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Research on marine accidents in Hainan jurisdiction based on FTA method

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RESEARCH ON MARINE ACCIDENTS IN HAINAN JURISDICTION BASED ON FTA METHOD

By

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DECLARATION

I certify that all the materials in this research paper that are not my own work have been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Research Paper: **Research of Marine Accidents in Hainan Jurisdiction Based on FTA Method**

Degree: **Msc**

Considering shipping industry boom in Hainan jurisdiction in recent years under the promotion of preferential policy and requirement of economic development for constructing an International Tourism Island, the risk of navigation is increasing with the climbing port throughput in this jurisdiction. To develop recommendations for managing risks through Risk Analysis (RA) on marine accident is necessary for enhancing maritime safety, including protection of life, health, the marine environment and property.

Recommended by the International Maritime Organization (IMO) in its guideline on hazard identification and risk analysis techniques, Fault Tree Analysis (FTA), a logical and graphical method, is a standard risk assessment technique that can be used to build a risk model through the construction and quantification of fault trees (IMO, 2002). FTA as an analysis technique that model possible combinations among system elements (Mullai, 2006), is a powerful tool in understanding casual factors and determine actual root causes of accidents.

The main aim of this paper is to take the advantage of FTA to analyze the marine accident in Hainan jurisdiction. Taking the type of collision as an example and examining the various potential factors that can lead to a collision accident, this paper will build a fault tree that pertains to collision accident and calculate the importance coefficients of basis events through qualitative analysis. Furthermore, recommendations on preventing collision accident will be given finally.

Key words: FTA, Marine Accidents, Hainan jurisdiction

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ABS	American bureau of Shipping
AIS	Automatic Identification System
APAR	Automatic Radar Plotting Aid
COLREGS	International Regulations for Preventing Collisions at Sea
DCPA	Distance to Closest Point of Approach
FSA	Formal Safety Assessment
FSC	Flag State Control
FTA	Fault tree analysis
GPS	Global Position System
ICOBE	Importance Coefficients of Basic Events
IEL	Immediate Economic Loss
IMO	International Maritime Organization
LL	The International Convention on Load Line
MCS	Minimal Cut Sets
MOT	Ministry of Transport of the People's Republic of China
MPS	Minimal Path-sets
MSA	Maritime Safety Administration
PSC	Port State Control
RA	Risk Analysis
SOLAS	International Convention for the Safety of Life at Sea
SRS	Ship’s Routing System
STCW	International Convention on Standards of Training, Certification and Watch keeping for Seafarers
TCPA	Time to Closest Point of Approach
VHF	Very High Frequency
VTS	Vessel Traffic Service

CHATER 1 INTRODUCTION

1.1 The Background of Research

1.1.1 The background of Hainan jurisdiction

Located in the south of China, Hainan Island occupies an area of 35,000 square kilometer (13,510 square miles) and with surrounding sea area of 2,000,000 square kilometers (772,000 square miles) was awarded with title of International Tourism Island by the government of China in 2010 (Travel China Guide). Under the promotion of preferential policy and requirement of economic development, shipping industry in Hainan jurisdiction has enjoyed fast boom since 2010.

According to the Statistical Communiqué released by Hainan Provincial Bureau of Statistics that the total cargo throughput in Hainan jurisdiction was 73,688,500 tons in 2009 and this number jumped to 110,055,200 tons in 2013 with growth of 49.35%, the passenger throughput increased by 24.06% from 28,457,300 persons in 2009 to 35,306,300 in 2013, and the total throughput of container climbed up to 1,367,100TEU in 2012 from 585,200TEU in 2009 with growth of 133.61%.

On the other hand, behind the rapid development of shipping industry in Hainan jurisdiction, the number of marine accidents increased steadily and the accidents have far reaching consequences both for economy and for human life.

According to the statistic of marine accidents[1] in Hainan jurisdiction by Hainan Maritime Safety Administration (MSA), the number of marine accidents (including ordinary accidents[2] and upper degrees) was 8 in the year of 2009 and this number increased to 15 in 2013, meanwhile, the immediate economic loss (IEL) resulting from marine accidents climbed to 20,740,000RMB in 2013 from16, 350,000RMB in 2009. As to the human life, there were 49 deaths as the result of the marine accidents

1 According to the Ship Traffic Accident Statistics Rules released by the Ministry of Transport of the People's Republic of China 2002 that marine accidents include: Collision, Sinking, Grounding, Contact, Wave, Wind, Fire/ Explosion and other marine accidents that cause injury and immediate loss.

2 Ordinary accidents include: A ship with gross tonnage up to 3,000 or horse power up to 3,000kw has the IEL between 500,000 and 3,000,000RMB or has person(s) seriously injured; a ship with gross tonnage from 500 to 3,000 or horse power between 1,500 and 3,000kw has IEL between 200,000 and 3,000,000RMB or has person(s) seriously injured; a ship with gross tonnage under 500 or horse power below 1,500kw has IEL between 100,000 and 200,000RMB or has person(s) seriously injured.

from the year of 2009 to 2013 and almost 10 lives were lost every year.

Table 1-1 Total Port Throughput& Marine Accident in Hainan Jurisdiction 2010-2013

Year	Total Port Throughput		Marine Accidents	
	Cargo (×10,000tons)	Passenger (×10,000persons)	Number	Immediate economic loss (×10,000RMB)
2009	7368.85	2845.73	8	1635
2010	8466.9	2777.4	5	1410
2011	9500.43	3148.32	7	1970
2012	11108.37	3255.33	11	2817
2013	11005.52	3530.63	15	2074

Source: Total Port Throughput data from Hainan Provincial Bureau of Statistics
Marine Accidents data from Hainan Maritime Safety Administration

Note: The marine accidents compiled in the table including ordinary accidents and upper degrees as classified according to the Ship Traffic Accident Statistics Rules

Generally speaking, from the data referring to the main throughputs between 2009 and 2013, the shipping industry in Hainan jurisdiction boomed with the conception of International Tourism Island after the year of 2010. On the other hand, the development of shipping industry in this jurisdiction accompanied with the increasing risk of marine transportation.

1.1.2 The estimated trend of shipping industry and marine accident in Hainan jurisdiction in the few years

With the help of the construction of Hainan International Tourism Island, the port infrastructure construction will keep an increase intensively in order to establish a safe, smooth, efficient and convenient logistics system. For example, a new Ro-Ro wharf (Xuwen Nanshan Ro-Ro wharf) is to be built as a modern channel connecting the Hainan province and Guangxi province with the capacity of 2,050,000 cars and 11,800,000 passengers per year (Luo, 2014).

Meanwhile, with the policy stimulation of International Tourism Island, the economy in the island continues to heat up. The conception of International Tourism Island will accelerate the development of tropical agriculture, real estate, automobile manufacturing and other industries, and will promote the development of shipping industry continuously. According to the anticipation of transport department of Hainan province, the cargo throughput of Hainan Island will climb to 227 million tons and 4,650,000 TEU in container throughput in the year of 2015 (Ji, 2011).

Considering the last few years' trend on marine accident with the port throughput, the number of marine accidents may continue to increase and the immediate economic loss caused by marine accidents would rise consequently in the future. Therefore, using the technique of RA to find the root causes of marine accident and develop recommendations for managing risks is necessary for enhancing maritime safety in Hainan jurisdiction.

1.2 The Background of FTA

Risk analysis is the process of examining the risks that could lead to the failure of a system qualitatively and quantitatively in order to determine the extent of risks and their relationship among risk components as well as to determine which risks are the most important to deal with.

> *The FTA technique is applicable for any Risk Analysis, but it is used most effectively to analyze accidents or problems that are characterized by a large number and complex combinations of events. It can be used as a tool to understand causal factors and determine actual root causes of accidents.*
>
> (Mullai, 2006, P117)

The technique of FTA, as a technique of RA, was originally developed in 1962 at Bell Laboratories by H.A. Watson. As a deductive analysis method, FTA gained widespread support and is often used as a failure analysis tool by reliability experts (Wikipedia, May 2014). With the steady improvement and development of modern computer applications, the technique of FTA has been widely used in the area of aerospace, electronics and chemical aspects. Furthermore, in the maritime domain, the technique of FTA has been mainly used in the rule-making process and marine accident analysis.

1.2.1 Application in rule-making process

In the year of 2002, the IMO established the Guidelines for Formal Safety Assessment (FSA) that could be used in the IMO rule-making process (IMO, 2002). In the guideline, the IMO introduced risk-based analysis and cost benefit assessment as a tool for use in the IMO rule-making process, aimed at enhancing maritime safety. The FSA comprises 5 steps: identification of hazards, risk analysis, risk control options, cost benefit assessment and recommendations for decision-making. FTA as a standard risk assessment technique that can be used to build a risk model through the construction and quantification of fault trees was recommended by IMO in the FSA step of Risk Analysis and has been given a brief introduction in the Appendix 3.

1.2.2 Application in marine-accident analysis

To find the causes of marine accident and give suggestions for preventing similar accidents happening again through accidents investigation and analysis is a fundamental job in enhancing maritime safety. The technique of FTA, as a useful tool in the marine accident analysis, can clearly find out the causes of marine accident and the connection between the various reasons, also can find the weakness of safety system and provide suggestions for improving the navigation safety. In practical application, researcher Hai Jun (from the Military Traffic Department of Military Traffic Institute, China), for example, analyzed the Military waterway transportation accidents by the means of FTA and identified the causes of some typical transport accidents. Pedro Ant˜ao and C. Guedes Soares (from Unit of Marine Technology and Engineering, Technical University of Lisbon) used the fault-tree models analyzing the accident Scenarios of RoPax Vessels. Moreover, Li Guo-ding (from Jimei University, China) found out the main causes of a marine accident through FTA etc. Considering the advantages of FTA in marine accident analysis, FTA was recommended by the American Bureau of Shipping (ABS) in its Guidance on the Investigation of Marine Incidents 2005.

The advantages of FTA in marine accident analysis are also reflected in the following three aspects: a well developed fault tree can represent the causal and logic relationship between accident (top event) and all contributing events concisely and graphically; FTA can help identify multiple-event failures in a marine accident; FTA can also show design and operational errors such as the failed layout and operation of navigation aids. Hence, FTA as a technique of RA could be used to find the root causes of marine accidents and develop recommendations for managing risks in Hainan jurisdiction.

1.3 Method of this Paper

The technique of FTA could be used to analyze the marine accidents quantitatively and qualitatively.

> *In quantitative risk analysis, an attempt is made to numerically determine the probabilities of various adverse events and the likely extent of the losses if a particular event takes place. Qualitative risk analysis, which is used more often, does not involve numerical probabilities or predictions of loss. Instead, the qualitative method involves defining the various threats, determining the extent of vulnerabilities and devising countermeasures should an attack occur.*
>
> (Rouse, 2010)

This paper will use FTA as a technique of RA to analyze the collision accident[1] (the choice of this type of accident will be discussed in chapter3) in Hainan jurisdiction qualitatively by constructing the top structure of collision fault tree according to the four stages in collision avoidance procedure (as shown in figure1-1) and take the four factors relative to marine accident (as shown in figure 1-2) into consideration while exploring the fault tree.

