especially during decommissioning manoeuvres, show that reduced risks have been increasing recently. It is very important to be able to determine what hydrodynamic effects they are for them to know that operations can be performed safely. If these effects can be properly identified, they can be seen in advance by ship captains or mooring captains and help to move in a timely manner [3].

2. Materials and methods

In order to analyse the risk of conflict or accidents that may occur during ship-to-ship tanker transfer operations, it is aimed to develop a model using error tree analysis. The root causes obtained after the literature review and expert opinions were revealed using error tree analysis and the probabilities were determined by taking expert opinions by using fuzzy logic applications. After that, the probability of a conflict accident, which is a peak event, was tried to be determined by error tree analysis.

2.1. Error tree analysis (Fault tree analysis)

Error tree analysis is a graphical modelling tool used to investigate the causes of failures and errors at various levels of a system. An error tree diagram is used to perform error tree analysis. The error tree diagram is graphical and logical modelling that shows in various ways that a certain error or failure can occur and looks like a tree from top to bottom that consists of certain logic symbols [6].

An error tree is a directed non-cyclic graph consisting of two types of nodes: events and gates. An event is a formation within a system, typically a failure of a subsystem to a single component. Events can be divided into simple spontaneous events (basic events) and intermediate events (intermediate events) caused by one or more other events. An event at the top of the error tree is called a top event (top event) and is an event that models the failure of the system under study. Error trees use logical gates to perform system analysis. Logical gates show how failures spread in the system, i.e., how failures in subsystems can combine to cause a system failure [7].

There are many error tree analysis symbols in use, but these symbols are generally divided into three groups: event symbols, door symbols and transfer symbols [8]. One of the commonly used is event symbols; a simple event (basic event) is a basic initial error that does not require further development and is shown in a circle shape. A peak or intermediate event (top event or intermediate event) is a decaying event that occurs after a logical combination of simple events. It contains the status of the system, a description of the activity and is indicated by its rectangular shape [9].

Symbols are commonly used in fault tree diagrams of the gate. 'The gate (and gate)' is a result of the realisation of the event only occurred as a result of showing the state of all input conditions; and 'the door (or gate)' is a result of the event occurring as a result of the realisation of at least one of the input conditions which illustrates the situation [6].

2.2. Model of the research

The research model consists of two parts: qualitative and quantitative research. In addition to the literature review within the scope of qualitative research, expert opinions were also taken and the root causes causing the 'conflict' peak event in the cases of ship-to-ship tanker transfer operations berthing were tried to be determined. With these root causes collected, an error tree was formed; simple and intermediate events that caused the peak event were determined; and the relationships between them were deciphered using logical gates. After that, again, expert opinions were taken and the transition to the quantitative process of the research was made. Expert opinions obtained by the fuzzy set theory method were collected by taking into account the determined weight coefficients and a single average value was obtained. These obtained values were converted into measurable numbers using the defuzzification method and the probability of a conflict peak event was calculated by performing an error tree analysis. An interpretation of the probability values obtained in the Results section was made.

2.3. Collection of data

Due to the fact that tanker transfer operations from ship to ship have a recent history, due to the lack of sufficient and reliable data reported, accident reports, industry publications reviews as well as expert opinions were used in the research model to collect data. After defining the problem in the qualitative period of the study and determining the main topic of the study, it is aimed to determine the root causes that lead to a collision accident, i.e., to the contact of ships with each other, during the berthing manoeuvres. In this context, current accident reports, academic publications on ship-to-ship transfer operations and sectoral publications have been examined and root causes have been determined. The current accident reports and the root causes collected after the literature review have been finalised by referring to the opinions of the experts.

The removal of the root cause and fault tree structure in the determination of the expert was referenced during the creation of ideas; his tenure as captain of distant ship transfer operations in different geographical regions with different ship manoeuvres being part of the criteria was taken into consideration.

2.4. Analysis

The process of creating a qualitative model of the research includes the process of deciphering the research problem and its variables, as well as taking expert opinions and creating an error tree structure based on the relationship between the variables. Referring to expert opinions by the author, the root causes that have been revealed by examining the existing academic publications, industry publications and accident reports, i.e., simple events have been defined, as indicated in Table 1, again taking into account interviews with experts. Identified root causes are given the numbers X1, X2, ... X31.

