Risk Analysis of Marine Accident in Inland Waterways of Bangladesh Using Fault Tree Analysis Method

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Ehtasham Ahmed Quraishi

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	Board of Examiners	
1.	Dr. Md. Shahjada Tarafder Professor Department of Naval Architecture and Marine Engineering Bangladesh University of Engineering and Technology, Dhaka	Chairman (Supervisor)
2.	Head Department of Naval Architecture and Marine Engineering Bangladesh University of Engineering and Technology, Dhaka	Member (Ex-Officio)
3.	Dr. Goutam Kumar Saha Professor Department of Naval Architecture and Marine Engineering Bangladesh University of Engineering and Technology, Dhaka	Member
	O in	

4. Dr. Zobair Ibn Awal

Member

Associate Professor Department of Naval Architecture and Marine Engineering Bangladesh University of Engineering and Technology, Dhaka

Commodore M Munir Hassan
Head, Dept. of Naval Architecture
& Marine Engineering,
MIST, Dhaka

Member (External)

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Ehtasham Ahmed Quraishi

Roll no.:1014122020

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To

My Respected Teachers

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ABSTRACT

As a riverine country, the inland waterways of Bangladesh plays a vital role in transportation of goods and personnel throughout the country in all seasons. But these waterways are not guaranteed to be safe for navigation due to effect of multiple factors. In last decades within 1981 to 2018 about 604 marine accidents in inland waterways of Bangladesh tools more than 5407 valuable lives. Due to the unique geographic location, complex navigation environment and intense vessel traffic, a considerable number of maritime accidents occurred in Bangladesh. Marine accidents adversely affect the human, the marine environment and properties and activities abroad ships and ashore in various forms and degree of extent. The effects of accidents vary from minor injuries to fatalities and form insignificant damage to very severe damage to the environment and property.

In this study, details analysis and investigation of root causes for marine accident in inland waterways of Bangladesh specially for collision and grounding has been carried out. Based on the data base of marine accidents from 1981 to 2018 collected from Department of Shipping (DOS) and Bangladesh Inland Water Transport Authority (BIWTA), this thesis conducted a risk analysis of maritime accidents by applying fault tree analysis (FTA) programme for the incidents collision and grounding as occurred. First, the potential problems which cause the collision and grounding accidents have been investigated and determined. Second, the occurrence of accidents has been shown with causal factors by the FTA method. Finally, the significance degree of the initial events causing occurrence of accidents have been put forth. The probability of the basic events as well as top event, i.e. collision and grounding was also calculated using FTA method to estimate or analyse the risk of accident occurrence.

The main reason for the accidents is originating from human error. The significance degree of the initial events cause accidents. For this purpose, an initial event analysis has been carried out. According to the FTA analysis, the first five basic reasons with the biggest share in the occurrence of collision accidents are respectively, faulty maneuver of master (FMM): 11%, violation of procedure or rule (VPR): 9%, lack of experience/training/qualification/competency of officer, master, crew (LETQC): 9%, improper/ uncoordinated avoiding operation (IUAO): 8% and negligence in watch keeping (NWK): 8%. Similarly, the initial events with the biggest share in the occurrence of grounding accidents are respectively, lack of experience/training/qualification/competency of officer, master, crew (LETQC): 13%, improper steering/course

keeping failure by quarter master (ISCCFQM): 10%, in-sufficient/improper marking of navigable channel (IIMNC): 9%, lack of knowledge on avoiding grounding situation (LKAGS): 9% and waterways are not maintained by authority (WWNM): 7%. It has been observed that in grounding accidents, bad weather conditions as well as human error also have an influence on accident occurrence.

FTA models for both collision and grounding has also been developed as bench mark for further analysis of such accidents. An accidents recording report form has prepared for future recording of accidents at international standard. Besides, an accident database of all the accidents occurred for last 38 years (1981 to 2018) with sufficient data and information has been formulated which will ease further analysis of accidents in different dimensions.

At the end of this thesis, based on the outcomes, some viable recommendations have been proposed in order to ensure greater safety of inland vessels of Bangladesh.

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7.

ABBREVIATIONS

ALARP : As Low a level as Reasonably Practicable

BIWTA : Bangladesh Inland Water Transport Authority

COLREG: International Regulations for Preventing Collisions at Sea

DOS : Department of Shipping

DPTC : Deck Personnel Training Center

ETA : Event Tree Analysis

FAHP : Fuzzy-Analytic Hierarchy Process

FHA : Functional Hazard Assessment

FMECA : Failure Modes, Effects and Criticality Analysis

FSA : Formal Safety Assessment

FTA : Fault Tree Analysis

GT : Gross Tonnage

HAZOP : Hazard and Operability Studies

IMO : International Maritime Organization

IWT : Inland Water Transport

LAD : Least Available Draft

MOCUS: Method of Obtaining Cut Sets

NEDECO: Netherlands Engineering Consultants

NUREG: Nuclear Regulatory Commission

PHA : Preliminary Hazard Analysis

RCO : Risk Control Options

RHD : Roads and Highways Department

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CHAPTER-1 INTRODUCTION

1.1 Introduction

Bangladesh is not only a littoral state but also a riverine state. This unique land is flushed by the Bay of Bengal on the south and criss-crossed by a network of about 700 waterways. There are some 23 coastal inland ports, 11 inland river ports and over 1300 launch terminals in the country. More than 10,000 registered different types of vessels are playing round the year in our inland water for transportation of cargoes, passengers and others necessities. Due to geographical advantages, waterways provide the cheapest mode of transportation. But many of the vessels are not having standard design in all aspect (hull design, machineries, safety arrangement, lifesaving appliance, navigational aids, etc.). Besides, the inland routes are hazardous due to insufficient navigational aids and marking. Moreover, many of the vessel operators'/navigators' are neither academically trained nor certified by appropriate authority and thereby they are not well aware of navigational safety in fair and adverse weather condition. All these lead to frequent marine accidents which is unexpected.

In last four decades, a total of about 604 accidents occurred in inland waters of Bangladesh. These accidents costs more than 5407 valuable lives. Whereas, a mere recording with insufficient information took place against each of the accidents. Several attempts have been made to mitigate the marine accident in inland routes and various papers and reports have been written on this issue. But no details analysis of accidents was performed following standard and international procedure to find out or confirm the root causes for such accidents which is necessary to mitigate accidents efficiently. Moreover, the accidents are not recorded with necessary data and information in a prescribed manner as followed by modern countries like USA, UK, New Zealand, Australia and others. On the basis of recorded data, accident analysis took place following different methods. Fault Tree Analysis (FTA) is a common and widely used and one of the simplest method to analyze marine accident. But this method requires details information and data to analyze each of the occurrences. It may be made, some use of their recording and analysis procedure but it will imprudent to totally depend on such recording since the type of vessels operating in our water and operating environment are not similar to those countries. Moreover, the data recorded in Bangladesh for each of the accident are very much insufficient to carry out analysis. Thus we need to record and study our cases differently

taking the procedure of modern countries as guideline and develop a separate accident recording and analysis method which will be appropriate for our application.

1.2 Literature Review

In the scientific literature there are several aspects in the study of maritime accidents which draw much attention from researchers around the world. One of them is to extract the mechanism of accident from the massive scale of data by applying accident causation analysis or pattern analysis. Based on the historical accident investigation report which contains navigation environment statistics, particulars of the ship involved and detailed description of the accident, the causes, consequences and characteristics of an accident can be discovered which are of great help in providing scientific and comprehensive support for qualitative and quantitative analysis.

In Bangladesh, number of discussion have been made and papers published to mitigate the inland waterways accidents. Huq and Dewan [1] studied the geographical locations of passenger launch accidents and provided some description of the accident sights along with description of the waterway networks. Khalil and Tarafder [2] conducted a survey on accidents occurred in the inland waterways during 1981-2004. The causes of accidents were revealed and a number of recommendations were put forward to ensure the greater safety of the passengers. They also discussed the issue of design modifications for improving the extra initial stability by downward shift of center of gravity and thereby preventing the vessels from capsizing in times of emergency. Chowdhury [3] attempted to develop a GIS based accident information system for water transport accidents and recommended future research to be conducted on navigational system integrated with meteorological forecasting systems. Some statistical analysis published by Awal et. al. [4] in an attempt to identify the accident characteristics dealing with accidents in the inland waterways of Bangladesh. The chains of faults are elucidated in his study with the intention of executing for future database development. The paper focused on the utilization of fault tree as a tool for prior identification of the dangers of water transports but due to non-availability of primary data of accidents, useable fault tree for contact type accidents could not be developed. The papers further discussed the unique safety characteristics of the inland water transportation system in Bangladesh. Rahman [5] provided decision makers with valid and reliable maritime accident information in order to make informed and hopefully better decisions and an analysis was

carried out to determine the common causes of accidents on passenger vessels. Rafiqul et. al. [6] carried out preliminary analysis of marine accidents in Bangladesh through Event Tree Analysis method. In recent years several studies conducted on maritime safety in the inland water ways of Bangladesh. However, none of the studies considered extensive usage of FTA in calculating and controlling risk factors and there is no such analysis in details which shows the relation among maritime accident parameters (root/basic causes) and means of continuous analysis of marine accident following internationally accepted method.

In order to improve the safety of navigation and promote the development of the shipping industry, a good number of research took place on marine accident in international level where FTA has been used extensively. Kose et. al. [7] explained systematic analyses of fishing boat accidents. Statistical data have been examined, the fault tree method being used in the determination of the importance of each factor. In this study, sinking of the ship has been selected as the main event and separated into sub-branches such as human error, structural error and shipping of fish on deck. As a result of the analysis, it has been manifested that human error is the main factor in accidents in fishing boats.

Dorp et. al. [8] assessed the probability of ferry collision in the Washington State Ferry (WSF) system using a dynamic system methodology that extends the scope of availed date with expert judgment. Pillay et al. [9] examined marine accidents of fishing boats in the period between 1992 and 1999, putting forth the common factors causing accidents and the relation of accidents with the boat length. Wang et. al. [10] presented the accident data collected from the Marine Accident Investigation Branch of UK and analyzed to determine the most common causes of accidents on fishing vessels and also assessed the safety of fishing vessel.

Antao and Soares [11] researched the possible hazards related to accidents which may arise from ro-ro and passenger ships (RoPax) and the role of human error in accidents. The study has focused on the relations of basic events which may result in accident. As a first step in accident analysis, Formal Safety Assessment (FSA) has been executed and the relation between accident-causing events as well as the relation of human error with the accident has been determined by means of the fault tree modeling. At the end of the study, it has been found that as significant a rate as 90% can be attributed to human error in grounding and collision accidents.

Eliopoulou and Papanikolau [12] examined in detail the raw accident data which are at very severe accident level, as occurred in oil tankers over 80.000 deadweight tonnage (dwt), in the period between 1978 and 2003 at Turkey, and they have evaluated the accidents using statistical methods. Eliopoulou et. al. [12] also carried out accident analysis in marine accidents in Aframax tankers (over 80.000 dwt) between 1978 and 2003, which caused environmental pollution and economical loss. The data related to the accidents have been obtained from Lloyd's Marine Information Services Ltd (LMIS) database. The data in the study have been evaluated by the expert team, a new data base, which is easier to evaluate in systematic sense, being constituted and the accidents have been graded. The fault tree and event tree programme being used. The occurrence of accidents resulting in economical loss and environmental pollution has been summarized and it has been observed that the accidents are highly related to human error.

Martins and Maturana [13], taking into account International Maritime Organization's (IMO's) FSA recommendations, have with numerical values analysed the human error contribution to collision and grounding accidents in tankers at Brazilian coasts. This analysis was carried out in three stages: identification of the hazard, risk analysis, and risk control. A fault tree has been made up by utilizing the data on initial events that cause accidents, and occurrence of accidents has been summarized with numerical data, the necessary safety precautions being determined.

Talay [14] conducted a root analysis of accidents based on historical incidents and a questionnaire survey to find out the risky conditions for navigational safety in a specific port area of Port of Haydarpaşa Zone, Istanbul, Turkey. The preliminary hazard analysis (PHA) and Fault Tree Analysis (FTA) were used for the evaluation of the accidents occurred during the period 1991-2010 in the research area. Mokhtari and Didani [15] conducted a research on marine accidents occurred in five Iranian shipping companies. The seventeen factors were found to be effective in occurrence of human error in these accidents and the four most influential factors were negligence, poor training, inadequate tools, and lack of skill and experience.

Chen et. al. [16] conducted a risk analysis of maritime accidents by applying Bayesian network and fault tree analysis. Ugurlu et. al. [17] determined the potential problems causing collision and grounding in oil tankers using FTA and gave some recommendations to solve the problem. Guan et. al [18] presented a fault tree model of fire and explosion accidents for dual fuel ship engine rooms.

To learn about FTA, an extensive review of the literature concerning fault trees was conducted. Lambert [19] gave good discussions of fault tree construction. A fine description of fault tree techniques and concepts is given by Vesely and Fussell [20]. The literature is replete with various methods for quantitative analysis with and without computer applications. Some of the more prominent in this area are research work of Crossetti [21] and Vesely [22].

In the area of qualitative analysis, the analysis by Chatterjee [23], Barlow et al. [24] and Larsen [25] is referred. In recent development of FTA model for analyzing marine accident, research papers of Zio [26], Antao and Soares [11], Rausand [27], Mullai and Paulsson [28], Ayyub [29] and Chen et al. [16], etc. were well consulted. To develop FTA model, guide line was taken from paper of Gordon [30], Ugurlu [31], Ombler [32], Toungsewut [33], Kristiansen [34] and Talay [14].

1.3 Objectives of the Present Research

The objectives of the present research are as follows:

- To develop a new database and reporting system for marine accidents and to improve accuracy or completeness of information submitted.
- To analyze the risk after developing an accident causation model using Fault Tree Analysis (FTA) method and also to focus the consequence of incidents.
- To identify all possible combinations of basic events that may result in a critical event in the system.
- To find the probability that the critical event (collision and grounding) will occur during a specified time interval or the frequency of the critical event.
- To compare the present probabilistic value with the results obtained from an open FTA programme (http://www.openfta.com) for checking the validity.
- To identify the barriers of the system that need to be improved to reduce the probability of the critical event.
- To develop risk models for collision and grounding of inland ships of Bangladesh and apply Risk Control Options (RCO) to measure the impact of policies in reducing risks.

CHAPTER-2

AREA OF RESEARCH

2.1 Overview of Inland Waterways of Bangladesh

In this research, Bangladesh inland waterways were chosen as the study area. Bangladesh is a deltaic plain of 147570 square kilometers criss-crossed by numbers of major and minor rivers along with their innumerable tributaries among which mighty rivers are the Padma, Meghna, Jamuna, Brahmaputra. Teesta, Surma and Karnaphuli. There is some geographical difference between the northern and southern part. The southern part includes an extensive coastal estuarine region containing isolated large and small offshore islands with very shallow continental shelves. The network of rivers, all of which eventually flow down to the Bay of Bengal. There are as many as 230 rivers, tributaries and distributaries which criss-crossed the landscape, covering a total length of 24140 km (Bangladesh Bureau of Statistics, 2003). Inland ports and other facilities include 11 major inland ports, 23 coastal island ports, 133 launch stations and more than 1,000 minor landing points located in rural areas.

The geographical features have made Bangladesh one of the most difficult areas in the world for which to provide a modern surface transport system suitable for guaranteed communication all over the year. Country boats, in the number of several hundred thousands, are traditional vessels which have been plying inland and coastal waters for hundreds of years and which play a key role as a rural mode of transportation of goods and people. The recent development is the steel hulled and powered vessels of different kinds (cargo, tanker, passenger, sand carrier, etc). More than 11,000 registered mechanized and non-mechanized vessels and thousands of country boats ply in the rivers of Bangladesh. But many of them are yet to achieve the required standard to ensure safe navigation.

The size and shape of waterways changes frequently. Their navigability are not marked and declared as frequent as they changes which creates navigation hazard. Besides, navigability of waterways could not be maintained with the limited resources and vast areas to cover. The weather is again unpredictable due to changes of six seasons. Thus, due to its unique geographic location, complicated environment and intense ship traffic, the risk of maritime accident is high for ships/vessels that navigate here.

In Bangladesh, being a country with many rivers, Inland Water Transport (IWT), is a major mode for the transportation of goods and people. IWT is important for the poor as well as it is the cheapest mode of transportation compared to road or rail. But unfortunately, the water transport sector has never got the attention as it deserves from the planners, researchers and aid-givers in Bangladesh. The sector had received little attention from the Government of Bangladesh with only limited resources allocated to its development. In addition, these resources were mostly used to develop the main routes (the ones most used by large mechanized vessels) while secondary rivers and transportation using country boats (mainly rural and non-mechanized vessels constructed in traditional design) were given second priority. As a matter of fact, the waterways and watercrafts remain nearly the same as they were one hundred years ago. It is a pity that every year countless people sacrifice their valuable lives in accidents in our inland waters.

Out of this 24140 km waterways, total 6,000 kilometers are accessible for movement of modern mechanized vessels during the monsoon season and some 3,800 kilometers are navigable around the year. Its inland water transport continues to be an important mode of transport not only in the inland movement of freight and passengers but also in the transportation of import and export items through the ports of Chittagong and Mongla. The high degree of penetration of the IWT network provides access to about 25% of the rural household in Bangladesh. Waterways network of Bangladesh is shown in Figure 2.1.

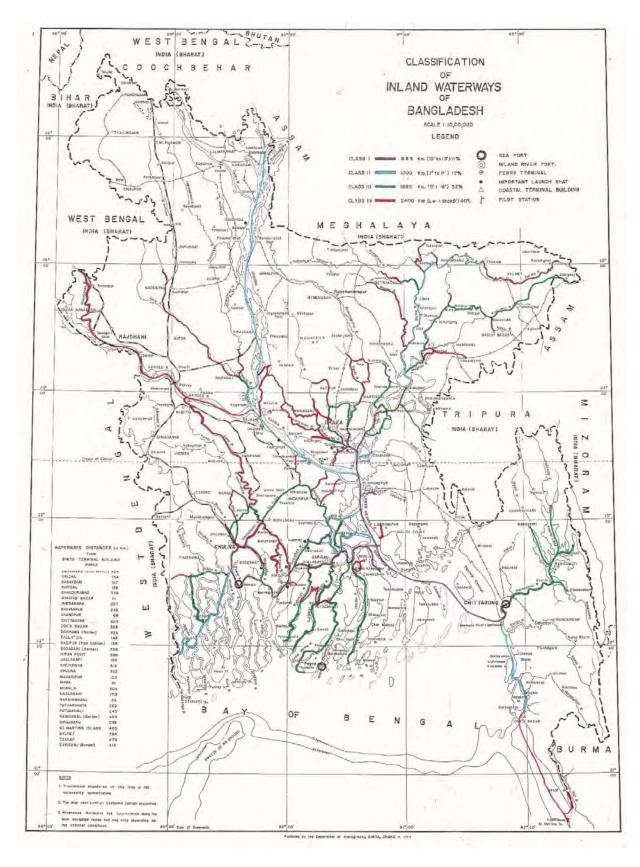


Figure 2.1: River network of Bangladesh (Source: BIWTA)

2.2 Classification of Waterways

A classification system for waterways of Bangladesh was introduced first in 1967 by a Dutch consulting firm, the Netherlands Engineering Consultants (NEDECO). Surveys on inland waterways and ports carried out principally based on the economic value and the navigational quality of the waterways. But it does not found practicable due to change of river flow and its navigability. Finally, the revised inland navigable waterway routes as agreed and classified by Bangladesh Inland Water Transpot Authority (BIWTA) fall into four groups as shown in Table 2.2 and the areas which cover under these four groups are given in Table 2.3. Out of these four class routes, according to BIWTA there are 374 places have so far been identified where BIWTA does not have any establishments. Those ports are used to load and upload the goods and passengers. In addition, there are eight in numbers ferry jetties which are used for the transportation of motor vehicles carrying goods and passengers (www.biwta.gov.bd/website).

Table 2.1: Classification of class routes

Class	Minimum	Length and	Minimum	Minimum	Description
	Draft	Percentage	Vertical	Horizontal	
			Clearance	Clearance	
Class- I	3.66 m	683 km	18.30 m	76.22 m	Least Available
		(11%)			Draft (LAD) of 3.6
					m required to be
					maintained round
					the year.
Class- II	2.13 m	1000 km	12.20 m	76.22 m	Links major ports or
		(17%)			place of economic
					importance to class
					I routes.
Class -III	1.52 m	1885 km	7.62 m	30.48 m	Being seasonal in
		(32%)			nature, it is not
					feasible to maintain
					higher LAD
					throughout the year
Class -IV	Less than 1.52	2400 km	5.00 m	20.00 m	These are seasonal
	m	(40%)			routes where
					maintenance of
					LAD of 1.5m or
					more in dry season
					not feasible
Total		5968 km			
		(100%)			

(Source: IWT Master Plan Study, 2009.)

Table 2.3: Areas of class routes

Class-I	Four trunk routes (depth 3.66m-3.96m, length about 683Km)
	Chittagong-Chowkighata-Chandpur-Shambhupara-Narayangong-Dhaka;
	Shambhupara-Demra;
	Shambhupara-Bhairab bazar, Ashuganj;
	Chowkighata-Barisal-Mongla-Khulna-Maheswarpasha.
Class-II	Eight link routes (depth 1.83m - 3.65m, length about 1,000 km)
	Mohanpur-Daikhawa;
	Bhairab Bazar-Chhatak;
	Chalna-Raimongal;
	Hijla-Saistabad;
	Satnal-Daudkandi;
	Chittagong-Cox's Bazar;
	Diara-Barisal via Nandir Bazar; and
	Chandpur-Ichuli.
Class-III	Twelve secondary routes (depth 0.91m - 1.82m, length about 1,905 km)
	Dilalpur-Fenchuganj-Zakiganj;
	Chittagong-Kaptai;
	Rangamati-Kaptai;
	Kaptai-Belaichari;
	Rangamati-Chotohorina;
	Rangamati-Mahalchari;
	Rangamati-Marisha;
	Sripur (Bhola)-Nazirpur-Char Montaz;
	Jhalakati-Barguna-Patharghata;
	Charpower-Patuakhali-Galachipa-Bara Baishdia;
	Bara Baishdia-Khepupara-Mohipur; and
	Khulna-Bardia-Manikdah.
Class-IV	Seasonal routes (depth less than 0.91m, length about 2,380 km).
	No Least Available Draft (LAD) is maintained for these routes.

2.3 Hazards/Vulnerability in Waterways

Literature review and informal interview and discussion with experts in marine sector, it is revealed that some factors which make the inland waterways vulnerable to accident are as follows:

Navigability, Traffic Flow and Vessel Types in Routes

A large number of vessels navigate through class-I route in comparison to other routes. Most of the vessels are mechanized steel hulled. The possibility of occurring accidents remains significant in this route for presence of intense traffic. The traffic in class-II route is average whereas traffic in class-III route is very less. There is no significant change in navigability in

class-III route. Vessels ply in this route are mainly wooden hull mechanized/non-mechanized boats with lower draft which are vulnerable to bad weather condition. Class-IV routes are seasonal routes which mainly becomes navigable in rainy season and no least available depth (LAD) is maintained for these routes.

High Traffic Density

The number of accidents in an area is proportional to the traffic volume. There are two types of traffic in the research area; the traffic in the same and longitudinal direction and crossing traffic in each direction. This situation makes the waterways most dangerous. Transit traffic, local traffic, passenger vessels, general cargo carriers, sand cargo, mechanized and non-mechanized wooden boats, fishing boats, etc create the high volume traffic in inland waterways. Moreover, waterways with narrow channels have geographical boundaries which usually cannot be extended. Increasing traffic density in these narrow channels create a high risk of marine accidents. Since the population of Bangladesh and their consumption is rapidly increasing, the maritime transportation scales up to reaching capacities. Observation at various river ports exposed that the intense traffic density in the ports prevent the vessels to berth alongside the pontoon and persuade them to resort to nose berthing. Due to acute congestion, the vessels keep colliding with each other recurrently, causing damage to the fender as well as the hull. These collision events are often ignored as long as these do not result in human death or severe hull damage. Other hazardous effects such as crack formation and propagation, metal fatigue and so on, leading to ultimate hull damage, often seem to be underrated.

Unsafe Acts of Ship

Lack of navigation and maneuvering control, ship's handling failure, over speed, lack of radar observation, position fixing error, lack of visual observation and other human error may fall under unsafe acts of ship. Loss of navigation and maneuvering control causes majority of collision accident. Inexperienced ship's handling will bring disaster for the vessel as well as passengers onboard. Fishing boats, foggy conditions and high volume traffic reduce the visual observation with naked eyes specially at night. Not following radar especially in maneuvering operation, increases the risk of an accident. Incorrect fixing of vessel's position generally resulted in an incident in narrow channel. Increasing the speed of the vessel in high volume traffic is a risky act for the navigation safety of the vessel. Accidents occurred in the research area have revealed that a relatively proportion of the accidents occur in poor visibility. Navigation without visual lookout, radar and other electronic aids can be assumed as a

contributing factor for the occurrence of accident. Human factor is important by the very fact that ships are still operated by humans. Human errors are evaluated as preconditions before unsafe acts of the accidents. Direct effects of the human errors in the occurrence of the accidents are well determined.

Overloading

Bangladesh is a riverine country and watercraft still remains the most economic mode of transport for the general masses. But due to shortage of required number of vessels, the overloading could not be stopped completely which enhances stability hazard. This accounts for the absence of prior ticketing system and insufficient steps taken by the authority to prevent overloading. Due to absence of prior ticketing system the actual number of passengers onboard remains unknown which allows continuing overloading more easily. Very often, the owners of passenger vessels tend to overload by doubling or tripling than the actual carrying capacity of their vessels to make more profit. This causes the vessel unstable and makes the matters worse. A safe design of the vessel is prerequisite for the stability of the vessel. But if a vessel inclines up to a certain angle (angle of vanishing stability), then it will not to be able to return of its upright condition. Thus it will incline more and losses its stability and finally it capsizes.

Unskilled and Incompetent Master/Crew/Operator

The prime requirement to ensure safe navigation is the operation of vessel by qualified operator. But at present the most alarming fact is the scarcity of trained, skilled and competent crews for the safe operation of the vessels. Deck Personnel Training Center (DPTC) has been unable to provide sufficient number of trained deck personnel to meet the current demand which compels the ship owners to rely on unskilled and untrained crews. This allows the vessels to be plied by incompetent masters and crews which often results in a danger.

High Siltation Rate

Bangladesh is located at the valley of the Himalayas. This causes very high sediment transportation through our rivers. The river gradient within Bangladesh is very low and thus significant amount of that sediment cannot be naturally transported to the Bay of Bengal and is deposited on the river beds. This reduces the water contain capacity as well as rate of water flow. Finally, it effects the navigability of waterways. The Ganges River mobilizes a total of 729 megatons of sediments annually through a narrow zone within its river valley. Under the present hydro-geological conditions, the river sedimentation is climatically controlled and is

predicted to produce a 2000 km long, 2 to 40 km wide and 25 to 50 m thick ribbon-shaped, well-sorted symmetrically skewed fine sand body. The river of Ganges is marked by its second highest siltation rate in the world.

Insufficient Dredging Facility

The waterways of Bangladesh needs continuous dredging service to ensure her navigability. The Government is also trying to expanse to the limit in solving this problem. However, the transportation sector in Bangladesh has been developed markedly in a biased manner, emphasizing more on the roads and highways department (RHD). Therefore, fund allocation for the IWT development is not satisfactory compared to roads and highways. In 2007-08, 79.64% of total ADP was allocated to RHD while IWT was given only 1.37%. In the same year, BIWTA spent 33.5% of its money for dredging related works. However, the repentant fact is that 56% of this money was spent to maintain ferry terminal and channel dredging which actually serves the RHD, leaving the main waterways in a miserable state. Annual dredging demand in core waterways network is estimated as 18 million cubic meters, while the annual productivity of the dredgers currently in work is 6.36 million cubic meters only. This is due to the shortage of dredgers as well as the aged state of most of the dredgers, resulting in reduced efficiency [4].

Insufficient Channel Marking and Limited Navigational Aids

Navigational aids like beacons, lighted & unlighted buoys, iron & bamboo marks etc. are used to mark shoals, channel bends, shallow patches etc. are used in waterway routes for the vessel safety. Only 1,561 km of waterways which is 26% of total waterways have been provided with the navigational aids for night navigation while 3,256 km which is 55% of total waterways have been equipped for the day navigation only. Moreover, pilotage service is provided with only 24 pilot boats and 26 pilot stations for navigation support in case of uncertainties in channels which are not sufficient at all for such a long river network.

Lack of Hydrographic Surveys

Required hydrographic surveys to all the classified waterways remain impossible due to low budget allocation. Only a limited number of navigation routes of 965 km which is 16% of total waterways were surveyed in 2006-2007 according to a need-based priority. Thus, due to all the short comings stated above, the current classification system of inland waterways is believed to outlive its usefulness.

Lack in Monitoring

IWT sector suffers not only from low budget allocation but also from insufficient manpower. Even though the Department of Shipping (DOS) started its journey with 45 personnel and one inspection boat in 1976. Nowadays, based on ratio, it is provided with lesser man power and no inspection boat despite of a rapid increase in the number and type of vessels. The impact is obvious as it is extremely difficult for such a small number of individuals to conduct inspection of vessels and to take necessary steps in order to ensure marine safety.

Inclement Weather

Inclement weather is one of the prime cause of marine accidents. Very often passenger vessels sink when they are caught in a sudden storm. Bangladesh enjoys generally a sub-tropical monsoon climate. While there are six seasons in a year, among those Winter, Summer and Monsoon are prominent. The pre-monsoon months from March to May are characterized by violent thunderstorms which are called Nor'westers in meteorological language but are known locally as Kalboishakhi (calamities of the month of Boishakh). They are called Nor'westers because they often approach a place from the north-westerly direction. In fact, they may come from any direction but the north-west is the most frequent direction. These thunderstorms are a striking phenomenon. They are usually of a short duration but are extraordinarily intense and severe. This Nor'westers can easily destabilize and capsize boats and ships if they occur in rivers.

Again, from June to October weather conditions are often very unpredicted over the Bay of Bengal. Cyclones, gusty winds and heavy rainfalls are the usual phenomena at this time of the year. In case of inclement weather, strong wind creates pressure on lateral area of superstructure or lateral area of the vessel exposed to the weather which tends to incline the vessel. For inclining, the vessel has to overcome the resistance of water exerted on the underwater volume. So, the ratio of the underwater volume to lateral area of superstructure plays a substantial role in the stability of passenger vessel. As per weather criterion of the Inland Shipping Stability rules, 2001 of Bangladesh maximum allowable wind pressure is equal to 0.0322 t/m². Passenger vessels stability under wind pressure largely depends on wind lever. It is the sole duty of every designer to keep the value of wind lever as low as possible. As per inland shipping stability rules- 2001, passenger vessels are not allowed to ply at a wind speed of more than 10 m/s. Several accidents have been happened due to inclement weather when the wind pressure is more than 0.0322 t/m² [5].