Meanwhile, suggestions from Captain Wu Feng[2], Chief Officer Zhou Jian[3] and Chief Officer Shi Xufei[4] will be taken into consideration when exploring the fault tree of collision accident.

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[1] Collision accidents could be defined as a self propelled ship striking or being struck by any other ships whilst at sea whether they are anchored or on the way; however, they do not include collisions with any underwater vessel/wreck and self propelled oil installations. (Soares & Ant˜ao, 2006)

[2] Wu Feng, 48 years old, is the Captain of M/V Nan Hong 938 of Zhan Jiang (CN) East Sea Shipping Co., Ltd.

[3] Zhou Jian, 33 years old, is the Chief Officer of M/V An Guo Shan of China Shipping Bulk Carrier Co., Ltd.

[4] Shi Xufei, 33 years old, is the Chief Officer of M/V Alam Bistart of Pacific Carriers Ltd. in Singapore.

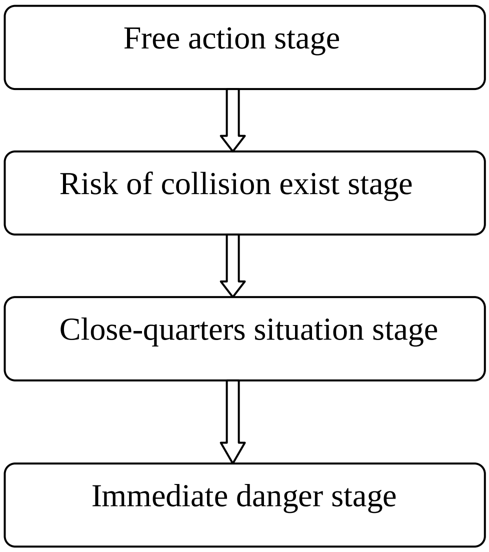

Figure 1-1: The four stages in collision avoidance procedure-1

Source: The Principles of Collision Prevention at Sea

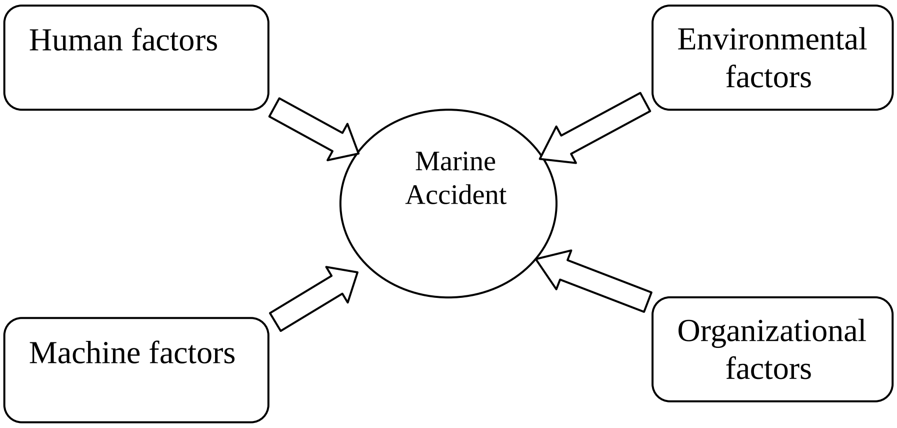

Figure 1-2: Main factors affecting the marine accident

1.4 The Purpose and Significance of this Research

By analyzing the marine accident with the method of FTA qualitatively, this paper will find out the root causes of the collision accident in Hainan jurisdiction as well as will provide safety suggestions on the prevention of such accident in order to reduce the probability of occurrence of collision accident and enhance the maritime safety in this area finally.

The purpose of this paper is in accordance with the aim of IMO in enhancing maritime safety by using risk analysis (IMO, 2002); in accordance with the requirement of Ministry of Transport of the People's Republic of China (MOT) in enhancing water-traffic-safety management by strengthening risk assessment (MOT, 2014); in accordance with the requirement of constructing Hainan International Tourism Island for safe and convenient water-way transportation and the requirement of Implementation Advice for Promoting Southeast Asian Shipping Hub and Logistics Center which released by the Government of Hainan Province 2014.

1.5 The Structure and Outcomes of This Work

After introducing the background and the purpose of this research in this chapter, Chapter 2 will give a brief introduction to the method of FTA with the purpose of introducing the principle and procedure of FTA as well as the advantages of this technique

Chapter 3 will use data collected from the Hainan jurisdiction to define the top event and refer to the stages in collision avoidance procedure to determine the top structure of the fault tree and finally explore each branch of the tree structure in detail to build a complete fault tree demonstrating how the basic events could cause a collision accident.

Chapter 4 will focus on calculating the minimal cut sets of fault tree and the importance coefficients of basic events in order to find out the causes of collision accident and the influence of basic events.

Chapter 5 will review the main methods that have been adopted in Hainan jurisdiction at first and then concentrate on analyzing the anti-collision measures through the technique of FTA as a complement to enhancing the shipping safety.

Chapter 6 contains an overall conclusion of this paper presenting a compilation of the findings and suggestions of previous chapters.

Based on the risk analysis by the means of FTA, 30 kinds of factors influencing collision accidents have been identified and almost 90% of them are related to human factor directly or indirectly. Through calculating, 14 minimal path-sets were acquired from the collision fault tree and 14 groups of combined recommendations were formulated according to the minimal path-sets for seafarers onboard and ship-safety managers of the ship companies. In order to promote the effective implication of those recommendations for preventing marine accident, this paper also gives 4 groups of suggestions for the local MSA.

CHAPTER 2 Brief Introduction to FTA

FTA was first used by Bell Telephone Laboratories in connection with the safety analysis of the Minuteman missile launch control system in 1962 and widely used in many areas for risk analysis through qualitative and quantitative analysis. i.e. Marine Propulsion System Reliability Research Based on Fault Tree Analysis (Dong et al., 2013); Fault-tree Models of Accident Scenarios of RoPax Vessels (Soares & Ant˜ao, 2006); Fault Tree Analysis of Clinical Alarms (Johnson, E., & Hyman, W. A., 2008), etc.

This chapter will give a basic knowledge on FTA from the aspects of its principle, symbols and professional terms, procedure as well as advantages with the purpose of helping understand the specific application of this technique in marine accidents in the following chapters.

2.1 Principle of FTA

Fault Tree Analysis is a deductive analysis method analyzing the reasons from the result. From a predefined undesired event (top event), this technique uses top-down approach and looks for the direct and indirect events of the top event layer upon layer thoroughly until the basic events are determined.

Using logic gates to connect these events, FTA forms an inverted tree diagram—fault tree which traces all branches of contributing events that could lead to the top event. Figure 2-1 is an example of structure block of fault tree depicting the logical interrelationships of contributing events that lead to the undesired event which is the top event of the fault tree.

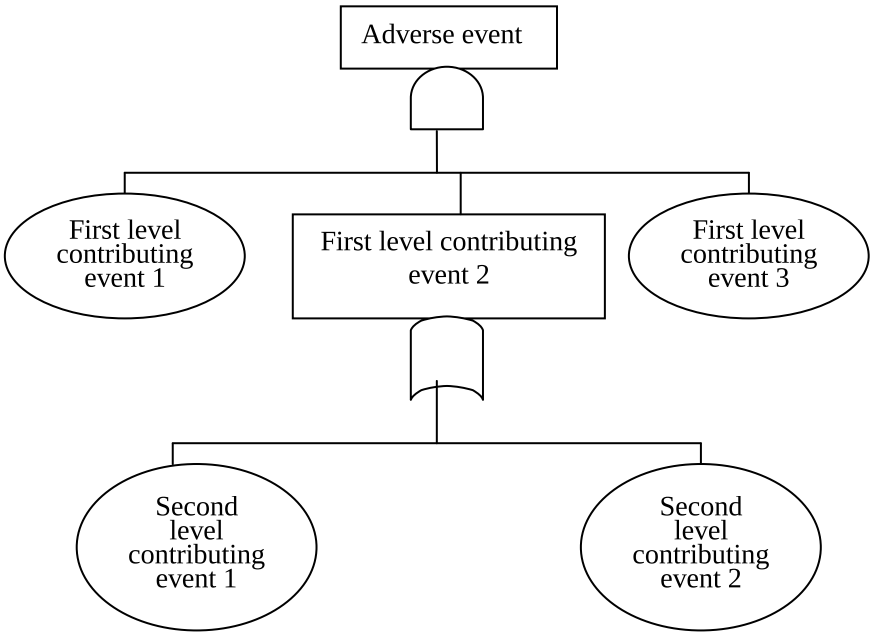

Figure 2-1: Example of structure block of fault tree

After creating the diagram, the analysis is then performed. Through both qualitative and quantitative analysis, the FTA will find out the potential causes of an accident and calculate the possibility of the top event when sufficient data is available as to the possibility of basic events. And finally, according to the result of qualitative analysis, FTA will give recommendations for designing remedies and countermeasures to the undesirable event.

2.2 Symbols and Professional Terms Used in FTA

During the process of constructing a fault tree, it needs unified symbols to demonstrate the role of different elements in the diagram such as top event, basic event and to present the logic relationship between the top event and its contributing events. However, symbols with the same meaning and role may be different in shape as to different designers and different softwares. Figure 2-2 shows the main fault tree symbols that will be used in the rest of this paper.

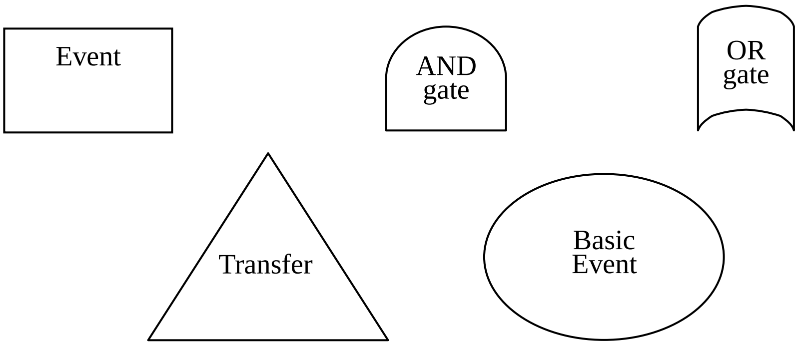

Figure 2-2: Fault tree symbols

*Top Event: Located at the top of the fault tree, top event is the predefined undesired event that needs to be analyzed, and is the combined result of all contributing events and conditions. In this paper, the top event mainly refers to the undesired marine accident.

*Basic Event: The basic events/ conditions, located at the bottom of a fault tree, represents a basic equipment failure or condition that requires no further development of failure causes such as poor visibility.

* Intermediate Event: located between the top event and a basic event, intermediate event is the results of one or more basic events or other intermediate events.

*AND Gate: Used when multiple elements must be combined together and all of the elements should present or failed simultaneously for a situation to exist or an event to occur, AND Gate presents the logic relationship of different level events/ conditions.