In the process of creating the error tree structure, the classification of the root causes was carried out by the author taking into account expert opinions. Tanker transfer operations from ship to ship, which is the subject of research, are an undesirable event for berthing manoeuvres, i.e., the peak event is designated as a 'conflict'. This peak event is then divided into two main events: internal errors and external errors. These two main events are connected by 'gates' to the peak event. There are 31 root causes within these main events. The model was deciphered by grouping them with intermediate events and using the main-click gates of error tree analysis. In the model, 'gate' is used in all the connections between events. Of the 31 root causes, 22 are grouped under internal and 9 are grouped among the main events of external errors. Figure 2 shows the error tree diagram created.

Table 1. Root causes and variables (created by the authors)

Root cause	Code	Root cause	Code
Main machine failure	X1	Lack of experience	X16
Rudder system error	X2	Lack of information	X17
Breaking the rope	X3	A state of overconfidence	X18
High speed	X4	Communication disorder	X19
The wrong angle of manoeuvre	X5	Command repeat error	X20
Inadequate planning	X6	Incomplete information meeting	X21
Commercial printing	X7	Language barrier	X22
Inadequate procedure	X8	Transfer zone error	X23
Unsafe personnel equipment	X9	Heavy traffic error	X24
Physical fatigue	X10	Restricted vision error	X25
Mental fatigue and stress	X11	Severe wind error	X26
Teamwork error	X12	Severe sea wave error	X27
Lack of situational awareness	X13	Cold climate error	X28
Making the wrong decision	X14	Faulty tug manoeuvre	X29
Lack of education	X15	The error of the astrolabe	X30
		Lashing captain error	X31

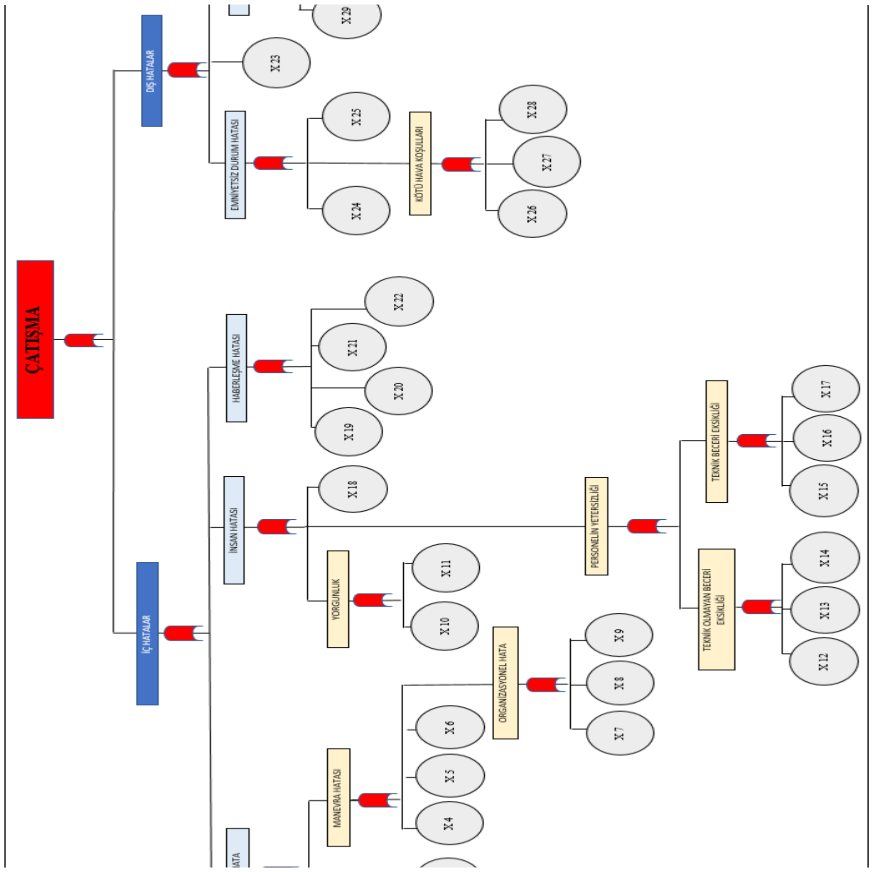

Figure 2. Error tree

2.4.1. Creation of a quantitative model

After the error tree structure was created, expert opinions were taken and *a priori* probabilistic values of the root causes were tried to be determined in the form of numerical data using the fuzzy set theory. After obtaining the numerical data, the probabilistic value of the peak event was determined by analysing the error tree using the ISOGRAPH software programme.

