

RECONSTRUCTION OF CAPSIZE TYPE OF ACCIDENTS BY FAULT TREE ANALYSIS

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ABSTRACT

This paper describes a research work on the reconstruction of capsizes of marine vehicles using fault tree analysis. Capsizes of marine vehicles are observed to take place all around the world; however, such accidents occur at an overwhelming rate in the inland waterways of Bangladesh. This paper, therefore, aims to illuminate the chains of faults working behind the high frequency of capsizes with a view to execute groundwork for future database development as well as accident analysis and reconstruction. Different factors triggering the accidents are enumerated in a structured form after scrutinizing the accident data. During accident investigation, the chain of faults squaring with the accidents can be easily identified with the help of an interactive system, being directly linked with the accident factors featured in the fault trees. A case study has been shown where the application of the developed tree is explained. Since the research has the limitation of being primarily based on secondary data sources, further research is recommended to refine it with the help of primary data. Finally some steps to improve the inland water transportation sector are recommended in order to restrict the factors contributing to marine accidents.

Key words: Fault tree analysis, hazard identification, accident database development, human factor.

NOMENCLATURE

ARI – Accident Research Institute
BIWTA – Bangladesh Inland Water Transport Authority
DOS – Department of Shipping
ERZ – Economic Resource Zone
FTA – Fault Tree Analysis

IWT – Inland Waterway Transportation
MAIB – Marine Accident Investigation Branch
MARS – Marine Accident Reporting Scheme
MOS – Ministry of Shipping
NSPAR – National Strategy for Accelerated Poverty Reduction

FAULT TREE ANALYSIS EVENT SYMBOLS

Primary Event Symbols

 BASIC EVENT - A basic initiating fault which requires no further development.

 UNDEVELOPED EVENT - An event which is not further developed either because it is of insufficient consequence or because information is unavailable.

Gate Symbols

 AND - Output fault occurs if all of the input faults occur.

 OR - Output fault occurs if a least one of the input faults occur.

 EXCLUSIVE OR - Output fault occurs if exactly one of the input faults occurs.

Transfer Symbols

 TRANSFER IN - Indicates that the tree is developed further at the occurrence of the corresponding TRANSFER OUT (e.g., on another page).

 TRANSFER OUT - Indicates that this portion of the tree must be attached at the corresponding TRANSFER IN.

1. INTRODUCTION

Bangladesh, a country having the area of 1,47,570 square kilometers, is inseparably entangled with a circuitous network of around 700 rivers [1] covering a length of 24,000 kilometers which is almost 7% of the

surface of the country. Bangladesh has about 9,000 square kilometers of territorial waters with a 720 kilometer long coast line and 20,000 square kilometers of economic resource zone (ERZ) in the sea [2]. She has a navigable waterway of 5,968 kilometers in length.

The major three river systems of the Ganges, the Brahmaputra and the Meghna converge in Bangladesh to form one of the world's largest deltas. These three rivers also generate one of the most complex river systems in the world [1]. The complex water network has spread in such a pattern that a huge portion of the country especially the southern tip and the offshore areas are hardly accessible by land transportation. Therefore, the transportation infrastructure of the country depends largely on waterways.

The IWT sector plays a vital role in the transportation sector of Bangladesh. A substantial portion of rural population (12.3%) only has a reasonable access to the transportation system through IWT which is half of all rural households who have access to river transport [3]. Thus IWT makes a significant contribution towards government's effort towards growth and reduction of poverty under NSPAR [4].

With the advancement of industrialization, the shipping industry of Bangladesh is also being developed markedly. Being no longer confined to indigenous pattern of country-boat and wooden ship, Bangladesh observed a sheer expansion of shipping business and also emerged as a ship exporter. To keep the economy smooth-running, a safe and secured marine transport system should be confirmed. But disruption to marine transport system as well as to growing commerce is mainly fetched by the high frequency of marine accidents.

An investigation data showed that more than 9000 people have died or been reported missing in the past 25 years due to passenger ferry accidents [5]. These were ascribed to various resources such as newspapers, journals and personal communications to the relevant offices (e.g., BIWTA and DOS, Bangladesh).