*OR Gate: Used when one or more multiple elements can cause a situation to exist or an event/condition to occur, OR Gate also presents the logic relationship of different level events/ conditions.

*Transfer Symbols: The fault tree, some times, is a big and comprehensive one. It is maybe difficult to display specifically all events some times. Therefore, transfer symbols are used to connect different parts of fault tree. The transfer-out symbol indicates that the fault tree is developed further whilst the transfer-in symbol is used to continue the undeveloped event.

Meanwhile, there are several professional terms used in the process of analysis. Following of this section will give a brief introduction to some main terms.

*Minimal cut-set: A cut set in a fault tree is a set of basic events whose (simultaneous) occurrence ensures that the TOP event occurs.

*Minimal path-sets: In contrast to the minimal cut-set can cause the accident, minimal path-set represents minimal combinations of normal component conditions leading to system success.

* Importance coefficients: Represents the appearance frequency of basic event in the minimal cut-set, reflects the influence degree of basic events to the top event.

2.3 Advantages of FTA

As has been noted that the FTA could be used for any risk analysis before and could be used to analyze accident effectively, this section will give a brief introduction to the advantages of FTA in analyzing marine accident.

(1) The analysis technique of FTA can find the various potential causes of an accident by constructing a fault tree, due to its use of deductive method when analyzing an accident; At the same time, a reliable and well developed fault tree can represent the causal and logic relationship between accident (top event) and all contributing events concisely and graphically.

(2) *"Most reactive and proactive analysis techniques only identify single-event failures. One significant advantage of the fault tree technique is that it can help identify multiple-event failures."* (Guidance on the Investigation of Marine Incidents, 2005) Marine accidents usually are the result of several failure events (Multiple-event failures) including human errors, bad environment, mechanical failures and management failures etc. Therefore, it is essential for investigators to use an accident analysis technique such as FTA with the function of analyzing multiple-event failures.

(3) *"A fault tree can also show design and operational errors. In some cases, equipment performs to its capabilities, but its capabilities are insufficient for the task" (Guidance on the Investigation of Marine Incidents, 2005).* For example, the AIS (automatic identification systems) as navigational equipment may fail to display information of other vessels when it is out of power or its designed power is too low to receive other vessels' signal.

(4) During the process of FTA, the minimal cut set could be calculated after a fault tree has been constructed and a successful tree could be built subsequently according to the minimal path-sets which are transformed from the minimal cut sets. One of the advantages of FTA is that measures for preventing accident could be obtained from the corresponding successful tree.

2.4 Procedures of FTA

Following are the key steps of FTA procedures which recommended in the RISK MANAGEMENT SYSTEM –RISK ASSESSMENT FRAMEWORKS AND TECHNIQUES (Mullai, 2006).

(1)Definition of the system or activity of interest;

(2)Definition of the top or initial event;

(3)Definition of the top structure of the tree;

(4)Exploring each branch of the tree structure in detail;

(5)Solving the fault tree for possible combinations of events;

(6)Identification of important failures;

(7)Quantitative analysis;

(8)Recommendations

As stated in Chapter 1, this paper will use FTA to analyze the risk of marine accident qualitatively with the purpose of finding out causes of marine accident and providing corresponding recommendations for enhancing navigation safety in Hainan jurisdiction consequently, so step1 and step7 will be omitted in the following chapters. Steps 2--4 will be carried out in next chapter—chapter 3 The Constructing of Fault Tree. Steps 5-6 will be represented in chapter 4 and recommendations of step 8 will be given in chapter 5.

CHAPTER 3 THE CONSTRUCTION OF FAULT TREE

The constructing of a fault tree needs to determine the top event and the top structure of the fault tree at first and then use deductive measure to expand the branches of the fault tree until basic events are identified. This chapter will use of data collected from the Hainan jurisdiction to define the top event and refer to the stages in collision avoidance procedure to determine the top structure of the fault tree and finally exploring each branch of the tree structure in detail to build a complete fault tree demonstrating how the basic events can cause a marine accident.

3.1 Define the Top Event of Fault Tree

Top event is the undesirable results which could be machinery failures, human errors, loss event/condition (including potential loss event/condition for near miss) and also could be an event or condition which is a knowledge gap. To define the top event of fault tree is to determine the scope of the analysis and the fault tree.

Commonly speaking, the top event in marine accident analysis is the (potential) loss event/condition. For the marine accident, referring to statistical type of marine accident in Hainan MSA, the following ship casualties/ accidents were considered:

- Collision
- Sinking
- Grounding
- Contact
- Wind
- Fire/ Explosion

Just as other researchers stated that “the collision events are among the most common ship accidents and continuous efforts have been made to prevent this event or mitigate the associated consequences. However, collisions are likely to happen in the future” (Soares & Ant˜ao, 2006). According to the statistics of marine accident from Hainan MSA, 100 marine accidents in total (ordinary degree and upper degrees) happened in the Hainan jurisdiction from the year of 2001 to 2013 and collision accidents occupied 32%.

Considering the number of marine accidents was increasing with the climbing port throughput in Hainan Island during the last years and this situation would be grimmer with the continuous promotion of International Tourism Island in the future. Notably, collision events as the most common ship accidents should be paid much closer attention. Therefore, this paper chooses the type of collision accident as the top event of fault tree to research with the purpose of finding out the potential causes of collision accidents after constructing a related fault tree.

3.2 Define the Top Structure of Fault Tree

Normally speaking, the ship collision is a dynamic procedure and the occurrence of a collision accident includes four stages. According to The Principles of Collision Prevention at Sea these stages are: Free action stage, Risk of collision exist stage, close-quarters situation stage and immediate danger stage (Zhao & Wang, 1999).

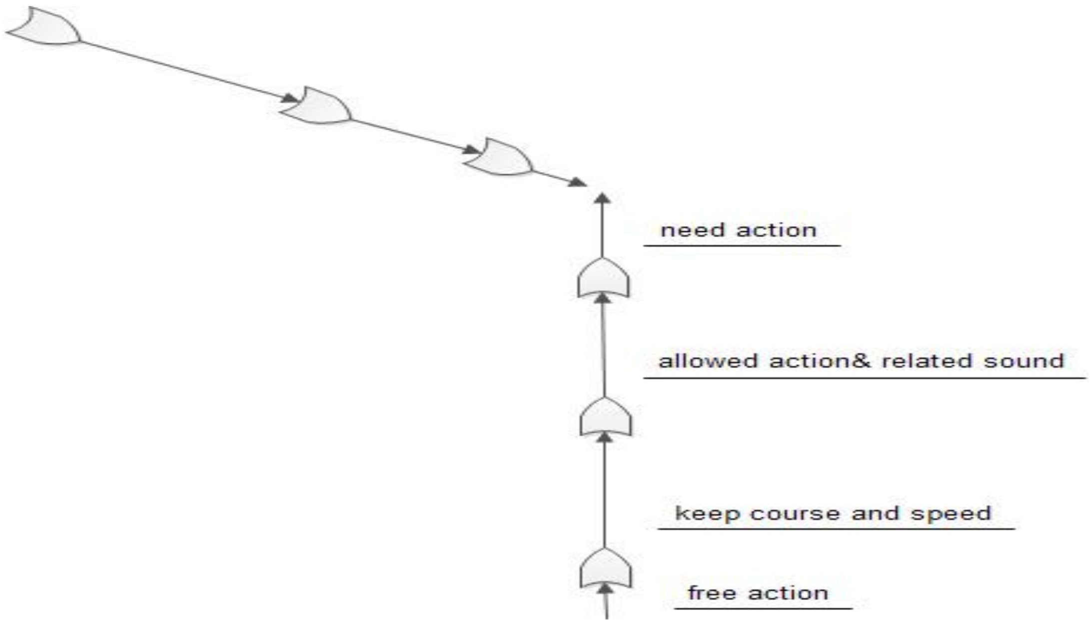

Figure 3-1: The four stages in collision avoidance procedure-2

Source: The Principles of Collision Prevention at Sea (P201)

●Free action stage: In a long distance before the existence of collision risk, the vessels' action is not restricted by the action rule and vessels can adopt free action. Usually, most of duty seafarers choose do nothing at this stage, while few of them take actions such as changing the vessels' speed or course due to the special waters where it has difficulty in avoiding collision and easily lead to uncoordinated behavior.

●Risk of collision exist stage: At the beginning of risk exists, *"action taken to avoid collision with another vessel shall be such as to result in passing at a safe distance.*

The effectiveness of the action shall be carefully checked until the other vessel is finally past and clear."(COLREGS: International Regulations for Preventing Collisions at Sea 1972 Rule 8/4) In reality, most vessels adopt proper actions such as changing course or lowering down speed or communicating with coming vessel at this stage. While some vessels do not adopt any action at this stage and lead the vessel steps into the next stage-- close-quarters situation stage. The detection of such risk through proper look-out is most important and is the premise of adopting anti-collision actions.

●Close-quarters situation stage: When the give-way vessel does not act according to the COLREGS as the risk of collision already exist, the stand-on vessel shall use signal and then be allowed to adopt anti-collision action alone for preventing collision. So we can say that the purpose of anti-collision action adopted by the give way vessel is to avoid the forming of Close-quarters situation and the Close-quarters situation can determined by whether the vessels could passing at a safe distance or not. In this stage, different from the risk of collision exist stage, the collision accident can not avoid through anti-collision actions adopted by give-way vessel alone. Therefore, it is important to assess the risk of collision and contact with coming vessel through navigational system to determine anti-collision actions.

●Immediate danger stage: In this stage, we may not define the collision as two vessels arrive at the same position at the same time but define it as two vessels pass each other with near miss that is smaller than the safe distance obviously. Therefore, immediate danger stage could be interpreted as the passing distance is smaller than safe distance although both vessels may have adopted best actions for preventing collision. In this stage, the Ship maneuverability plays a key role.

If all vessels navigate according to the rules of COLREGS and adopt right actions among the four stages, collision accidents would not happen. Of course, this model was constructed on the precondition that the weather is acceptable and the ships' propulsion/ steering system are in good order. Therefore, the top structure of fault tree could be constructed according to these stages in collision avoidance procedure as shown in figure3-2.