CHAPTER-3

STATISTICAL ANALYSIS OF ACCIDENTS IN INLAND WATERWAYS OF BANGLADESH

3.1 Accident Data

One of the important aim of this study is to compile and maintain a technical accident database working as a tool for in-depth accident analysis. Therefore, emphasis has been given on collection of accident data from various sources such as records and reports of Ministry of Shipping (MOS), Department of Shipping (DOS) and Bangladesh Inland Water Transport Authority (BIWTA). It was observed that DOS and BIWTA store accident data essentially for legal purposes and give more emphasis on the parameters related to legal issues. Many of the important information of accident like weather, river/sea condition of the area when the accident happened and others are insufficient in the accident record register and investigation reports. Therefore, extractions of scientific data from these records & reports were very much cumbersome, time consuming and in many of the cases impossible.

Numbers of accident investigation reports, conducted by the committee of MOS and DOS, were collected and studied to conduct case study. These investigations were mainly conducted for legal purpose. Even though these reports guides to learn the trend of accidents and how the different factors are influencing or contributing to the marine accidents.

However, for total of 604 accidents found in records. Out of this, maritime accidents are being considered in this investigation/analysis whose required data are available. A database has been developed using Microsoft Excel which comprises the accident date, vessel name, registration number, type of vessel, principal particulars of vessel, gross tonnage, place of accident, accident route, reason behind the accident and number of loss of lives due to these accidents, etc.

In this study, accidents occurred for different types of vessel in inland routes have been separated into seven categories. Appendix-A illustrates marine accident statistics for those vessels. The three accidents most encountered in those vessels are, respectively, collision, grounding, and sinking. The total number of collision and grounding accidents is 375 (three hundred and seventy-five). 366 (three hundred and sixty-six) of these accidents are collisions and 09 (nine) of them are groundings. According to the information in most of the collision

and grounding accidents occurring in passenger vessels, the vessel is lost in whole or becomes unseaworthy. This puts forth the importance of marine accidents examined in the study.

3.2 Statistical Analysis of Accidents in Inland Waterways of Bangladesh (During 1981 to 2018)

Statistical analysis of collected accident data in inland waterways of Bangladesh during the period of 1981 to 2018 was carried out to determine the nature of accidents and the influence of different parameters in occurring accidents. The analysis took place in different dimension and graphical presentation is shown for easy understanding of the phenomena of accidents.

604 accidents during the period 1981-2018 are analysed to expose possible reasons of incidents by using existing statistical data. Number of accidents analysed as:

- 366 Collision
- 9 Grounding
- 4 Fire
- 2 Bottom rupture
- 93 Sinking
- 1 Bang
- 57 Nor'westers
- 50 Overloading
- 1 Electric short circuit
- 2 Nor'westers and overloading
- 19 Others

Collisions and groundings come out as the major and most common incidents. These two types of accidents are investigated by using Fault Tree Analysis in this research. A number of accidents exist with their unexpected and large-scale impacts on safety of life and marine environment based on these accidents that occurred in the history. Accidents occurred during the period 1991-2018, are represented with a fault tree as given in Figure 3.1.

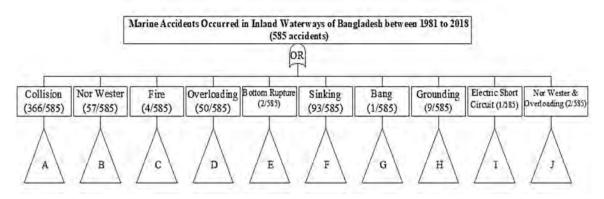
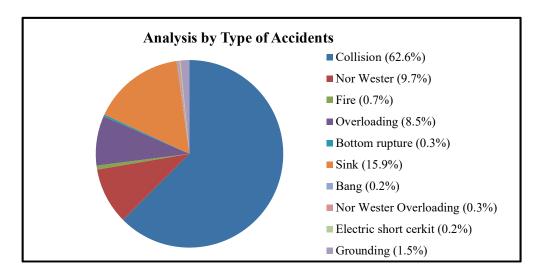


Figure 3.1: FTA of the accidents occurred in the research area

3.2.1 Distribution of Accidents by Type

Collision, grounding, sinking, fire, bottom rupture, etc. are common nature of accidents in inland waterways of Bangladesh. Among those collision is very frequent. Improper operation of vessel is the main reason for such accident. Figure 3.2 shows that majority type of accident is collision and it is 62.6% of total accident. Three hundred and sixty-six in number accidents are collision out of 604 in number total accidents. Grounding is having 1.5% contribution to the total number of accidents. The least frequent accident types are fire (0.7%) and bottom rupture (0.3%). Percentage of occurrence of other types of accident is shown in Figure 3.2.



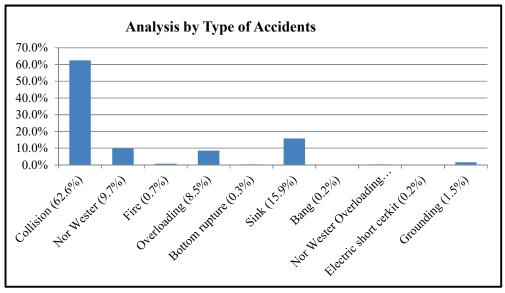
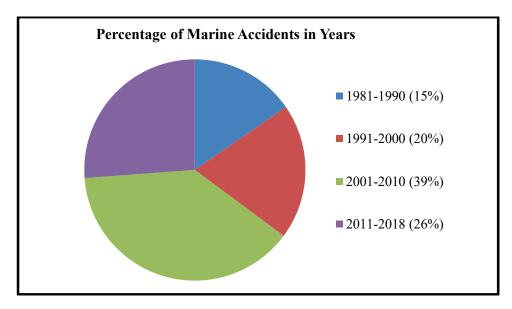


Figure 3.2: Analysis by type of accidents

Priority may be given to reduce collision accident since majority of accidents are collision. Attempt may be taken by government in establishing more training institute to produce skilled and knowledgeable operators.

3.2.2 Percentage of Accidents in Years

Accidents data has been analysed for the accidents between 1981 to till 2018. Year wise occurrence of accident has been shown in Figure 3.3. It is observed that remarkable number of accidents took place within 2001 to 2018 and that is 39% of total accidents. Again, there is remarkable reduction of occurrence of accident in the years of 2011 to 2018 which is 26% of total accidents. With a query to Department of Shipping and BIWTA, it is learnt that within these years the authority did not allow to navigate any vessel especially passenger vessel in bad weather condition and navigation at night has been restricted. This actions has dramatically reduced the accident number.



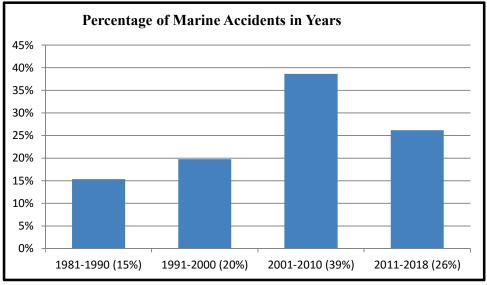
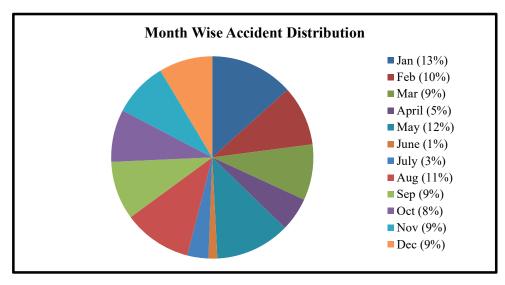


Figure 3.3: Percentage of marine accidents in years

Navigation in bad weather condition is strictly and at night as convenient may be avoided to reduce the probability of occurring accident.

3.2.3 Season of Accident

Bangladesh enjoys generally a sub-tropical monsoon climate. The pre-monsoon months from March to May are characterized by violent thunderstorms which are called Nor'westers. The vessels specially the passenger vessels and ferries are usually exposed to the hostile environment in the rivers during these months when the deadly nor'wester strike the country almost every evening. From Figure 3.4, it has been observed that almost 26% accidents of total vessel accidents are found to occur during the months of March to May when violent nor'westers lashes the country frequently.



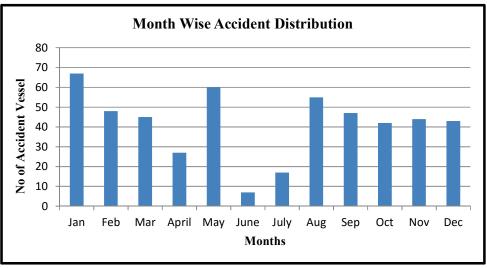
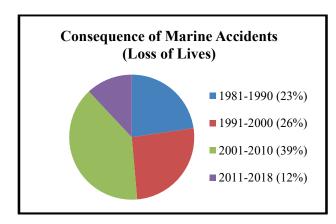


Figure 3.4: Month wise accident distribution

These three months (March, April and May) should be treated as an emergency period in the maritime calendar of Bangladesh. Seminars on marine safety should be organized throughout the country in the first week of March every year and the owners, masters and the crew should be instructed to participate in the same. Good words may sometimes win their ears. Vessels may operate with special precaution and observing weather forecast to avoid accident due to bad weather condition specially between the month of March to May. Moreover, the Government should ban passenger vessels and ferries from traveling at night during the stormy weather.

3.2.4 Consequence of Accidents (Loss of Lives)

A total of about 604 marine accidents in inland waterways of Bangladesh tools more than 5407 valuable lives within 1981 to 2018. The year wise loss of lives is shown in Figure 3.5. It is found that the loss of lives has been reduced from highest 39% to 12% in recent years, that is from 2011 to 2018. During discussion with concerned authority, it is opined that general awareness of passengers and operators have a significant effect on reducing accidents.



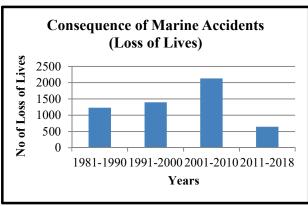


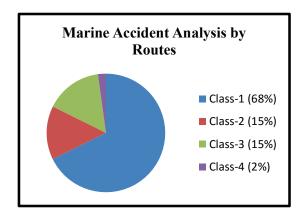
Figure 3.5: Consequence of marine accidents (loss of lives)

General awareness among the passengers and operators may be improved through media, seminar, posturing, leaflet and other means to deduce the accidents as viewed between the year 2011 to 2018.

3.2.5 Analysis on Accident Routes

Inland waterways are classified into four routes. These are class-I, class-III and class-IV. In analysis, as shown in Figure 3.6 that 68% accident in class-I, 15% in class-II, 15% in class-III and 2% in class-IV route have been occurred. Maximum accident has occurred in

class-I route. Large number of vessels navigate through class-I route and it is the most used route. But while visiting this route physically, it is observed that the navigable channel is not sufficiently marked and traffic is not controlled.



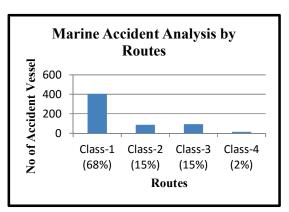
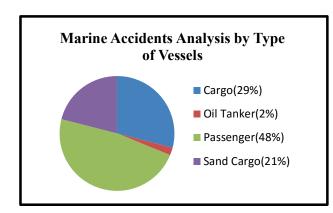


Figure 3.6: Marine accident analysis by routes

To minimize overall number of accidents, special care may be taken to reduce accident in class-I route.

3.2.6 Accidents According to Vessels' Type

Various types of vessels are travelling in our inland waters. Among those passenger vessel, cargo carrier, oil tanker, sand cargo vessels, wooden country boats, mechanized wooden boats, boats with sails, etc, are very common. Analysis of accident shows from Figure 3.7 that passenger vessel accident is 48% of total accidents which is highest in number. From 1981 to 2018, total number of passenger vessel accident is 221 out of 462 in number marine vessel accidents. General cargo, sand cargo and oil tanker have contributed 29%, 21% and 2% to total accidents respectively.



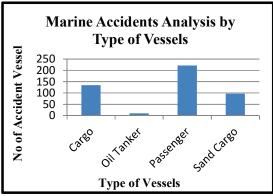


Figure 3.7: Marine accidents analysis by type of vessels

Special care may be taken to reduce the accident of passenger vessel since 48% of total accidents has occurred for passenger's vessels. A detailed survey of each passenger vessel may be carried out once every year. It is the responsibility of the ship surveyors to check the fitness of the watercraft and issue an annual certificate. Any passenger vessel/ferry failing to obtain such a certificate must not be allowed to operate in river routes.

3.2.7 Analysis on Principal Particulars

The vessels ply in inland waterways of Bangladesh ranges from 10 to 90 meter in length. Through analysis it is prevailed that major number of accidents took place for the vessel length between 10 to 40 meters which is 54% of total accidents. Figure 3.8 shows that probability of occurring accident reduces from vessels above 50 m of length.

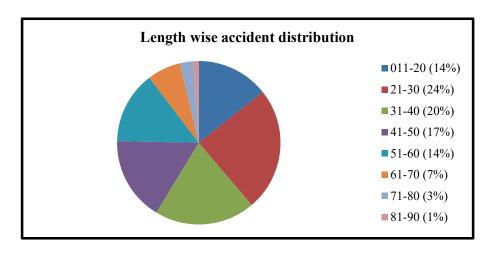
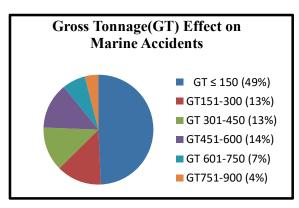


Figure 3.8: Length wise accident distribution

Vessels with higher length, may be above 50 meters can be designed and constructed to reduce the number of accident.

3.2.8 Effect of Gross Tonnage (GT)

General gross tonnage of most of the vessels in accident data was found within 150 tons. Many of the vessels gross tonnage is even below 50 tons. It is observed from Figure 3.9 that 49% of accident vessels are below 150 tons of gross tonnage whereas vessels of more than 150 tons of gross tonnage has occurred only 13% of total accidents.



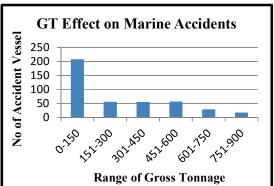


Figure 3.9: Effect of gross tonnage (GT) on marine accidents

Small gross tonnage vessels have more accidents than large ones. So, particular attention has to be given on the design and regulations of smaller vessels. Vessel of more than 150 tons gross tonnage may reduce the possibility of occurrence accident.

3.2.9 Areas of Accident

Attempt has been taken to find out the accident prone areas. It is found that higher number of accident has taken place at Barishal, Chandpur and Narayanganj areas. It is mainly due to over traffic, negligence in operation, unsuitability and overloading of vessel, etc. The vulnerable or accident prone areas are marked on route map as in Figure 3.10 and number of accidents occurred in different areas is shown in Table 3.1.

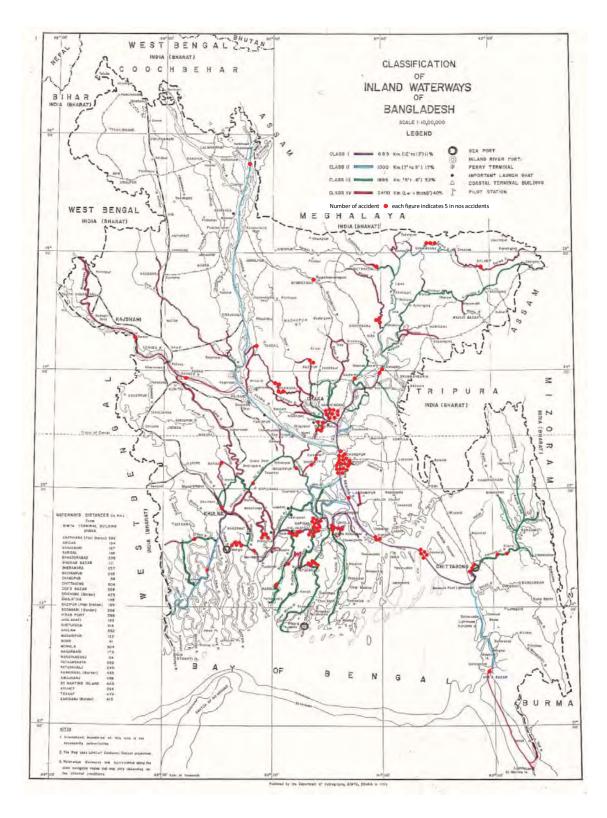


Figure 3.10: Accident prone areas

Table 3.1: Areas of accident

Sr	Areas of Accident	Number of	Remarks
No		Accidents	
1.	Chandpur	94	Accident prone area
2.	Foridpur	3	
3.	Bhola	34	Accident prone area
4.	Shoriatpur	7	
5.	Bagerhat (Mongla)	31	Accident prone area
6.	Patuakhali	26	
7.	Khulna	26	
8.	Gopalganj	4	
9.	Sunamgonj	15	
10.	Dhaka	41	Accident prone area
11.	Shirajgonj	2	
12.	Narshingdi	4	
13.	Barishal	80	Accident prone area
14.	Noakhali	12	-
15.	Jhalokhathi	18	
16.	Pirojpur	19	
17.	Gazipur	6	
18.	Netrokona	4	
19.	Sondip	16	
20.	Chittagong	34	Accident prone area
21.	Narayangonj	45	Accident prone area
22.	Rangpur	3	•
23.	Manikgonj	18	
24.	Munshigonj	20	
25.	Kishorgonj	8	
26.	Narail	3	
27.	Cox's bazar	5	
28.	Brammonbaria	9	
29.	Sylhet	2	
30.	Madaripur	4	
31.	Lokkhipur	5	
32.	Shatkhira	1	
33.	Rajshahi	1	
34.	Borguna	4	
	Total accident =	604	

Traffic must be controlled in accident prone areas and vessel may navigate with additional precaution to minimize accidents.

3.3 Accident Investigation Reports

It is very much necessary to know in details of each and every occurrence of accident prior to analysis the accidents. Again the accident record register of the Department of shipping was not sufficient to provide necessary data and informations of accidented to be analysed. Thus, initiative was taken to carry out study of details accident investigation reports from the Department of shipping and BIWTA. But, details accident investigation was carried out for few number of accident and reports were made available. Moreover, mainly these investigations were carryout for legal purpose. Thus, these reports do not cover or include many of information/data necessary for analysis. Even though, trend of accidents was well understood through the study of reports.

3.4 Records of Accidents

The Department of Shipping is responsible to record the data and information in details of accidents for all types of vessel. At the same time, BIWTA keeps records for only passenger vessels in addition to the Department of Shipping. But practice is not yet made by any of these departments to record the accidents with sufficient data and information. Only the very basic information like the vessel name, name of owner, place of accident, date of accident, causes of accident, loss of lives and injury are recorded in a very simple register under Department of Shipping and BIWTA which is again not at all sufficient/competent to carry out any detail analysis on any accident following standard procedure. Vessels principal particulars, registration no, weather condition, time of accident, tide, current, depth of water, wind direction & speed, navigational aids, navigational hazards, qualification of crews, etc are not specified while recording. Thus, it is felt well to formulate an accident reporting/recording system for Bangladesh.

3.5 Formulation of Accident Report Form

Recording of accidents data is very much necessary and pre-requisite for any analysis, research work or further investigation. The data has to be recorded just after the occurrence of accident to ensure the accuracy and validity of accident information. The record data must include all the necessary information in details so that accident scenario and reasons behind the occurrence of the accident can be assessed well.

Keeping the requirement discussed above, attempt has been taken to formulate an accident report form. Existing accident report forms of different developed countries like USA, UK, Netherland, Turkey, Switzerland, New Zealand, Australia, etc. has been examined well which having internationally recognition. While forming the report form the perspective of Bangladesh was considered seriously and judiciously. Taking consideration of all possible

areas and requirement, an accident report form has formulated for future record of accident which is attached as Appendix-B. The form may be named as, "Accident Report/ Record/ Investigation Form". This form may be promulgated by the Department of Shipping, Bangladesh.

3.6 Occasion of Using Report Form

This form satisfies the requirements for written reports of any accidents found in inland routes of Bangladesh. The kinds of accidents that must be reported are described in the following instructions. A vessel accident must be reported if it occurs upon the navigable waters of the BD, its territories or possessions; or whenever an accident involves an inland vessel; wherever the accident may occur. The accident must involve one of the following:

- a. All accidental/intentional collision, groundings, capsizing, sinking, bottom rapture, fire, or any other incident which creates a hazard to navigation, environment or the safety of the vessel.
- b. Loss of main propulsion or primary steering, or an associated component or control system; the loss of which causes a reduction of the maneuvering capabilities of the vessel. Loss means that systems, component parts, subsystems, or control systems do not perform the specified or required function.
- c. An occurrence materially and adversely affecting the vessel's river or sea worthiness or fitness for service or route including but not limited to fire, flooding, failure or damage to fixed fire extinguishing systems, lifesaving equipment or bilge pumping systems.
- d. Loss of life.
- e. An injury that requires professional medical treatment (beyond first aid).
- f. An occurrence not meeting any of the above criteria but resulting damage to property, material or personnel.

CHAPTER-4

RISK ANALYSIS TECHNIQUES

4.1 Introduction

The objective of this chapter is to study a set of tools and techniques that we need to utilize in the process of carrying out a risk analysis. In order to understand the application, importance and role of these techniques in the context of risk analysis, it is of crucial importance to first gain an understanding of the basic concepts of risk analysis, as well as the underlying components of risk. There are the following techniques can be applied for risk assessment [34]:

- Preliminary Hazard Analysis (PHA)
- Hazard and Operability Studies (HAZOP)
- Failure Mode, Effect and Criticality Analysis (FMECA)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)

These techniques are utilized in relation to different aspects of risk analysis. The Preliminary Hazard Analysis (PHA) methodology is used to identify possible hazards, i.e. possible events and conditions that may result in any severity. A more extensive hazard identification method is Hazard and Operability Studies (HAZOP) which searches much more systematically for system deviations that may have harmful consequences. The Failure Mode, Effect and Criticality Analysis (FMECA) can be used to identify equipment/system failures and assess them in terms of causes, effects and criticality. The application of an FMECA gives enhanced system understanding as well as an improved basis for quantitative analysis. Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) are the most commonly used methods in terms of establishing the probability of occurrence and the severity of the consequences for hazards in the context of risk analysis.

Among those FTA method has been chosen to analyze the risk of marine accidents in inland waterways of Bangladesh since FTA is the most commonly used method in the context of risk analysis. Thus, this chapter therefore, gives a brief introduction to risk analysis & assessment and some useful basic theory related to system description and structures of risk analysis.

4.2 Risk Analysis and Risk Assessment

The word risk is used in a variety of contexts and in many senses. In general, it can be defined as the possibility of an undesired consequence, but is often regarded as a function of probability and consequence. In many contexts, risk is used rather technically. Risk is then a combination of the frequency or probability of occurrence and the consequence of a specified hazardous event. The risk of an accident is defined as the product of the probability of occurrence of the accident and the consequences of that accident. The accident is a constituent element of the risk. Risk analysis encompasses a wider range of processes than accident analysis, including exposure analysis and risk estimation and presentation.

There are different definitions of accidents and incidents exist. An accident is an undesired event that results in adverse consequences, for example injury, loss of life, economic loss, environmental damage and damage to or loss of property. Accidents are due to an unexpected combination of conditions or events. The root reasons of the accidents are causal factors. Causal factors lead to error and if the error combines with the necessary conditions then accident event occurs. And accidents cause certain losses. The occurrence of accidents as per IMO is shown at Figure 4.1.

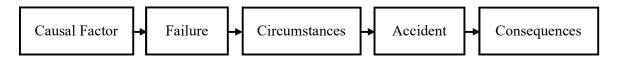


Figure 4.1: Marine accident occurrence, IMO [35]

The purpose of accident and incident analyses is to determine their causes and the specific factors that contribute to them. Accident analysis, which always implies an accident model, is a very important process for providing input to the development of proactive and cost-effective regulations. An accident model is an abstract conceptual representation of the occurrence and development of an accident. It describes the way of viewing and thinking about how and why an accident occurs and predicts the phenomenon [17].

4.2.1 Understanding Risk and Safety

Risk analysis involves analysing a system in terms of its risks. As pointed out earlier, the concept of risk is central to any discussion of safety. There is a steadily increasing focus on safety in all aspects of life and in a maritime context risk analysis is nowadays a relatively

common investigative and diagnostic element in reviewing system performance with the objective of identifying areas for improvement. Different people tend to understand the term 'safety' differently and for the sake of this chapter the following definition proposed by Kuo [36] can be useful: 'Safety is a perceived concept which determines to what extent the management, engineering and operation of a system are free from danger to life, property and the environment'.

As mentioned above, risks and safety are closely linked. But how should we understand the term 'risk'? Risk is a parameter used to evaluate or judge the significance of hazards in relation to safety and as mentioned in the introduction to this chapter, hazards are the possible events and conditions that may result in severity. Risk (R) is normally evaluated as a function of the severity of the possible consequences (C) for a hazard and the probability of occurrence (P) for that particular hazard:

$$R = f(C, P) \tag{4.1}$$

Both the possible consequences (C) and the probability of occurrence (P) are functions of various parameters such as human factors, operational factors, management factors, engineering factors and time. It is normal to use the simplest possible relation between C and P, i.e. the product of the two to calculate the risk (R):

$$R = C. P (4.2)$$

Given this simple equation, we can better understand risk as a concept. For example, a high consequence (C) and a high probability of occurrence (P) for a certain given hazard mean that the risk is high which will often be considered as intolerable from a safety perspective. On the other hand, a low consequence (C) and a low probability (P) represent a low risk level. A low level of risk will normally be perceived as tolerable in a safety context but may even be negligible if it is really low. The risk level that results from a high consequence and a low probability or vice versa, will often be tolerable but may in extreme cases be either negligible or intolerable. The hazards needing special attention are those where both consequence and probability are significant.

Given this knowledge, estimated risk of hazards can be used to make informed decisions in terms of improving safety. Safety can be improved by reducing the risk and risks can be reduced by reducing the severity of the consequences, reducing the probability of occurrence, or a combination of the two.

4.2.2 The Risk Analysis and Risk Assessment Process

Risk analysis is the process of calculating the risk for the identified hazards. Experts in this field of study often distinguish between risk analysis and risk assessment. Risk assessment is the process of using the results obtained in the risk analysis (i.e. the risks of hazards) to improve the safety of a system through risk reduction. This involves the introduction of safety measures, also known as risk control options (RCO) [34]. A principal diagram for the process of risk analysis and risk assessment is illustrated in Figure 4.2.

The first step in the process of risk analysis and risk assessment is to make a problem definition and system description, e.g. to define the vessel and/or the activity whose risks are to be studied. The second step of the process is to perform a hazard identification exercise where possible events and conditions that may result in any severity are identified. Once the hazards have been identified, it is time to perform the risk analysis which is the process of estimating the risks, either qualitatively or quantitatively. First a frequency analysis is used to estimate how likely it is that the different accidents/hazards will occur (i.e. the probability of occurrence). In parallel with the frequency analysis, consequence modeling evaluates the resulting consequences/effects if the hazards really occur. In a maritime context, an accident may have an effect on the vessel, its passengers and crew, the cargo and/or the environment. When both the frequency and the consequence of each hazard have been estimated, they are combined to form a measures of overall risk. Risk may be presented in many different and complementary forms. Figure 4.3 illustrates the principle of risk presentation using a specific risk acceptance criterion. Figure 4.3 also incorporates an assessment of the hazards in terms of risk, indicating whether they are intolerable (i.e. unacceptable), tolerable (i.e. acceptable) or negligible using continuous risk scales.

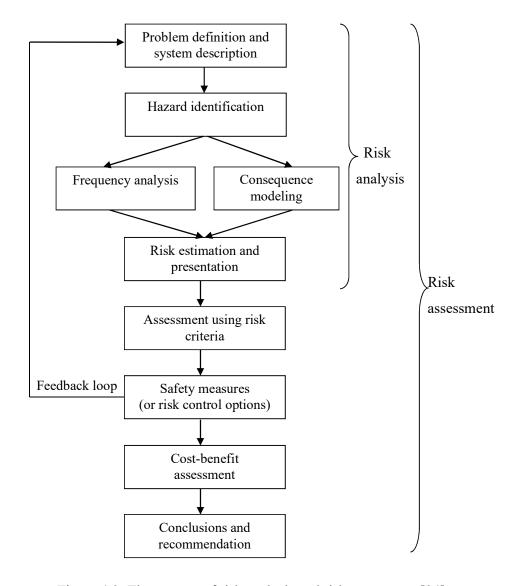


Figure 4.2: The process of risk analysis and risk assessment [34]

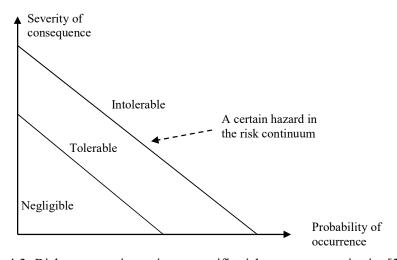


Figure 4.3: Risk presentation using a specific risk acceptance criterion[34]

Often and particularly in qualitative risk analysis, discrete risk scales are used to assess the relative importance of hazards in terms of risks. An example of such a discrete risk scale is given in Figure 4.4.

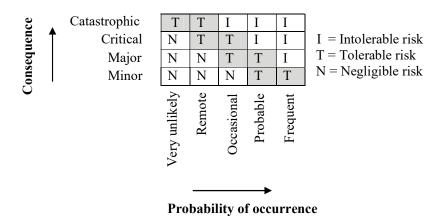


Figure 4.4: Risk presentation using discrete risk scales[34]

In order to make intolerable risks tolerable or to reduce the risks of hazards to as low a level as reasonably practicable (ALARP), the introduction of safety measures into the system will be necessary. A safety measure may, for example, be the construction and implementation of a marine evacuation system on board a ship. Cost-benefit analysis is a useful tool with regard to assessing safety measures because such an analysis evaluates whether the benefits of such measures justify the costs involved in implementing them. The benefits can be estimated by repeating the risk assessment process with the proposed safety measures in place, thereby introducing an iterative loop into the assessment process as shown in Figure 4.2. Based on the process described above, conclusions may be drawn and recommendations proposed to the ship owner or ship operator, etc.