Overloading and crowding at one side may be held accountable for a great number of capsizing events in Bangladesh. Disaster lurks when the problem of overloading is associated with structural faults. The IMO criteria applied to the vessels showed that the crowding of passengers on one side during a crisis posed a greater risk than the beam wind. During cataclysms, people run amok at one side and simultaneously stability of the vessel gets harmed by the storm; in most of the cases the vessel at this stage gets overturned by the combined effect of crowding of people at one side and storm [6].

Since the existing accident database of Bangladesh has deficiencies, this paper focuses on using the FTA as a tool of developing an improved database. For

accomplishing this, previous research papers provided with accident factors and the data on previous accidents from different authentic sources are carried out. Keeping a categorized top-level system failure at top position, the branches of its immediate earlier factors are arranged in a descending order which end up with the initial faults.

2. LITERATURE REVIEW

In Bangladesh, very few works had been done regarding an in-depth analysis of marine accidents. Out of them, most were limited to the identification of major types of accidents, the stimulating factors and their statistical distributions. The hazards involved with the indigenous marine vehicles in Bangladesh were featured extensively by Awal [7]. Another investigation by Awal et al. revealed some interesting findings portraying the major causes of passenger vessel accidents [8]. Awal et al. in a similar kind of research produced a statistical study of the primary causes of accidents of various types of vessels [9]. An investigation of accidents, executed by Zahanyar and Haque, enumerated the factors triggering marine disasters and proposed some actions for the prevention of accidents [10]. Bangladesh Transport Sector Study (BTSS) categorized the marine accidents highlighting the major types of launch disasters [11]. A significant contribution was made by BIWTA, conducting the safety and stability parameters of the passenger vessels [12].

Furthermore, some significant works were done regarding the improvement of stability to enhance the probability of ship survival. Iqbal, et al. performed a profound analysis on the structural and other faults including the diminishing stability at lower angle of inclination which contributes a lot to capsizing. This paper also featured a graphical representation of significant heeling moment due to wind and crowding of passengers [6]. Addressing the stability hazard issue with restrictions like shallow draft and restricted hull size, Podder suggested the use of sunken deck to increase stability [13]. Khalil and Tarafder proposed some adaption of ship design for the acquisition of extra initial stability by upward shift of centre of gravity to prevent the vessel from capsizing [14]. Iqbal, et al. devised an efficient way to increase the restoring lever at large heeling angles by providing additional reserve of buoyancy through the addition of totally inflatable lifting bags under the rigid fender of the vessel [15].

Aside from these, there are some other works being equally applicable in Bangladeshi perspective. Concluding the factors behind the loss of stability, Kruger, et al. highlighted capsizing probability as a function of metacentric height of the vessel and recommended a demand for the introduction of additional criteria to the IMO intact stability code, accounting for dynamic phenomena related to the behavior of ships in rough weather [16]. Addressing a

similar issue, Umeda and Ikeda proposed a more physics oriented approach in stead of the classical approach to use capsizing probability as a relative measure for establishing stability criteria [17].

These works hashed out different features of capsizing in Bangladesh distinctly. No work has been done yet to find the relationship among the attributes resulting in a fiasco. As a result, a good compilation of events triggering capsizing is still elusive. To serve the purpose of obtaining a scientific and practical accident database system through comprehensive analysis of accident events, FTA is a remarkable tool to start with. In a book named 'Fault Tree Handbook with Aerospace Applications', Vesely, et al. propounded that FTA provides visual, logic model of the basic causes and intermediate events leading to the top event. The qualitative information obtained from FTA is of equal importance to the quantitative information provided [18].

Although no work has been done on Bangladeshi perspective by using FTA, some valuable researches were accomplished on other perspectives. Amrozowicz, et al. applied FTA on grounding and represented a probabilistic risk assessment [19]. Basu and Bhattacharya applied FTA on the system failure of floating structures particularly featuring structural failure and compartment flooding [20]. Presenting a fault tree on capsizing issue, Webb performed risk assessment and reviewed human factors related to the risk of capsizing during design and operation [21].

One of the paramount issues about capsizing is human factor. Rothblum suggested that the lion's share of accident factors is involved with human error [22]. Enumerating the human factors successfully Psaraftis, et al. recommended putting more emphasis on human factor than technological solution for reducing the risk of marine accidents [23]. Talley, et al. concluded that human mistakes result in higher number of fatalities in passenger vessel accidents than environmental and vessel related causes [24]. Calhoun addressed the issue of shipboard operator fatigue and proposed incorporation of human factor to ship design to prevent fatigue as well as reduce human error to a minimum level to ensure marine safety [25].