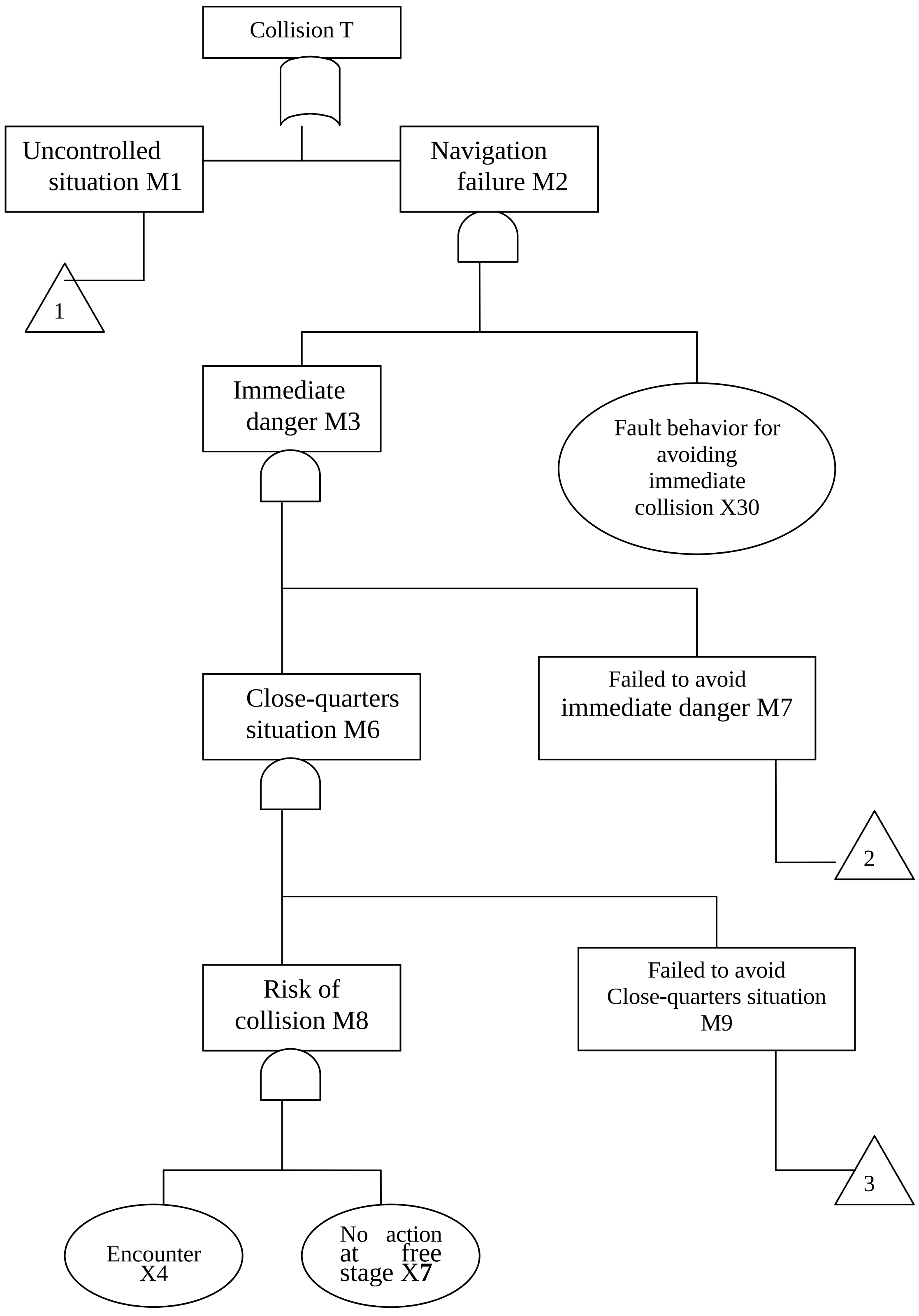

Figure 3-2: Top structure of fault tree (need to be explored)

3.3 Exploring Each Branch of the Tree Structure in Detail

Simply speaking, a system includes various elements and there are organic connection between elements and elements, elements and system, system and external environment. The stability of a system based on the stable connections otherwise the system will be in chaos.

As to the collision system, same as a normal system, it includes three main elements which are: Personal sub-system, environmental Context and Machinery sub-system. (Zheng &Wu, 2001, P70) In other words, the existence of collision system is based on the existence of those three elements with organic connection. When we research on the collision accident, the research purpose is to find measures to avoid accident or decrease probability of the collision accident by studying the mechanism of collision accident and analyzing the related causes. However, one should bear in mind that the system of collision accidents is also one sub-system of navigation system, therefore it needs to take other sub-system of navigation system that may impact the vessel collision into consideration when studying the mechanism of collision accident. Because the Qiongzhou VTS (vessel traffic service) center has been set up and the Ship's Routing System (SRS) in Qiongzhou Strait has been practiced, hence VTS and SRS will be taken into consideration when exploring the fault tree.

Furthermore, because arranging sufficient seafarers to keep proper look-out and persons to supervise is important for preventing marine accidents, such management aspect will also be taken into consideration when exploring the fault tree. In another word, all components (including environmental context, organizational/management infrastructure, personal and machinery) showed in the integrated system Figure 1-2 in Chapter 1 will be considered during the process of exploring fault tree.

Following fault trees (from figure 3-3 to figure 3-7) are constructed according to the top structure (figure 3-2) one by one.

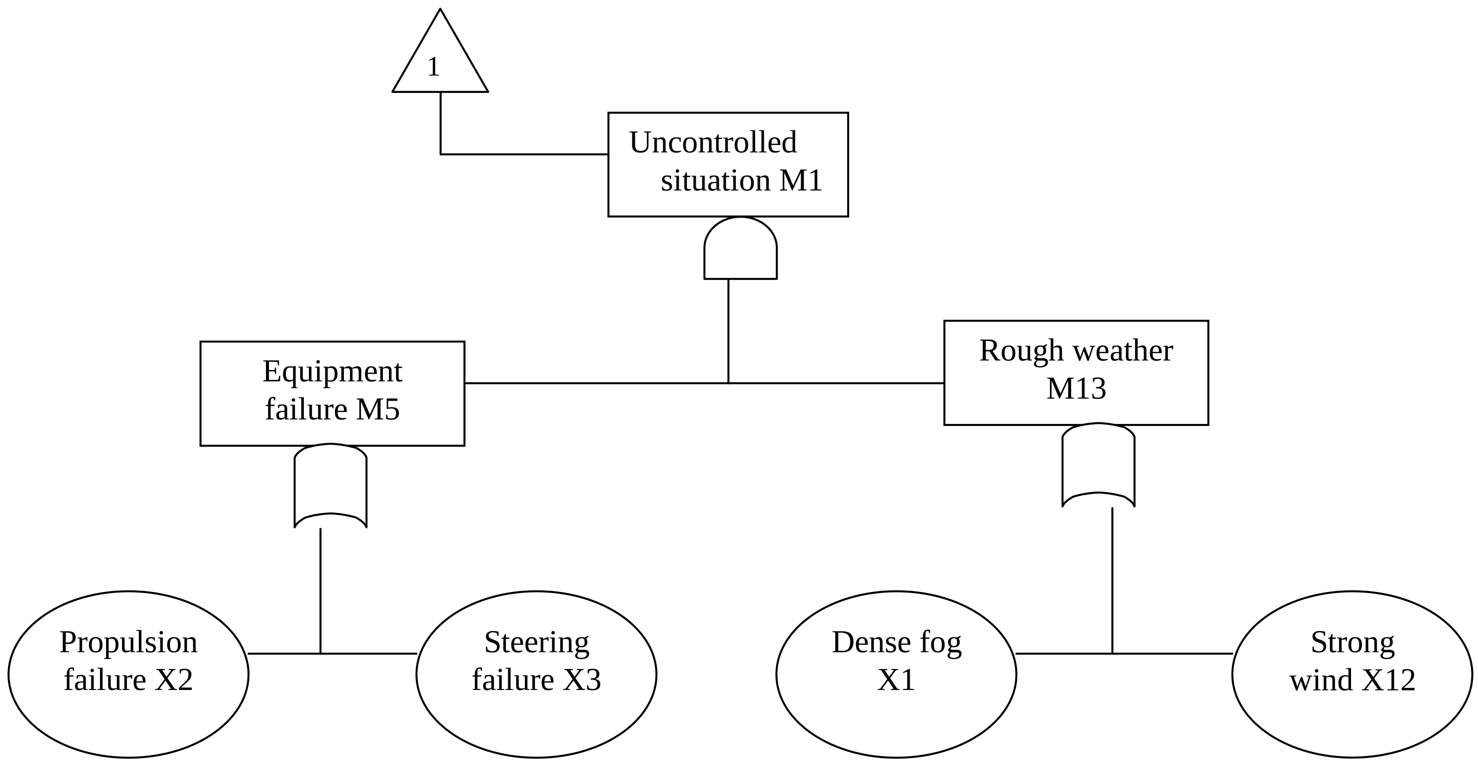

Figure 3-3: Developed fault tree (continued)

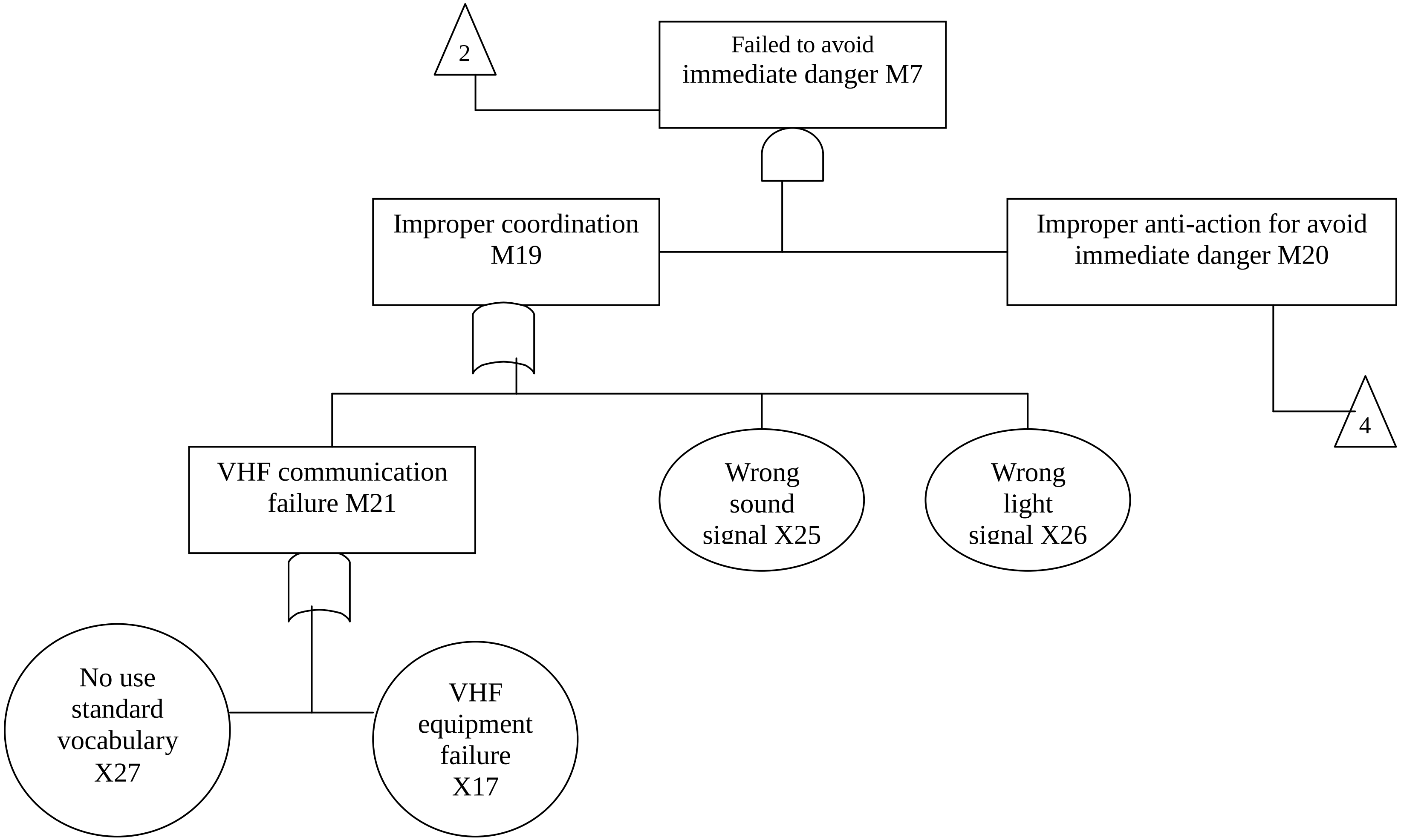

Figure 3-4: Developed fault tree (continued)