Each of the risk analysis techniques presented later, can be utilized as tools within the risk analysis and assessment framework presented in Figure 4.2. For example, both Preliminary Hazard Analysis (PHA) and Hazard and Operability Studies (HAZOP) can be used to identify possible hazards. Fault Tree Analysis (FTA) is useful in carrying out the frequency analysis, while Event Tree Analysis (ETA) is a common method used to study possible consequences of hazards.

4.2.3 Analysis Approaches

Risk analysis can be performed quantitatively and/or qualitatively. If any performance is measured with values or by terms in the analysis it is, by definition, a quantitative analysis. A comprehensive and total risk analysis should include the use of both qualitative and quantitative approaches and techniques. The qualitative approach may be included already in the system description phase of the risk analysis process. Both approaches give important and supplementary information about the system.

4.2.4 Required Resources

When performing a risk analysis and risk assessment, several resources are required for a successful result. First, the analyst(s) must have considerable experience with and understanding of the system under consideration. This is crucial in terms of identifying the real issue for the analysis, being able to identify and recognize the involved hazards, as well as to establish frequency/probability and consequence models that, as correctly as possible, represent the real world. Substantial knowledge is also necessary in order to be able to make the right simplifying assumptions that keep the complexity of the assessment process within acceptable levels. Such assumptions may include deciding which systems and activities should be included or excluded in the analysis.

Another important resource for the risk analysis and assessment process is statistical data, because these can give an indication of accident frequency and the most likely consequences when a certain hazard occurs. In a maritime context, where the number of serious accidents is quite low due to relatively small ship populations, historical recordings over several decades may be used to establish a statistical basis for risk analyses. The use of statistical data means that risk analysts should be well trained in statistical techniques.

Because of the inherent complexity of most risk assessments, such analyses normally need to combine the work of several people with a wide range of different backgrounds. Therefore, the analyses teamwork and communication skills are of utmost importance.

4.2.5 Limitations of Risk Analysis

Risk analysis (and assessment) is a powerful tool in obtaining information and increased understanding of a system, its hazards, and the accident mechanisms. This information and

understanding makes us able to implement risk control options and thus improve the system's safety. However, one should be aware of the limitations of such analysis, especially in relation to quantitative analysis. The lack of good statistical data due to limited experience is probably the most significant and common limitation in quantitative analysis. This is particularly clear in a maritime context where the number of large-scale accidents is quite low. Lack of statistical data results in huge uncertainties in the outcomes of the analyses and one should therefore always evaluate these uncertainties and include this evaluation in the decision and recommendation process.

The complexity of most systems makes it necessary to make several simplifying assumptions in order to be capable of performing the analysis. These simplifications also create uncertainties.

A major limitation of traditional risk analyses is that human and organizational factors are usually not given adequate attention. During the last decades it has become a well-established fact that human and organizational factors affect the safety of technically complex systems, conventional ships and other vessels being no exception. These factors materialize themselves as active failures and latent conditions that breach the defenses that prevent hazards from becoming severe losses. In technical systems that interact with humans, active human failures are normally considered to be the largest single cause of accidents. Investigations suggest that approximately 60% of all accidents are caused directly by human errors. In addition, some accidents are more indirectly caused by human errors, being a result of so-called organizational factors (e.g. company policies, attitude towards safety, etc.). It is normally easier to take the human and organizational factors into account in qualitative than in quantitative risk analyses.

CHAPTER-5 STUDY TECHNIQUE

5.1 Research Methodology

Accident models are simplified representations of accidents that have already occurred or might occur in real life. Each accident model has its own characteristics based on what types of causal factors it highlights. To understand the mechanisms of accidents and to develop accident prevention and control strategies, the existing accident data were collected first from a number of sources, including the Department of Shipping and BIWTA, reliable accident information sources, recognized shipping information systems, the maritime and general media and a wide range of internet based publications. The information were aggregated in a database in order to generate the tables, graphs, charts and maps in the document. The figures were represent a relatively accurate overview of the accidents that happened in and around inland waterways of Bangladesh during 1981-2018 although comprehensive reporting was not fully guaranteed. After that accident models were developed to support accident investigations.

Moreover, an initial witness statement for reporting a maritime accident for inland waterways of Bangladesh was proposed and distributed to the officials and operators of marine sectors who were believed to have knowledge, experience and information related to the incident. Using the form allows a single investigator to collect data from multiple personnel simultaneously. The completed forms were then reviewed by the investigator to determine the order of the interviews and potential issues or questions to discuss during the interview.

The risk were assessed using Fault Tree Analysis (FTA) programme for the incidents as collision and grounding occurred in inland waterways. First the potential problems which cause the collision and grounding accidents determined were investigated. Second, the occurrence of accidents were shown with causal factors by the FTA method.

The same accident data were analysed using open FTA programme to check the validity of results. The results were compared with some reference data. A set of RCOs were developed and their effects were calculated to determine the change in the probability of collision and grounding accidents. And finally, the significance degree of the initial events causing occurrence of accidents were put forth.

In order to achieve the objectives, the methodology of the research can be graphically presented as shown in Figure 5.1.

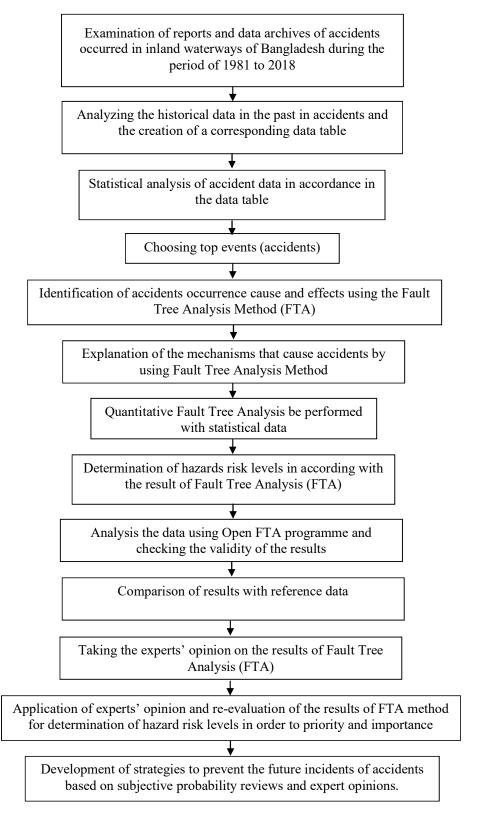


Figure 5.1: Methodology of Research

5.2 Fault Tree Method for Analysis of Accident

5.2.1 Introduction

FTA might be the best known method which is most frequently employed in risk/safety analysis. A fault tree analysis (FTA) can be used to identify the subsystems that are most critical for the operation of a given system or to analyse how undesirable events occur. Fault tree analysis was introduced in 1962 by H. S. Watson at Bell Telephone Laboratories in connection with a safety evaluation of the Minuteman intercontinental ballistic missile launch control system. This chapter will present some features of the method. It will show how simpler kinds of fault trees can be generated and only briefly discussion on probabilistic estimates [27].

A fault tree is a top-down logic diagram that displays the interrelationships between a potential critical event in a system and the causes of this event. The causes at the lowest level are called *basic/primary events* and may be component failures, environmental conditions, human errors, and normal events i.e. events that are expected to occur during the life span of the system [27].

Domain of application

Fault tree analysis was originally applied in the nuclear power and chemical processing domains. However, the method is generic and could potentially be applied in any domain. Recent applications have taken place in the shipping, chemical process control and hydro power plant domains.

5.2.2 Principle

In the context of risk analysis, the FTA method is used to analyse the way an unwanted event occurs, as well as its causes. By the use of a logical diagram the relationship between the causes of the event (e.g. the failure of a certain engine component) is visualized. The main structure of the fault tree analysis method is illustrated in Figure 5.2

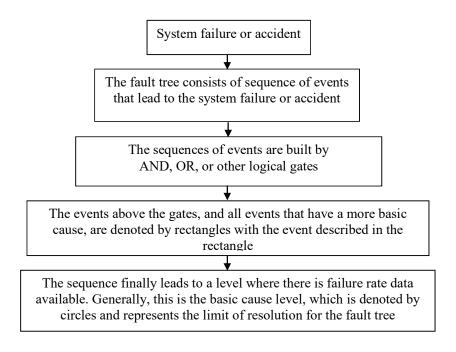


Figure 5.2. Principle of a fault tree [14]

5.2.3 Method Description

Fault trees are used to graphically depict the failures leading up to accidents as well as their causes. They use tree-like diagrams to define failure events and possible causes in terms of hardware failures and/or human errors. The process begins by identifying the failure or top event, which is placed at the top of the fault tree. Contributing events are then placed below using AND and OR logic gates. AND gates are used when more than one event causes a failure, whereby all the events placed directly underneath an AND gate must occur together for the failure event above to occur. OR gates, on the other hand, are used when the failure event could be caused by any one contributory event in isolation.

The Binary Approach

The FTA method assumes binary operational modes which means that an event either occurs or it does not (e.g. a failure alarm is given or not given). An event statement can then be designated as *true* or *false*. This can also be expressed in terms of the logical values 1 and 0, meaning that binary logic and Boolean algebra can be applied. Hence, degraded operations or events are not analysed in fault trees.

Procedure and advice

Step 1: define failure event. The failure or event under analysis should be defined first. This may be either an actual event that has occurred (retrospective incident analysis) or projected failure event (predictive analysis). This event then becomes the top event in the fault tree.

Step 2: collect data regarding failure event. Fault tree analysis is dependent upon accurate data regarding the incident under analysis. The next step involves collecting data regarding the incident in question; for fault trees this can involve a range of activities, including interviews with those involved in the incident or SMEs, analysing reports or inquiries into the incident and observing recordings of the incident.

Step 3: determine causes of failure event. Once the failure event has been defined, the contributory causes associated with the event should be defined. The nature of the causes analysed is dependent upon the focus of the analysis. Typically, human error and hardware failures are considered. It is useful during this phase to use various supporting materials, such as documentation regarding the incident, task analyses outputs, and interviews with SMEs or those involved in the incident.

Step 4: AND/OR classification. Once the cause(s) of the failure event are defined, the analysis proceeds with the AND or OR causal classification phase. Each causal factor identified during Step 3 should be classified as either an AND or an OR event. If two or more contributory events combine to contribute to the failure event, then they are classified as AND events. If two or more contributory events can cause the failure even when they occur separately, then they are classified as OR events. Again, it is useful to use SMEs or the people involved in the incident under analysis during this phase.

Steps 3 and 4 should be repeated until each of the initial causal events and associated causes are investigated and described fully.

Step 5: construct fault tree diagram. Once all events and their causes have been defined fully, they should be put into the fault tree diagram. The fault tree should begin with the main failure or top event at the top of the diagram with its associated causes linked

underneath as AND/OR events. Next, the causes of these events should be linked underneath as AND/OR events. The diagram should continue until all events and causes are exhausted fully or until the diagram satisfies its purpose.

Step 6: review and refine fault tree diagram. Constructing fault trees is a highly iterative process. Once the fault tree diagram is complete, it should be reviewed and refined, preferably using SMEs or the people involved in the incident.

Step 7: Analyze the Fault Tree Qualitatively. A qualitative evaluation of the fault tree may be carried out on the basis of the minimal cut sets. The criticality of cut set depends principally on the *order* of the cut set. A cut set of order one is usually more critical than a cut set of order two or more. When we have a cut set of order one, the TOP event will occur as soon as the corresponding basic event occurs. When a cut set has two basic events, both of these have to occur at the same time to cause the TOP event to occur. Another important factor is the *type* of basic events in a minimal cut set. The criticality of the various cut sets may also be ranked.

Step 8: Analyze the Fault Tree Quantitatively. If it is assumed that the basic events are statistically independent and that we have knowledge about the probability of occurrence of each of the basic events in the fault tree, the probability of occurrence of the TOP event, importance measures, and so on. These can be calculated by using the formulas in Section 5.3 and 5.4.2. In most cases, this analysis will be done by a fault tree analysis program. Depending on the program, the number of different measures that can be calculated will vary [36].

The flowchart for fault tree construction is given in Figure 5.3.

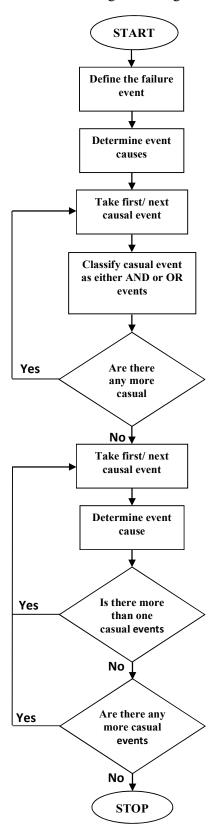


Figure 5.3: Flowchart for fault tree construction [37]

5.2.4 Symbols Used in FTA

Events, states and logic gates are basic concepts. The logical diagram used in an FTA consists of a set of gates and event symbols that describe the relationship between causes and event symbols that characterize the causes. There are several variants of these. Table 5.1 shows the most commonly used fault tree symbols together with a brief description of their interpretation. A number of more advanced fault tree symbols are available but are not covered in this paper.

The first three refer to *failure events* that describe a fault of some kind. They can be events in a strict sense, i.e. something that happens but may also refer to a faulty state, e.g. a component that has failed. The **AND** *gates* and **OR** *gates* are used to provide logical connections between the various events in the tree.

Table 5.1: Symbols used in Fault Tree Analysis

Symbol	Designation	Function
	Basic event	Basic event or failure
	Event	Event resulting from more basic events
	Undeveloped event	Causes are not developed further
A ₁ E ₁ E ₂ E ₃	AND gate	Output event A occurs only if all input events (E ₁ , E ₂ and E ₃) occur simultaneously
A E ₁ E ₂ E ₃	OR gate	Output event A occurs if any one of the input events E _i occurs
Transfer-out Transfer-in	Transfer symbol	Indicates that the tree is developed further in another place. The transfer out symbol indicates that the fault tree is developed further at the occurrence of the corresponding transfer-in symbol.

Not standard	Extended fault tree	Suggested for the handling of non-binary influences
	Influence arrow	Events above are influenced in some way, e.g. increasing probability
	Influencing event	Event or circumstance influencing higher events, not of the binary type

A fault tree can be large and there is often a need to divide a tree into several smaller ones. The transfer symbol (triangle) is used for connecting a lower tree to a higher level tree.

FTA presumes a strictly formal binary approach. However, its logical format makes it appealing to use it in other application. These could be called soft fault trees. In order to handle this consistently and clearly, two additional symbols are proposed.

5.3 General System Structures

In the quantitative analysis, two basic characteristics (or elements) of a system are considered. These are the series structure and the parallel structure. When all components in a system or subsystem have to function in order to allow the system as a whole to function, the components are arranged in a series structure. If, however, only one of the components has to function for the whole system to function, the components are arranged in a parallel structure. If two equal components are in a parallel structure they are redundant[34].

Reliability Block Diagrams

A fault tree diagram (with only AND and OR gates) can always be converted to a reliability block diagram and vice versa. This is illustrated in Figure 5.4. A reliability block diagram shows the logical connections of functioning items that are needed to fulfill a specified system function. Each function is represented as a functional block and is drawn as a square (see Figure 5.4). If we can proceed through a functional block from one endpoint to the other, we say that the item is functioning [27].

The reliability block diagram in Figure 5.4(i) represents a series structure that will fail if item 1 fails, or item 2 fails, or item 3 fails. A series structure always corresponds to an or-gate in the fault tree when the basic events represent item failure.

The reliability block diagram in Figure 5.4(ii) is a parallel structure that will fail only when item 1 fails, and item 2 and item 3 fails. It is therefore clear that the parallel structure corresponds to an AND-gate.

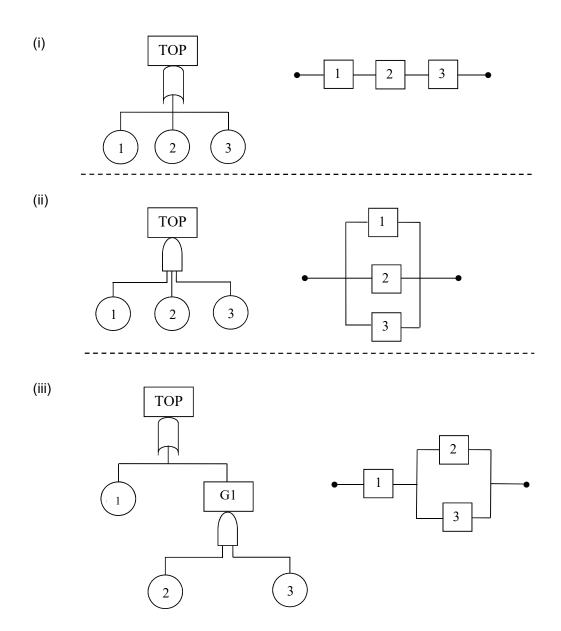


Figure 5.4: Relationship between some simple fault tree diagrams and reliability block diagrams.

Note that to save space, we have omitted the rectangles describing the basic events in the fault trees in Figure 5.4. In practical applications, we should always give proper descriptions of the events in the fault tree.

The probability of structure failure for a series structure and parallel structure is presented below:

Series structure

$$P_{SF} = P_1 \cdot P_2 \cdot ... \cdot P_n = \prod_{i=1}^{n} P_i$$

ture (5.1)

Parallel structure

$$P_{SF} = 1 - (1 - P_1).(1 - P_2)....(1 - P_n) = 1 - \prod_{i=1}^{n} (1 - P_i)$$
(5.2)

Where P_{SF} = reliability of structure and P_i = reliability of structure i. The reliability P is defined as the survival probability of a component or system and is dependent on the operation time and operational conditions. The failure probability Q is equal to the probability of non-survival (1-P).

5.3.1 Probability Equation and Boolean Logic Operations

In the logic of certainty (Boolean logic), an event can either occur or not occur. Thus, it is represented by a statement or proposition which can only be either true or false and at a certain point in time after the experiment is performed, the analyst will know its actual state [26].

Correspondingly, to event E we can associate an indicator variable X_E which takes the value of 1 when the event occurs in the experiment and 0 when it does not. As a counter-example, the statement "It may rain tomorrow" does not represent an event because it does not imply a 'true' or 'false' answer. We define the following operations involving Boolean events:

Negation: Given event E, represented by the indicator variable X_E , its negation \overline{E} is described by

$$\overline{X}_{E} = 1 - X_{E} \tag{5.3}$$

Union: The event (A U B), union of the two events A and B, is true, e.g. XAUB = 1, if any one of A or B is true (i.e. for OR gate). Hence,

$$X_{AUB} = 1 - (1 - X_A)(1 - X_B)$$

= $1 - \prod_{j=A,B} (1 - X_j)$
= $\coprod_{j=A,B} X_j$
= $X_A + X_B - X_A X_B$ (5.4)

Often in practice this event is indicated as A +B.

Intersection: The event $(A \cap B)$, intersection of the events A and B, is true, e.g. $X_{A \cap B} = 1$, if both A and B are simultaneously true (i.e. for AND gate). Hence,

$$X_{A} \cap B = X_{A}X_{B} \tag{5.5}$$

Often in practice this event is indicated as AB and referred to as the joint event A and B.

Mutually exclusive events: Two events A and B are said to be mutually exclusive if their intersection is the null set, i.e.

$$X_{A \cap B} = 0$$

$$X_{A \cdot X_{B}} = 0 \tag{5.6}$$

5.3.2 Probability Laws

As previously mentioned, to the generic random event E is associated an indicator variable X_E which takes the value of 1 when the event occurs in the experiment and 0 when it does not. Correspondingly, a real number p(E) is assigned to measure the probability of E and which satisfies the three Kolmogorov axioms. Given the binary nature of the indicator variable, X_E can only take values of 0 or 1 so that [26]:

$$p(E) = p(X_E = 1).1 + p(X_E = 0).0 = E[X_E]$$
 (5.7)

5.3.3 Union of Non-Mutually Exclusive Event

Consider n events E_n not mutually exclusive. Their union E_U is associated with an indicator variable X_U which is the extension of the Equation 5.4 for the union of the two events A and B. For example, for the intersection of the three events A, B and C we have [26]:

$$X_{U} = 1 - \prod_{j=A,B,C} (1 - X_{j})$$

$$= 1 - (1 - X_{A})(1 - X_{B})(1 - X_{C})$$

$$= X_{A} + X_{B} + X_{C} - X_{A}X_{B} - X_{A}X_{C} - X_{B}X_{C} + X_{A}X_{B}X_{C}$$
(5.8)

Following Equation 5.7, the probability of the event EU can then be computed applying to Equation 5.8, the (linear) expectation operator. More generally, for the union of **n** non-mutually exclusive events:

$$P(E_{U}) = E[X_{U}] = \sum_{j=1}^{n} E[X_{j}] - E\left[\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} X_{i} X_{j}\right] + \dots + (-1)^{n+1} \prod_{j=1}^{n} E[X_{j}]$$

$$= \sum_{j=1}^{n} P(E_{i}) - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} P(E_{i} \cap E_{j}) + \dots + (-1)^{n+1} \prod_{j=1}^{n} P(E_{j}) \quad (5.9)$$

From an engineering practice point of view, it is often necessary to introduce reasonably bounded approximations of Equation 5.9. Keeping only the first sum, one obtains an upper bound,

$$P(E_U) \le \sum_{j=1}^{n} P(E_j)$$
 (5.10)

Whereas keeping the first two sums gives a lower bound,

$$P(E_U) \ge \sum_{j=1}^n P(E_j) - \sum_{i=1}^{n-1} \sum_{j=i+1}^n P(E_i \cap E_j)$$
 (5.11)

More refined upper and lower bounds can then be obtained by alternately keeping an odd or even number of sum terms in Equation 5.9.

Since in reliability and risk calculations the probability of high order joint events is very small, it is common practice to use the upper bound (Equation 5.10), which is often referred to as the **rare-event** approximation.

5.3.4 Conditional Probability

In many practical situations, it is important to compute the probability of an event A given that another event B has occurred. This probability is called the conditional probability of **A** given **B** and it is given by the ratio of the probability of the joint event $A \cap B$ over the probability of the conditioning event B, viz. [26].

$$P(A/B) = \frac{P(A \cap B)}{P(B)}$$
 (5.12)

Intuitively, P (A/B) gives the probability of the event A not on the entire possible sample space Ω but on the sample space relative to the occurrences of B. This is the reason for the normalization by P(B) of the probability of the joint event P(A \cap B) in Equation 5.12.

Based on the conditional probability, it is possible to introduce the concept of statistical independence: event A is said to be statistically independent from event B if P(A|B) = P(A), In other words, knowing that B has occurred does not change the probability of A. From Equation 5.12, it follows that if A and B are statistically independent $P(A \cap B) = P(A)P(B)$. Note that the concept of statistical independence should not be confused with that of mutual exclusivity ($X_AX_B = 0$) which is actually a logical dependence: knowing that A has occurred ($X_A = 1$), guarantees that B can not occur ($X_B = 0$).

5.4 Approach of Fault Tree Analysis

A fault tree can be analyzed both **qualitatively** and **quantitatively**. These approaches are described in more details.

5.4.1 Qualitative Analysis

Qualitative Approach: Construction

The first task of a fault tree analysis is to describe the system and its components/subsystems down to a sufficient level of detail (see Figure 5.8). The next task is to construct the fault tree for a particular unwanted system failure using this system description. It is important that all the failures in the fault tree are given precise definitions. The unwanted event or accident target for the analysis is referred to as the top event of the fault tree. The description of the top event should give answers to what the event is, where it occurs and when it occurs.

The occurrence of the top event is always dependent on two or more conditions or failures on a more detailed, i.e. lower, level. The main task in the FTA approach is to systematically define and structure the conditions or causes that directly lead to the top event. These events should be defined in such a way that only a limited number of causes lead to the top event. Some literature recommends only defining two causes on the lower level at a time, but for some complex system failures this may not be realistic. The causes directly leading to the top event are at the second level in the fault tree [34].

When the events are defined and structured, the next task is to assess the logical relation between the causes. Generally, either the top event is dependent on a simultaneous occurrence of these causes on the second level, or only one of the causes may lead to the top event. In the first case an AND gate is used and in the last case an OR gate is used (see Table 5.1). This procedure is then repeated to establish the logical relations between the causes on the third level of the fault tree, and so on. When the causes are described in such a detail that failure data (i.e. failure frequency) is available, the fault tree construction is finished and ready for quantitative analysis.

Qualitative Approach: Minimal Cut Sets

The objective of qualitative FTA is to establish a general view and understanding of the fault tree construction. This can be achieved by establishing sets of events that have special

characteristics. A set of basic events in the fault tree that triggers the top event by occurring simultaneously is called a cut set of the fault tree. A Minimal cut set is a set of causes where none of the included causes can be excluded without the causes losing their status as a cut set [34].

To establish the cut sets of a fault tree a systemized algorithm called MOCUS (method of obtaining Cut Sets) can be applied. The MOCUS algorithm is represented by four steps:

- 1. Consider the top event.
- 2. Replace the event with the events on the second level according to the following criteria: If the events on the lower level are connected through an OR gate they are written in separate rows. If they are connected through an AND gate they are written in separate columns.
- 3. Perform step 2 successively for all events that are not basic events.
- 4. When all events are basic events the events in each row constitute a cut set.

Minimal Cut Sets

A fault tree provides valuable information about possible combinations of basic events that can result in the TOP event. Such a combination of basic events is called a cut set and is defined as:

Cut set: A cut set in a fault tree is a set of basic events whose (simultaneous) occurrence ensures that the TOP event occurs. The most interesting cut sets are those that are minimal.

Minimal cut set: A cut set is said to be minimal if the set cannot be reduced without losing its status as a cut set.

For small and simple fault trees, it is feasible to identify the minimal sets by inspection without a formal procedure/algorithm. For large or complex fault trees, an efficient algorithm is needed.

Finding Minimal Cut Sets

There are two methods to find out minimal cut sets of fault tree. These are:

- a. Boolean Algebra Reduction Method
- b. MOCUS Algorithm Method

These two methods are discussed in details using the same sample of fault tree (Figure 5.6) for better understanding.

Boolean Algebra Reduction Method

The first technique to be discussed is the Boolean reduction method. This is a process of manipulating the coded tree according to basic Boolean operations. Consider the gates shown below in Figure 5.5.

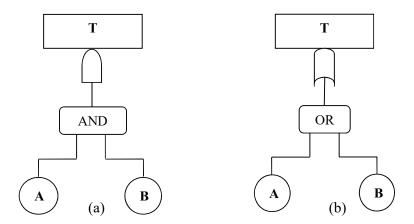


Figure 5.5: AND and OR Gates

The AND gate shown in Figure 5.4(a) is equivalent to the Boolean expression:

$$T = A \cap B = AB$$
.

The OR gate in Figure 5.4(b) is equivalent to:

$$T = A \cup B = A+B$$
.

Boolean algebra is an algebra of sets. Various laws and theorems usually used in Boolean algebra are summarized below. \overline{A} is the logical complement of A.

In Boolean algebra, binary states 1 and 0 are used to represent the two states of each event (i.e. occurrence and non-occurrence). Any event has an associated Boolean variable. Events A and B can be described as follows using Boolean algebra:

$$A = \left\{ \frac{1}{0} \frac{\text{event occurs}}{\text{event does not occur}} \right\}$$

$$B = \left\{ \frac{1}{0} \frac{\text{event occurs}}{\text{event does not occur}} \right\}$$

Suppose "+" stands for "OR" and "." for "AND". Suppose "\overline{A}" stands for "not A". Then the typical Boolean algebra rules are described as follows:

Identity laws:

$$A + 0 = A$$

$$A + 1 = 1$$

$$A \cdot 0 = 0$$

$$A \cdot 1 = A$$

Indempotent laws:

$$A + A = A$$

$$A \cdot A = A$$

Complementative laws:

$$A.\overline{A} = 0$$

$$A + \overline{A} = 1$$

Commutative laws:

$$A + B = B + A$$

$$A \cdot B = B \cdot A$$

Associative laws:

$$(A+B)+C = A+(B+C)$$

$$(A . B) . C = A . (B . C)$$

Distributive laws:

$$A \cdot (B + C) = A \cdot B + A \cdot C$$

$$A + (B . C) = (A + B) . (A + C)$$

Absorption laws:

$$A + A \cdot B = A$$

$$A.(A+B)=A$$

De Morgan's laws:

$$(\overline{A}.\overline{B}) = \overline{A} + \overline{B}$$

$$(\overline{A+B}) = \overline{A} \overline{B}$$

Other laws:

$$\overline{0} = 1$$

$$\overline{1} = 0$$

$$\overline{(A)} = A$$

The above rules can be used to obtain the minimum cut sets leading to a top event in a fault tree. The occurrence probability of a top event can then be obtained from the associated minimum cut sets.

Let us consider the sample of fault tree shown at Figure 5.6,

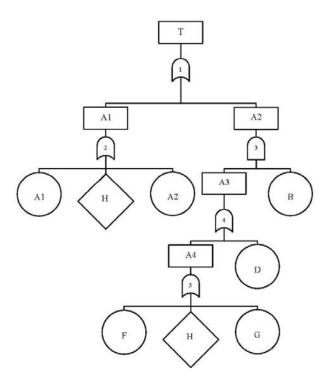


Figure 5.6: Sample of fault tree

The Boolean equation for the tree are:

$$T = A1 + A2$$

$$A3 = A4 + E$$

$$A1 = B + H + C$$

$$A4 = F + H + G$$

$$A2 = A3 (D)$$

Substituting yields

$$T = B + H + C + (F + H + G + E) D$$

$$= B + H + C + FD + HD + GD + ED$$

$$= B + H (1+D) + C + FD + GD + ED$$

$$= B + H + C + FD + GD + ED [Applying Boolean Laws]$$

Removing redundancies according to laws of Boolean algebra,

The expression T = B + H + C + FD + GD + ED is obtained. The terms on the right side of the equality correspond exactly to the minimal cut sets. In general there is a one to one correspondence between the minimal cut sets for a fault tree and the terms of the fully expanded, non-redundant Boolean expression of the TOP event.

MOCUS Algorithm Method

The second method has probably received the most recognition. It was introduced under the name Method of Obtaining Cut Sets (MOCUS) by Fussell and Vesely [20]. It is a downward moving algorithm. The basis for this algorithm is that an AND gate always increases the size of a cut set while an OR gate always increases the number of cut sets. If all the primary events are different, this algorithm will immediately give all the minimal cut sets. If replication occurs among the primary events, a search will reveal the minimal cut sets. An example in the simplest way to explain the use of this algorithm, refer again to the sample example of fault tree at Figure 5.6. A list matrix is created using the inputs to the OR gate under the TOP event.

A1

A2

An OR gate creates additional rows and an AND gate creates additional columns. Now replacing A1.

В

Η

 \mathbf{C}

A2

Now, A2 which is preceded by an AND gate.