Based on the knowledge, developed from these research works and the evaluation of accident data, derived from various authentic sources, FTA is applied on capsizing, to assess the impact of an intermediate event on the final failure.

3. DATA COLLECTION

The pivotal part of the research work is data collection from legitimate sources and winnow the pertinent issues with extensive accuracy. But, lack of authentic data sources as well as shortage of extensive analysis of capsizes makes the data processing extremely difficult. So data are collected from various

sources to develop a good concept on capsizing triggering factors in Bangladesh.

3.1. Data Source

The accident database tool is developed with both the primary and secondary data. The primary data are collected through a structured observation method [26], unstructured interview of the personnel at the corresponding expertise and survey with a questionnaire form for collecting data from the crews and regular passengers of IWT sector.

The prime source of secondary data is the research paper published in various journals and conference proceedings. Others are the accident data from secondary sources, compiled at ARI and various publications of the governing bodies such as BIWTA, MOS and DOS. The data are also collected from the reports of various newspapers. In order to conduct case study, 3 accident investigation reports by MOS as well as 26 capsizing reports published by MAIB and MARS were collected and studied to gain a proper insight to the factors contributing to capsizing.

3.2. Some Findings Regarding the Current Status of Marine Safety in Bangladesh

Structured observation, unstructured interview and literature study revealed some facts such as overloading together with discrete and non-uniform passenger flow, which enhances stability hazard. During the main public holidays such as Eid and Puja, a massive population is transferred from Dhaka to the other parts of the country within a very short period. This creates a huge pressure on the transportation system as the means of transportation are limited. So overloading is a prevalent issue here.

It is important to note that the vessels are kept overloaded not only during this particular period but also all over the year, even though there is no waterway transportation crisis. 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. In addition, the incompetency between BIWTA and DOS allows this phenomenon keep going easily. DOS is directly responsible for ensuring ship safety by preventing irregularities but it has insufficient man power while BIWTA has it somehow with 22 officials only but does has deficiency to enforce the orders.

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 coerces the ship owners to rely on unskilled and untrained crews. This allows the vessels to be

plied by inept masters and crews which often results in a pitfall [5].

4. DOMINO THEORY OF ACCIDENT CAUSATION

Domino theory was developed by Heinrich. He devised a five-step accident sequence in which each factor would actuate the next step just like a row of falling dominoes [27]. The sequence of accident factors were as follows:

1. Ancestry and social environment.
2. Worker fault.
3. Unsafe act together with mechanical and physical hazard.
4. Accident.
5. Damage or injury.

Heinrich believed that removing a single domino from the row would prevent the accident. According to him, the key domino, to be removed from the sequence, is number 3. This paper works on this step by analyzing the accident causes and arranging them in a chain of events leading to the top-level system failure.

5. DEVELOPMENT OF FAULT TREE ON CAPSIZE

Capsize, a top-level system failure, is intensely related to buoyancy and stability of the vessel. These two factors fluctuate as result of interaction with other influences such as ship design, loading, ship steering and so on [21]. Vessels capsize due to C1- loss of stability and C2- no restoration of stability.

Stability loss is discussed into two parts: SS- static stability loss and DS- dynamic stability loss. Static stability of a vessel is lost due to SS1- reduced buoyancy or SS2- reduced transverse stability. Reduction in buoyancy is a function of FLD- flooding or LoE- overloading, while transverse stability of a vessel reduces as a result of SS21- GM/GZ reduction or SS22- heeling moments. Improper opening and poor drainage system keep a ship vulnerable to flooding and the problem becomes severe during cataclysms while the ship's stability is harmed by extreme beam wind. GM/GZ reduction is prior to poor loading or overloading and any of the events from FSE- free surface effect of liquid within the hull or SS221- cargo shift or CRWD- rush of passengers in one place results in producing heeling moments vulnerable for the ship stability. During storms, people stampede towards one place while the ship hull is exposed to a severe beam wind. The concurrent effect of severe beam wind and rush of people in one side triggers heeling moment as well as reduction in transverse stability and subsequent loss of static stability.