2.4.2. Process of calculating the error probabilities of root causes

Since the conflict regarding ship-to-ship transfer operations tanker accidents that had occurred during berthing manoeuvres, a sufficient number of reliable statistical data are available; fault tree analysis and Bayesian network structure were created before the possibilities, and experts were consulted to determine the root cause. The experts whose opinions will be consulted in the process of determining the possibilities of the root causes included in the network structure; three different experts were selected by paying attention to the fact that they participated in ship-to-ship transfer operation manoeuvres in different geographical regions with ships of different types and tonnage in which they worked as a remote captain or guide captain. Although each of the experts has the competence of a remote road captain, the weight of their opinions expressed on the possibilities of root causes will not be at the same level due to the different characteristics of each of them, such as their current profession, industry experience, education level and STS experience. In other words, by taking a weighted average when determining the probability of a root cause, we cannot accept the evaluation of each specialist as effective to the same extent. For this reason, the effect of experts on probabilities, i.e., when determining their weight, the weight coefficient of each specialist is determined in Table 3, taking into account the weight criteria specified in Table 2.

Table 2. Expert weight coefficient determination criteria (established by the authors)

Factor	Classification	Score
Profession	Academician / Remote Road Captain	5
	Guide Captain	4
	Remote Road Captain	3
	First Police Officer	2
	Second Police Officer	1
Marine service	>15 years	5
	12–15 years	4
	9–12 years	3
	6–9 years	2
	<6 years	1
Education level	Postgraduate	5
	Graduate	4
	License	3
	College	2
	Vocational High School	1
STS experience	>50 operations	5
	35–50 operations	4
	20–35 operations	3
	5–20 operations	2
	<5 operations	1

3. Results

Table 3. Expert profile and weight coefficients (formed by the authors)

Number of specialists	Job	Marine service	Level of education	STS experience	Weight factor	Coefficient of gravity
S1	3	4	3	3	3+4+3+3=13	13/42=0.277
S2	4	5	3	4	4+5+3+4=16	16/42=0.340
S3	5	4	4	5	5+4+4+5=18	18/42=0.383

In order to obtain expert opinions, fuzzy logic and fuzzy set theory methods were used. The fuzzy set theory makes it possible to analyse the safety and reliability of systems under uncertain conditions. Experts were asked to use the verbal variables given in Table 4 instead of numerical expressions when answering questions. When determining the verbal variables, tables with a different number of linguistics and numerical variables can be selected. In the study conducted by Chen and

Hwang [10], eight different variable scales were specified. In this study, seven verbal variables and four numerical variable tables were used to estimate the root cause probabilities. The reason for using the seven-variable table is due to the fact that the typical estimate of the memory capacity of a person is 7 ± 2 parts, and the appropriate number of comparisons that people can judge at a time is in the range of 5 and 9 [11].

Table 4. Verbal variables and fuzzy membership functions (created by the authors)

The verbal variable	Meaning	Trapezoid membership functions
Very low (VL)	The probability of occurrence of possible events is almost impossible	(0, 0.20) (0, 0.1, 0.1, 0.2)
Low (L)	The probability of occurrence of possible phenomena is quite low	(0.10, 0.30) (0.1, 0.2, 0.2, 0.3)
Little low (LL)	The probability of occurrence of possible phenomena is low, but it can be	(0.20, 0.50) (0.2, 0.3, 0.4, 0.5)
Medium (M)	The probability of occurrence of possible events has equal chances	(0.40, 0.60) (0.4, 0.5, 0.5, 0.6)
Little high (LH)	It is likely that possible events will occur	(0.50, 0.80) (0.5, 0.6, 0.7, 0.8)
High (H)	Possible incidents are most likely to occur	(0.70, 0.90) (0.7, 0.8, 0.8, 0.9)
Very high (WY)	The probability of the occurrence of possible events is very high, it is almost certain	(0.8, 1.0) (0.80, 0.9, 1.0, 1.0)

After the expert interviews, the verbal expressions indicated by each expert are based on Table 4 and the root causes and are shown in Table 5.