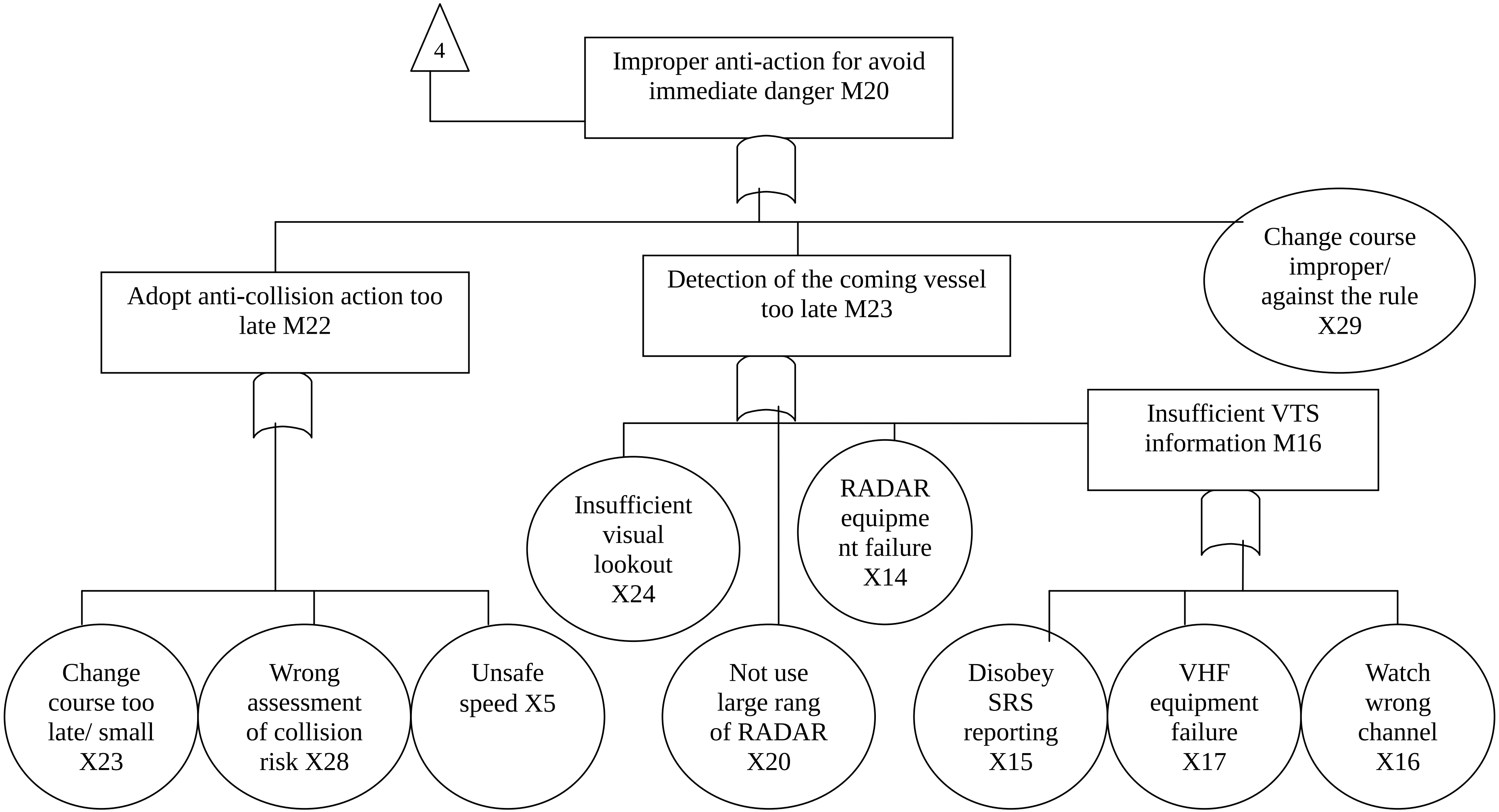

Figure 3-5: Developed fault tree (continued)

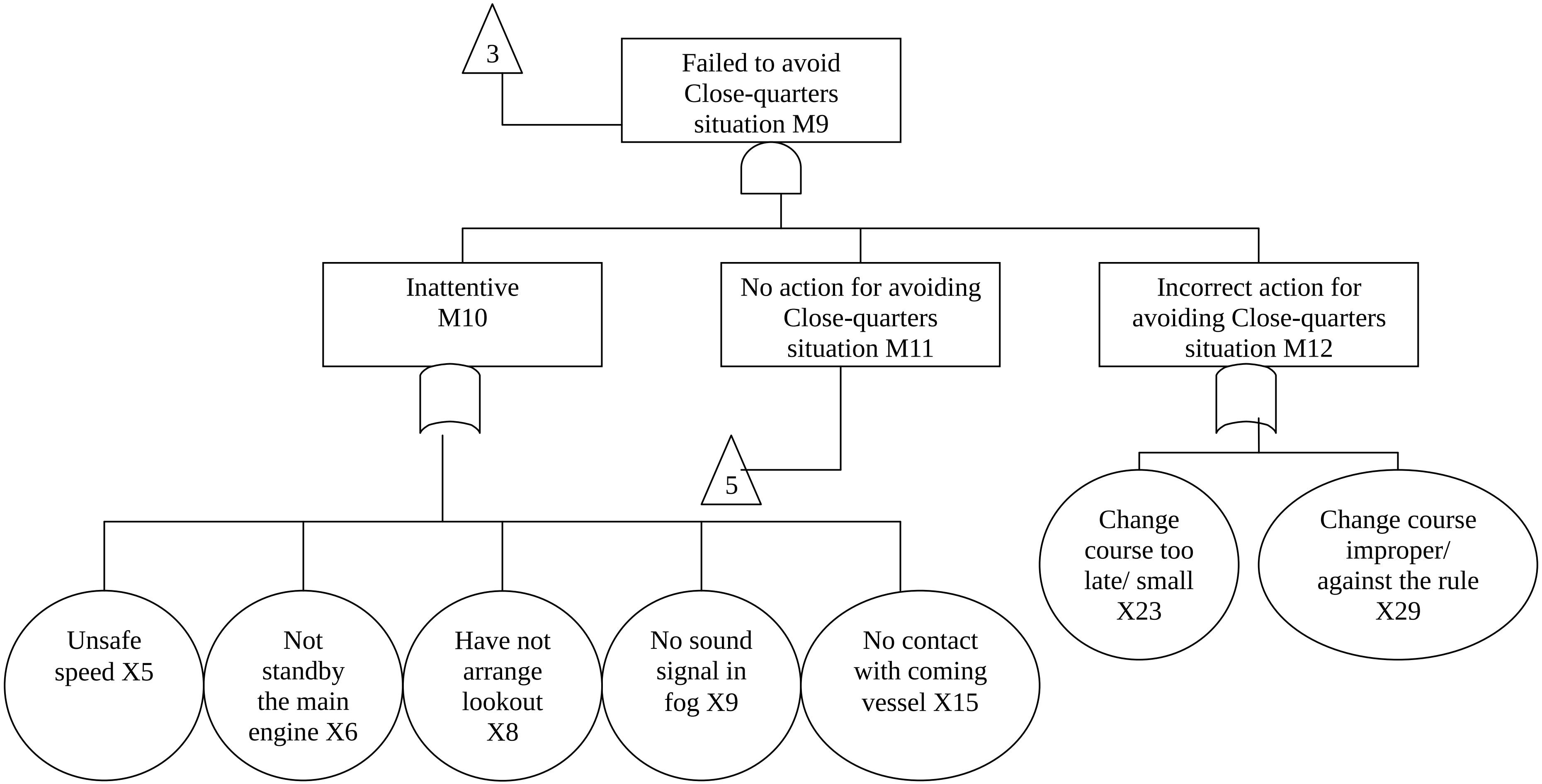

Figure 3-6: Developed fault tree (continued)