Dynamic stability loss is initiated by DS1- synchronicity of the vessel with waves or DS2- large

rolling angle or DS3- large acceleration. A large rolling angle may lead to the total loss of the vessel and a large acceleration causes massive cargo loss or damage, severe damage to machinery or major safety relevant systems and structural overload of safety relevant members. It is seen that large accelerations occur at high values of initial GM and there is no particular criteria to limit the stability accordingly (maximum GM limits) [16]. It is observed on the vessels of Bangladesh that, the vessels have high initial meta-centric height but GZ diminishes terribly while the ship lists at larger angles [7]. Large rolling angles occurs either at low values of initial GM or during broaching situations [21]. Synchronicity with waves occurs due to ROL- excessive rolling or Env- resting on steep wave for a certain time. Excessive rolling is ascribed to ROL1- insufficient roll damping or DCE- critical resonance or DCE- very low initial GM. Insufficient roll damping is liable to the selection of unsuitable rolling reducer or the lack of sufficient number of rolling reducers.

C22- insufficient or C21- delayed actions to restore stability during high time may capsize the vessel. Insufficient action is the result of Del- delayed action or Err- erroneous action.

The whole capsize mechanism is illustrated in the figure I.

6. APPLICATION OF THE DEVELOPED FAULT TREE

In 27 November, 2009 at 10:45 PM a passenger ferry, MV KOKO-4, capsized causing death to 81 people. The sequence of the causes behind this accident is demonstrated in the figure II.

From the investigation report [28], it was seen that the vessel was extremely overloaded. Since the vessel was not able to accommodate such a high amount of people it is assumed that the load distribution was very poor.

The vessel was rolling against the impact of the wave. Although this rolling action was not responsible for the capsize event, together with insufficient or unsuitable rolling reducers, the ship might have a very low GM which might have been exacerbated due to poor load distribution raising the center of gravity. This situation might enhance the loss of stability at a lower angle of inclination during the ultimate failure event. In addition, a lot of people gathered together in the port side for buying ticket and disembarking which created a great heeling moment and was proved to be a disastrous factor later on.

The fore side of the vessel was attached to the ground which, in combination with the previous crowding factor, instigated imbalance to the ship and lowered the aft portion. At that time aft maneuvering caused the ship to be lower more and water started to ingress from the starboard side. The people were so frightened that they crowded together to the port side.

As a result, the vessel got imbalanced and capsized instantly. Here the aft maneuvering by the master suggested that an action was attempted to restore stability which ended in a failure. The report defined this action as erroneous one. The lowering of the aft side which drew water was not reported to be a vital threat as the water did not create any free surface effect. It was the rush of the panicked people amok one side of the vessel, under the startling circumstances, which ensued capsized.

7. DISCUSSION AND LIMITATIONS

In Bangladesh, accident reporting and the subsequent accident prevention procedures are still in an unsophisticated and primitive state. No remedial measure seems sufficient since it does not correspond with the Domino or chain of events ending in a disaster. Therefore, this paper accentuates the importance of reporting accidents in a proper way by uncovering the incidents behind a marine accident elaborately.

Being primarily based on secondary data sources is the main limitation of this research work. The primary data source includes observation and interviews which are always questionable. Moreover, collecting data from legitimate sources and filtering the relevant issues with extensive precision results in a small number of extensive analyses of accident events. This is a big limitation of this work as such type work demands a larger sampling. Certain events in the fault trees are not further developed due to shortage of genuine data sources. Furthermore, most of the events, ended in a factor relating to the human element, are not developed further.

8. RECOMMENDATIONS

Since the situation of ship safety has aggravated abysmally in recent years, this is the high time some proper and innovative insights are given to the accident prevention scheme.

- A rich and powerful database has to be developed as soon as possible through proper investigation. The fault tree may be a quantum leap forward in this investigation procedure.
- The fault tree is recommended to be refined and developed further by direct investigation of accidents through an interactive system.
- As soon as the database is developed, a careful analysis of the data will result in the discovery of certain chain of events triggering a debacle. The accident mitigation process should be based on this analysis.
- Resolving the ambiguity between DOS and BIWTA, the corresponding authority should be given enough number of personnel and power to stop vessels from overloading. Furthermore, a prior ticketing system and an

electric onboard passenger counter may serve this purpose.

9. CONCLUSION

This paper focuses on developing fault tree for different types of accidents as a suitable tool for the collection and analysis of accident data to identify hazardous chain of events. The error reduction technique as well as accident mitigation process should be based on the facts discovered from the fault tree.

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Figure I: Capsize FTA