В

Η

C

A3 D

Now, A3 which is preceded by an OR gate.

В

Η

 \mathbf{C}

A4 D

E D

Now, A4 which is preceded by an OR gate.

В

Η

 \mathbf{C}

F D

H D

G D

E D

Since primary event H was replicated in the tree; a search reveals that HD is not a minimal cut set, the minimal cut sets are {B}, {H}, {C}, {FD}, {GD}, {ED} which agrees with previous results.

We are then left with the following six cut sets: {B}, {H}, {C}, {FD}, {GD}, {ED} and the reliability block diagram corresponding to the fault tree in Figure 5.6 is shown in Figure 5.7.

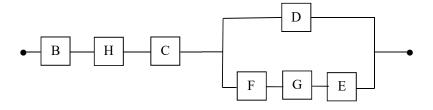


Figure 5.7: Reliability block diagram corresponding to the fault tree in Figure 5.6

In Figure 5.7, the fault tree is converted to a reliability block diagram, from which the minimal cut sets can easily be seen. This approach is, however, not feasible for large fault trees and therefore an efficient algorithm is required.

Minimal Cut Set Importance

In fact, qualitative analysis is generally restricted to identification of the minimal of the minimal cut sets and the ordering of those cut sets by size. These features are included under qualitative analysis here to highlight the fact that they are not dependent upon probabilistic failure data for the primary events.

In the literature search of fault tree analysis, only two methods of determining minimal cut set importance were discovered. Fussell [38] presents one method of determining minimal cut set importance. I_K is defined as the probability the mode failure is causing system failure when the system has failed. Let A be defined as the event a minimal cut set K has failed and B as the event the system is in the failed state, i.e. the TOP event has occurred. Then,

$$I_{K} = P(A/B) = \frac{P(A) P(B/A)}{P(B)}$$

However, given that a minimal cut set has failed the probability the system has failed is P(B/A) = 1. Hence,

$$I_{K} = \frac{P(A)}{P(B)}$$

Those minimum cut sets with the highest value of I_K are the most critical.

5.4.2 Quantitative Analysis

Quantitative Approach- Description

Quantitative analysis of the fault tree consists of transforming its logical structure into an equivalent probability form and numerically calculating the probability of occurrence of the top event from the probabilities of occurrence of the basic events. The probability of the basic event is the failure probability of the component or subsystem during the mission time of interest [26].

The qualitative approach in FTA aims at understanding the formation of the fault tree and establishing a general picture. This can be obtained through event sets having special characteristics. In the fault tree, the basic event sets trigger the main event when they are

simultaneous, and these sets are called cut sets in the fault tree. The minimum cut set is defined as the minimum set of system components. It is a logic set diagram formed in the system.

In the event that the fault tree for a top event contains independent basic events which appear only once in the tree structure, the top event probability can be obtained by working the basic event probabilities up through the tree. In doing so, intermediate gate event (AND or OR) probabilities are calculated by starting at the base of the tree and working upwards until the top event probability is obtained.

Small fault trees can be evaluated manually. However, large and complex fault trees require the aid of computerized methods for evaluation. Methods for FTA include the analytical method, Monte Carlo simulation and binary decision diagram. Due to the limitations in using the Monte Carlo simulation, an analytical approach (e.g. minimal cut sets determination) is more frequently used for evaluation of a fault tree. The application of Monte Carlo simulation to fault tree evaluation involves a series of trials. In a given trial each initial event either occurs or does not occur, the occurrence being determined by the sampling. In order to evaluate the failure frequency of the top event, it is necessary to assign numerical values to all inputs and the logic gates. The values are mathematically estimated through the tree from bottom to top and there arriving at a predicted frequency for top events. The sensitivity of prediction to the data which is uncertain, should always be checked to determine whether or not variation in such data would have serious effects on the results [10].

Quantitative Approach: Calculation

The quantitative analysis of fault tree uses the failure probability q_i of the basic events and the fault tree gates to calculate the probability of the top event Q_0 . This calculation is quite straight forward. For basic events combined through an OR gate the series structure equation established in section 5.3 is used. For events combined through an AND gate the parallel structure equation is used (when using these equations it must be remembered that the reliability $p_i = (1 - q_i)$, where q_i is the failure probability). Consequently, it is easier to trigger events combined through an OR gate than events combined through an AND gate. Conditional probabilities (i.e. AND gates in fault trees) are generally very common in fault tree calculations.

The failure probability of basic event for any accident/failure/occurrence can also be calculated using the following equation [17]:

Probability value of primary event =
$$\frac{\text{The rate of contribution to the accident of initial event}}{\text{The total number of accident X The total year of accident}}$$
(5.13)

In order to calculate rate of contribution to the accident of each initial event, accidents related to that initial event are determined and the other reasons which cause these accidents (initial events) are determined. The total number of initial events of accidents is found for each accident and the effect of each initial event on occurrence of the accident has been thought equally. A total of the effect value in those accidents related to this initial event is taken and thus total value of each initial event on occurrence of the accident is calculated.

The total number of accidents expresses the number of accidents related to all type of vessels which occurred between certain years. The total ship year expression expresses the subject period.

Quantitative Approach: Assessment

In the qualitative analysis the minimal cut sets of the fault tree are established. Each of these cut sets includes one unique set of basic events which by occurring simultaneously trigger the top event. Consequently, it is important to prevent the occurrence of a basic cause (or basic event) that is present in several cut sets in order to reduce the likelihood of top event occurrence. Because the basic causes are present in several cut sets, this may be applied to calculate a measure of importance for each basic cause. A common importance measure applied on fault trees is the **Vessley-Fussell measure of importance**, **I**^{VF}. This is the probability that at least one minimal cut set that contains the basic event *i* is failed at time *t*, given that the top event is triggered at time *t*. This can be calculated by the following equation:

$$I^{VF}(i \mid t) = P$$

Hence:

$$I^{VF}(i \mid t) = \frac{Q_{ki}(t)}{Q_0(t)}$$
 (5.14)

where, Q_{ki} = the probability that one minimal cut set containing the basic cause i is failed at time t and Q_0 = probability of occurrence for the top event.

The m minimal cut sets in which the basic cause i is present are not independent because the same basic causes may be present in more than one cut set. However, by assuming that the m cut sets are independent, the higher limit of Q_{ki} can be estimated using the $I^{VF}(i|t)$ equation above and the parallel structure equation presented earlier [34].

This assumption is implemented in the following equation:

$$I^{VF}(i|t) \approx \frac{1 - \prod_{j=i}^{m} (1 - Q_{ki,j}(t))}{Q_0(t)}$$
 (5.15)

where, m = number of minimal cut sets where basic cause <math>i is present.

5.5 Sensitivity Analysis

A sensitivity analysis is carried out to determine how much the TOP event probability changes when one or more input parameters are changed. Questions of interest may, for example, concern the effect on the TOP event probability if all failure rates of a special group of components were 50% higher than that the nominal value. For this purpose, the possibility values of event sets which cause occurrence of collision and grounding accidents have been altered systematically. Possibility values of the initial events in such event sets have been increased and decreased by 10 times, independently of each other, changes in the contribution rate of initial events to accident and in their significance degree being observed.

5.6 Importance of Basic Events

Several importance measures have been developed to measure the relative importance of a basic event, in comparison to other basic events, with respect to the TOP event probability. The importance of a basic event has two sources: (i) the probability of the basic event, and (ii) where the basic event is placed in the fault tree diagram.

5.7 Application of Importance Measures

Very often, it is found that relatively few events contribute significantly to the TOP event probability. It is also commonly seen that the events cluster in groups that differ by orders of magnitude from one another. In these cases, their importance are so dramatically different that they are generally not dependent on the preciseness of the data used to calculate the TOP event probability.

The main benefits of the importance measures are that they can:

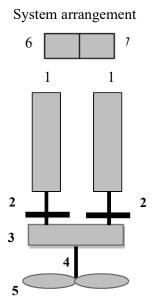
- Identify basic events with the greatest need to be improved, maintained, or controlled.
- Identify the basic events for which we need to obtain high-quality data. A basic event with low importance will have a very low influence on the TOP event probability. Spending resources to get very accurate data for such events may thus be a waste of money. A relevant approach is therefore first to calculate the TOP event probability and one or more importance measures based on approximate input parameters, and then concentrate the data acquisition resources on the most important basic events.

5.8 Computer Programme for Fault Tree Analysis

Small fault tree diagrams can be drawn by pen and paper or by using a drawing program, but a dedicated fault tree program will be needed for larger fault trees. Several computer programs for fault tree analysis are available. Most of these programs have a graphical frontend that allows the user to construct and modify fault tree diagrams and have implemented routines for identifying minimal cut sets, calculating the TOP event probability and importance measures, and so on.

Example Problem:

Construct a fault tree where the top event is, "Loss of propulsion power for a vessel", taking consideration of general arrangement of propulsion system as described at Figure 5.8. Then perform a qualitative and quantitative fault tree analysis using the algorithms and methods described in this chapter.



System components

No	Component
1	Main Diesel Engine
2	Clutch
3	Gear
4	Shaft Line
5	Controllable Pitch Propeller
6	Spare parts
7	Tools

Figure 5.8: Propulsion system arrangement.

Solution:

It is assumed that the information shown in Table 5.2 is commonly available and known.

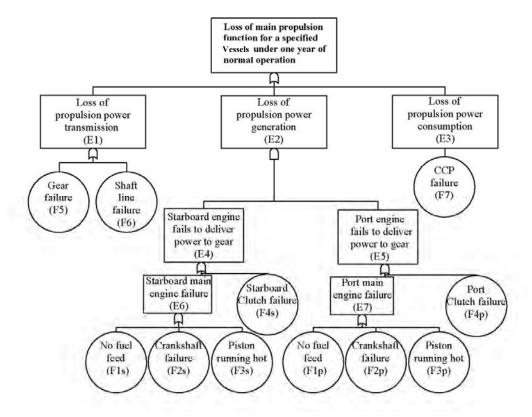


Figure 5.9. Fault tree for the top event of 'Loss of propulsion for a vessel'

Qualitative Approach: Fault Tree Construction

The top event is already defined as 'Loss of propulsion for the vessel'. A simple way to break down the propulsion system is to emphasize on power transition in the main propulsion system. There are three independent events that may result in the top event. These are the 'loss of propulsion power transmission' in the shaft lines or gear, 'loss of propulsion power generation' from the engines and 'loss of propulsion power consumption' due to propeller failure. Only one of these events has to occur in order to trigger the top event. Hence these three events have to be combined by an OR gate. The fault tree for the problem can be structured as shown in Figure 5.9.

The 'Loss of propulsion power transmission' event in Figure 5.9 can be caused by gear failure and/or shaft line failure (see Figure 5.8) and must therefore be combined through the use of an

OR gate. The loss of propulsion power consumption' event only includes the event of controllable pitch propeller (CPP) failure. In terms of the event of loss of propulsion power generation', both the starboard and port engines must fail to deliver power to the gear. An AND gate must therefore be used for these two events. There are two ways each engine can fail to deliver power to the gear: by failure of the clutch and by failure of the engine itself. An OR gate must be used for these events because one is sufficient for the engine to fail to deliver power to the gear. The events of main engine failure (both starboard and port engines) in Figure 5.9 need to be treated in further detail. The causes or basic failure events 1, 2 and 3 (see Table 5.2) are all gathered in the 'main engine failure' event, and these have to be combined through the use of an OR gate since one of the causes is enough for the main engine to fail. The main engine failure modes can be arranged/modelled in a fault tree as shown in Figure 5.9.

Table: 5.2. Failure data calculated for a sailing operation of one year (336 days)

Failure	Failure description	Reliability probability p	Failure probability q	
F1	No fuel feed	0.730	0.270	
F2	Crankshaft failure	0.973	0.027	
F3	Piston running hot	0.984	0.016	
F4	Clutch failure	0.948	0.052	
F5	Gear failure	0.764	0.236	
F6	Shaft line failure	0.971	0.029	
F7	CPP failure	0.813	0.187	

Qualitative Approach: Establishing Minimal Cut Sets

The MOCUS algorithm is applied (subscript s = Starboard, subscript p = Port):

MOCUS Step 1:

'Loss of main propulsion power for a specified vessel under one year of normal operation.'

MOCUS Step 2:

E1 E2 E3 MOCUS Step 3.1: For the 'Loss of propulsion power transmission' event (i.e. E1 in the fault tree):

F5 F6 E2 E3

MOCUS Step 3.2: For the 'Loss of propulsion power generation' event (i.e. E2 in the fault tree):

F5	
F6	
E4	E5
E3	

MOCUS Step 3.3: For the event that 'starboard engine fails to deliver power to gear' (i.e. E4 in the fault tree):

F5	
F6	
As	E5
F4s	E5
E3	

MOCUS Step 3.4: For the event of 'starboard main engine failure' (i.e. E6 in the fault tree; see Figures 5.7):

F5	
F6	
F1s	E5
F2s	E5
F3s	E5
F4s	E5
E3	

MOCUS Step 3.5: For the event of 'port main engine failure' (i.e. E7 in the fault tree; see Figures 5.7):

K_1	F5	
K_2	F6	
К3	F1s	F1p
K_4	F2s	F1p
K5	F3s	Flp
K ₆	F4s	Flp
K7	F1s	F2p
K8	F2s	F2p
K9	F3s	F2p
K_{10}	F4s	F2p
K_{11}	F1s	F3p
K_{12}	F2s	F3p
K_{13}	F3s	F3p
K ₁₄	F4s	F3p
K_{15}	F1s	F4p
K_{16}	F2s	F4p
K ₁₇	F3s	F4p
K_{18}	F4s	F4p
K19	F7	

MOCUS Step 4:

There are 19 possible combinations of basic causes (or basic event failures) for the propulsion system (each row). There are mostly two basic causes in each cut set. It is advantageous to have as many basic causes in each cut set as possible, and one and two basic causes in each cut set is not much. The cut sets K_1 , K_2 and K_{19} include only one basic cause. Hence the top event is triggered when one of these basic causes occurs. It would therefore be advantageous to implement redundancy or other reliability improving measures for these cut sets. For example, would the use of two independent propeller systems create redundancy and hence reduce the risk for top event occurrence? This may, however, not be practicable.

Quantitative Approach: Fault Tree Calculations

There are several interesting calculations that should be performed. The probability of the top event Q_0 is certainly of particular interest. The probabilities for each cut sets are also of interest.

Normally some computerized calculation program, such as a spreadsheet, would be applied to calculate the top event probability. Here, on the other hand, the events are calculated manually using the series and parallel structure equations presented in Section 5.3. The series structure equation is used to calculate OR gates and the parallel structure is used to calculate AND gates (it must be remembered that the reliability $p_i=1-q_i$, where q_i is the failure probability). Failure data are given in Table 5.2.

As shown in Table 5.3, the probability for the top event of 'loss of main propulsion function for a specified vessel under one year of normal operation' is 0.465. This means that there is a 46.5% chance that this particular unwanted, and potentially very dangerous, event will occur.

Table 5.3. Calculation of top events failure probability Q₀

Events	Formulas	Probability
		Values
Q _{E7}	$= 1 - P_{E7} = 1 - [P_{F1}.P_{F2} P_{F3}.] = 1 - [(1 - q_{F1}).(1 - q_{F2}).(1 - q_{F3})]$	0.301
Q _{E6}	$= 1 - [(1-q_{F1}).(1-q_{F2}).(1-q_{F3})]$	0.301
Q _{E5}	$= 1 - [(1 - Q_{E7}).(1 - q_{F4})]$	0.337
Q _{E4}	$= 1 - [(1 - Q_{E7}).(1 - q_{F4})]$	0.337
Q _{E2}	$= 1 - P_{E2} = 1 - [1 - (1 - P_{E4}) \cdot (1 - P_{E5})] = Q_{E5} \cdot Q_{E4}$	0.114
Q _{E3}	$=q_{F7}$	0.187
Q _{E1}	$= 1 - [(1 - q_{F5}) \cdot (1 - q_{F6})]$	0.258
Q_0	$= 1 - [(1 - Q_{E1}).(1 - Q_{E2}).(1 - Q_{E3})]$	0.465

Quantitative Approach: Assessment of Basic Cause Importance

To assess the importance of the different basic causes, the cut sets' failure probability is calculated as in Table 5.4, using the given failure probability data in Table 5.2.

Table 5.4. Calculation of cut sets' failure probabilities

K_1	F5		$Q_{K1} = 0.236$
K_2	F6		$Q_{K2} = 0.029$
K3	F1s	F1p	$Q_{K3} = 0.073$
K4	F2s	F1p	$Q_{K4} = 0.0073$
K ₅	F3s	F1p	$Q_{K5} = 0.0043$

K_6	F4s	F1p	$Q_{K6} = 0.014$
K7	F1s	F2p	$Q_{K7} = 0.0073$
K ₈	F2s	F2p	$Q_{K8} = 0.00073$
К9	F3s	F2p	$Q_{K8} = 0.00043$
K ₁₀	F4s	F2p	$QK_{10} = 0.0014$
K ₁₁	F1s	F3p	$QK_{11} = 0.0043$
K ₁₂	F2s	F3p	$QK_{12} = 0.00043$
K ₁₃	F3s	F3p	$QK_{13} = 0.00026$
K ₁₄	F4s	F3p	$QK_{14} = 0.00083$
K ₁₅	F1s	F4p	$QK_{15} = 0.014$
K ₁₆	F2s	F4p	$QK_{16} = 0.0014$
K ₁₇	F3s	F4p	$QK_{17} = 0.00083$
K ₁₈	F4s	F4p	$QK_{18} = 0.056$
K ₁₉	F7		$QK_{19} = 0.187$
	l .		

According to the Vessley-Fussell measure of component importance, the importance ranking of the basic causes (or failures) is established as shown in Table 5.5. The ranking of the components is the 'repairman's' ranking. If propulsion is lost, the most likely failure is related to the gear, i.e. basic cause/failure event F5, and so on. Other measures of importance should be applied at the design stage.

Table 5.5: Importance ranking based on Vessley-Fussell measure of importance

Primary Events/	Relevant Cut Sets	$1-\prod(1-Q_{Ki})$	$ m I^{VF}$	Ranking
Basic Causes				
F1	K ₃ , K ₇ , K ₁₁ , K ₁₅	0.0966	0.208	3
F2	K4, K8, K12, K16	0.0098	0.021	6
F3	K ₅ , K ₉ , K ₁₃ , K ₁₇	0.0061	0.013	7
F4	K ₆ , K ₁₀ , K ₁₄ , K ₁₈	0.071	0.150	4
F5	K ₁	0.236	0.507	1
F6	K ₂	0.029	0.062	5
F7	K ₁₉	0.187	0.402	2

5.9 Resources and Skills Required

Fault tree analysis requires some training and experience. The analysis is time-consuming but not difficult once the technique has been mastered. Many computer programs are available to assist the analyst in the construction, editing, and quantitative analysis.

To carry out a fault tree analysis, the study team has to have a thorough knowledge about the system and how it is operated. A quantitative fault tree analysis needs a lot of input data, as outlined in previous discussion [39,40].

5.10 Standards and Guidelines

Several standards and guidelines for fault tree analysis have been developed. Some of the most important are:

- Fault Tree Analysis (FTA) (IEC 61025, 2(06) is the main international standard for fault tree analysis.
- Fault Tree Handbook, U.S. Nuclear Regulatory Commission (NUREG-0492, 1981) was one of the first comprehensive treatments of fault tree analysis and is still a valuable reference.
- Fault tree handbook with aerospace applications may be considered a follow-up of NUREG-0492 (1981) and is one of the best and most comprehensive references on fault tree analysis.
- Guidelines for Hazard Evaluation Procedures has a very good chapter on fault tree analysis.

CHAPTER-6

ANALYSIS OF COLLISION AND GROUNDING ACCIDENT USING FTA

6.1 Approach of Analysis

Both qualitative and quantitative methods are used with a Fault Tree approach to analyze the risk of navigation safety in the research area. Construction of the fault tree and establishing the minimal cut sets are determined in the qualitative side of this research. Calculation of the fault trees and assessment of the importance of the different basic causes for the accidents are related with the construction and minimal cuts sets are determined in the quantitative side. Collisions and groundings come out as the major incidents out of 604 accidents during the period of 1981-2018 and these two types of accidents are investigated with Fault Tree Analysis in this research by using existing statistics indicated in Chapter-3.

6.2 Analysis of Collision Accident

Collisions are defined as events where two vessels accidentally come into contact with each other. This may lead to sinking, grounding or to a fire on the vessel but these are counted as collisions if this was the cause. There have been totally 366 collisions from 604 accidents inland waterways of Bangladesh in last 38 years during the period of 1981 to 2018. This is equivalent to an average of 10 collisions involvements per calendar year.

Collision accident is an accident-type bearing the first degree of risk for all types of vessels specially for passenger vessels. Thus, the FTA for the collision accidents have been handled first. The FTA can be seen as a logical and graphical method highly used to evaluate the probability of one undesirable event or accident occurring as a result of failures.

6.2.1 Factors Affecting Ship's Collision

There are many factors affecting ship collision. For this analysis, 53 factors as basic events is found based on collision accident data analysis. These are:

- 1. Main Engine Failure (MEF).
- 2. Steering Failure (SF).
- 3. Auxiliary Machinery Failure (AMF).

- 4. Violation of Traffic Rule (VTR).
- 5. Violation of Procedure or Rule (VPR).
- 6. Over Speed (OS).
- 7. Faulty Maneuver of Master (FMM).
- 8. Piloting Failure (PF).
- 9. Lack of Communication between Vessels (LCBV).
- 10. Improper/Insufficient Use of Bridge Navigational Equipment (IIUBNE).
- 11. Insufficient Knowledge on Navigational Equipment (IKNE).
- 12. Insufficient Navigational Equipment (INE).
- 13. Lack of Bridge Resource Management (LBRM).
- 14. Insufficient Channel Marking (ICM).
- 15. Inappropriate Route/Course Selection (IARCS).
- 16. Environmental Restriction (Visibility, Wind& Wave) (ER).
- 17. Bad Weather Condition (BWC).
- 18. Insufficient Information of Weather Forecast (IIWF).
- 19. Insufficient Communication Equipment (ICE).
- 20. Lack in Use of Visual Signaling (LUVS).
- Lack of Experience/Training/Qualification/Competency of Officer, Master, Crew (LETQC).
- 22. Interpretation Failure (IF).
- 23. Fatigue/Sleeplessness (FS).
- 24. Alcohol Abuse (AA).
- 25. Maneuver in Close Company (MCC).
- 26. Ship Handling in Narrow Water (SHNW).
- 27. Non Standardized of Equipment (NSE).
- 28. Poor Stability Condition of Vessel (PSC).
- 29. Lack of Knowledge on Collision Avoiding Situation / Avoiding Collision Situation/Collision Course/ Head on Situation/Close Quarter Measure (LKCAS).
- 30. Over Loading (OL).
- 31. Communication Equipment Failure (CEF).
- 32. Navigational System Failure (NSF).
- 33. Navigational Light Failure (NLF).
- 34. Insufficient Navigational Lights onboard (INLO).
- 35. Lack of Radar Observation (LRO).
- 36. Negligence/ Reluctances in Performing Duty (NRPD).
- 37. Poor Visibility (PV).
- 38. Navigate/ Maneuver on Wrong/ inappropriate Course (NWC).
- 39. Negligence in Watch Keeping (NWK).
- 40. Wrong Assessment of Situation (WAS).
- 41. Improper Steering Operation (ISO).
- 42. Improper Look Out (ILO).
- 43. Improper Emergency Operation (IEO).
- 44. Uncoordinated Avoiding Operation (UAO).
- 45. Improper Avoiding Operation (IAO).

- 46. Deviated from Safe Course/Channel (DFSCC).
- 47. Rough Sea (RS).
- 48. Maneuver Error of Watch Keeping Officer (MEWO).
- 49. Lack in Use of Communication Equipment (LUCE).
- 50. Poor Maneuvering Ability of Vessel (PMAV)
- 51. Cyclone/Strong Wind (CSW)
- 52. Strong Current/Wave (SCW)
- 53. Improper Design and Drawing (IDD)

Out of these 53 causes, a fault tree for ship collision accident in inland waterways of Bangladesh was constructed using 33 prominent causes, since these causes are so interrelated with other causes and to reduce the size of fault tree. The basic events for collision model are shown in Table 6.1

6.2.2 Basic Events Probability for Collision

The probability of a basic event means the frequency of a basic event leading to ship's collision accident in this research. The probability of a maritime accident is affected by different parameters, i.e. weather, technical failure and human factors. The FTA model of marine accident is built to estimate the probability based on the ship accident statistics data. The failure probability of basic events is calculated using Equation 6.1 based on the specific fault tree for ship's collision accidents in inland waterways of Bangladesh [17]:

Probability value of primary event =
$$\frac{\text{The rate of contribution to the accident of initial event}}{\text{The total number of accident X The total year of accident}}$$
 (6.1)

In order to calculate rate of contribution to the accident of each initial event, accidents related to that initial event are determined and the other reasons, which cause these accidents (initial events), are determined. The total number of initial events of accidents is found for each accident and the effect of each initial event on occurrence of the accident has been thought equally. A total of the effect value in those accidents related to this initial event is taken and thus total value of each initial event on occurrence of the accident is calculated.

The total number of accidents expresses the number of accidents (either collision/grounding/fire/sinking/any other) related to the vessels which occurred between certain years. The total year of accident expression expresses the subject period.

Following the above expression, the probability values of basis/primary events for collision accidents in inland waterways of Bangladesh was calculated from collected data of collision accident between 1981 to till current year, i.e. 2018 (last 38 years) for 346 vessels having collision accident. The calculated probability values of basic events are shown at Table 6.1 and the probability calculations of all the basic events related to collision are represented in Appendix-C.

Table: 6.1 Calculated probability values of basic events for Collision

Sr			Probability
	Primary Events causing Collision Accidents	Abbreviation	Value
1	Inappropriate Route/Course Selection	IARCS	3.12E-04
2	Improper / Insufficient Use of Bridge Navigational	III IDNIE	
	Equipment	IIUBNE	5.63E-04
3	Negligence in Watch Keeping	NWK	1.84E-03
4	Wrong Assessment of Situation	WAS	1.09E-03
5	Improper Look Out	ILO	1.10E-03
6	Improper Steering Operation	ISO	1.06E-03
7	Violation of Procedure or Rule	VPR	2.12E-03
8	Maneuver in Close Company	MCC	6.66E-04
9	Maneuver Error of Watch Keeping Officer	MEWO	6.88E-04
10	Faulty Maneuver of Master	FMM	2.57E-03
11	Poor Maneuvering Ability of Vessel	PMAV	4.37E-04
12	Improper/ Uncoordinated Avoiding Operation	IUAO	1.86E-03
13	Lack of Communication between Vessels	LCBV	6.96E-04
14	Insufficient Communication Equipment	ICE	1.41E-04
15	Communication Equipment Failure	CEF	1.41E-04
16	Lack in Use of Communication Equipment	LUCE	9.89E-05
17	Insufficient Knowledge on Navigational Equipment	IKNE	2.40E-04
18	Lack of Experience/Training/Qualification/	LETQC	1.99E-03
	Competency	-	
19	Interpretation Failure	IF	7.07E-04
20	Fatigue/ Sleeplessness	FS	7.80E-04
21	Alcohol Abuse	AA	3.42E-04
22	Lack of Knowledge on Collision Avoiding	LKCAS	1.15E-03
	Situation		
23	Poor Visibility	PV	1.02E-03
24	Deviated from Safe Course/ Channel	DFSCC	1.09E-03
25	Over Speed	OS	9.01E-04
26	Cyclone/Strong Wind	CSW	9.36E-04
27	Strong Current/Wave	SCW	3.08E-04
28	Main Engine Failure	MEF	1.14E-04
29	Steering Failure	SF	3.04E-04
30	Auxiliary Machinery Failure	AMF	9.89E-05
31	Non Standardized of Equipment	NSE	1.90E-04
32	Improper Design and Drawing	IDD	3.27E-04
33	Poor Stability Condition of Vessel	PSC	4.45E-04

6.2.3 Qualitative Approach: Construction of FTA Model for Collision

Basic factors causing accidents are called initial events in the FTA programme. The marine accident data have shown that accidents are caused by a single reason or by a chain of reasons. For this purpose, a plenty of accident occurrence combinations have been formed, through which the FTA might yield the most realistic results, and the fault tree containing the dual accident occurrence combinations which were formed.

Collision accident is an accident-type bearing the first degree of risk for all types of vessels especially for passenger vessels. Thus, the FTA for the collision accidents have been handled first. Data is available for 366 collision accidents. Based on such data, out of 53 causes, 33 prominent causes/initial events causing collision accidents have been gathered to construct fault tree model for collision since these causes are so interrelated with other causes. The possible intermediate event sets have also been constituted. Figure 6.1 gives a fault tree formation for collision accidents.

There are seven intermediate event sets which cause occurrence of collision accidents. In the fault tree formation, these event sets have been linked with "OR" gates/doors to the top event, "Collision". These are failures associated with navigation and maneuvering (NMF), communication (CF), failure (ONF), detection failure (DF), illegal behavior/action (IBA), uncontrolled situation/factors (USF) and non-standardization (NS). Combination of the initial events contained in such intermediate event sets is sufficient for the occurrence of collision accidents which are again arranged through AND/OR gates as necessary under intermediate events.

6.2.4 Qualitative Approach: Finding Minimum Cut Sets for Collision

As shown in the fault tree of collision (Figure 6.1), a collision can occur if the following set of causes are occurring; the navigation and maneuvering failure, communication failure, operator's/navigator's failure, detection failure, illegal behavior/action, uncontrolled situation/factors and non-standardization. Among those; inappropriate route/course selection, improper/ insufficient use of bridge navigational equipment, negligence in watch keeping, wrong assessment of situation, improper look out, improper steering operation, violation of procedure or rule, maneuver in close company, faulty maneuver of master and improper/ uncoordinated avoiding operation are the main reason/root causes for the navigation and maneuvering failure. Improper/insufficient use of bridge navigational equipment, improper look out, poor visibility are the causes of detection failure and over speed, improper look out, deviated from safe course/channel are the illegal behavior/action. There are some situation/factors which are beyond controlled of human being like poor visibility, cyclone/strong wind, strong current/wave, main engine failure, steering failure, auxiliary machinery failure. Non standardized of equipment, improper design and drawing and poor stability condition of vessel also lead to collision accident.

-----Figure 6.1: Fault tree of collision accident-----

Minimum cut sets for collision fault tree was found using both the Boolean Algebra Reduction method and MOCUS Algorithm method.