Table 5. Expert verbal opinions on root causes (created by the authors)

Root causes	Specialist 1	Specialist 2	Specialist 3	Root causes	Specialist 1	Specialist 2	Specialist 3
X1	VL	VL	L	X17	L	VL	M
X2	L	VL	VL	X18	LL	L	L
X3	LL	LL	LL	X19	AY	LL	M
X4	VL	L	LL	X20	L	VL	LL
X5	L	L	LL	X21	L	L	M
X6	L	VL	L	X22	M	VL	LL
X7	M	LL	LL	X23	L	VL	VL
X8	L	VL	VL	X24	VL	L	L
X9	M	L	LL	X25	VL	VL	L
X10	LL	L	M	X26	LL	L	M
X11	LL	O	L	X27	L	L	LL
X12	L	VL	M	X28	L	VL	VL

X13	LL	D	M	X29	VL	VL	VL
X14	L	VL	LL	X30	VL	VL	L
X15	L	VL	LL	X31	L	VL	VL
X16	M	LL	LL				

The fact that verbal variables are used to evaluate the possibilities allows experts to give their answers in a certain comfortable way, while in order to obtain numerical data, these verbal expressions must be converted into fuzzy numbers corresponding to them. At this point, since each expert has a different opinion, it is necessary to perform the process of combining expert opinions appropriately by taking into account expert weight coefficients. In cases where there is more than one expert opinion, different methods of combining are used to combine opinions based on fuzzy set theory. In this study, the similarity agreement method formulas, which were expressed by Hsu and Chen [12], were used. As an example, the calculation for combining expert opinions for the root cause of 'X-9 unsafe personnel equipment' is shown in Table 6.

Table 6. The merge account for the simple incident 'X-9 unsafe personnel equipment'

Specialist 1		0.4	0.5	0.5	0.6
Specialist 2		0.1	0.2	0.2	0.3
Specialist 3		0.2	0.3	0.4	0.5
S (S12)	0.7		AA (U1)	0.775	
S (S13)	0.85		AA (U2)	0.775	
S (S23)	0.85		AA (U3)	0.85	
RA (S1)	0.3229		CC (U1)	0.2997	
RA (S2)	0.3229		CC (U2)	0.3316	
RA (S3)	0.3541		CC (U3)	0.3685	
U. A. K. (S1)	0.276596				
U. A. K. (S2)	0.340426				
U. A. K. (S3)	0.382979				
Combining		0.226784	0.326784	0.363641	0.463641

The same merge calculation was repeated for all simple events to reach the fuzzy number values in Table 7.

Table 7. Combined simple numbers of root causes (created by the authors)

Simple events	Fuzzy numbers after merge calculation
X1	(0.035, 0.135, 0.135, 0.235)
X2	(0.030, 0.130, 0.130, 0.230)

X3	(0.200, 0.300, 0.400, 0.500)
X4	(0.105, 0.205, 0.240, 0.340)
X5	(0.135, 0.235, 0.270, 0.370)
X6	(0.067, 0.167, 0.167, 0.267)
X7	(0.259, 0.359, 0.430, 0.530)
X8	(0.030, 0.130, 0.130, 0.230)
X9	(0.227, 0.327, 0.364, 0.464)
X10	(0.237, 0.337, 0.369, 0.469)
X11	(0.231, 0.331, 0.363, 0.463)
X12	(0.168, 0.268, 0.268, 0.368)
X13	(0.237, 0.337, 0.369, 0.469)
X14	(0.102, 0.202, 0.237, 0.337)
X15	(0.102, 0.202, 0.237, 0.337)
X16	(0.259, 0.359, 0.430, 0.530)
X17	(0.168, 0.268, 0.268, 0.368)
X18	(0.130, 0.230, 0.259, 0.359)
X19	(0.364, 0.464, 0.527, 0.627)
X20	(0.102, 0.202, 0.237, 0.337)
X21	(0.201, 0.301, 0.301, 0.401)
X22	(0.313, 0.413, 0.449, 0.549)
X23	(0.030, 0.130, 0.130, 0.230)
X24	(0.070, 0.170, 0.170, 0.270)
X25	(0.035, 0.135, 0.135, 0.235)
X26	(0.237, 0.337, 0.369, 0.469)
X27	(0.135, 0.235, 0.270, 0.370)
X28	(0.030, 0.130, 0.130, 0.230)
X29	(0.000, 0.100, 0.100, 0.200)
X30	(0.035, 0.135, 0.135, 0.235)
X31	(0.030, 0.130, 0.130, 0.230)

After combining expert opinions and creating fuzzy sets of numbers from verbal variables, the next stage is the process of producing a measurable result from these fuzzy numbers, i.e., the rinsing process. As a result of the rinsing process, failure probability is obtained for each simple event. Due to the different techniques that can be used in the rinsing process, the applicability of the centre of gravity rinsing method is much easier and simpler than other methods [13]. A single numerical value was revealed by multiplying the fuzzy numbers in Table 8 for each root cause using the centre of gravity rinsing formulas.