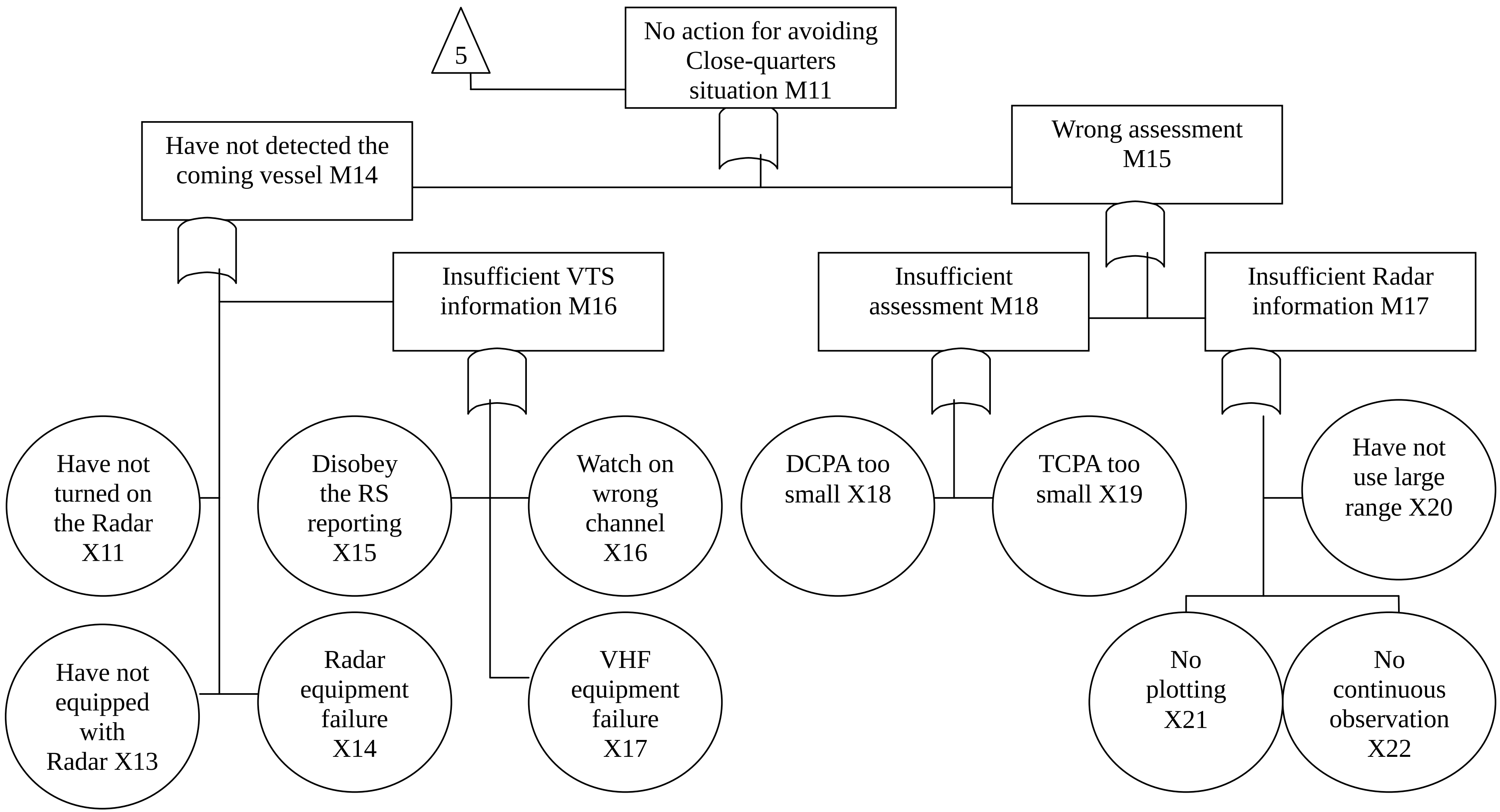

Figure 3-7: Developed fault tree (continued)

CHAPTER 4 ANALYZE THE CAUSES OF COLLISION ACCIDENT

In order to find out the causes of collision accidents, it is necessary to analyze the fault tree and find out which basic event or combined events can result in the occurrence of the top event. In the technique of FTA, calculating the minimal cut sets (MCS) could identify which basic event or combined events as the causes of top event. Furthermore, it also can determine the extent of impact of basic events contributing to the top event (collision accident) by calculating the importance coefficients of basic events (ICOBE). Thus, this chapter will focus on calculating the MCS of fault tree and the ICOBE(s) of basic events with the purpose of finding out the causes of collision accidents and the influence of basic events.

4.1 Minimal Cut Sets

If all basic events happen in a fault tree, the top event will happen. However, the top event would still happen when only one or few basic events happened factually. Therefore, after the fault tree of collision accident has been built, it is an important step to search all basic events combinations which could lead to the occurrence of top event (collision accident). These combinations are known as Minimal Cut Sets.

According to the logic relationship of events in the fault tree of collision, the Boolean algebra formula for calculating MCS could be derived as follow:

$T=M_1+M_2=M_5M_3+M_3X_{30}$

$=(X_2+X_3)(X_1+X_{12})+M_6M_7X_{30}$

$=(X_2+X_3)(X_1+X_{12})+X_8M_9M_{19}M_{20}X_{30}$

$=(X_2+X_3)(X_1+X_{12})+X_4X_7M_{10}M_{11}M_{12}X_{30}(M_{21}+X_{25}+X_{26})(M_{22}+M_{23}+X_{29})$

$=(X_2+X_3)(X_1+X_{12})+X_4X_7(X_5+X_6+X_8+X_9+X_{15})(M_{14}+M_{15})(X_{23}+X_{29})X_{30}$

$(X_{27}+X_{17}+X_{25}+X_{26})(X_{23}+X_{28}+X_5+X_{24}+X_{20}+X_{14}+M_{16}+X_{29})$

$=(X_2+X_3)(X_1+X_{12})+X_4X_7(X_5+X_6+X_8+X_9+X_{15})(X_{11}+X_{13}+X_{14}+M_{16}+M_{18}+M_{17})$

$(X_{23}+X_{29})X_{30}(X_{27}+X_{17}+X_{25}+X_{26})(X_{23}+X_{28}+X_5+X_{24}+X_{20}+X_{14}+M_{16}+X_{29})$

$=(X_2+X_3)(X_1+X_{12})+X_4X_7(X_5+X_6+X_8+X_9+X_{15})$

$(X_{11}+X_{13}+X_{14}+X_{15}+X_{16}+X_{17}+X_{18}+X_{19}+X_{20}+X_{21}+X_{22})$

$(X_{23}+X_{29})X_{30}(X_{27}+X_{17}+X_{25}+X_{26})$

$(X_{23}+X_{28}+X_5+X_{24}+X_{20}+X_{14}+X_{15}+X_{16}+X_{17}+X_{29})$

With the help of software (Easy draw), 314 cut sets were found. Obviously, one of the cut sets happened, the top event (collision accident) would happen necessarily. In another word, there are 314 probabilities that can lead to ship collision accident in Hainan jurisdiction.

4.2 The Importance Coefficients of Basic Events

All basic events have impact on the top event; however, their extent of impact is different. Ignoring the occurrence probability of basic events, analyzing the extent of impact of basic events contributing to the top event barely helps to pick out the basic events that should be paid more attention to. In the technique of FTA, the extent of impact of basic events could be expressed as Importance Coefficients of Basic Events. The formula for calculating the ICOBE showed as follows:

$$I_k(i)=\frac{1}{k}\sum_{r=1}^{k}\frac{1}{m_r(X_i \in E_r)} \qquad (i=`,2,3,\cdots,n)$$

Here, the “k” is the amount of cut sets; “m_r” is basic events; “X_i” is the repeated times of basic events in the minimal cut sets “E_r”

With the help of software--Easy draw, the ICOBE showed in the Table 4-1.

Table 4-1 Importance Coefficients of Basic Events

Basic events	Importance Coefficients
X30, X4, X7	0.993539147950
X23, X29	0.919620574460
X25, X26, X27	0.792958432524
X2, X3, X1, X12	0.750000000000
X5, X6, X8, X9, X10	0.635197371218
X11, X13, X14, X15, X16	0.376527555087
X18, X19, X20, X21, X22	0.376527555087
X17	0.272023843328

4.3 Main Causes of Collision Accident in Hainan Jurisdiction

According to the combination of basic events (MCS) and the ICOBE, the main causes of ship collision accidents in Hainan jurisdiction are listed in the order of importance as follows:

(1) When the target vessel comes into the scope of self-ship, the encounter situation is formed with the intersection of both vessels' courses (X4). At the stage of free action, due to blind confidence or because the coming vessels have not been detected, duty seafarers take no action while adopting permissive attitude to the approach of target vessel (X7). After close-quarters situation has been formed, due to careless or lack of skilled manoeuvre ability, the duty officer adopts fault behavior for avoiding immediate collision (X30).

(2) At the free action stage, due to the blind confidence or wrong assessment of the collision risk, duty officer adopts anti-collision actions but with too late opportunity or with too small margin that lead to the close-quarters situation (X23). This fault may also exist at the close-quarters situation stage which would

cause the formation of immediate danger. Another similar fault is that the duty seafarer adopts anti-collision actions which disobey the rules of COLREGS (X29).

(3) According to the rules of COLREGS, vessels should sound signal in the fog area and light signal when the visibility is poor letting other vessels around know the motivation of self-vessel. The right sound/ light signal are important methods for coordinating anti-collision action for all vessels too. However, some seafarers are not familiar with the rules of COLREGS or because of carelessness and wrong sound / light signal some times (X25/ X26). During the VHF communication process, using nonstandard vocabulary (X27) could lead to the misunderstanding of coming vessels' intention and the possible occurrence of collision accidents.

(4) When unexpected rough weather emerges on sea, some vessels keep on shipping in dense fog or strong wind (X1/X12). This kind of adverse environment may be an unignored and uncontrolled factor to the ship collision accident some times. The ships' propulsion/ steering system failure (X2/ X3) could lead to the ship collision accident where the vessel density is high.

(5) Vessels adopt unsafe speed (X5). Before or after collision risk exists, seafarers did not standby the main engine for emergency (X6). This kind of fault may connect with the seafarers' alertness. In poor visibility or with high ship density, officer dose not arrange sufficient seafarers to keep good lookout (X8). This failure may deprive the duty officer of surrounding information and give a wrong assessment to the collision risk. Where the visibility is poor, ship dose not send out sound signal (X9) according to the rules of COLREGS. When anti-collision actions are needed, duty officers do not communicate with coming vessel(s) through VHF (X10) to coordinate each other's action.

(6) Ship is not equipped with RADAR(s) according to the requirement of

International Convention for Safety of Life at Sea (SOLAS) for International voyage ship or requirement of The Rules of Navigation Ships Statutory Inspection Technology 2012 for domestic voyage ship in China (X13); RADAR(s) on board has/have not been turn on (X11) to help the duty officer detecting other vessels/obstacles' position/trend; The equipments of RADAR has broken down (X14); Officer had not reported to the port control center before the ship went into the Ship's Routing System (SRS) in Qiongzhou Strait (X15) / seafarer has turned on the VHF (very high frequency) equipment but watches on a wrong channel (X16)/ the VHF equipment on board has broken down (X17), which leads to lack of traffic information about the Strait from the Qiongzhou VTS; The Distance at Closest Point of Approach (DCPA) was too small (X18)/ the Time at Closest Point of Approach (TCPA) was too small (X19), which makes the duty officer give a wrong assessment to the collision risk. The duty officer does not use large range of RADAR to detect the long distance vessels or obstacles (X20)/ not observe the RADAR continuously (X22)/ not plot the target ship (X21), which leads to lack of RADAR information sufficiently.

CHAPTER 5 ANALYZE THE ANTI-COLLISION MEASURES

Once a marine accident happens, it will directly affect the safety of crew and causes economic and environmental damage possibly. Meanwhile, the marine salvage is not as timely as on land, so preventing the occurrence of marine accident at sea is particularly important. To ensure the safety of marine transport, Hainan MSA has adopted safety management measures from technical and management aspects according to the related international marine conventions such as SOLAS and STCW, and has made considerable progress in the management of marine transport. However, it is notable that the amount of marine accident increases along with the growth of port throughput.

Therefore, this chapter will review the main methods that have been adopted in Hainan jurisdiction at first and then concentrate on the analysis of anti-collision measures through the technique of FTA as a complement to enhancing the shipping safety.

5.1 Main Measures Have Been Adopted

China, as an important member of IMO, is well aware of the responsibilities and obligations concerning the safety, security and environmental performance of shipping industry. To ensure the safety of navigation, Hainan, as a province of China, has adopted the measures established by IMO and measures combined with its practical situation for preventing marine accidents in its jurisdiction.