6.2.4.1 Boolean Algebra Reduction Method

In order to calculate the probability of ship collision accident, firstly the fault tree is expressed by Boolean algebra, then the Boolean algebra is simplified to acquire minimum cut sets. Following the fault tree model for collision (Figure 6.1), the ship's collision event can be expressed by the equation:

$$K_{COLLISION} = NMF + CF + ONF + DF + IBA + USF + NS$$
 (6.2)

Intermediate events are expressed as,

$$NF = IARCS + IIUBNE + NWK + WAS + (ILO \times ISO) + VPR + MCC$$

$$MF = MEWO + FMM + PMAV + IUAO$$

$$NMF = IARCS + IIUBNE + NWK + WAS + (ILO \times ISO) + VPR + MCC + MEWO +$$

$$FMM + PMAV + IUAO$$

$$CF = LCBV + ICE + CEF + LUCE$$

$$ONF = IKNE + LETQC + IF + FS + AA + LKCAS + NWK$$

$$DF = (ILO \times PV)$$

$$IBA = (ILO \times DFSCC) + OS$$

$$USF = CSW + SCW + MEF + SF + AMF$$

$$NS = NSE + IDD + PSC$$

Putting these values of intermediate and basic events in Equation 6.2, the cut sets of collision are,

$$\begin{split} K_{COLLISION} = & \ NMF + CF + ONF + DF + IBA + USF + NS \\ = & \ IARCS + IIUBNE + \textbf{NWK} + WAS + (ILO \times ISO) + VPR + MCC + MEWO + \\ & \ FMM + PMAV + IUAO + LCBV + ICE + CEF + LUCE + IKNE + LETQC + IF + \\ & \ FS + AA + LKCAS + \textbf{NWK} + (PV \times ILO) + (ILO \times DFSCC) + OS + CSW + SCW + MEF + SF + AMF + NSE + IDD + PSC \end{split}$$

$$= IARCS + IIUBNE + NWK + WAS + (ILO \times ISO) + VPR + MCC + MEWO + FMM + PMAV + IUAO + LCBV + ICE + CEF + LUCE + IKNE + LETQC + IF + FS + AA + LKCAS + (PV \times ILO) + (ILO \times DFSCC) + OS + CSW + SCW + MEF + SF + AMF + NSE + IDD + PSC$$

6.2.4.2 MOCUS Algorithm Method

Applying MOCUS algorithm as discussed in previous chapter, the process to find out minimal cut sets for Collision accidents in inland waterways of Bangladesh is shown below:

MOCUS Step-1

'Probability of Collision risk in inland waterways of Bangladesh'

MOCUS Step-2

Occurrence of collision in inland waterways of Bangladesh is based on seven intermediate events. They are the navigation and maneuvering failure, communication failure, operator's/navigator's failure, detection failure, illegal behavior/action, uncontrolled situation/factors and non-standardization. For AND and OR gates of the collision tree,

NMF
CF
ONF
DF
IBA
USF
NS

MOCUS Step-3

For the, 'navigation and maneuvering failure, communication failure, operator's/navigator's failure, detection failure, illegal behavior/action, uncontrolled situation/factors and non-standardization' events (i.e. NMF, CF, ONF, DF, IBA, USF and NS in the fault tree of collision model)

NF	
MF	
LCBV	
ICE	
CEF	
LUCE	
IKNE	
LETQC	
IF	

FS	
AA	
LKCAS	
NWK	
ILO	PV
FD	
OS	
EF	
INTF	
NSE	
IDD	
PSC	

MOCUS Step-4

For the, 'navigation failure, maneuvering failure, failed in the duty, external factors and internal factors' events (i.e. NF, MF, FD, EF and INTF in the fault tree)

IARCS	
IIUBNE	
NWK	
WAS	
OE	
PF	
MFBRM	
AE	
LCBV	
ICE	
CEF	
LUCE	
IKNE	
LETQC	
IF	
FS	
AA	
LKCAS	
NWK	
ILO	PV
ILO	DFSCC
OS	
CSW	
SCW	
MEF	
SF	
AMF	
NSE	
IDD	
PSC	

MOCUS Step-5

For the, 'operation error, procedure failure, maneuvering failure in bridge resource management and avoiding error' events (i.e. OE, PF, MFBRM and AE in the fault tree)

IARCS	
IIUBNE	
NWK	
WAS	
ILO	ISO
VPR	
MCC	
MEWO	
FMM	
PMAV	
IUAO	
LCBV	
ICE	
CEF	
LUCE	
IKNE	
LETQC	
IF	
FS	
AA	
LKCAS	
NWK	
ILO	PV
ILO	DFSCC
OS	
CSW	
SCW	
MEF	
SF	
AMF	
NSE	
IDD	
PSC	

MOCUS Step-6

Since, the primary event Negligence in Watch Keeping (NWK) replicated in the tree, thus finally the minimal cut set will be,

IARCS	
IIUBNE	
NWK	
WAS	
ILO	ISO
VPR	
MCC	
MEWO	
FMM	
PMAV	
IUAO	
LCBV	
ICE	
CEF	
LUCE	
IKNE	
LETQC	
IF	
FS	
AA	
LKCAS	
ILO	PV
ILO	DFSCC
OS	
CSW	
SCW	
MEF	
SF	
AMF	
NSE	
IDD	
PSC	

6.2.5 Quantitative Approach: Assessment of Basic Cause Importance

To assess the importance of the different basic causes, the cut sets' failure probability is calculated as in Table 6.2, using the given failure probability data in Table 6.1. According to the Vessley-Fussell measure of component importance as discussed at Chapter 5, the importance ranking of the basic causes (or failures) is also established as shown in Table 6.4.

Table 6.2: Calculation of cut sets' failure probabilities for collision

\mathbf{K}_1	IARCS		Q _{K1}	=	3.12E-04
K_2	IIUBNE		Q _{K2}	=	5.63E-04
K_3	NWK		Q K3	=	1.84E-03
K_4	WAS		Q _{K4}	=	1.09E-03
K_5	ILO	ISO	Q K5	=	1.17E-06
K_6	VPR		Q_{K6}	=	2.12E-03
K ₇	MCC		Q K7	=	6.66E-04
K_8	MEWO		Q_{K8}	=	6.88E-04
K9	FMM		Q K9	=	2.57E-03
K_{10}	PMAV		Q K10	=	4.37E-04
K_{11}	IUAO		Q K11	=	1.86E-03
K_{12}	LCBV		Q K12	=	6.96E-04
K_{13}	ICE		Q K13	=	1.41E-04
K_{14}	CEF		Q K14	=	1.41E-04
K_{15}	LUCE		Q K15	=	9.89E-05
K_{16}	IKNE		Q K16	=	2.40E-04
K_{17}	LETQC		Q K17	=	1.99E-03
K_{18}	IF		Q K18	=	7.07E-04
K_{19}	FS		Q K19	=	7.80E-04
K_{20}	AA		Q K20	=	3.42E-04
K_{21}	LKCAS		Q K21	=	1.15E-03
K_{22}	ILO	PV	Q K22	=	1.12E-06
K_{23}	ILO	DFSCC	Q K23	=	1.20E-06
K_{24}	OS		Q K24	=	9.01E-04
K_{25}	CSW		Q K25	=	9.36E-04
K_{26}	SCW		Q K26	=	3.08E-04
K_{27}	MEF		Q K27	=	1.14E-04
K_{28}	SF		Q K28	=	3.04E-04
K_{29}	AMF		Q K29	=	9.89E-05
K_{30}	NSE		Q K30	=	1.90E-04
K_{31}	IDD		Q K31	=	3.27E-04
K_{32}	PSC		Q _{K32}	=	4.45E-04

It is observed that there are 32 possible combinations of basic causes (or basic event failures) for the collision accident. There are mostly single basic cause in each cut set. From the values of cut sets it is prevailed that cut set K₉, i.e. the faulty maneuver of master (FMM) having most significant effect in triggering failure of top event and it is the most risky event for collision accident whereas, the cut set K₂₂, i.e. the combination of improper look out (ILO) and poor visibility (PV) having least effect in triggering failure of top event.

Assessment of Risk Level

Failure probability of cut sets (QK_i) is represented in Table 6.3. There are four level of risks evaluated in Table 6.3. High risk level indicates the failure probabilities of the cut set between 0.001- 0.003. Medium level risk indicates the failure probabilities of cut set between 0.0001- 0.00095. Low level risk indicates the failure probabilities of cut set between 0.00001- 0.000099. Negligible risk is assumed as the probabilities between 0.000001- 0.000002.

Table 6.3: Risk level of the cut sets based on failure probabilities for collision accidents

Risk Level	Failure Probability of Cut Sets						
HIGH RISK (QK _i between 0.001- 0.003)	Qк3	Qĸ4	QK6	QK9	Q _{K11}	QK17	QK21
$\begin{array}{c} \textbf{MEDIUM RISK} \\ (QK_i \text{ between} \\ 0.0001 - 0.00095) \end{array}$	QK1 QK14 QK26	QK2 QK16 QK27	QK7 QK18 QK28	QK8 QK19	QK10 QK20 QK31	QK12 QK24	QK13 QK25
LOW RISK (QK _i between 0.00001 – 0.000099)	QK26	QK29	QK28	Q _{K30}	QK31	Q _{K32}	
NEGLIGIBLE RISK (QK _i between 0.000001 – 0.000002)	QK5	QK22	QK23				

High level risks may be illustrated if there is highest probability/possibility of occurring collision and it causes loss of life or serious injuries, oil spill and/or loss of the vessel. Medium level risks is illustrated if there is medium probability/possibility of occurring collision and it causes a medium injuries and/or a serious damage on vessel. Low level risks is illustrated if there is low probability/possibility of occurring collision and it causes a minor damage on vessel (need to take towage service). Negligible risks is illustrated if there is very less probability/possibility of occurring collision and it causes no damage or minor damage on vessel i.e. not need to take towage service [14].

6.2.6 Importance Ranking of Basic Events for Collision, Applying Vessley-Fussell Measure of Importance

As per ranking calculated applying Vessley-Fussell measure of component importance, faulty maneuver of master (FMM) having most significant effect in occurring collision accident and then the violation of procedure or rule (VPR), lack of experience/training/qualification/competency (LETQC), improper/ uncoordinated avoiding operation (IUAO) and so on as shown in Table 6.4.

Table 6.4: Importance ranking of basic events applying Vessley-Fussell measure of importance

Primary Events/ Basic Causes	Relevant Cut Sets	$1-\prod(1-Q_{Ki})$	$I^{VF} = \frac{1 - \prod (1 - Q_{Ki})}{Q_{COLLISION}}$	Ranking
IARCS	K ₁	3.12E-04	0.01305	20
IIUBNE	K ₂	5.63E-04	0.02356	15
NWK	K ₃	1.84E-03	0.07699	5
WAS	K ₄	1.09E-03	0.04561	7
ILO	K ₅ , K ₂₂ , K ₂₃	3.49E-06	0.000146	28
ISO	K ₅	1.17E-06	0.000049	30
VPR	K ₆	2.12E-03	0.08870	2
MCC	K ₇	6.66E-04	0.02787	14
MEWO	K ₈	6.88E-04	0.02879	13
FMM	K9	2.57E-03	0.10753	1
PMAV	K ₁₀	4.37E-04	0.01828	17
IUAO	K ₁₁	1.86E-03	0.07782	4
LCBV	K ₁₂	6.96E-04	0.02912	12
ICE	K ₁₃	1.41E-04	0.00589	25
CEF	K ₁₄	1.41E-04	0.00589	25
LUCE	K ₁₅	9.89E-05	0.00414	27
IKNE	K ₁₆	2.40E-04	0.01004	23
LETQC	K ₁₇	1.99E-03	0.08326	3
IF	K ₁₈	7.07E-04	0.02958	11
FS	K ₁₉	7.80E-04	0.03264	10
AA	K ₂₀	3.42E-04	0.01431	18
LKCAS	K ₂₁	1.15E-03	0.04812	6
PV	K ₂₂	1.12E-06	0.000047	31
DFSCC	K ₂₃	1.20E-06	0.000050	29

Primary Events/ Basic Causes	Relevant Cut Sets	$1-\prod(1-Q_{Ki})$	$I^{VF} = \frac{1 - \prod (1 - Q_{Ki})}{Q_{COLLISION}}$	Ranking
OS	K ₂₄	9.01E-04	0.03769	9
CSW	K ₂₅	9.36E-04	0.03916	8
SCW	K ₂₆	3.08E-04	0.01289	21
MEF	K ₂₇	1.14E-04	0.00477	26
SF	K ₂₈	3.04E-04	0.01272	22
AMF	K ₂₉	9.89E-05	0.00414	27
NSE	K ₃₀	1.90E-04	0.00795	24
IDD	K ₃₁	3.27E-04	0.01368	19
PSC	K ₃₂	4.45E-04	0.01862	16

6.2.7 Quantitative Approach: Calculation of Probability Value for Collision Model

From Collision model (Figure 6.1), for AND and OR gate, it is found based on Boolean algebra that:

$$Q_{\text{COLLISION}} = 1 - (1 - Q_{\text{NMF}}) \cdot (1 - Q_{\text{CF}}) \cdot (1 - Q_{\text{ONF}}) \cdot (1 - Q_{\text{DF}}) \cdot (1 - Q_{\text{IBA}}) \cdot (1 - Q_{\text{USF}}) \cdot (6.3)$$

Intermediate events are:

$$\begin{array}{lll} Q_{OE} &=& Q_{ILO} \cdot Q_{ISO} \\ &=& 1.10 \times 10^{-3} \cdot 1.06 \times 10^{-3} \\ &=& 1.17 \times 10^{-6} \\ \\ Q_{PF} &=& 1 - (1 - Q_{VPR}) \cdot (1 - Q_{MCC}) \\ &=& 1 - (1 - 2.12 \times 10^{-3}) \cdot (1 - 6.66 \times 10^{-4}) \\ &=& 2.78 \times 10^{-3} \\ \\ Q_{NF} &=& 1 - (1 - Q_{IARCS}) \cdot (1 - Q_{IIUBNE}) \cdot (1 - Q_{NWK}) \cdot (1 - Q_{WAS}) \cdot (1 - Q_{OE}) \cdot (1 - Q_{PF}) \cdot \\ &=& 1 - (1 - 3.12 \times 10^{-4}) \cdot (1 - 5.63 \times 10^{-4}) \cdot (1 - 1.84 \times 10^{-3}) \cdot (1 - 1.09 \times 10^{-3}) \cdot (1 - 1.17 \times 10^{-6}) \cdot \\ &(1 - 2.78 \times 10^{-3}) \\ &=& 6.57 \times 10^{-3} \\ \\ Q_{MFBRM} &=& 1 - (1 - Q_{MEWO}) \cdot (1 - Q_{FMM}) \\ &=& 1 - (1 - 6.88 \times 10^{-4}) \cdot (1 - 2.57 \times 10^{-3}) \\ &=& 3.26 \times 10^{-3} \\ \\ Q_{AE} &=& 1 - (1 - Q_{PMAV}) \cdot (1 - Q_{IUAO}) \\ &=& 1 - (1 - 4.37 \times 10^{-4}) \cdot (1 - 1.86 \times 10^{-3}) \\ &=& 2.30 \times 10^{-3} \\ \\ Q_{MF} &=& 1 - (1 - Q_{MFBRM}) \cdot (1 - Q_{AE}) \\ &=& 1 - (1 - 3.26 \times 10^{-3}) \cdot (1 - 2.30 \times 10^{-3}) \\ &=& 5.55 \times 10^{-3} \\ \end{array}$$

$$\begin{aligned} &Q_{NMF} &= 1 - (1 - Q_{NF}) \cdot (1 - Q_{MF}) \\ &= 1 - (1 - 6.79 \times 10^{-3}) \cdot (1 - 5.55 \times 10^{-3}) \\ &= 1.23 \times 10^{-2} \\ &Q_{CF} &= 1 - (1 - Q_{LCBV}) \cdot (1 - Q_{ICE}) \cdot (1 - Q_{CEF}) \cdot (1 - Q_{LUCE}) \\ &= 1 - (1 - 6.96 \times 10^{-4}) \cdot (1 - 1.41 \times 10^{-4}) \cdot (1 - 1.41 \times 10^{-4}) \cdot (1 - 9.89 \times 10^{-5}) \\ &= 1.08 \times 10^{-3} \end{aligned}$$

$$Q_{ONF} &= 1 - (1 - Q_{IKNE}) \cdot (1 - Q_{LETQC}) \cdot (1 - Q_{IF}) \cdot (1 - Q_{FS}) \cdot (1 - Q_{AA}) \cdot (1 - Q_{LKCAS}) \cdot (1 - Q_{NWK}) \\ &= 1 - (1 - 2.40 \times 10^{-4}) \cdot (1 - 1.99 \times 10^{-3}) \cdot (1 - 7.07 \times 10^{-4}) \cdot (1 - 7.80 \times 10^{-4}) \cdot (1 - 3.42 \times 10^{-4}) \cdot (1 - 1.55 \times 10^{-3}) \cdot (1 - 1.84 \times 10^{-3}) \\ &= 7.03 \times 10^{-3} \end{aligned}$$

$$Q_{DF} &= Q_{ILO} \times Q_{PV} \\ &= 1.10 \times 10^{-3} \times 1.02 \times 10^{-3} \\ &= 1.12 \times 10^{-6} \end{aligned}$$

$$Q_{ED} &= Q_{ILO} \times Q_{DFSCC} \\ &= 1.10 \times 10^{-3} \times 1.09 \times 10^{-3} \\ &= 1.20 \times 10^{-6} \end{aligned}$$

$$Q_{IBA} &= 1 - (1 - Q_{FD}) \cdot (1 - Q_{OS}) \\ &= 1 - (1 - 1.20 \times 10^{-6}) \cdot (1 - 9.01 \times 10^{-4}) \\ &= 9.02 \times 10^{-4} \end{aligned}$$

$$Q_{EF} &= 1 - (1 - Q_{CSW}) \cdot (1 - Q_{SCW}) \\ &= 1 - (1 - 9.36 \times 10^{-4}) \cdot (1 - 3.08 \times 10^{-4}) \\ &= 1.24 \times 10^{-3} \end{aligned}$$

$$Q_{INTF} &= 1 - (1 - Q_{MEF}) \cdot (1 - Q_{SF}) \cdot (1 - Q_{AMF}) \\ &= 1 - (1 - 1.14 \times 10^{-4}) \cdot (1 - 3.04 \times 10^{-4}) \cdot (1 - 9.89 \times 10^{-5}) \\ &= 5.17 \times 10^{-4} \end{aligned}$$

$$Q_{USF} &= 1 - (1 - Q_{EF}) \cdot (1 - Q_{NFF}) \\ &= 1 - (1 - 1.24 \times 10^{-3}) \cdot (1 - 5.17 \times 10^{-4}) \\ &= 1.76 \times 10^{-3} \end{aligned}$$

$$Q_{NS} &= 1 - (1 - Q_{NSE}) \cdot (1 - Q_{DDD}) \cdot (1 - Q_{PSC}) \\ &= 1 - (1 - 1.90 \times 10^{-4}) \cdot (1 - 3.27 \times 10^{-4}) \cdot (1 - 4.45 \times 10^{-4}) \\ &= 9.62 \times 10^{-4} \end{aligned}$$

Putting the values of intermediate events in Equation 6.3,

$$\begin{split} Q_{COLLISION} &= 1 - (1 - Q_{NMF}) \cdot (1 - Q_{CF}) \cdot (1 - Q_{ONF}) \cdot (1 - Q_{DF}) \cdot (1 - Q_{IBA}) \cdot (1 - Q_{USF}) \cdot \\ &\quad (1 - Q_{NS}) \\ &= 1 - (1 - 1.23 \times 10^{-2}) \cdot (1 - 1.08 \times 10^{-3}) \cdot (1 - 7.03 \times 10^{-3}) \cdot (1 - 1.12 \times 10^{-6}) \cdot \\ &\quad (1 - 9.02 \times 10^{-4}) \cdot (1 - 1.76 \times 10^{-3}) \cdot (1 - 9.62 \times 10^{-4}) \\ &= 2.39 \times 10^{-2} \end{split}$$

This means that there is a **2.39%** chance that this particular unwanted and potentially dangerous event (Collision) will occur in inland route of Bangladesh for one year period.

6.3 Analysis of Grounding Accident

Grounding is defined as cases where a vessel comes into contact with the sea bed or shore, including underwater wrecks. If the ship is stuck fast, this is known as 'stranding'. If the ship sinks, this is sometimes known as 'wreck'. The category wreck/stranded is equivalent to the term grounding used here.

There have been 9 groundings accidents in the research area during the last 38 years period 1981-2018. One of the grounding resulted in major fatality with 33 people and another with 3 people. None of the other groundings resulted in any fatalities. Statistics have been taken from the data in Appendix-A.

Grounding accident is an accident-type bearing certain degree of risk for all types of vessels. Thus, the grounding accidents has been analysed through FTA in following manner.

6.3.1 Factors Affecting Ship's Grounding

There are many factors affecting ship grounding. For this analysis, 67 factors as basic/primary events is found based on grounding accident data analysis. These are:

- 1. Main Engine Failure (MEF).
- 2. Steering Failure (SF).
- 3. Auxiliary Machinery Failure (AMF).
- 4. Violation of Traffic Rule (VTR).
- 5. Violation of Procedure or Rule (VPR).
- 6. Over Speed (OS).
- 7. Faulty Maneuver of Master (FMM).
- 8. Piloting Failure (PF).
- 9. Improper Use of Bridge Navigational/Sounding Equipment (IUBNSE).
- 10. Insufficient Knowledge on Navigational Equipment (INNE).
- 11. Insufficient Navigational/Sounding Equipment (INSE).
- 12. Lack of Bridge Resource Management (LBRM).
- 13. Insufficient Channel Marking (ICM).
- 14. Inappropriate Route Selection (IARS).
- 15. Environmental Restriction (Visibility, Wind& Wave) (ER).
- 16. Bad Weather Condition (BWC).
- 17. Insufficient Information of Weather Forecast (IIWF).
- 18. Lack of Experience/Training/Qualification/Competency of Officer, Master, Crew (LETQC).
- 19. Interpretation Failure (IF).
- 20. Fatigue/Sleeplessness (FS).

- 21. Alcohol Abuse (AA).
- 22. Ship Handling in Narrow Water (SHNW).
- 23. Non Standardized of Equipment (NSE).
- 24. Poor Stability Condition of Vessel (PSC).
- 25. Lack of Knowledge on Avoiding Grounding Situation (LKAGS).
- 26. Over Loading (OL).
- 27. Navigational System Failure (NSF).
- 28. Lack of Radar Observation (LRO).
- 29. Negligence/Reluctances in Performing Duty (NRPD).
- 30. Poor Visibility (PV).
- 31. Navigate/Maneuver on Wrong/Inappropriate Course (NWC).
- 32. Negligence in Watch Keeping (NWK).
- 33. Wrong Assessment of Situation (WAS).
- 34. Improper Steering Operation (ISO).
- 35. Improper Look Out (ILO).
- 36. Improper Emergency Operation (IEO).
- 37. Uncoordinated/Improper Avoiding Operation (UIAO).
- 38. Deviated from Safe Course/Channel (DFSCC).
- 39. Rough Sea (RS).
- 40. Manoeuver Error of Watch Keeping Officer (MEWO).
- 41. Steered through Restricted Waterways (STRW)
- 42. Dynamic Positioning Failure(DPF)
- 43. Course Change (CC)
- 44. Improper Design and Drawing (IDD)
- 45. Update Charts/Publication not used onboard (UCPNU)
- 46. Charts/Publication are not Updated by Authority (CPNU)
- 47. Waterways are not Maintained by Authority (WWNM)
- 48. Position Estimation Error (PEE)
- 49. Sensor/Navigation Equipment Error (SNEE)
- 50. Delayed in Action in Coming back to Safe Track (DACST)
- 51. Improper Steering/Course Keeping Failure by Quarter Master (ISCCFQM)
- 52. Improper/Insufficient Use of Depth Gauge/Sounding Equipment (IIUSE)
- 53. Information Acquisition Failure (IAF)
- 54. Violation of Regulation (VOR)
- 55. Strong Current/Wave (SCW)
- 56. Cyclone/Strong Wind (CSW)
- 57. Anchor Failure (AF)
- 58. In-sufficient/Improper Marking of Navigable Channel (IIMNC)
- 59. Assistance is not Requested (ANR)
- 60. Assistance not Arrived (ANA)
- 61. Inability to Provide Assistance (Delayed arrival/inability of pilot/unsuitable pilot ship) (IPA)
- 62. Inappropriate Voyage Plan (IVP)
- 63. Selection of Inappropriate Anchorage (SIA)

- 64. Interpretation Failure of Watch Keeping Officer/Master (IFWM).
- 65. Interpretation Failure of Bridge Navigation Equipment (Radar, GPS, Ecosounder, etc) (IFBNE).
- 66. Poor Maneuvering Ability of Vessel (PMAV)
- 67. Selection of Inappropriate Anchorage (SIA)

Out of these 67 causes, a fault tree for ship grounding accident in inland waterways of Bangladesh was constructed using 40 prominent causes, since these causes are so interrelated with other causes and to reduce the size of fault tree. The basic events for grounding model are shown in Table 6.5

6.3.2 Basic Events Probability for Grounding

Like collision accident, following the Equation no 6.1, the probability values of basis/primary events for grounding accidents in inland waterways of Bangladesh was calculated from collected data of grounding accident between 1981 to till current year, i.e. 2018 (last 38 years) for 09 vessels having grounding accident. The calculated probability values of basic events are shown at Table 6.5 and the probability calculations of all the basic event related to groundings are represented in Appendix-D.

Table 6.5: The calculated probability values of basic events for Grounding

Sr	Primary/Basic Events Causing Grounding	Abbreviation	Probability
	Accidents		Value
1	Selection of Inappropriate Anchorage	SIA	2.92E-04
2	In-sufficient/Improper Marking of Navigable		
	Channel	IIMNC	1.32E-03
3	Update Charts/Publication not used onboard	UCPNU	1.46E-04
4	Charts/ Publication are not updated by Authority	CPNU	1.46E-04
5	Waterways are not Maintained by Authority	WWNM	1.02E-03
6	Position Estimation Error	PEE	4.39E-04
7	Sensor/ Navigation Equipment Error	SNEE	2.92E-04
8	Delayed in Action in Coming back to Safe Track	DACST	2.92E-04
9	Improper Steering/Course Keeping Failure by		
	Quarter Master	ISCCFQM	1.61E-03
10	Maneuver Error of Watch Keeping Officer	MEWO	1.61E-03
11	Faulty Maneuver of Master	FMM	3.80E-03
12	Poor Maneuvering Ability of Vessel	PMAV	1.46E-04
13	Uncoordinated/Improper Avoiding Operation	UIAO	2.92E-04
14	Assistance is not Requested	ANR	2.92E-04
15	Assistance not Arrived	ANA	1.46E-04

Sr	Primary/Basic Events Causing Grounding Accidents	Abbreviation	Probability Value
16	Inability to Provide Assistance (Delayed arrival/		, 5255
	inability of pilot/ unsuitable pilot ship	IPA	1.46E-04
17	Insufficient Knowledge on Navigational Equipment	IKNE	1.46E-04
18	Lack of Experience/Training/Qualification/		
	Competency of Officer, Master, Crew	LETQC	2.05E-03
19	Interpretation Failure	IF	2.92E-04
20	Fatigue/Sleeplessness	FS	5.85E-04
21	Alcohol Abuse	AA	2.92E-04
22	Lack of Knowledge on Avoiding Grounding		
	Situation	LKAGS	1.32E-03
23	Negligence in Watch Keeping	NWK	5.85E-04
24	Improper/Insufficient Use of Bridge		
	Navigational/Sounding Equipment	IIUBNSE	8.77E-04
25	Improper Look Out	ILO	1.46E-03
26	Deviated from Safe Course/Channel	DFSCC	4.39E-04
27	Improper/Insufficient Use of Depth		
	Gauge/Sounding Equipment	IIUSE	1.02E-03
28	Violation of Regulation	VOR	7.31E-04
29	Poor Visibility	PV	5.85E-04
30	Cyclone/Strong Wind	CSW	7.31E-04
31	Strong Current/Wave	SCW	4.39E-04
32	Anchor Failure	AF	5.85E-04
33	Main Engine Failure	MEF	1.46E-04
34	Steering Failure	SF	5.85E-04
35	Auxiliary Machinery Failure	AMF	1.46E-04
36	Non Standardized of Equipment	NSE	1.46E-04
37	Improper Design and Drawing	IDD	2.92E-04
38	Poor Stability Condition of Vessel	PSC	1.46E-04
39	Interpretation Failure of Watch Keeping		
	Officer/Master	IFWM	4.39E-04
40	Interpretation Failure of Bridge Navigation		
	Equipment (Radar, GPS, Ecosounder, etc)	IFBNE	2.92E-04

6.3.3 Qualitative Approach: Construction of FTA Model for Grounding

Grounding accident is an accident-type bearing certain degree of risk for all types of vessels. Data is available for 09 grounding accidents. Based on such data, out of 67 causes, 40 prominent causes/initial events causing grounding accidents have been gathered to construct fault tree model for grounding since these causes are so interrelated with other causes and possible intermediate event sets have been constituted. Figure 6.2 gives a fault tree formation for grounding accidents.

Fig 6.2: Fault tree of grounding accidents...... to be inserted

There are eight intermediate event sets which cause occurrence of grounding accidents. In the fault tree formation, these event sets have been linked with "OR" gates/doors to the top event, "Grounding". These are failures associated with navigation and maneuvering (NMF), assistance pilotage failure (APF), operator's/navigator's failure (ONF), detection failure (DF), illegal behavior/action (IBA), uncontrolled situation/factors (USF), non-standardization (NS) and interpretation failure (IF). Combination of the initial events contained in such intermediate event sets is sufficient for the occurrence of grounding accidents which are again arranged through AND/OR gates as necessary under intermediate events.

6.3.4 Qualitative Approach: Finding Minimum Cut Sets for Grounding

As shown in the fault tree of grounding (Figure 6.2), a grounding can occur if the following set of causes are occurring; the navigation and maneuvering failure, assistance (pilotage) failure, operator's/navigator's failure, detection failure, illegal behavior/ action, uncontrolled situation/factors, non-standardization and interpretation failure. Among those; selection of inappropriate anchorage, in-sufficient/improper marking of navigable channel, update charts/publication not used onboard, waterways are not maintained by authority, position estimation error improper steering/course keeping failure by quarter master, faulty maneuver of master and uncoordinated/improper avoiding operation are the main reason/root causes for the navigation and maneuvering failure.

Minimum cut sets for grounding fault tree was found using both the Boolean Algebra Reduction Method and MOCUS Algorithm Method.