Table 8. Rinsed error probabilities for each simple event

Simple events	There may be aggravated errors	Simple events	There may be aggravated errors
SE 1	0.135	SE 17	0.268
SE 2	0.130	SE 18	0.244
SE 3	0.350	SE 19	0.495
SE 4	0.222	SE 20	0.219
SE 5	0.252	SE 21	0.301
SE 6	0.167	SE 22	0.431
SE 7	0.394	SE 23	0.130
SE 8	0.130	SE 24	0.170
SE 9	0.345	SE 25	0.135
SE 10	0.353	SE 26	0.353
SE 11	0.347	SE 27	0.252
SE 12	0.268	SE 28	0.130
SE 13	0.353	SE 29	0.100
SE 14	0.219	SE 30	0.135
SE 15	0.219	SE 31	0.130
SE 16	0.394		

The final stage in calculating the probabilities of root causes is the process of calculating the error probabilities from the defuzzified failure possibilities. In this process, equation (1), which was developed by Onisawa [14], was used.

$$1 / 10^{K,}\ \text{DHO} \neq 0$$

$$\text{HO} = 0,\ \text{DHO} = 0,\ K = \left(\frac{1-\text{DHO}}{\text{DHO}}\right)^{\frac{1}{3}} \times 2.301 \qquad (1)$$

In equation (1), HO is the error probabilities and DHO is the dualised error probabilities, while the value of *K* is a constant coefficient. As a result, the error probability values in Table 9, which were obtained using the formula above, were also assigned as the error probability in the Bayesian network model for each simple event.

Table 9. Calculation of error probabilities for each simple event

Simple events	There may be aggravated errors	*K*-constant coefficient	Error probabilities
SE 1	0.135	4.271	0.00005
SE 2	0.130	4.337	0.00005

SE 3	0.350	2.828	0.00148
SE 4	0.222	3.492	0.00032
SE 5	0.252	3.305	0.00050
SE 6	0.167	3.932	0.00012
SE 7	0.394	2.655	0.00221
SE 8	0.130	4.337	0.00005
SE 9	0.345	2.848	0.00142
SE 10	0.353	2.815	0.00153
SE 11	0.347	2.842	0.00144
SE 12	0.268	3.218	0.00061
SE 13	0.353	2.815	0.00153
SE 14	0.219	3.514	0.00031
SE 15	0.219	3.514	0.00031
SE 16	0.394	2.655	0.00221
SE 17	0.268	3.218	0.00061
SE 18	0.244	3.352	0.00044
SE 19	0.495	2.316	0.00483
SE 20	0.219	3.514	0.00031
SE 21	0.301	3.046	0.00090
SE 22	0.431	2.524	0.00299
SE 23	0.130	4.337	0.00005
SE 24	0.170	3.903	0.00013
SE 25	0.135	4.271	0.00005
SE 26	0.353	2.815	0.00153
SE 27	0.252	3.305	0.00050
SE 28	0.130	4.337	0.00005
SE 29	0.100	4.786	0.00002
SE 30	0.135	4.271	0.00005
SE 31	0.130	4.337	0.00005

3.1. Calculation of peak event probability by the error tree analysis

After calculating the probabilities of the root causes. an error tree analysis was performed and the error probability for the ‘conflict’ event, which is a peak event, was calculated using the ISO-GRAPH software programme and the peak event probability value was calculated as ‘0.0263’, as shown in Figure 3.