5.1.1 Technical measures

In order to ensure navigation safety as well as to prevent and reduce marine accidents, the International Maritime Organization (IMO) promotes vessels should be designed, constructed and maintained in compliance with safety requirement and be equipped with high-tech equipments (such as RADAR, ARPA, GPS, AIS) assisting navigation by establishing and publishing many Conventions, codes, guidelines and standards (such as SOLAS, LL1966 etc.). Hainan MSA has implemented the standards made by IMO for international voyage ships and the standards formulated by the Chinese government for domestic voyage vessels through the Ship-certification System and Port/Flag State Control System.

5.1.2 Management measures

In addition to the implementation of the International Regulations for Preventing Collisions at Sea (COLREGS)(unified the rule and standards for preventing collision), the International Convention on Standards of Training, Certification and Watch keeping for Seafarers (STCW 78/95)(with the purpose of improving seafarers quality and ability), as well as the International Management Code for the Safe Operation of Ship and for Pollution Prevention (the ISM Code)(with the purpose of enhance shipping safety through management), Hainan jurisdiction has adopted additional measures to prevent marine accidents.

In the year of 2002, to enhance the traffic management in Qiongzhou Strait of Hainan jurisdiction, the Qiongzhou Strait vessel traffic service (VTS) has been set up. Furthermore, commenced from 2007, the Ship's Routing System (SRS) in Qiongzhou Strait was practiced to make the ship traffic smoothly. Furthermore, a local regulation (Hainan Province Qiongzhou Strait Waters Navigation Safety Management Regulation) has been established and takes into effect from May 2003 with the purpose of improving the navigation safety in this area.

Although we can not deny the positive role of those measures and their obvious effect in enhancing navigation safety, many marine accidents still happen every year and a great amount of economic losses caused by accidents in the Hainan jurisdiction indeed. Beyond that, the tendency of marine accidents seems will keep rise as the result of increasing throughput in the future.

Hence, we should take other more active measures to improve the risk management on water transport. Considering the navigation-safety situation and the trend of Hainan jurisdiction, using the technique of RA, as a complement to technical and management measures, to analyze the marine accident and find out the root causes of marine accidents will be helpful for enhancing the safety-management level in navigation domain.

In the last chapter, the causes of collision accident in Hainan jurisdiction have been found by calculating the MCS and ICOBE. Following of this chapter will concentrate on building the success tree of avoiding collision accident referring to the fault tree of collision accident and the minimal path-sets (MPS) will be calculated out consequently. Finally, measures for preventing collision accident in Hainan jurisdiction will be given according to the MPS at the end of this chapter.

5.2 Minimal Path-sets

5.2.1 Building the success tree of collision prevention

In contrast to the fault tree of collision accident, a success tree of collision prevention presents the paths of preventing the happening of collision accident graphically. In another words, the collision accident will not happen when the paths to collision accident are been blocked according to the success tree. After the success tree of collision accident has been built, the MPS could be calculated out for formulating anti-collision measures.

Due to the dual relationship between fault tree and success tree, it is easy to construct the success tree of collision accident after the fault tree has been built in chapter 3. In the process of building the success tree of collision accident, it need to exchange the logic gate (AND gate change to OR gate and vice versa) that is listed in the fault tree.

From figure5-1 to figure5-3 showing the success tree of collision accident which is constructed according to the fault tree of collision accident in Hainan jurisdiction from figure 3-2 to 3-7.

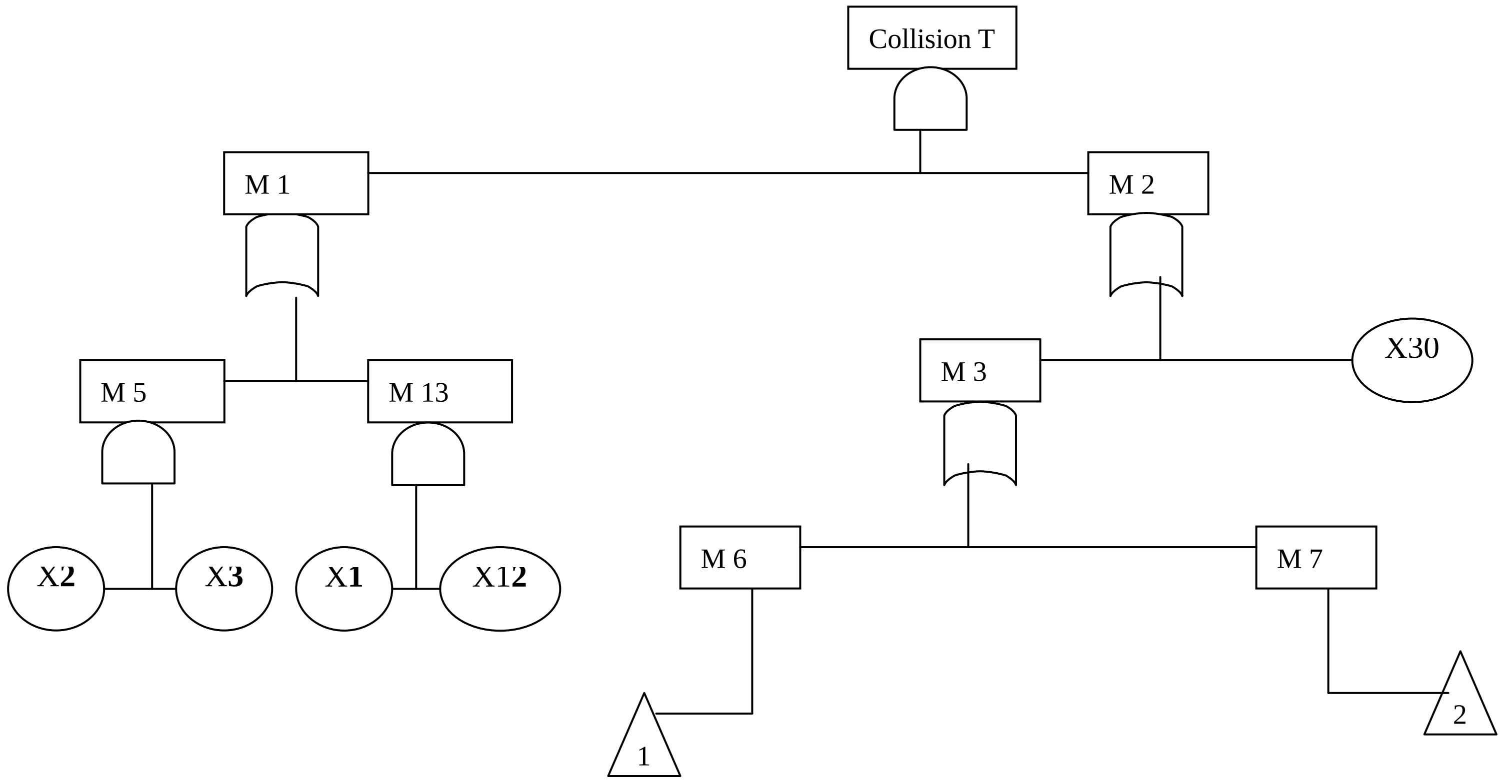

Figure5-1: Success tree of collision accident (need to be explored)

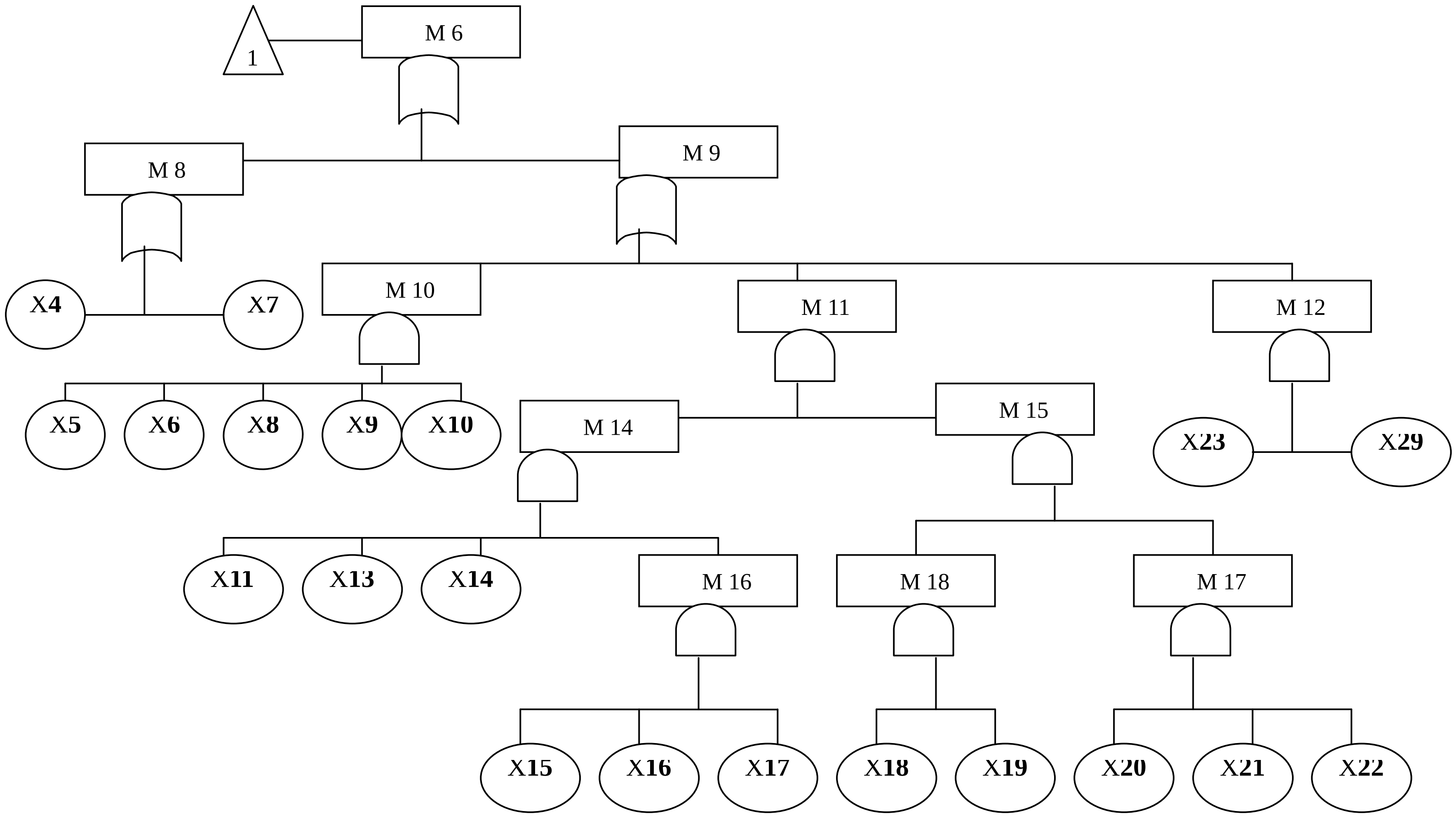

Figure5-2: Success tree of collision accident (continued)