6.3.4.1 Boolean Algebra Reduction Method

In order to calculate the probability of ship grounding accident, firstly the fault tree is expressed by Boolean algebra, then the Boolean algebra is simplified to acquire minimum cut sets. Following the fault tree model for grounding (Figure 6.2) and applying Boolean equation, the ship grounding event can be expressed by the equation:

$$K_{GROUNDING} = NMF + APF + ONF + DF + IBA + USF + NS + IF$$
 (6.4)

Intermediate events are expressed as,

NF = SIA + IIMNC + UCPNU + CPNU + WWNM + PEE + SNEE + DACST + ISCCFQM $MF = (MEWO \times FMM) + PMAV + UIAO$

Putting these values of intermediate and basic events in Equation 6.4, Cut Sets for Grounding are:

$$\begin{split} K_{GROUNDING} &= NMF + APF + ONF + DF + IBA + USF + NS + IF \\ &= SIA + IIMNC + UCPNU + CPNU + WWNM + PEE + SNEE + DACST \\ &+ ISCCFQM + (MEWO \times FMM) + PMAV + UIAO + ANR + ANA + IPA \\ &+ IKNE + LETQC + IF + FS + AA + LKAGS + NWK + (IIUBNSE \times ILO) \\ &+ (ILO \times DFSCC \times IIUSE) + VOR + PV + CSW + SCW + AF + MEF + SF \\ &+ AMF + NSE + IDD + PSC + (IFWM \times IFBNE) \end{split}$$

6.3.4.2 MOCUS Algorithm Method

Applying MOCUS Algorithm as discussed in previous, the process to find out minimal cut sets for Grounding Accidents in inland waterways of Bangladesh is shown below:

MOCUS Step-1

'Probability of Grounding risk in inland waterways of Bangladesh'

MOCUS Step-2

Occurrence of grounding in inland waterways of Bangladesh is based on eight intermediate events. They are the navigation and maneuvering failure, assistance (pilotage) failure, operator's/navigator's failure, detection failure, illegal behavior/ action, uncontrolled situation/factors, non-standardization and interpretation failure. For AND and OR gates of the grounding tree,

NMF	
APF	
ONF	
DF	
IBA	
USF	
NS.	
IF	

MOCUS Step-3.1

For the, 'navigation and maneuvering failure, assistance (pilotage) failure, operator's/navigator's failure, detection failure, illegal behavior/ action, uncontrolled situation/factors, non-standardization and interpretation failure' events (i.e. NMF, APF, ONF, DF, IBA, USF, NS and IF in the fault tree of grounding model)

NF	
MF	
ANR	
ANA	
IPA	
IKNE	
LETQC	
IF	
FS	
AA	
LKAGS	
NWK	
IIUBNSE	ILO
FD	
VOR	
EF	
INTF	
NSE	
IDD	
PSC	
IFWM	IFBNE

MOCUS Step-3.2

For the, 'navigation failure, maneuvering failure, failed in the duty, external factors and internal factors' events (i.e. NF, MF, FD, EF and INTF in the fault tree)

SIA		
IRTS		
DFSTC		
MFBRM		
AE		
ANR		
ANA		
IPA		
IKNE		
LETQC		
IF		
FS		
AA		
LKAGS		
NWK		
IIUBNSE	ILO	
DFSCC	ILO	IIUSE
VOR		
PV		
CWS		
SCW		
AF		
MEF		
SF		
AMF		
NSE		
IDD		
FSC		
IFWM	IFBNE	

MOCUS Step-3.3

For the, 'Inappropriate route/track selection, deviation from safe track/ channel, maneuvering failure in bridge resource management and avoiding error' events (i.e. IRTS, DFSTC, MFBRM and AE in the fault tree)

SIA		
IIMNC		
UCPNU		
CPNU		
NWNM		
PEE		
SNEE		
DACST		
ISCCFQM		
MEWO	FMM	

PMAV		
UIAO		
ANR		
ANA		
IPA		
IKNE		
LETQC		
IF		
FS		
AA		
LKAGS		
NWK		
IIUBNSE	ILO	
DFSCC	ILO	IIUSE
VOR		
PV		
CWS		
SCW		
AF		
MEF		
SF		
AMF		
NSE		
IDD		
PSC		
IFWM	IFBNE	

6.3.5 Quantitative Approach: Assessment of Basic Causes Importance

To assess the importance of the different basic causes, the cut sets' failure probability is calculated as in Table 6.6, using the given failure probability data in Table 6.5. According to the Vessley-Fussell measure of component importance, the importance ranking of the basic causes (or failures) is also established as shown in Table 6.8.

Table 6.6: Calculation of cut sets' failure probabilities for Grounding

K_1	SIA			$Q_{K1} = 2.92E-04$
K_2	IIMNC			$Q_{K2} = 1.32E-03$
K_3	UCPNU			$Q_{K3} = 1.46E-04$
K_4	CPNU			$Q_{K4} = 1.46E-04$
K_5	NWNM			$Q_{K5} = 1.02E-03$
K_6	PEE			$Q_{K6} = 4.39E-04$
K_7	SNEE			$Q_{K7} = 2.92E-04$
K_8	DACST			$Q_{K8} = 2.92E-04$
K_9	ISCCFQM			$Q_{K9} = 1.61E-03$
K_{10}	MEWO	FMM		$Q_{K10} = 6.12E-06$
K_{11}	PMAV			$Q_{K11} = 1.46E-04$
K_{12}	UIAO			$Q_{K12} = 2.92E-04$
K_{13}	ANR			$Q_{K13} = 2.92E-04$
K_{14}	ANA			$Q_{K14} = 1.46E-04$
K_{15}	IPA			$Q_{K15} = 1.46E-04$
K_{16}	IKNE			$Q_{K16} = 1.46E-04$
K_{17}	LETQC			$Q_{K17} = 2.05E-03$
K_{18}	IF			$Q_{K18} = 2.92E-04$
K_{19}	FS			$Q_{K19} = 5.85E-04$
K_{20}	AA			$Q_{K20} = 2.92E-04$
K_{21}	LKAGS			$Q_{K21} = 1.32E-03$
K_{22}	NWK			$Q_{K22} = 5.85E-04$
K_{23}	IIUBNSE	ILO		$Q_{K23} = 1.28E-06$
K_{24}	DFSCC	ILO	IIUSE	$Q_{K24} = 6.54E-10$
K_{25}	VOR			$Q_{K25} = 7.31E-04$
K_{26}	PV			$Q_{K26} = 5.85E-04$
K_{27}	CWS			$Q_{K27} = 7.31E-04$
K_{28}	SCW			$Q_{K28} = 4.39E-04$
K_{29}	AF			$Q_{K29} = 5.85E-04$
K_{30}	MEF			$Q_{K30} = 1.46E-04$
K_{31}	SF			$Q_{K31} = 5.85E-04$
K_{32}	AMF			$Q_{K32} = 1.46E-04$
K_{33}	NSE			$Q_{K33} = 1.46E-04$
K_{34}	IDD			$Q_{K34} = 2.92E-04$
K_{35}	PSC			$Q_{K35} = 1.46E-04$
K ₃₆	IFWM	IFBNE		$Q_{K36} = 1.28E-07$

According to the analysis results, 36 minimum cut sets causing occurrence of grounding accidents have been found. It shows that minimum cut sets where grounding accidents are at maximum level is for cut set K_{17} i.e. lack of experience/training/qualification/ competency (LETQC) and it is the most risky event for grounding accident whereas, the cut set K_{24} , i.e. the combination of deviated from safe course/channel (DFSCC), improper look out (ILO) and improper/insufficient use of depth gauge/sounding equipment (IIUSE) having least effect in triggering failure of top event (Table 6.6).

Assessment of Risk Level

Failure probability of cut sets (QK_i) and four level of risks are presented in Table 6.7. High risk level indicates the failure probabilities of the cut set between 0.001- 0.003. Medium level risk indicates the failure probabilities of cut set between 0.0001- 0.0008. Low level risk indicates the failure probabilities of cut set between 0.00001- 0.000007 & 0.0000001- 0.0000002. Negligible risk is assumed as the probabilities between 6.00E-10 to 7.00E-10.

Table 6.7: Risk level of the cut sets based on failure probabilities for grounding accidents

Risk Level	Failure Probability of Cut Sets						
HIGH RISK (QK _i between 0.001- 0.003)	Q _{K2}	QK5	QK9	QK17	QK21		
MEDIUM RISK (QK _i between 0.0001- 0.0008)	QK1 QK12 QK20 QK30	QK3 QK13 QK22 QK31	QK4 QK14 QK25 QK32	QK6 QK15 QK26 QK33	QK7 QK16 QK27 QK34	QK8 QK18 QK28 QK35	QK11 QK19 QK29
LOW RISK (QK _i between 0.000001-0.000007 & 0.0000001- 0.0000002)	QK10	Q _{K23}	QK36				
NEGLIGIBLE RISK (QK _i between 6.00E-10 to 7.00E-10)	QK24						

High level risks may be illustrated if there is highest probability/possibility of occurring grounding and it causes loss of life or serious injuries, oil spill and/or loss of the vessel. Medium level risks is illustrated if there is medium probability/possibility of occurring grounding and it causes a medium injuries and/or a serious damage on vessel. Low level risks is illustrated if there is low probability/possibility of occurring grounding and it causes a minor damage on vessel (need to take towage service). Negligible risks is illustrated if there is very less probability/possibility of occurring grounding and it causes no damage or minor damage on vessel i.e. not need to take towage service [14].

6.3.6 Importance Ranking of Basic Events for Grounding, Applying Vessley-Fussell Measure of Importance

As per ranking calculated applying Vessley-Fussell measure of component importance, the lack of experience/training/qualification/competency (LETQC) having most significant effect in occurring grounding accident and then the improper steering/course keeping failure by Quarter Master (ISCCFQM), in-sufficient/improper marking of navigable channel (IIMNC), waterways are not maintained by authority (WWNM) and so on.

Table 6.8: Importance ranking of basic events applying Vessley-Fussell measure of importance

Primary Events/ Basic Causes	Relevant Cut Sets	$1-\prod(1-Q_{Ki})$	$I^{VF} = \frac{1 - \prod (1 - Q_{Ki})}{Q_{GROUNDING}}$	Ranking
SIA	K ₁	2.92E-04	0.0179	7
IIMNC	K ₂	1.32E-03	0.0809	3
UCPNU	K ₃	1.46E-04	0.00895	8
CPNU	K ₄	1.46E-04	0.00895	8
WWNM	K ₅	1.02E-03	0.063	4
PEE	K ₆	4.39E-04	0.0085	9
SNEE	K ₇	2.92E-04	0.0179	7
DACST	K ₈	2.92E-04	0.0179	7
ISCCFQM	K9	1.61E-03	0.0988	2
MEWO	K ₁₀	6.12E-06	0.00038	10
FMM	K ₁₀	6.12E-06	0.00038	10
PMAV	K ₁₁	1.46E-04	0.00895	8
UIAO	K ₁₂	2.92E-04	0.0179	7
ANR	K ₁₃	2.92E-04	0.0179	7
ANA	K ₁₄	1.46E-04	0.00895	8
IPA	K ₁₅	1.46E-04	0.00895	8
IKNE	K ₁₆	1.46E-04	0.00895	8
LETQC	K ₁₇	2.05E-03	0.1257	1
IF	K ₁₈	2.92E-04	0.0179	7
FS	K ₁₉	5.85E-04	0.0358	6
AA	K ₂₀	2.92E-04	0.0179	7
LKAGS	K ₂₁	1.32E-03	0.0809	3
NWK	K ₂₂	5.85E-04	0.0358	6

Primary Events/ Basic Causes	Relevant Cut Sets	$1-\prod(1-Q_{Ki})$	$I^{VF} = \frac{1 - \prod (1 - Q_{Ki})}{Q_{GROUNDING}}$	Ranking
IIUBNSE	K ₂₃	1.28E-06	0.000079	11
ILO	K ₂₃ , K ₂₄	1.28E-06	0.000079	11
DFSCC	K ₂₄	6.54E-10	0.00000004	13
IIUSE	K ₂₄	6.54E-10	0.00000004	13
VOR	K ₂₅	7.31E-04	0.0448	5
PV	K ₂₆	5.85E-04	0.0358	6
CSW	K ₂₇	7.31E-04	0.0448	5
SCW	K ₂₈	4.39E-04	0.0085	9
AF	K ₂₉	5.85E-04	0.0358	6
MEF	K ₃₀	1.46E-04	0.00895	8
SF	K ₃₁	5.85E-04	0.0358	6
AMF	K ₃₂	1.46E-04	0.00895	8
NSE	K ₃₃	1.46E-04	0.00895	8
IDD	K ₃₄	2.92E-04	0.0179	7
PSC	K ₃₅	1.46E-04	0.00895	8
IFWM	K ₃₆	1.28E-07	0.0000079	12
IFBNE	K ₃₆	1.28E-07	0.0000079	12

As it has been shown on the Table 6.8, negligence in watch keeping (NWK), violation of regulation (VOR), cyclone/strong wind (CSW) are other affecting factors for groundings in inland waterways of Bangladesh. Grounding causes are also dominated by handling errors and shallow waters in operating area.

6.3.7 Quantitative Approach-Calculation of Probability Value for Grounding Model

From Grounding model (Figure 6.2), for AND and OR gate, it is found based on Boolean algebra that:

$$\begin{array}{ll} Q_{GROUNDING} & = 1 - (1 - Q_{NMF}) \cdot (1 - Q_{APF}) \cdot (1 - Q_{ONF}) \cdot (1 - Q_{DF}) \cdot (1 - Q_{IBA}) \cdot (1 - Q_{USF}) \cdot \\ & (1 - Q_{NS}) \cdot (1 - Q_{IF}) \end{array} \tag{6.5}$$

Intermediate events are:

$$\begin{array}{ll} Q_{IRTS} &= 1 - (1 - Q_{IIMNC}) \cdot (1 - Q_{UCPNU}) \cdot (1 - Q_{CPNU}) \cdot (1 - Q_{WWNM}) \\ &= 1 - (1 - 1.32 \times 10^{-3}) \cdot (1 - 1.46 \times 10^{-4}) \cdot (1 - 1.46 \times 10^{-4}) \cdot (1 - 1.02 \times 10^{-3}) \\ &= 2.629 \times 10^{-3} \end{array}$$

$$\begin{aligned} &\text{Qdestc} = 1 - (1 - Q_{\text{FED}}, (1 - Q_{\text{SNEE}}), (1 - Q_{\text{DACSTD}}, (1 - Q_{\text{ISCCFQM}}) \\ &= 1 - (1 - 4.39 \times 10^4), (1 - 2.92 \times 10^4), (1 - 2.92 \times 10^4), (1 - 1.61 \times 10^3) \\ &= 2.631 \times 10^3 \end{aligned}$$

$$&\text{QNF} = 1 - (1 - Q_{\text{SLA}}), (1 - Q_{\text{IRTS}}), (1 - Q_{\text{DESTC}}) \\ &= 1 - (1 - 2.92 \times 10^4), (1 - 2.629 \times 10^3), (1 - 2.631 \times 10^3) \\ &= 5.54 \times 10^3 \end{aligned}$$

$$&\text{QMFBERM} = Q_{\text{MEWO}} \times Q_{\text{FMM}} \\ &= 1.61 \times 10^3 \times 380 \times 10^3 \\ &= 6.12 \times 10^6 \end{aligned}$$

$$&\text{QAE} = 1 - (1 - Q_{\text{PMAV}}), (1 - Q_{\text{UAO}}) \\ &= 1 - (1 - 1.46 \times 10^4), (1 - 2.92 \times 10^4) \\ &= 4.38 \times 10^4 \end{aligned}$$

$$&\text{QMF} = 1 - (1 - Q_{\text{MERM}}), (1 - Q_{\text{MED}}) \\ &= 1 - (1 - 6.12 \times 10^4), (1 - 4.38 \times 10^4) \\ &= 4.44 \times 10^4 \end{aligned}$$

$$&\text{QNMF} = 1 - (1 - Q_{\text{NF}}), (1 - Q_{\text{MF}}) \\ &= 1 - (1 - 2.92 \times 10^4), (1 - 4.44 \times 10^4) \\ &= 5.98 \times 10^4 \end{aligned}$$

$$&\text{QAPF} = 1 - (1 - Q_{\text{ANR}}), (1 - Q_{\text{ANA}}), (1 - Q_{\text{IPA}}) \\ &= 1 - (1 - 2.92 \times 10^4), (1 - 1.46 \times 10^4), (1 - 1.46 \times 10^4) \\ &= 5.84 \times 10^4 \end{aligned}$$

$$&\text{QonF} = 1 - (1 - Q_{\text{RNE}}), (1 - Q_{\text{LETOC}}), (1 - Q_{\text{IF}}), (1 - Q_{\text{ES}}), (1 - Q_{\text{AA}}), (1 - Q_{\text{LKAGS}}), \\ &= (1 - (1 - 1.32 \times 10^3), (1 - 5.85 \times 10^4), (1 - 2.92 \times 10^4), (1 - 5.85 \times 10^4), (1 - 2.92 \times 10^4), \\ &= 5.26 \times 10^3 \end{aligned}$$

$$&\text{QDF} = Q_{\text{BUBINSE}} \times Q_{\text{BLO}} \\ &= 8.77 \times 10^4 \times 1.46 \times 10^3 \\ &= 1.28 \times 10^6 \end{aligned}$$

$$&\text{QED} = Q_{\text{BLOS}} \times Q_{\text{DESC}} \times Q_{\text{BUSE}} \\ &= 1.46 \times 10^3 \times 4.39 \times 10^4 \times 1.02 \times 10^3, \\ &= 6.54 \times 10^{10}, (1 - 7.31 \times 10^4), \\ &= 7.31 \times 10^4 \end{aligned}$$

$$Q_{\text{EBA}} = 1 - (1 - Q_{\text{PV}}), (1 - Q_{\text{CSW}}), (1 - Q_{\text{SCW}}) \\ &= 1 - (1 - 6.54 \times 10^{-10}), (1 - 7.31 \times 10^4), (1 - 4.39 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^3 \times 10^4, (1 - 2.92 \times 10^4), \\ &= 1.75 \times 10^$$

$$\begin{aligned} Q_{\text{INTF}} &= 1 - (1 - Q_{\text{AF}}) \cdot (1 - Q_{\text{MEF}}) \cdot (1 - Q_{\text{SF}}) \cdot (1 - Q_{\text{AMF}}) \\ &= 1 - (1 - 5.85 \times 10^{-4}) \cdot (1 - 1.46 \times 10^{-4}) \cdot (1 - 5.85 \times 10^{-4}) \cdot (1 - 1.46 \times 10^{-4}) \\ &= 1.46 \times 10^{-3} \end{aligned}$$

$$Q_{\text{USF}} &= 1 - (1 - Q_{\text{EF}}) \cdot (1 - Q_{\text{INTF}}) \\ &= 1 - (1 - 1.75 \times 10^{-3}) \cdot (1 - 1.46 \times 10^{-3}) \\ &= 3.21 \times 10^{-3} \end{aligned}$$

$$Q_{\text{NS}} &= 1 - (1 - Q_{\text{NSE}}) \cdot (1 - Q_{\text{IDD}}) \cdot (1 - Q_{\text{PSC}}) \\ &= 1 - (1 - 1.46 \times 10^{-4}) \cdot (1 - 2.92 \times 10^{-4}) \cdot (1 - 1.46 \times 10^{-4}) \\ &= 5.84 \times 10^{-4} \end{aligned}$$

$$Q_{\text{IF}} &= Q_{\text{IFWM}} \times Q_{\text{IFBNE}} \\ &= 4.39 \times 10^{-4} \times 2.92 \times 10^{-4} \\ &= 1.28 \times 10^{-7} \end{aligned}$$

Putting the values of intermediate events in Equation 6.5,

$$\begin{array}{ll} Q_{GROUNDING} &= 1 - \left(1 - Q_{NMF}\right).\left(1 - Q_{APF}\right).\left(1 - Q_{ONF}\right).\left(1 - Q_{DF}\right).\left(1 - Q_{IBA}\right).\left(1 - Q_{USF}\right).\\ &= 1 - \left(1 - 5.98 \times 10^{-3}\right).\left(1 - 5.84 \times 10^{-4}\right).\left(1 - 5.26 \times 10^{-3}\right).\left(1 - 1.28 \times 10^{-6}\right).\\ &= 1.63 \times 10^{-2} \end{array}$$

This means that there is a 1.63% chance that this particular unwanted and potentially dangerous event (Grounding) will occur in inland waterways of Bangladesh for one year period.

6.4 Sensitivity Analysis

A sensitivity analysis has been carried out in the FTA programme in order to minimize the margin of error in the possibility values. For this purpose, the possibility values of event sets which cause occurrence of collision and grounding accidents have been altered systematically. Possibility values of the initial events in such event sets have been increased and decreased by 10 times independently of each other. Changes in the contribution rate of initial events to accident and in their significance degree being observed. Tables 6.9 and 6.10 gives the possibility changes in initial events with high significance degree for collision and grounding accident respectively.

Table 6.9: Variation of collision accident probability if primary events probability values are increased and decreased by 10 times

Sr	Primary Events Causing Collision Accidents	Nominal Probability Value of Basic Event (X)	Nominal Probability Value of Collision	Probability Value of Collision at (10X) Increase (+) of Basic Event's Probability Value	Probability Value of Collision at (10X) Decrease (-) of Basic Event's Probability Value	Probability Value of Collision Increased (%)	Probability Value of Collision Decreased (%)
1	Inappropriate Route/Course Selection (IARCS)	3.12E-04	2.36E-02	2.64E-02	2.34E-02	11.86 %	0.85 %
2	Improper / Insufficient Use of Bridge Navigational Equipment (IIUBNE)	5.63E-04	2.36E-02	2.86E-02	2.31E-02	21.19 %	2.12 %
3	Negligence in Watch Keeping (NWK)	1.84E-03	2.36E-02	5.58E-02	2.04E-02	136.44 %	13.56 %
4	Wrong Assessment of Situation (WAS)	1.09E-03	2.36E-02	4.11E-02	2.27E-02	74.15 %	3.81 %
5	Improper Look Out (ILO)	1.10E-03	2.36E-02	2.37E-02	2.36E-02	0.42 %	0.00 %
6	Improper Steering Operation (ISO)	1.06E-03	2.36E-02	2.36E-02	2.36E-02	0.00 %	0.00 %
7	Violation of Procedure or Rule (VPR)	2.12E-03	2.36E-02	4.23E-02	2.18E-02	79.24 %	7.63 %
8	Maneuver in Close Company (MCC)	6.66E-04	2.36E-02	2.95E-02	2.30E-02	25.00 %	2.54 %
9	Maneuver Error of Watch Keeping Officer (MEWO)	6.88E-04	2.36E-02	2.97E-02	2.30E-02	25.85 %	2.54 %
10	Faulty Maneuver of Master (FMM)	2.57E-03	2.36E-02	4.63E-02	2.14E-02	96.19 %	9.32 %
11	Poor Maneuvering Ability of Vessel (PMAV)	4.37E-04	2.36E-02	2.75E-02	2.32E-02	16.53 %	1.69 %
12	Improper/ Uncoordinated Avoiding Operation (IUAO)	1.86E-03	2.36E-02	4.00E-02	2.20E-02	69.49 %	6.78 %
13	Lack of Communication between Vessels (LCBV)	6.96E-04	2.36E-02	2.97E-02	2.30E-02	25.85 %	2.54 %
14	Insufficient Communication Equipment (ICE)	1.41E-04	2.36E-02	2.49E-02	2.35E-02	5.51 %	0.42 %
15	Communication Equipment Failure (CEF)	1.41E-04	2.36E-02	2.49E-02	2.35E-02	5.51 %	0.42 %
16	Lack in Use of Communication Equipment (LUCE)	9.89E-05	2.36E-02	2.45E-02	2.35E-02	3.81 %	0.42 %
17	Insufficient Knowledge on Navigational Equipment (IKNE)	2.40E-04	2.36E-02	2.57E-02	2.34E-02	8.90 %	0.85 %
18	Lack of Experience/Training/Qualificat ion/ Competency (LETQC)	1.99E-03	2.36E-02	4.12E-02	2.19E-02	74.58 %	7.20 %
19	Interpretation Failure (IF)	7.07E-04	2.36E-02	2.98E-02	2.30E-02	26.27 %	2.54 %
20	Fatigue/ Sleeplessness (FS)	7.80E-04	2.36E-02	3.05E-02	2.29E-02	29.24 %	2.97 %
21	Alcohol Abuse (AA)	3.42E-04	2.36E-02	2.66E-02	2.33E-02	12.71 %	1.27 %
22	Lack of Knowledge on Collision Avoiding Situation (LKCAS)	1.15E-03	2.36E-02	3.37E-02	2.26E-02	42.80 %	4.24 %

Sr	Primary Events Causing	Nominal	Nominal	Probability	Probability	Probability	Probability
	Collision Accidents	Probability	Probability	Value of	Value of	Value of	Value of
		Value of	Value of	Collision	Collision at	Collision	Collision
		Basic	Collision	at (10X)	(10X)	Increased	Decreased
		Event (X)		Increase	Decrease (-)	(%)	(%)
				(+) of	of Basic		
				Basic	Event's		
				Event's	Probability		
				Probability	Value		
				Value			
23	Poor Visibility (PV)	1.02E-03	2.36E-02	2.36E-02	2.36E-02	0.00 %	0.00 %
24	Deviated from Safe Course/ Channel (DFSCC)	1.09E-03	2.36E-02	2.36E-02	2.36E-02	0.00 %	0.00 %
25	Over Speed (OS)	9.01E-04	2.36E-02	3.16E-02	2.28E-02	33.90 %	3.39 %
26	Cyclone/Strong Wind (CSW)	9.36E-04	2.36E-02	3.19E-02	2.28E-02	35.17 %	3.39 %
27	Strong Current/Wave (SCW)	3.08E-04	2.36E-02	2.63E-02	2.34E-02	11.44 %	0.85 %
28	Main Engine Failure (MEF)	1.14E-04	2.36E-02	2.46E-02	2.35E-02	4.24 %	0.42 %
29	Steering Failure (SF)	3.04E-04	2.36E-02	2.63E-02	2.34E-02	11.44 %	0.85 %
30	Auxiliary Machinery Failure (AMF)	9.89E-05	2.36E-02	2.45E-02	2.35E-02	3.81 %	0.42 %
31	Non Standardized of Equipment (NSE)	1.90E-04	2.36E-02	2.53E-02	2.35E-02	7.20 %	0.42 %
32	Improper Design and Drawing (IDD)	3.27E-04	2.36E-02	2.65E-02	2.33E-02	12.29 %	1.27 %
33	Poor Stability Condition of Vessel (PSC)	4.45E-04	2.36E-02	2.75E-02	2.32E-02	16.53 %	1.69 %

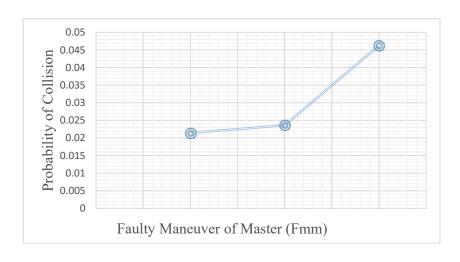
Table 6.10: Variation of grounding accident probability if primary events probability values are increased and decreased by 10 times

Sr	Primary/Basic Events Causing	Nominal	Nominal	Probability	Probability	Probability	Probability
	Grounding Accidents	Probability	Probability	Value of	Value of	Value of	Value of
		Value of	Value of	Grounding	Grounding	Grounding	Grounding
		Basic	Grounding	at (10X)	at (10X)	Increased	Decreased
		Event (X)		Increase	Decrease (-)	(%)	(%)
				(+) of	of Basic		
				Basic	Event's		
				Event's	Probability		
				Probability	Value		
				Value			
1	Selection of Inappropriate	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
1	Anchorage (SIA)	2.72L-04	1.03L-02	1.00L-02	1.00L-02	13.34 /0	1.04 /0
2	In-sufficient/Improper Marking	1.32E-03	1.63E-02	2.80E-02	1.51E-02	71.78 %	7.36 %
	of Navigable Channel (IIMNC)	1.32L-03	1.03L-02	2.00L-02	1.51E-02	71.70 70	7.30 70
3	Update Charts/Publication not	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
	used onboard (UCPNU)	1.102 01	1.03E 02	1.731 02	1.01E 02	7.50 70	1.23 70
4	Charts/ Publication are not	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
	updated by Authority (CPNU)	1.102 01	1.03E 02	1.73E 02	1.01E 02	7.50 70	1.23 70
5	Waterways are not Maintained	1.02E-03	1.63E-02	2.53E-02	1.53E-02	55.21 %	6.13 %
	by Authority (WWNM)						
6	Position Estimation Error (PEE)	4.39E-04	1.63E-02	2.01E-02	1.59E-02	23.31 %	2.45 %
7	Sensor/ Navigation Equipment	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
	Error (SNEE)	2.72104	1.0312-02	1.001-02	1.00L-02	13.37 /0	1.04 /0
8	Delayed in Action in Coming	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
G	back to Safe Track (DACST)	2.9215-04	1.03E-02	1.00E-02	1.00E-02	13.34 /0	1.04 /0

Sr	Primary/Basic Events Causing Grounding Accidents	Nominal Probability Value of Basic Event (X)	Nominal Probability Value of Grounding	Probability Value of Grounding at (10X) Increase (+) of Basic Event's Probability Value	Probability Value of Grounding at (10X) Decrease (-) of Basic Event's Probability Value	Probability Value of Grounding Increased (%)	Probability Value of Grounding Decreased (%)
9	Improper Steering/Course Keeping Failure by Quarter Master (ISCCFQM)	1.61E-03	1.63E-02	3.05E-02	1.48E-02	87.12 %	9.20 %
10	Maneuver Error of Watch Keeping Officer (MEWO)	1.61E-03	1.63E-02	3.05E-02	1.48E-02	87.12 %	9.20 %
11	Faulty Maneuver of Master (FMM)	3.80E-03	1.63E-02	1.63E-02	1.63E-02	0.00 %	0.00 %
12	Poor Maneuvering Ability of Vessel (PMAV)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
13	Uncoordinated/Improper Avoiding Operation (UIAO)	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
14	Assistance is not Requested (ANR)	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
15	Assistance not Arrived (ANA)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
16	Inability to Provide Assistance (Delayed arrival/ inability of pilot/ unsuitable pilot ship (IPA)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
17	Insufficient Knowledge on Navigational Equipment (IKNE)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
18	Lack of Experience/Training/Qualificati on/ Competency of Officer, Master, Crew (LETQC)	2.05E-03	1.63E-02	3.44E-02	1.44E-02	111.04 %	11.66 %
19	Interpretation Failure (IF)	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
20	Fatigue/Sleeplessness (FS)	5.85E-04	1.63E-02	2.14E-02	1.57E-02	31.29 %	3.68 %
21	Alcohol Abuse (AA)	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
22	Lack of Knowledge on Avoiding Grounding Situation (LKAGS)	1.32E-03	1.63E-02	2.80E-02	1.51E-02	71.78 %	7.36 %
23	Negligence in Watch Keeping (NWK)	5.85E-04	1.63E-02	2.14E-02	1.57E-02	31.29 %	3.68 %
24	Improper/Insufficient Use of Bridge Navigational/Sounding Equipment (IIUBNSE)	8.77E-04	1.63E-02	1.63E-02	1.63E-02	0.00 %	0.00 %
25	Improper Look Out (ILO)	1.46E-03	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
26	Deviated from Safe Course/Channel (DFSCC)	4.39E-04	1.63E-02	2.01E-02	1.59E-02	23.31 %	2.45 %
27	Improper/Insufficient Use of Depth Gauge/Sounding Equipment (IIUSE)	1.02E-03	1.63E-02	2.53E-02	1.53E-02	55.21 %	6.13 %
28	Violation of Regulation (VOR)	7.31E-04	1.63E-02	2.27E-02	1.56E-02	39.26 %	4.29 %
29	Poor Visibility (PV)	5.85E-04	1.63E-02	2.14E-02	1.57E-02	31.29 %	3.68 %
30	Cyclone/Strong Wind (CSW)	7.31E-04	1.63E-02	2.27E-02	1.56E-02	39.26 %	4.29 %
31	Strong Current/Wave (SCW)	4.39E-04	1.63E-02	2.01E-02	1.59E-02	23.31 %	2.45 %
32	Anchor Failure (AF)	5.85E-04	1.63E-02	2.14E-02	1.57E-02	31.29 %	3.68 %
33	Main Engine Failure (MEF)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %

Sr	Primary/Basic Events Causing	Nominal	Nominal	Probability	Probability	Probability	Probability
	Grounding Accidents	Probability	Probability	Value of	Value of	Value of	Value of
		Value of	Value of	Grounding	Grounding	Grounding	Grounding
		Basic	Grounding	at (10X)	at (10X)	Increased	Decreased
		Event (X)		Increase	Decrease (-)	(%)	(%)
				(+) of	of Basic		
				Basic	Event's		
				Event's	Probability		
				Probability Value	Value		
				value			
34	Steering Failure (SF)	5.85E-04	1.63E-02	2.14E-02	1.57E-02	31.29 %	3.68 %
35	Auxiliary Machinery Failure (AMF)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
36	Non Standardized of Equipment (NSE)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
37	Improper Design and Drawing (IDD)	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %
38	Poor Stability Condition of Vessel (PSC)	1.46E-04	1.63E-02	1.75E-02	1.61E-02	7.36 %	1.23 %
39	Interpretation Failure of Watch Keeping Officer/Master (IFWM)	4.39E-04	1.63E-02	2.01E-02	1.59E-02	23.31 %	2.45 %
40	Interpretation Failure of Bridge Navigation Equipment (Radar, GPS, Ecosounder, etc) (IFBNE)	2.92E-04	1.63E-02	1.88E-02	1.60E-02	15.34 %	1.84 %

Changes of probability for collision and grounding with the changes of basic events probability is also shown in Figure 6.3 and 6.4 respectively. It is observed that higher ranking events have significant influence/effect on occurring the top event i.e. with the increases or decreases of their probability values, the probability value of top event changes significantly. Whereas lower ranking event has less influence on top event with their changes of probability value. Among those faulty maneuver of master, violation of procedure or lack of rule. experience/training/qualification/competency of officer. master, crew. improper/ uncoordinated avoiding operation, negligence in watch keeping having significant influence/effect and auxiliary machinery failure, main engine failure, insufficient communication equipment, non-standardized of equipment having less influence on occurring collision accident. Again, lack of experience/training/qualification/competency of officer, master, crew, improper steering/course keeping failure by quarter master, insufficient/improper marking of navigable channel, lack of knowledge on avoiding grounding situation, waterways are not maintained by authority having significant influence/effect and main engine failure, poor stability condition of vessel, insufficient knowledge on navigational equipment (IKNE) update charts/publication not used onboard having less influence on occurring grounding accident. Thus, emphasis may be given to control the higher influencing primary events/causes to reduce the probability of occurring collision and grounding accident significantly.