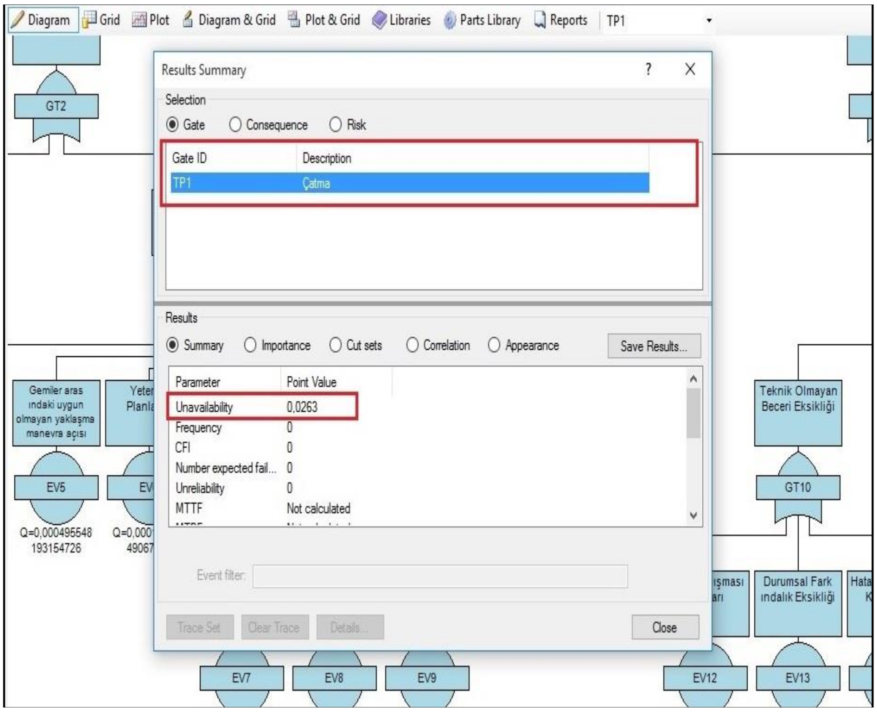

Figure 3. Peak event probability calculation with error tree analysis

Discussion

Tanker transfer operations from ship to ship during navigation, the inferences obtained by using the error tree analysis feature for the risk assessment of conflict accidents during berthing manoeuvres and the safety measures to be taken to prevent a conflict accident are examined in this section. It is seen that the simple event of 'rope break' has a high sensitivity, i.e., its effect on the occurrence of a 'conflict' accident. If one or more of the mooring ropes break during the decoupling manoeuvre, contact between the ships is necessary and ship officers at the manoeuvre site should be careful in order to avoid a conflict situation. If the windlass grip settings of the windlass are well made, the rope will be prevented from breaking by attaching the windlass to the rope before the breaking force of the rope. The fact that the sending and receiving of ropes between ships is carried out in a controlled and synchronised manner by establishing proper communication between the officers of both ships will again be one of the important measures to prevent rope break situations.

It has been observed that the other variables that are sensitive to the 'conflict' accident are 'main machine failure' and 'rudder system error'. Since both ships will be able to make course and speed adjustments according to each other during the docking manoeuvres carried out in the cruise, it will be possible to continuously use the ship's main machine and rudder system. For this reason, the STS manoeuvres of the ship's main and auxiliary machines must have been checked before, including the sternway and emergency stop systems. The rudder system should be controlled both remotely and manually in the rudder room, including the emergency rudder control system. The indicators showing the position of the main machine and the rudder located on the bridge swallows should be in good condition and their lighting should be operational for night operations.

Before starting the STS manoeuvres, both ships should discuss the operation plan and agree on the route and speed information to be followed, the communication systems to be used, mooring plans and emergency planning. Again, during this meeting, information such as manoeuvring characteristics of their ships, critical main engine speeds and corresponding deceleration values should also be shared between the ships. Before the operation, the team members of both ships on the bridge should gather and review the operation stages. If there is a binding captain, the binding captain should also be part of this meeting and the planned stages of operations should be discussed.

It has been observed that the 'communication sensitivity' variable has a high effect on the 'conflict' event in the error tree analysis interpretations made. In order to avoid communication difficulties during decommissioning manoeuvres, the primary and backup communication channels to be provided with the language and communication to be used between the ships should be determined at the meeting to be held before the operation. These communication systems should be tested at the beginning of the manoeuvre. In addition, both ships must ensure that safe communication is established between themselves, the deckhouse and the engine room, as well as the responsible ship's personnel located at the head, stern and manifold area manoeuvre sites. A public navigation alert should be broadcast over VHF to alert nearby ships before starting STS operation [15]. In order to avoid risks caused by a 'command repeat error', it should be noted that the transmitted commands are verified by repeating them. The machine and rudder commands that have been given should be checked by the responsible officer to make sure that the correct command has been applied.