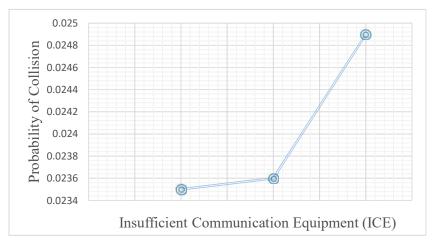
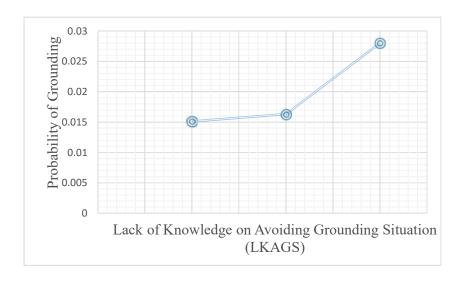


Figure 6.3: Changes of collision probability with the changes of basic events probability



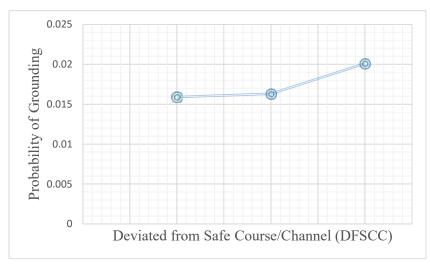


Figure 6.4: Changes of grounding probability with the changes of basic events probability

6.5 Use of FTA Software and Validity of Results

In this study, to validate the result calculated manually and carry out FTA modelling, the Open FTA programme has been used. The Open FTA program which is a fault tree analysis (FTA) programme, has been used for making risk analysis in marine accidents occurring in inland waterways of Bangladesh. This is a top-level programme developed for FTA. This programme enables to form, modify, and analyse fault trees. The Open FTA programme has been designed for international recognition in the fields of marine, aviation, space, medical materials, nuclear materials, and defense. Open FTA is the open source product name for Formal-FTA, a product developed by Auvation (http://www.openfta.com) [17].

The manually calculated result was validated through Open FTA programme as well as Excel programme. FTA models for collision and grounding was drawn and necessary data input of basic events was given in the programme. Then programme was run and details analysis was carried out. Finally, similar results were found as analysed manually. The fault tree model for collision and grounding as constructed using FTA programme and result obtained is appended at Figure 6.5 & 6.6 and Table 6.11, 6.12 & 6.13, 6.14 respectively.

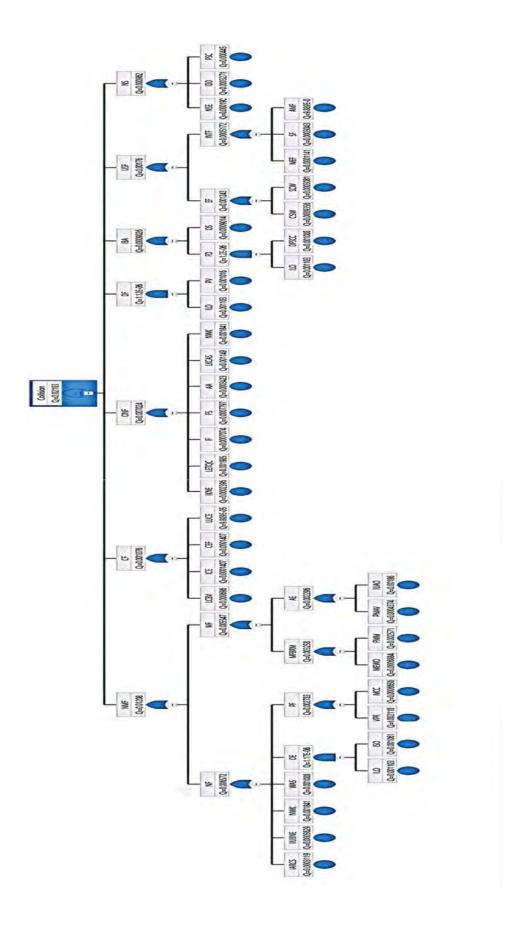


Figure 6.5: Fault tree obtained from software analysis for collision accidents

Table 6.11: Probability values of basic events obtained from software analysis for collision model

Event Des	Unavailability	Marginal Imp	Critical Imp	Risk Ach	Risk Reduct	Diagnostic Im
FMM	0.00257111	0.980696	0.115531	45.8187	1.13062	0.117805
VPR	0.0021185	0.980251	0.0951499	45.8187	1.10516	0.0970668
LETQC	0.00198538	0.980121	0.0891591	45.8187	1.09789	0.0909675
IUAO	0.00185987	0.979998	0.0835121	45.8187	1.09112	0.0852166
NWK	0.00184085	0.979979	0.0826566	45.8187	1.0901	0.0843453
LKCAS	0.00114863	0.9793	0.0515393	45.8187	1.05434	0.0526287
WAS	0.00108778	0,97924	0.0488057	45.8187	1.05131	0.0498404
CSW	0.000935639	0.979091	0.0419734	45.8187	1.04381	0.0428697
os	0.000901408	0.979057	0.0404364	45.8187	1.04214	0.0413013
FS	0.000779699	0.978938	0.0349723	45.8187	1.03624	0.0357248
(E	0.000707434	0.978867	0.0317287	45.8187	1.03277	0.0324137
LCBV	0.000696024	0.978856	0.0312166	45.8187	1.03222	0.0318909
MEWO	0.000688417	0.978849	0.0308752	45.8187	1.03186	0.0315424
MCC	0.000665597	0.978826	0.029851	45.8187	1.03077	0.0304968
IIUBNE	0.000562905	0.978726	0.0252429	45.8187	1.0259	0.0257916
PSC'	0.000444999	0.97861	0.0199531	45.8187	1.02036	0.0203893
PMAV	0.000437392	0.978603	0.0196119	45.8187	1.02	0.0200407
AA	0.000342307	0.97851	0.015347	45.8187	1.01559	0.0156841
(DD)	0.000327093	0,978495	0.0146647	45.8187	1.01488	0.014987
IARCS	0.00031188	0.97848	0.0139824	45.8187	1.01418	0.0142899
SCW	0.000308076	0.978476	0.0138118	45.8187	1.01401	0.0141156
SF	0.000304273	0,978473	0.0136413	45.8187	1.01383	0.0139414
SCW	0.000308076	0.978476	0.0138118	45.8187	1.01401	0.0141156
SF	0.000304273	0.978473	0.0136413	45.8187	1.01383	0.0139414
IKNE	0.000239615	0.978409	0.0107418	45.8187	1.01086	0.0109788
NSE	0.00019017	0.978361	0.00852479	45.8187	1.0086	0.00871334
ICE	0.000140726	0.978313	0.00630804	45.8187	1.00635	0.00644788
CEF	0.000140726	0.978313	0.00630804	45.8187	1.00635	0.00644788
MEF	0.000114102	0.978286	0.00511448	45.8187	1.00514	0.005228
LUCE	9.88886E-05	0.978272	0.00443249	45.8187	1.00445	0.00453094
AMF	9.88886E-05	0.978272	0.00443249	45.8187	1.00445	0.00453094
ILO	0.00110299	0.00309212	0.000156268	1.14152	1.00016	0.00125908
DESCC	0.00108778	0.00107668	5.36622E-05	1.04928	1.00005	0.00114138
ISO	0.00106115	0.00107665	5.23474E-05	1.04928	1.00005	0.00111344
PV	0.00101551	0.0010766	5.00936E-05	1.04928	1.00005	0.00106555

Table 6.12: Minimum cut sets' obtained from software analysis for collision

	Minimal Cut Se	Order	Unavailability	Contribution 9	
†	FMM	1	0.00257111	0.116594	
2	VPR.	1	0.0021185	0.096069	
3	LETQC	1	0.00198538	0.0900323	
4	IUAO	1	0.00185987	0.0843406	
5	NWK	Ť	0.00184085	0.0834782	
6	LKCAS	1	0.00114863	0.0520877	
7	WAS	1	0,00108778	0.049328	
8	CSW	1	0,000935639	0.042429	
9	os	1	0.000901408	0.0408767	
10	FS	7	0,000779699	0.0353575	
11	IF	1	0.000707434	0.0320805	
12	LCBV	1	0,000696024	0.0315631	
13	MEWO	1	0.000688417	0.0312181	
14	MCC	1	0.000665597	0.0301833	
15	IIUBNE	1	0,000562905	0.0255264	
16	PSC	1	0.000444999	0.0201797	
17	PMAV	1	0.000437392	0.0198347	
18	AA	7	0,000342307	0.0155228	
19	IDD	1	0.000327093	0.0148329	
20	IARCS	1	0.00031188	0.014143	
21	SCW	1	0.000308076	0.0139705	
22	SF	1	0.000304273	0.0137981	
23	IKNE	1	0.000239615	0.010866	
24	NSE	1	0,00019017	0.00862376	
25	ICE	1	0.000140726	0.00638159	
26	CEF	1	0.000140726	0.00638159	
27	MEF	1	0.000114102	0.00517426	
28	LUCE	1	9.88886E-05	0.00448437	
29	AMF	1	9.88886E-05	0.00448437	
30	DFSCC.ILO	2	1,1998E-06	5.44083E-05	
31	ILO.ISO	2	1.17044E-06	5.30766E-05	
32	ILO,PV	2	1.1201E-06	5.07937E-05	

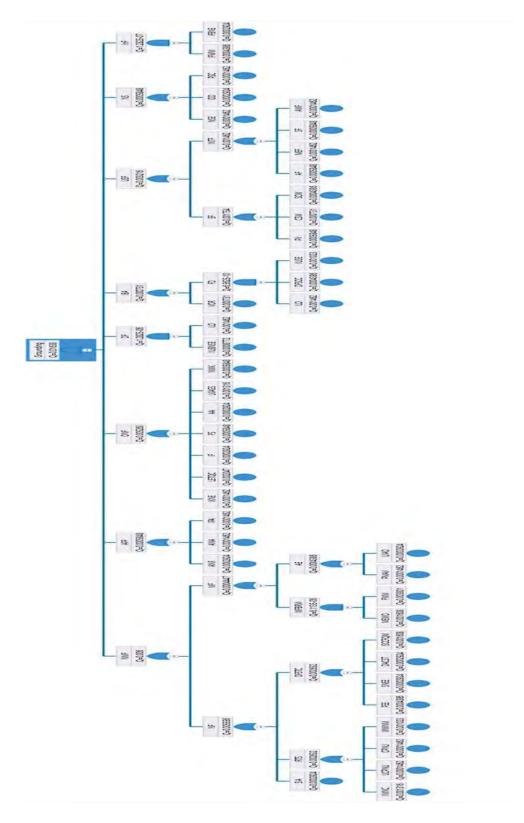


Figure 6.6: Fault tree obtained from software analysis for grounding accidents

Table 6.13: Probability values of basic events obtained from software analysis for grounding

Event	Unavailability	Marginal Im	Critical Imp	Diagnostic Im	Risk Achieve	Risk Reduct
LETQC	0.00204678	4	0.124943	0.126734	61.9184	1.14278
ISCCFQM	0.00160819	1	0.0981692	0.0996195	61.9452	1.10886
IIMNC	0.00131579	1	0.0803202	0.0815303	61,9631	1.08733
LKAGS	0.00131579	1	0.0803202	0.0815303	61.9631	1.08733
WWNM	0.00102339	1	0.0624713	0.0634308	61.9809	1.06663
VOR	0.000730994	1	0.0446223	0.0453207	61.9988	1.04671
CSW	0.000730994	1	0.0446223	0.0453207	61.9988	1.04671
FS	0.000584795	1	0.0356979	0.0362618	62.0077	1.03702
NWK	0.000584795	4	0.0356979	0.0362618	62.0077	1.03702
PV	0.000584795	1	0.0356979	0.0362618	62.0077	1.03702
ΑF	0.000584795	1	0.0356979	0.0362618	62,0077	1.03702
SF	0.000584795	1	0.0356979	0.0362618	62.0077	1.03702
PEE	0.000438596	1	0.0267734	0.0272002	62.0166	1.02751
SCW	0.000438596	1	0.0267734	0.0272002	62.0156	1.02751
SIA	0.000292398	1	0.017849	0.0181361	62,0255	1.01817
SNEE	0.000292398	1	0.017849	0.0181361	62.0255	1.01817
DACST	0.000292398	ो.	0.017849	0.0181361	62.0255	1.01817
UIAO	0.000292398	1	0.017849	0.0181361	62.0255	1.01817
ANR	0.000292398	1	0.017849	0.0181361	62.0255	1.01817
IF	0.000292398	1	0.017849	0.0181361	62.0255	1,01817
АΑ	0.000292398	1	0.017849	0.0181361	62.0255	1.01817
IDD	0.000292398	1	0.017849	0.0181361	62.0255	1.01817
UCPNU	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
CPNU	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
PMAV	0.000146199	4	0.00892448	0.00906937	62.0344	1.009
ANA	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
IPA	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
IKNE	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
MEF	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
AMF	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
NSE	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
PSC	0.000146199	1	0.00892448	0.00906937	62.0344	1.009
FMM	0.00380117	0.00160819	0.000373158	0.00417291	1.0978	1.00037
MEWO	0.00160819	0.00380117	0.000373158	0.00198074	1.23166	1.00037
ILO	0.00146199	0.000877642	7.83249E-05	0.0015402	1.0535	1.00008
IIUSE	0.00102339	6.41222E-07	4.0058E-08	0.00102343	1.00004	T
IIUBNSE	0.000877193	0.00146199	7.82848E-05	0.000955409	1.08917	1.00008
IFWM	0,000438596	0.000292398	7.82848E-06	0.000446421	1.01784	1.00001
DFSCC	0.000438596	1.49619E-06	4.0058E-08	0.000438636	1.00009	1
IFBNE	0.000292398	0.000438596	7.82848E-06	0.000300224	1.02677	1.00001

Table 6.14: Minimal cut sets' result for grounding

	Minis	nal Cut Set	Order	Unavailabilit	Contribution
1	LETQ	C	Ť	0.00204678	0.124943
2	ISCCF	QM	1	0.00160819	0.0981692
3	IBMN	5	Ť	0.00131579	0.0803202
4	LKAG	S	1	0.00131579	0.0803202
5	WWN	IM	1	0.00102339	0.0624713
5	VOR		1	0.000730994	0.0446223
7	CSW		1	0.000730994	0.0446223
8	FS		1	0.000584795	0.0356979
9	NWK		1	0.000584795	0.0356979
10	PV		1	0.000584795	0.0356979
11	AF		1	0.000584795	0.0356979
12	SF		1	0.000584795	0.0356979
13	PEE		1	0.000438596	0.0267734
14	SCW		1	0.000438596	0.0267734
15	SIA		Ť	0.000292398	0.017849
16	SNEE		1	0.000292398	0.017849
17	DACS	T	1	0.000292398	0.017849
18	UIAO		1	0.000292398	0.017849
19	ANR		1	0.000292398	0.017849
20	JF.		1	0.000292398	0.017849
21	AA		1	0.000292398	0.017849
22	IDD		1	0.000292398	0.017849
23	UCPN	10	1	0.000146199	0.00892448
24	CPNU	I)	Ť.	0.000146199	0.00892448
25	PMA	/	1	0.000146199	0.00892448
26	ANA		1	0.000146199	0.00892448
27	IPA		1	0.000146199	0.00892448
28	IKNE		1	0.000146199	0.00892448
29	MEF		Ť	0.000146199	0.00892448
30	AMF		1	0.000146199	0.00892448
31	NSE		3	0.000146199	0.00892448
32	PSC		1	0.000146199	0.00892448
33	FMM.	MEWO	2	6.11299E-06	0.000373158
34	HUBN	SE.ILO	2	1.28245E-06	7.82848E-05
35	IFBNE	IFWM	2	1.28245E-07	7.82848E-06
36	DFSC	C,IIUSE,ILO	3.	6.56222E-10	4.0058E-08
Summa	ary l				
		Count			
223-0324		EXAMPLE.			
1		32			
2 3		1			

Total: 36

6.6 Opinion of Experts

Experts' opinion was taken on possible causes of collision and grounding accidents in inland waterways of Bangladesh and influences or vulnerability of causes on occurring accidents. Opinions were seeked through interview to operators, crews, pilots, surveyors, inspectors, administrators, owners and other knowledgeable persons related in marine sectors. Ways/means of accident recording/reporting was also discussed with experts to standardized the accident recording system of Bangladesh. Their valuable opinion and suggestions were considered and included in the analysis process.

6.7 Results and Discussion

The accident data has been analysed in details through fault tree analysis method and using Excel programme. The result of FTA model is also validated through, Open FTA software. The outcome comes in many dimensions which are discussed below:

The minimum combinations necessary for accident occurrence are called minimum cut set in the FTA. A quantitative analysis has been carried out for purpose of determining minimal cut sets which cause collision and grounding accidents. According to the analysis results, 32 minimum cut sets causing occurrence of collision accidents and 36 minimal cut sets causing occurrence of grounding accidents have been found. Minimal cut sets where collision accidents are at maximum level is the, Faulty Maneuver of Master (FMM) or Violation of Procedure or Rule (VPR) as shown in Table 6.4 and 6.12.

Minimal cut sets where grounding accidents are at maximum level are the, Lack of Experience/Training/Qualification/Competency (LETQC)" or the "In-sufficient/Improper Marking of Navigable Channel (IIMNC)) as shown in Table 6.8 and 6.14.

When accidents occurrence are examined, it has been seen that 73% of the collision accidents and 55% of the grounding accidents have occurred as a result of human-error-originated basic factors.

Another important result obtained from FTA is the significance degree of the initial events which cause accidents. For this purpose, an initial event analysis has been carried out. According to the analysis results, the first five basic reasons with the biggest share in the occurrence of collision accidents are respectively, faulty maneuver of master (FMM): 11%, violation of procedure or rule (VPR): 9%, lack of experience/training/qualification /competency of officer, master, crew (LETQC): 9%, improper/uncoordinated avoiding operation (IUAO): 8% and negligence in watch keeping (NWK): 8% (Figure: 6.7).

The initial events with the biggest share in the occurrence of grounding accidents are respectively: lack of experience/training/qualification/competency of officer, master, crew (LETQC):13%, improper steering/course keeping failure by quarter master (ISCCFQM):10%, in-sufficient/improper marking of navigable channel (IIMNC): 9%, lack of knowledge on avoiding grounding situation (LKAGS): 9% and waterways are not maintained by authority (WWNM): 7%. It has been observed that in grounding accidents, bad weather conditions as well as human error also have an influence on accident occurrence (Figure: 6.8).

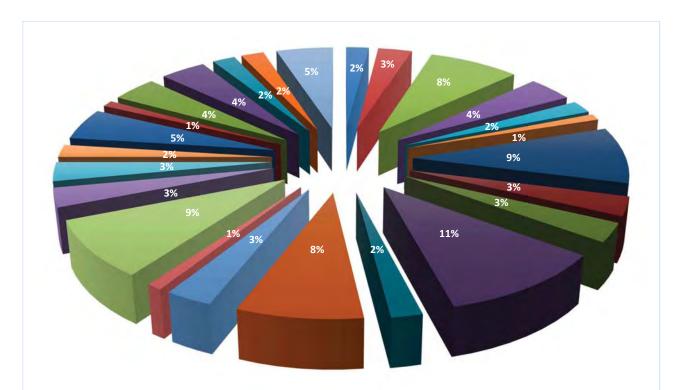


Figure 6.7: Result of analysis of initial events for collision

- Inappropriate Route/Course Selection (IARCS) : 2%
- Improper / Insufficient Use of Bridge Navigational Equipment (IIUBNE) :3%
- Negligence in Watch Keeping (NWK) :8%
- Wrong Assessment of Situation (WAS) : 4%
- Improper Look Out (ILO) : 2%
- Improper Steering Operation (ISO) :1%
- Violation of Procedure or Rule (VPR) :9%
- Maneuver in Close Company (MCC) : 3%
- Maneuver Error of Watch Keeping Officer (MEWO) :3%
- Faulty Maneuver of Master (FMM) : 11%
- Poor Maneuvering Ability of Vessel (PMAV) : 2%
- Improper/ Uncoordinated Avoiding Operation (IUAO) :8%
- Lack of Communication between Vessels (LCBV) : 3%
- Insufficient Knowledge on Navigational Equipment (IKNE : 1%
- Lack of Experience/Training/Qualification/Competency (LETQC) : 9%
- Interpretation Failure (IF) : 3%
- Fatigue/ Sleeplessness (FS) : 3%
- Alcohol Abuse (AA) : 2%
- Lack of Knowledge on Collision Avoiding Situation (LKCAS) :5%
- Poor Visibility (PV) : 1%
- Over Speed (OS) : 4%
- Cyclone/Strong Wind(CSW) : 4%
- Steering Failure(SF) : 2%
- Poor Stability Condition of Vessel(PSC) : 2%
- Others:5%

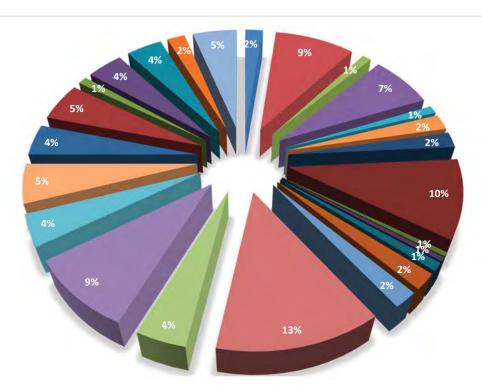


Figure 6.8: Result of analysis of initial events for grounding accidents

- Selection of Inappropriate Anchorage (SIA) :2%
- In-sufficient/Improper Marking of Navigable Channel (IIMNC):9%
- Update Charts/Publication not used onboard (UCPNU) :1%
- Waterways are not Maintained by Authority (WWNM) :7%
- Position Estimation Error (PEE) : 1%
- Sensor/ Navigation Equipment Error (SNEE) : 2%
- Delayed in Action in Coming back to Safe Track (DACST) :3%
- Improper Steering/Course Keeping Failure by Quarter Master (ISCCFQM) :10%
- Maneuver Error of Watch Keeping Officer (MEWO) : 1%
- Faulty Maneuver of Master (FMM) : 1%
- Poor Maneuvering Ability of Vessel (PMAV) : 1%
- Uncoordinated/Improper Avoiding Operation (UIAO) : 2%
- Assistance is not Requested (ANR) : 2%
- Lack of Experience/Training/Qualification/Competency of Officer, Master, Crew (LETQC)
- Fatigue/Sleeplessness (FS) : 4%

- : 13%
- Lack of Knowledge on Avoiding Grounding Situation (LKAGS) :9%
- Negligence in Watch Keeping (NWK) : 4%
- Violation of Regulation (VOR) :5%
- Poor Visibility (PV) : 4%
- Cyclone/Strong Wind (CSW) :5%
- Strong Current/Wave (SCW) : 1%
- Anchor Failure (AF) : 4%
- Steering Failure (SF) : 4%
- Improper Design and Drawing (IDD) : 2%
- Others : **5**%

Change of the human-error originated basic events has a significant impact on the occurrence of collision and grounding accidents. Two main factors in the occurrence of collision accidents are faulty maneuver of master (FMM) and violation of procedure or rule (VPR).

Both of such initial events arise from human error. It has been observed that when the possibility value of an initial event arising from faulty maneuver of master (FMM) is reduced to minimum level (-10x), the possibility value of collision accidents decreases by 9%, and when it is raised to the maximum level (+10x), the possibility value of collision accident increase by 96% (Table 7.9). This manifests the importance of faulty maneuver of master (FMM) in the occurrence of collision accidents.

Two main factors which cause the occurrence of grounding accidents originate from human error. First of them is the lack of experience/training/qualification/competency of officer, master, crew (LETQC). It has been observed that when the possibility value of an initial event arising from experience/training/qualification/competency of officer, master, crew (LETQC) is reduced to the minimum level(-10x), the possibility value of grounding accidents decreases by 11%, and when it is raised to the maximum level(+10x), the possibility value of grounding accidents increased by 111% (Table 6.10).

For collision accidents, if faulty maneuver of master (FMM), violation of procedure or rule (VPR), lack of experience/training/qualification/competency of officer, master, crew (LETQC), improper/uncoordinated avoiding operation (IUAO) and negligence in watch keeping (NWK) could be improved and probability values of those reduced to the minimum level, accident occurrences would be reduced to a high extent.

For grounding accidents, if lack of experience/training/qualification/competency of officer, master, crew (LETQC), improper steering/course keeping failure by quarter master (ISCCFQM), in-sufficient/improper marking of navigable channel (IIMNC), lack of knowledge on avoiding grounding situation (LKAGS) and waterways are not maintained by authority (WWNM), could be taken care and probability values of those reduced to the minimum level, accident occurrences would be reduced to a high extent.

It is worthwhile to mention here that the Deck Personnel Training Centre at Narayanganj is the appropriate institution to train manpower for marine area. Attention should be paid to further develop this institution and establishing more such institutes giving national importance [41].

According to accident analysis results, bad weather conditions, improper design and drawing, poor stability condition of vessel, non-standardized equipments, insufficient navigational & communication equipments, etc. also have an impact on the occurrence of accidents; however, the dominant factor in the occurrence of accidents is human-error-originated initial events which needs to be taken care.

Comparison of Results with Reference Data/Value

The calculated probability values of primary/basic events causing collision and grounding accidents in inland waterways of Bangladesh (between 1981 to 2018) and the overall probability value of collision and grounding was compared with reference data/value. This research compared the result with the result obtained by Ugurlu, et. al [17] for all the oil tankers accident (collision & grounding) occurred throughout the world between 1998 to 2010 and the collision & grounding accidents occurred in the Port of Haydarpaşa Zone, Istambul, Turkey was studied by Talay, et. al [14] during the period of 1991 to 2010. The compared values for collision and grounding are shown at Table 6.15 and 6.16 respectively.

The collision and grounding data registered in GISIS (Global Integrated Shipping Information System) were investigated for oil tankers by Ugurlu, et. al. [17]. The database includes the information of the collision and grounding accidents during the period between 1998 and 2010 in oil tankers. The risk assessments were carried out using fault tree analysis (FTA) programme for the incidents as collision and grounding occurred in oil tankers.

Again, collision and grounding accidents in the Port of Haydarpaşa Zone, Istanbul, Turkey was studied by Talay, et. al [14]. This study is conducted on a root analysis of accidents based on historical incidents and a questionnaire survey to find out the risky conditions for navigational safety in Port of Haydarpaşa Zone. The analysis techniques as preliminary hazard analysis (PHA) and Fault Tree Analysis (FTA) are used for the evaluation of the accidents occurred during the period of 1991 to 2010 in the research area.

Table 6.15: Comparison of probability values with reference data/value for Collision accident

Sr	Primary/Basic Events Causing Collision Accidents	Probability Values for Accidents in Inland waterways of Bangladesh (1981-2018)	Reference Probability Values (Primary Events)	Collision Probability in Inland waterways of Bangladesh (1981-2018)	Reference Collision Probability Value	Remarks
1	Inappropriate Route/Course Selection (IARCS)	3.12E-04	1.62E-04			
2	Improper / Insufficient Use of Bridge Navigational Equipment (IIUBNE)	5.63E-04	6.09E-04			
3	Negligence in Watch Keeping (NWK)	1.84E-03	2.26E-01			
4	Wrong Assessment of Situation (WAS)	1.09E-03	1.33E-03			In compariso
5	Improper Look Out (ILO)	1.10E-03	6.9E-02			n, probability
6	Improper Steering Operation (ISO)	1.06E-03	5.02E-04			value of primary/
7	Violation of Procedure or Rule (VPR)	2.12E-03	4.88E-05	2.36E-02	2.60E-02	basic events and top event
8	Maneuver in Close Company (MCC)	6.66E-04	5.02E-04			i.e. Collision
9	Maneuver Error of Watch Keeping Officer (MEWO)	6.88E-04	2.34E-04			was found similar with
10	Faulty Maneuver of Master (FMM)	2.57E-03	5.02E-04			reference data
11	Poor Maneuvering Ability of Vessel (PMAV)	4.37E-04	-			
12	Improper/ Uncoordinated Avoiding Operation (IUAO)	1.86E-03	2.17E-04			
13	Lack of Communication between Vessels (LCBV)	6.96E-04	1.03E-03			

Sr	Primary/Basic	Probability	Reference	Collision	Reference	Remarks
	Events Causing Collision Accidents	Values for Accidents in	Probability Values	Probability in Inland	Collision Probability	
	Comsion Accidents	Inland	(Primary	waterways	Value	
		waterways of	Events)	of	varae	
		Bangladesh	_:::::)	Bangladesh		
		(1981-2018)		(1981-2018)		
14	Insufficient	1.41E-04	6.09E-04	,		
	Communication					
	Equipment (ICE)					
15	Communication	1.41E-04	1.03E-03			
	Equipment Failure					
	(CEF)					
16	Lack in Use of	9.89E-05	7.32E-05			
	Communication					
17	Equipment (LUCE)	2.405.04	(OOF O4			
17	Insufficient	2.40E-04	6.09E-04			
	Knowledge on Navigational					
	Equipment (IKNE)					
18	Lack of	1.99E-03	1.33E-03			
10	Experience/Trainin	1.77L-03	1.33L-03			
	g/Qualification/					
	Competency					
	(LETQC)					
19	Interpretation	7.07E-04	1.33E-03			
	Failure (IF)					
20	Fatigue/	7.80E-04	2.07E-04			
	Sleeplessness (FS)					
21	Alcohol Abuse	3.42E-04	6.70E-05			
	(AA)					
22	Lack of Knowledge	1.15E-03	2.34E-04			
	on Collision					
	Avoiding Situation					
23	(LKCAS) Poor Visibility	1.02E.02	7.33E-04			
23	(PV)	1.02E-03	7.33E-04			
24	Deviated from Safe	1.09E-03	1.62E-04			
	Course/ Channel					
	(DFSCC)					
25	Over Speed (OS)	9.01E-04	3.2E-02			
26	Cyclone/Strong	9.36E-04	7.33E-04			
	Wind (CSW)					
27	Strong	3.08E-04	6.5E-02			
	Current/Wave					
	(SCW)					

Sr	Primary/Basic	Probability	Reference	Collision	Reference	Remarks
	Events Causing	Values for	Probability	Probability	Collision	
	Collision Accidents	Accidents in	Values	in Inland	Probability	
		Inland	(Primary	waterways	Value	
		waterways of	Events)	of		
		Bangladesh	ĺ	Bangladesh		
		(1981-2018)		(1981-2018)		
28	Main Engine	1.14E-04	6.71E-05			
	Failure (MEF)					
29	Steering Failure	3.04E-04	2.03E-04			
	(SF)					
30	Auxiliary	9.89E-05	6.71E-05			
	Machinery Failure					
	(AMF)					
31	Non Standardized	1.90E-04	-			
	of Equipment					
	(NSE)					
32	Improper Design	3.27E-04	-			
	and Drawing (IDD)					
33	Poor Stability	4.45E-04	-			
	Condition of					
	Vessel (PSC)					

Table 6.16: Comparison of probability values with reference data/value for Grounding accident

Sr	Primary/Basic Events Causing Grounding Accidents	Probability Values of Accidents in Inland waterways of Bangladesh (1981-2018)	Reference Probability Values (Primary Events)	Grounding Probability in Inland waterways of Bangladesh (1981-2018)	Reference Grounding Probability	Remarks
1	Selection of Inappropriate Anchorage (SIA)	2.92E-04	1.42E-04			
2	In- sufficient/Improper Marking of Navigable Channel (IIMNC)	1.32E-03	3.52E-04			
3	Update Charts/Publication not used onboard (UCPNU)	1.46E-04	4.48E-05			In comparison probability
4	Charts/ Publication are not updated by Authority (CPNU)	1.46E-04	3.52E-04			value of primary/basic events
5	Waterways are not Maintained by Authority (WWNM)	1.02E-03	4.33E-04	1.63E-02	2.60E-02	and top event i.e. Grounding was found
6	Position Estimation Error (PEE)	4.39E-04	1.37E-04			similar with reference
7	Sensor/ Navigation Equipment Error (SNEE)	2.92E-04	4.07E-05			data
8	Delayed in Action in Coming back to Safe Track (DACST)	2.92E-04	6.72E-05			
9	Improper Steering/Course Keeping Failure by Quarter Master (ISCCFQM)	1.61E-03	6.72E-05			
10	Maneuver Error of Watch Keeping Officer (MEWO)	1.61E-03	6.59E-04			
11	Faulty Maneuver of Master (FMM)	3.80E-03	6.72E-05			

Sr	Primary/Basic	Probability	Reference	Grounding	Reference	Remarks
	Events Causing	Values of	Probability	Probability	Grounding	
	Grounding	Accidents in	Values	in Inland	Probability	
	Accidents	Inland	(Primary	waterways		
		waterways of	Events)	of		
		Bangladesh	ĺ	Bangladesh		
		(1981-2018)		(1981-2018)		
12	Poor Maneuvering	1.46E-04	-			
	Ability of Vessel					
	(PMAV)					
13	Uncoordinated/Imp	2.92E-04	3.15E-05			
	roper Avoiding					
	Operation (UIAO)			_		
14	Assistance is not	2.92E-04	3.37E-04			
	Requested (ANR)					
15	Assistance not	1.46E-04	1.02E-04			
	Arrived (ANA)			_		
16	Inability to Provide	1.46E-04	1.49E-04			
	Assistance					
	(Delayed arrival/					
	inability of pilot/					
	unsuitable pilot					
1.7	ship (IPA)	1.465.04	1.275.04	_		
17	Insufficient	1.46E-04	1.37E-04			
	Knowledge on					
	Navigational (IVNE)					
18	Equipment (IKNE) Lack of	2.05E-03	2.08E-01	_		
18		2.03E-03	2.08E-01			
	Experience/Trainin g/Qualification/					
	Competency of					
	Officer, Master,					
	Crew (LETQC)					
19	Interpretation	2.92E-04	6.59E-04	1		
	Failure (IF)					
20	Fatigue/Sleeplessne	5.85E-04	1.90E-04	1		
	ss (FS)					
21	Alcohol Abuse	2.92E-04	6.70E-05	1		
	(AA)					
22	Lack of Knowledge	1.32E-03	6.59E-04	1		
	on Avoiding					
	Grounding					
	Situation (LKAGS)]		
23	Negligence in	5.85E-04	2.08E-01			
	Watch Keeping					
	(NWK)					

Sr	Primary/Basic Events Causing Grounding Accidents	Probability Values of Accidents in Inland waterways of Bangladesh (1981-2018)	Reference Probability Values (Primary Events)	Grounding Probability in Inland waterways of Bangladesh (1981- 2018)	Reference Grounding Probability	Remarks
24	Improper/Insufficie nt Use of Bridge Navigational/Soun ding Equipment (IIUBNSE)	8.77E-04	3.08E-04			
25	Improper Look Out (ILO)	1.46E-03	2.08E-01			
26	Deviated from Safe Course/Channel (DFSCC)	4.39E-04	1.04E-04			
27	Improper/Insufficie nt Use of Depth Gauge/Sounding Equipment (IIUSE)	1.02E-03	1.37E-04			
28	Violation of Regulation (VOR)	7.31E-04	1.07E-04			
29	Poor Visibility (PV)	5.85E-04	8.30E-02			
30	Cyclone/Strong Wind (CSW)	7.31E-04	4.07E-04			
31	Strong Current/Wave (SCW)	4.39E-04	4.07E-04			
32	Anchor Failure (AF)	5.85E-04	1.42E-04			
33	Main Engine Failure (MEF)	1.46E-04	5.09E-04			
34	Steering Failure (SF)	5.85E-04	2.04E-04			
35	Auxiliary Machinery Failure (AMF)	1.46E-04	5.09E-04			
36	Non Standardized of Equipment (NSE)	1.46E-04	5.09E-04			
37	Improper Design and Drawing (IDD)	2.92E-04	-			

Sr	Primary/Basic Events Causing Grounding Accidents	Probability Values of Accidents in Inland waterways of Bangladesh (1981-2018)	Reference Probability Values (Primary Events)	Grounding Probability in Inland waterways of Bangladesh (1981- 2018)	Reference Grounding Probability	Remarks
38	Poor Stability Condition of Vessel (PSC)	1.46E-04	-			
39	Interpretation Failure of Watch Keeping Officer/Master (IFWM)	4.39E-04	6.59E-04			
40	Interpretation Failure of Bridge Navigation Equipment (Radar, GPS, Ecosounder, etc) (IFBNE)	2.92E-04	1.37E-04			

In comparison, the probability values of basic/primary events and top events for collision and grounding accidents in inland waterways of Bangladesh found similar to that of reference data except few. Differences observed for some of the values due to differences in operating areas, operating environment, type & standard of vessels, qualifications of officers & crews and many more. Thus, it means that the outcome of the proposed FTA models of collision and grounding accidents for inland waterways Bangladesh is effective and the analysed result is acceptable.

Relevant Findings

In the present research, survey is conducted to collect data/information regarding the marine accidents took place in inland routes of BD during the last 38 years. The various causes that led to these disasters and the grey areas have been identified. Some of those are discussed below:

a. It is yet to practice of constructing vessels for inland routes following approved design and drawing. It is also imperative that the construction of the vessel be supervised and certified by a qualified naval architect. Vessel may not be issued with a registration number unless its design is approved by a qualified naval architect. The unregistered vessels must be driven off the river routes.

- b. All ship's bulkheads can be so arranged as to form watertight compartments. These should be of such a size that for passenger vessels, any two adjacent compartments could be flooded without causing ship to sink.
- c. The port inspectors can play the most vital role in avoiding riverine accidents. They must not allow a vessel to leave a port in an overloaded condition or when a storm warning exists against safe navigation. Hence it is strongly recommended that a system of Port Clearance should be introduced. Each vessel must obtain such a clearance certificate prior to its departure from the port.
- d. Numbers of accident took place at the confluence of the river Padma, Meghna and Dakatia. The confluence is a risk-prone turbulent zone where many disasters occurred because of the existence of a gigantic whirlpool there. The vessels may be advised to avoid the confluence of the Padma, Meghna and Dakatia from July to mid-October [41].
- e. Our inland routes becomes virtually a death trap for vessels as well as passengers at night mainly due to very poor signaling system. Inadequate signal lights, underwater shoals and absence of danger marks about river currents have made the routes most unsafe. Most of the beacon lights and buoys remain out of order or insufficient than as required. Sufficient number of beacon lights and buoys are needed in different routes because the rivers are in spate and very risky at the downstream.
- f. Safety of inland shipping is primarily dependent on two factors namely, river-worthiness of the craft and navigability of waterways. River-worthiness of a ship embraces the fitness of the ship's hull, machinery, stores, equipment and crew. Getting a river-worthy vessel is a complete process including design, construction, certification, maintenance and operation. River worthiness for many of the vessels are yet to achieve.
- g. Many of the operators do not have a license to operate the vessels. They are not well trained and skilled. Moreover, they do not have proper knowledge on Convention on the International Regulations for Preventing Collisions at Sea (COLREG) and training on the rules and regulation involved in navigating the vessels [42].

CHAPTER-7

CONCLUSIONS AND RECOMMENDATIONS

In this thesis, a brief model of collision and grounding accident in inland waterways of Bangladesh has been proposed for risk analysis. First, a structure model has been developed to show the relationship among various accident parameters and then guide line is shown to analyse the accidents both qualitatively and quantitatively. Finally, the qualitative and quantitative analysis took place using the collected accident data through FTA methodology. The accident models developed for collision and grounding accident will act as a bench mark and the literature will help to guide in analyzing such accidents. FTA models could be used as a system which updates the risk levels whenever an accident occurs. In light of that the following could be concluded:

- a. The main factor in the occurrence of collision and grounding accidents is human error. Seventy-three per cent of the basic reasons causing occurrence of collision accidents and 55% of the basic reasons causing occurrence of grounding accidents arise from human error.
- b. The main factor in the occurrence of collision accidents is faulty maneuver of master and whereas, the main factor in the occurrence of grounding accidents is lack of experience/training/qualification/competency of officer, master and crew.
- c. Reasons leading to human-error-originated initial events for collision accidents are: faulty maneuver of master; violation of procedure or rule; lack of experience/training/qualification/competency of officer, master, crew; improper/uncoordinated avoiding operation and negligence in watch keeping.
- d. Reasons leading to human-error-originated initial events for grounding accidents are lack of experience/training/qualification/competency of officer, master, crew; improper steering/course keeping failure by quarter Master, lack of knowledge on avoiding grounding situation, etc.

e. A high percentage of death and pollution cases in inland routes of BD, originates from human error. One of the effective methods in reducing risks associated with human error in the ships' activities is to ensure the highest applicable degree of education, certification and qualification standards for the seamen employed or to be employed by such ships [42].

Recommendations

In order to minimize the occurrence of marine accidents in inland routes of Bangladesh following have been suggested/put forth:

- a. Faulty maneuver of Master; violation of procedure or rule; lack of experience/training/qualification/competency of Officer, Master, Crew; improper/uncoordinated avoiding operation; negligence in watch keeping having significant influence/effect on occurring collision accident. Again, lack of experience/training/qualification/competency of officer, master, crew; improper steering/course keeping failure by Quarter Master; insufficient/improper marking of navigable channel; lack of knowledge on avoiding grounding situation; waterways are not maintained by authority having significant influence/effect and on occurring grounding accident. Thus, emphasis may be given to control the higher influencing primary events/causes to reduce the overall probability of occurring collision and grounding accident significantly.
- b. Since, major number of accidents took place for the vessel length between 10 to 40 meters, vessels with higher length (may be above 50 meters) can be designed and constructed to reduce the number of accident.
- c. Through analysis, it is prevailed that vessel of more than 150 tons gross tonnage will reduce the possibility of occurrence accident. Thus, vessel of more than 150 tons gross tonnage is suggested to bring in use in inland waterways of Bangladesh to minimize accidents. Particular attention has to be given on the design and regulations of smaller vessels.

- d. Special care may be taken to reduce the accident of passenger vessel since 48% of total accidents has occurred for passenger's vessels.
- e. Priority may be given to reduce collision accident since majority of accidents are collision.
- f. To minimize overall number of accidents, special care may be taken to reduce accident in class-I route.
- g. General awareness among the passengers and operators may be improved through media, seminar, posturing, leaflet and other means to deduce the accidents as viewed between the year 2011 to 2018.
- h. General awareness may be grown to reduce accidents in accidents prone areas (Barishal, Chandpur, Narayanganj and others) and the most vulnerable areas in route may be marked with appropriate sign to provide cautionary signals to the operators as generally used on road.
- i. Vessels may operate with special precaution and observing weather forecast to avoid accident due to bad weather condition specially between the month of March to May. Moreover, the government should ban passenger vessels and ferries from traveling at night during the stormy weather.
- j. Passenger vessel/ferry failing to obtain fitness and survey certificate must not be allowed to operate in river routes.
- k. No vessels should be permitted to ply unless it possesses well trained officers, masters and crews.
- 1. Navigable channel/route must be marked with appropriate and sufficient navigational aids to ensure safe navigation specially to avoid grounding.

- m. River or sea worthiness as applicable for vessel must be ensured and implemented by appropriate authority. It is high time to go for modernization and redesigning of the watercrafts considering their suitability in inland waters of Bangladesh.
- n. Safety can only be fully ensured if rules and regulations are properly implemented and the owners are force to keep their vessel fit and free from overloading.
- o. Navigability in waterways in different classes of routes must be maintained throughout the year by appropriate authority doing regular dredging.

However, there are still many aspects of this research which need to be improved. Firstly, the results have been still inconclusive because of insufficient and incomplete accident data as recorded in Department of Shipping and BIWTA. The accident data need to be collected and then recorded in more detail as per proposed record form so that Fault Tree Analysis (FTA) could be applied more effectively to analyse accidents. Secondly, due to the small scale of the data set, it was difficult to build a proper fault tree to calculate the probability of an accident. This means the probability of accident calculated for accident model is higher than the historical data. In the further study, the uncertainty and bias of data may be analyzed and then the accuracy of the model will be improved with an optimized structure. Besides, accident model for sinking, fire, explosion, bottom rupture and other types of accidents which could not be drawn due to insufficient data, can be developed and analysed. Further more, the risk assessment process may be progressed in future researches.

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APPENDICES

APPENDIX A: Marine Accident Data for Inland Waterways of Bangladesh (soft copy attached in CD)

APPENDIX B: Marine Accident Report Form for Inland Waterways of Bangladesh

APPENDIX C: Rate of Contribution of Initial Events to Collision Accident (soft copy attached in CD)

APPENDIX D: Rate of Contribution of Initial Events to Grounding Accident

Appendix-B: Marine Accident Report Form for Inland Waterways of Bangladesh

	REPORT OF MARINE ACCIDENT SECTION I. GENERAL INFORMATION													
		SECTION I. GEN	IERAL II	NFORMATIC	<u>)N</u>									
1. Name of Vessel	2. Registration no	3. Nationality	4. Ca	ll sign	5. Certificate issued at:									
6. Type of Vessel	7. Length	8. Breath	9. Dra	aft Aft:	10. Gross tonnage									
11. Dead weight tonnage	12. Year of Built	13. Hull material (Steel, wood etc.)	(0	ropulsion liesel, petrol, ail, etc)	15. If vessel classed, by whom: ABS/ LLOYDS/RINA/BV, etc.									
16. Name of Owner: Address:	17. Name, of Operating Co. Address:	18. Name of Maste or Person in Charge Address:	r 19. N	ame of Pilot	20. Operating Route									
		SECTION II. ACC	IDENT I	NFORMATIO	DN .									
21. Date of Occurrence	22. Time (Local)	23. Location (Latitu applicable)			24. Accident Place: Inland waters Inshore waters Offshore waters At Harbour At Berth									
25. Type of Inciden	<u>t</u>													
Collision Of vessels With a fixed of the description of the descript	g object d object	Grounding Intentiona Unintentio			 ☐ Fire ☐ Explosion ☐ Sinking ☐ Capsizing ☐ Flooding ☐ Structural Failure 									
26. Navigation Info	<u>rmation</u>													
Operation at the Time Underway Anchored Moored/Berthed Drifting Towing Being Towed Fishing		Speed			of Departure									
27. Environmental	<u>Conditions</u>													
Water Calm Choppy Rough Very Rough					Time Daylight Twilight Night Sunrise									

Visibility: Good Poor Hazy Distance: (Miles of Visibility)		Wind Speed & : Direction Current Speed : & Direction	Stat	State of Sea/Water: O calm (glassy) (no waves) 1 calm (rippled) (0-0.25m waves) 2 smooth (0.25-0.5m waves) 3 slight (0.5-1m waves) 4 moderate (1-2m waves) 5 rough (2-4m waves) 6 very rough (4-6m waves) 7 high (6-9m waves) 8 very high (9-14m waves) 9 phenomenal (over 14m waves)							
28. Causes of Accident											
Main Engine Failure Steering Failure Auxiliary Machinery Failure Violation of Traffic Rule Violation of Procedure or Rule Over Speed Faulty Maneuver of Master Piloting Failure Lack of Communication between Vessels Insufficient Use of Bridge Navigational Equipment Insufficient Knowledge on Navigational Equipment Insufficient Navigational Equipment Lack of Bridge Resource Management Failure of Look Out Insufficient Channel Marking Inappropriate Route Selection Environmental Restriction (Visibility, Wind& Wave) Bad Weather Condition Insufficient Information of Weather Forecast Insufficient Communication Equipment Lack in Use of Visual Signaling Lack of Experience/Training/ Qualification/ Competency of Officer, Master, Crew Fatigue/Sleeplessness Alcohol Abuse Maneuver in Close Company	Lack of Situation Over Local Communication Navigation Insuffication Navigation Navigatio	coading unication Equipment Failure tional System Failure tional Light Failure ient Navigational Lights Onboard Radar Observation ence/ Reluctances in Performing Dusisibility Tug Boat Manoeuver ient Tug Boat Use te/ Maneuver on Wrong/ Inappropri ence in Watch Keeping Assessment of Situation er Steering Operation er Look Out er Emergency Operation dinated Avoiding Operation er Avoiding Operation er Avoiding Operation def from Channel Sea over Error of Watch Keeping Officer Use of Communication Equipment def through Restricted Waterways ic Positioning Failure change laneuvering Characteristics laneuvering Ability of Vessel etation Failure of Bridge Navigation	iate		Improper Design and Drawing Update Charts/ Publication not used onboard Charts/ Publication are not update by Authority Waterways are not Maintained by Authority Position Estimation Error Sensor/ Navigation Equipment Error Delayed in Action in Coming back to Safe Track Coarse Keeping Failure by Quarter Master Improper Use of Depth Gauge/Sounding Equipment Information Acquisition Failure Violation of Regulation Strong Current/ Wave Cyclone/ Strong Wind Anchor Failure Insufficient Marking of Navigable Channel Improper Marking of Channel Assistance is not Requested Assistance not Arrived Inability to Provide Assistance (Delayed arrival/ inability of pilot/ unsuitable pilot ship) Inappropriate Voyage Plan Interpretation Failure of Watch Keeping Officer/Master						
Ship Handling in Narrow Water Non Standardized of Equipment	_	nent (Radar, GPS, etc) on of Inappropriate Anchorage									

29. <u>Use of Fire Fighting or Emergency Equipment</u>											
Fire Fighting Equipment											
☐ Failed											
☐ Inadequate											
Lifesaving equipment											
☐ Failed											
☐ Inadequate											
30. <u>Damage Statement</u>											
Damage to:											
	rate damage										
_ Iviodo	amage										
	erty damage										
only	, ,										
31. Causality Elements	1		-	1							
No. of Persons Onboard											
Death- How Many?											
Death- How Many? Missing- How Many?											
Injured- How Many?											
Illjuled- How Mally ?	•••••										
SECTION III, PERSON	INEL ACCIDE	NT INFORM	ATION (ADDITIONAL	PAGES MAY	BE ATTACHED)						
32. Person Involved											
Gender	Name				Status						
☐ Male					☐ Crew						
☐ Female	A d dva a a				Passenger						
	Address	Other									
Causality											
☐ Dead											
☐ Injured											
☐ Missing											
Date of Death	Telephone No	<u> </u>			Job Position						
Date of Death	Telephone No).			JOD POSITION						
33. Activity of Person at time of A	Accident		34. Specific Location of	Accident on Ve	essel						
35. Type of Accident (Fall, Caug	ght between, etc	;)	36. Resulting Injury (Cu	ut, Bruise, Fract	ture, Burn, etc)						
37. Part of Body Injured			38. Equipment Involved	in Accident							
39. Specific Object, Part of Equip	oment or Substa	ance (Chemical	Solvent etc.) that directly	v produced the	iniurv						
		(,	, ,	, ,						

	SECTION IV. INCIDENT DESCRIPTION
	SECTION IV. INCIDENT DESCRIPTION
Incident Descriptio	n
Use the space below insufficient space, prov	to provide a full description (including a diagram) of the incident and events leading up to the incident (if vide a separate page)
Description of dam	age to vessel
Description of Inci-	Jané
Description of incid	dent
Diagram of Inciden	t:
	OFOTION V. DEDCON MAKING THIS DEDORT
	SECTION V. PERSON MAKING THIS REPORT
Name	
Address	
Designation	
Telephone No	
•	
Signature	
Date	

Amplifying Information for Completing the Form:

- 1. Sr no 23 " Location"- It is preferable to specify the location of accident by the latitude and longitude to the nearest tenth of a minute. If the latitude and longitude is unknown or not implacable than reference to a known landmark or object (buoy, light, etc.) with distance and bearing to the object is permissible.
- 2. SECTION III Personnel Accident Information Section III must be completed for a death or injury. In addition, applicable portions of Section I, II and IV must be completed. If more than one death or injury occurs in a single incident, complete this section for one of the persons injured or killed and attach additional pages following same section for each additional person.

3. SECTION IV – Incident Description - Describe the sequence of events which led up to this accident. Include your opinion of the primary cause and any contributing causes of the accident. Briefly describe damage to vessel, its cargo. and other vessels/property. Include any recommendations you may have for preventing similar accident. A diagram may clearly describe the occurrence of the incident.

Submission of Report Form

The Department of shipping may designate or authorize any inspector, surveyor or any other persons with marine knowledge to prepare the report form. The designated person must visit the place of accident soon after it occurrence to complete the report form effectively. He may interview related personnel to know the occurrence in details as deemed necessary. After filling the form with all necessary information as specified, the form will be submitted to the same department at the quickest means.

Appendix-D: Rate of Contribution of Initial Events to Grounding Accident

			Rate of Contribution of Initial Events to Grounding Accident																																						
No of Accident Event	Accident Date	Vessel Name	Selection of Inappropriate Anchorage (SIA)	In-sufficient/Improper Marking of Navigable Channel (IIMNC)	Update Charts/Publication not used onboard (UCPNU)	Charts/ Publication are not updated by Authority (CPNU)	Waterways are not Maintained by Authority (WWNM)	Position Estimation Error (PEE)	Sensor/ Navigation Equipment Error (SNEE)	Delayed in Action in Coming back to Safe Track (DACST)	Improper Steering/Course Keeping Failure by Quarter Master (ISCCFQM)	Maneuver Error of Watch Keeping Officer (MEWO).	Faulty Maneuver of Master (FMM).	Poor Maneuvering Ability of Vessel (PMAV)	Uncoordinated/Improper Avoiding Operation (UIAO)	Assistance is not Requested (ANR)	Inability to Provide Assistance (Delayed arrival/ inability of pilot/ unsuitable pilot ship) (IPA) Assistance not Arrived (ANA)	Insufficient Knowledge on Navigational Equipment (IKNE)	Lack of Experience/Training/Qualification/Competency of Officer, Master, Crew (LETQC)	Interpretation Failure (IF)	Fatigue/Sleeplessness (FS)	Alcohol Abuse (AA)	Lack of Knowledge on Avoiding Grounding Situation(LKAGS)	Negligence in Watch Keeping (NWK)	Improper/Insufficient Use of Bridge Navigational Equipment (IIUBNE)	Improper Look Out (ILO)	Deviated from Safe Course/Channel (DFSCC)	Improper/Insufficient Use of Depth Gauge/Sounding Equipment (IIUSE	Violation of Regulation (VOR)	Poor Visibility (PV)	Cyclone/Strong Wind (CSW)	Strong Current/Wave (SCW)	Anchor Failure (AF)	Main Engine Failure (MEF)	Steering Failure (SF)	Auxiliary Machinery Failure (AMF)	Non Standardized of Equipment (NSE)	Improper Design and Drawing (IDD)	Poor Stability Condition of Vessel (PSC)	Interpretation Failure of Watch Keeping Officer/Master (IFWM)	Interpretation Failure of Bridge Navigation Equipment (Radar, GPS, Ecosounder, etc) (IFBNE)
1.	7/11/1997	MV Salauddin-						0.15	0.05		0.25			0.05	0.1								0.15		0.15	0.05								0.05							
2.	20/9/2008	BIWTC MV BB-1134	0.1		0.05																					0.05	0.05	0.1		0.2	0.25		0.2								
3.	10/8/2009	MV Prince of Madhur Khola		0.15		0.05	0.15					0.15	0.1		0	.1										0.15						0.15									
4.	19/8/2009	MV Modina-2										0.1	0.3				0.05		0.2							0.05	0.1	0.05										0.1	0.05		
5.	16/1/2010	MT Sydpolen								0.1							0.05	0.05		0.1				0.2					0.25										().15	0.1
6.	20/1/2010	MV Sunny										0.15	0.4								0.2														0.2		0.05				
7.	21/4/2011	MV Bipasha							0.05		0.1	0.1	0.25						0.2			0.1			0.05	0.1										0.05					
8.	8/8/2013	MV Mouchak		0.3			0.2				0.2	0.05	0.25																												
9.	3/9/2015	MV Princes Monika																	0.3				0.3		0.1	0.1		0.2													
Rat	e of Con	tribution	0.1	0.45	0.05	0.05	0.35	0.15	0.1	0.1	0.55	0.55	1.3	0.05	0.1 0	.1	0.05 0.05	0.05	0.7	0.1	0.2	0.1	0.45	0.2	0.3	0.5	0.15	0.35	0.25	0.2	0.25	0.15	0.2	0.05	0.2	0.05	0.05	0.1	0.05).15	0.1
Pro	bability	value	2.92E-04	1.32E-03	1.46E-04	1.46E-04	1.02E-03	4.39E-04	2.92E-04	2.92E-04	1.61E-03	1.61E-03	3.80E-03	1.46E-04	2.92E-04	2 92F-04	1.46E-04 1.46E-04	1.46E-04	2.05E-03	2.92E-04	5.85E-04	2.92E-04	1.32E-03	5.85E-04	8.77E-04	1.46E-03	4.39E-04	1.02E-03	7.31E-04	5.85E-04	7.31E-04	4.39E-04	5.85E-04	1.46E-04	5.85E-04	1.46E-04	1.46E-04	2.92E-04	1.46E-04	4.39E-04	2.92E-04