4. Conclusion

We have seen that the effect of the 'commercial pressure' variable is high in experiencing organisational errors during docking manoeuvres. In order to avoid operational errors, ship captains and mooring captains should not feel commercial pressure on them related to the operation. In order for the operation to be carried out safely, it should be remembered that the ship's captains are ultimately authorised to start, stop or cancel the operation by the ship's equipping, operating and chartering companies.

In order to avoid risks caused by inadequate procedures, ship-operating companies should ensure that there are adequate procedures for ship-to-ship tanker transfer operations prepared in accordance with the rules on their ships. In order to reduce the risks caused by 'human error' that will cause conflict accidents, attention should be paid to the safety personnel equipment of ships. Unlike normal port operations, STS operations have more risks and it is important that personnel with sufficient training, knowledge, and experience are on board. In addition, since it is operated in both port shift and cruise shift conditions, it is important that the number of personnel on board is at a sufficient level to adapt to rest periods in order to prevent the occurrence of situational awareness and fatigue-related risks.

In order not to encounter unsafe situations during manoeuvres, weather reports of the transfer zone should be constantly monitored. According to the wind and sea conditions, the route and speed adjustments of the ships should be made appropriately. Although the STS transfer zones are branded as special transfer zones, one should be vigilant and keep a good lookout for the presence of small vessels such as boats or fishermen.

References

[1] A. Zenios, "Verification of ship compliance according to industry standards in ship-to-ship transfer operation," Tech. Rep., 2016.

[2] Y. Zhuang and W. Su, "Risk analysis on ship to ship (STS) crude oil transfer at sea," in *Proc. Int. Conf. Transp. Inf. Saf. (ICTIS)*, Jun. 2015, pp. 746--753.

[3] B. De Decker, "Ship-ship interaction during lightering operations," M.S. thesis, NTNU, Trondheim, Norway, 2006.

[4] E. Pedersen, E. Shimizu, and T. E. Berg, "On the development of guidance system design for ships operating in close proximity," in *Proc. IEEE/ION Position, Location Navigat. Symp.*, May 2008, pp. 966--971.

[5] A. Witkowska, S. Roman, and W. Przemysław, "Trajectory planning for service ship during emergency STS transfer operation," in *Proc. Polish Control Conf.* Cham, Switzerland: Springer, 2017, pp. 514--523.

[6] J. E. Vessely, "Storm over ST VIEW," *Mech. Eng.*, vol. 103, no. 1, pp. 51--52, 1981.

[7] P. Antao and C. G. Soares, "Fault-tree models of accident scenarios of RoPax vessels," *Int. J. Autom. Comput.*, vol. 3, no. 2, pp. 107--116, Apr. 2006.

[8] E. A. Quraishi, "Risk analysis of marine accident in inland waterways of Bangladesh using fault tree analysis method," Tech. Rep., 2019.

[9] H. E. Lambert and N. J. Alvares, "The PEPCON disaster-causative factors and potential preventive and mitigative measures," Lawrence Livermore Nat. Lab., Livermore, CA, USA, Tech. Rep., Jul. 2003.

[10] J.-K. Chen, T. I. S. Hwang, and C.-R. Yang, "Comparison of effects following the intracorporeal injection of papaverine and prostaglandin E_1," *Brit. J. Urol.*, vol. 69, no. 4, pp. 404--407, Apr. 1992.

[11] D. Huang, T. Chen, and M.-J.-J. Wang, "A fuzzy set approach for event tree analysis," *Fuzzy Sets Syst.*, vol. 118, no. 1, pp. 153--165, Feb. 2001.

[12] H.-M. Hsu and C.-T. Chen, "Aggregation of fuzzy opinions under group decision making," *Fuzzy Sets Syst.*, vol. 79, no. 3, pp. 279--285, May 1996.

[13] W. Van Leekwijck and E. E. Kerre, "Defuzzification: Criteria and classification," *Fuzzy Sets Syst.*, vol. 108, no. 2, pp. 159--178, 1999.

[14] T. Onisawa, "An approach to human reliability in man-machine systems using error possibility," *Fuzzy Sets Syst.*, vol. 27, no. 2, pp. 87--103, Aug. 1988.

[15] A. P. Golaya and N. Yogeswaran, "Maritime communication: From flags to the VHF data exchange system (VDES)," *Maritime Affairs, J. Nat. Maritime Found. India*, vol. 16, no. 2, pp. 119--131, Jul. 2020.