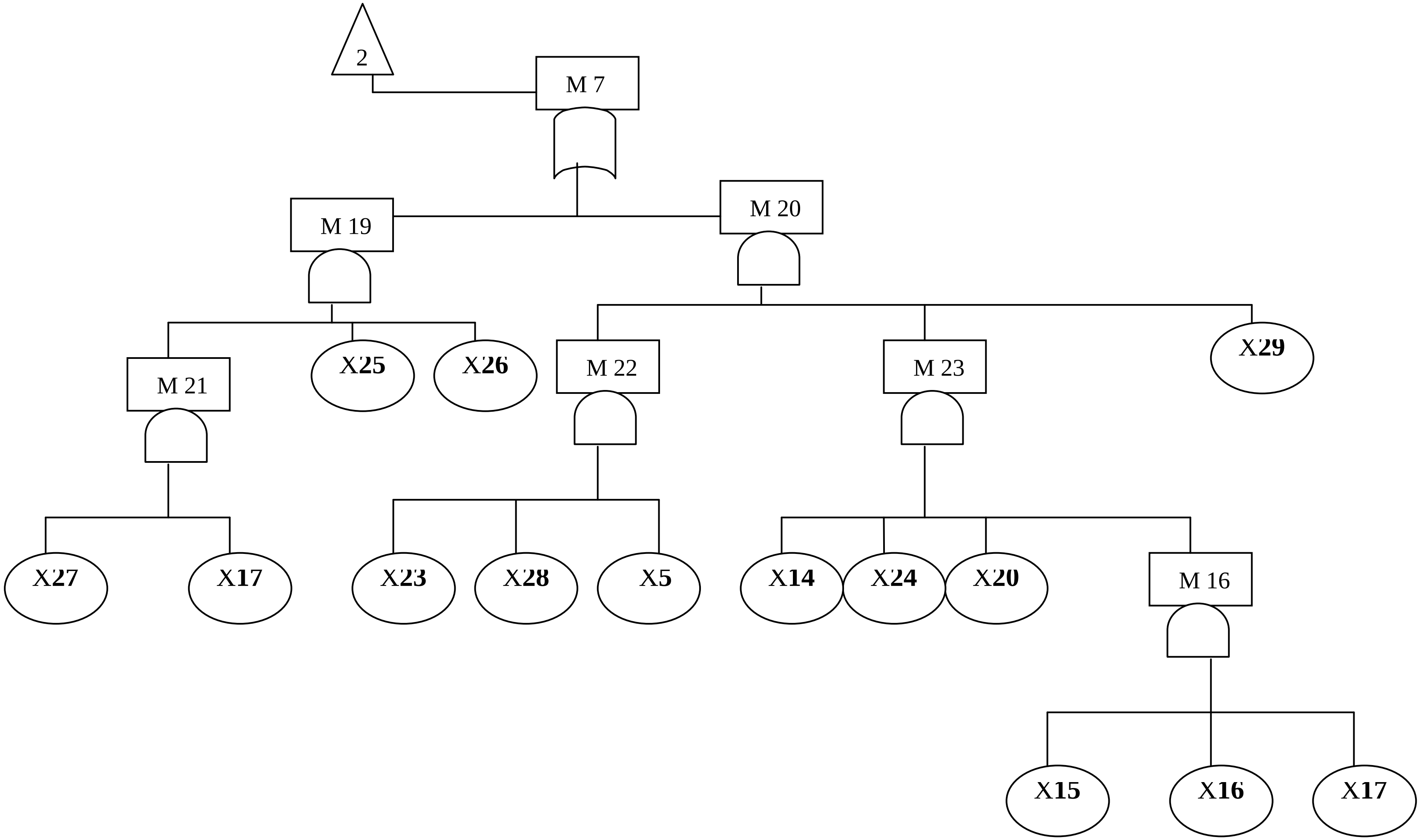

Figure5-3: Success tree of collision accident (continued)

5.2.2 The calculation of minimal path-sets

After success tree has been built, the next step is to calculate the MPS of fault tree. In fact, the MPS of fault tree is equal to the MCS of success tree. Therefore, the MPS could be calculated out by the following Boolean algebra formula:

$T=M_1'M_2'=(M_5'+M_3')(M_3'+X_{30}')$

$=(X_2'X_3'+X_1'X_{12}')(M_6'+M_7'+X_{30}')$

$=(X_2'X_3'+X_1'X_{12}')(X_8'+M_9'+M_{19}'+M_{20}'+X_{30}')$

$=(X_2'X_3'+X_1'X_{12}')(X_4'+X_7'+M_{10}'+M_{11}'+M_{12}'+X_{30}'+M_{21}'X_{25}'X_{26}'+M_{22}'M_{23}'X_{29}')$

$= X_2'X_3' X_4'+ X_2'X_3' X_{30}'+ X_1' X_4' X_{12}'+ X_1'X_{12}' X_{30}'+ X_2'X_3' X_{27}'X_{17}'X_{25}'X_{26}'+ X_1'X_{12}'X_{27}'X_{17}'X_{25}'X_{26}'+ X_2'X_3'X_5'X_6'X_8'X_9'X_{10}'+ X_1'X_{12}'X_5'X_6'X_8'X_9'X_{10}'+ X_2'X_3' X_7'+ X_1' X_7'X_{12}'+ X_2'X_3' X_{11}'X_{13}'X_{14}'X_{15}'X_{16}'X_{17}' X_{18}'X_{19}'X_{20}'X_{21}'X_{22}'+ X_2'X_3' X_{23}' X_{29}'+ X_1'X_{11}' X_{12}'X_{13}'X_{14}'X_{15}'X_{16}'X_{17}' X_{18}'X_{19}'X_{20}'X_{21}'X_{22}'+ X_1'X_{12}' X_{23}'X_{29}'$

According to the result of the formula listed above and with the help of software, there are 14 MPS(s):

P1={X2, X3, X4}

P2={X2, X3, X30}

P3={X1, X4, X12}

P4={X1, X12, X30}

P5={X2, X3, X17, X25, X26, X27}

P6={X1, X12, X17, X25, X26, X27}

P7={X2, X3, X5, X6, X8, X9, X10}

P8={X1, X5, X6, X8, X9, X10, X12}

P9={X2, X3, X7}

P10={X1, X7, X12}

P11={X2,X3,X11,X13,X14,X15,X16,X17,X18,X19,X20,X21,X22}

P12={X2, X3, X23, X29}

P13={X1,X11,X12,X13,X14,X15,X16,X17,X18,X19,X20,X21,X22}

P14={X1, X12, X23, X29}

As long as the basic events listed in the MPS do not happen, the collision accident could be avoided. Therefore, the measures for preventing collision accidents in Hainan jurisdiction could be derived according to the MPS.

5.3 Anti-collision Measures for seafarers and shipping companies

According to the 14 minimal path-sets, measures and requirement for preventing collision accident could be obtained as follows:

(1) The ship's propulsion system is the power source of the ship, it is essential to ensure safety of normal navigation, the safety of life and the safety of property. Therefore, the requirement for high reliability of propulsion system is the basic element to collision prevention. To ensure the serviceability and high efficiency of propulsion system, the ship company should keep regular check and test to the ship's propulsion system (such as test the shortest/crash stopping distance) and make the strict propulsion-system maintenance planning into its PMS (Plan Maintenance System). Meanwhile, engineers on board should keep the main engine in good status through routine maintenance.

The ship maneuverability will play an important role in the process of collision prevention when there is a collision risk. If the steering system failure or lags in response, collision accident would happen although the decision for avoiding accident was right. Therefore, attention equal to propulsion system should be paid to the steering system in order to ensure the steering system could work smoothly and comply with the time requirement as stated in the SOLAS Ⅱ/1-Reg.29.3.2

Once the encounter situation emerges, there is collision risk possibly and this risk will be higher when a ship crosses the traffic lane or violates the main flow direction of ship occasionally. To ensure the safe navigation, ship navigating in Hainan jurisdiction should comply with the rule of Qionzhou SRS and report the vessel's position and motivation to the VTS when entering into the traffic lane. Through the coordination by VTS, the probability of encounter will decrease. Furthermore, vessels should take careful observation and change its course early to increase the DCPA when the encounter situation has been formed.

(2) In the stage of immediate danger, the collision can not be avoided through the anti-collision action by only one vessel (Xiong，Li & Zhou, 2010). In other words, the collision may be prevented under the most effective measures by both approaching vessels when the immediate danger has formed and this is under the premise of ship's propulsion and steering system are in good status. In this stage, the seafarers' psychological quality and maneuvering ability plays a key role. Therefore, seafarers could not place undue reliance on the automatic navigation system and should be arranged to maneuver the ship by hand regularly in order to familiarize with the vessels' maneuverability. At the same time, ship companies should organize regular training for cultivating the seafarers' psychological quality of calm, bold but cautious when confronting the immediate danger.

(3) As the uncontrollable factor in ship collision accident, rough weather may not affect the navigation frequently but can not be ignored. In the strong wind, ship's true track could hardly be controlled and the seafarers' mentality could be affected with the ship shaking, which is a potential factor that may lead to a collision accident. Meanwhile, considering the impact of blink area of RADAR and the impact of dense fog restricts to the detection of other vessels' position/motivation, rough weather will seriously affect the assessment of collision risk and the adoption of anti-collision measure.

In Hainan jurisdiction，fog is likely to appear in the 1st quarter of a year and typhoon usually emerges in the 3rd quarter of a year (Navigation Guarantee Department of the Chinese Navy Headquarters, 2011, P131). Therefore, vessels shipping in the Hainan jurisdiction during that period should pay close attention to the weather forecast and decide the beginning of voyage carefully referring to its anti-wind capability as well as close attention to the suggestion of port control.

If navigating in rough weather, duty officer should contact the VTS center frequently for sufficient information of other vessels' intention around as well as change self-ship's motivation according to the suggestion of the local VTS to decrease the probability of encounter with other vessels.

(4) It is better to stop engine and wait for rough weather to pass especially when the seafarers are lack of confidence in good seamanship performance. Collision accident would happen inevitably because it is easy to enter into the stage of immediate danger when there is dense fog or strong wind and the seafarers can not maneuver the vessel effectively at the same time.

(5) In the process of preventing collision accident, coordination among vessels is important even if the propulsion and steering system is in good condition. Without concerted action, ships may approach to the same point at the same time, which will lead to the occurrence of collision accident. Therefore, using VHF contact with other vessel and giving visual/ sound signal to present ships' intention before adopting anti-collision action will help to avoid ship collision.

Seafarers should take regular maintenance to the VHF equipments (including the antenna，circuit, power source and terminals etc) according to the ships' Plan for Maintenance& Repair of Radio Equipment and keep them in good status. It is better to check the performance of VHF equipments before the voyage confirming the effective communication distance and the quality of voice communication. When collision risk exists, seafarers should contact the coming vessel actively and use standard phrases according to the SMCP (Standard Marine Communication Phrases) that could avoid misunderstanding of each other.

However, the VHF has been widely used in preventing collision accident, it can not replace the position of sound/light signal for the VHF communication may be interfered by other vessels at the same time. Therefore, sound and light signal as the conventional methods used to reflect ship's motivation and intention should be complied according to the COLREGS strictly. In practical work, Seafarers should release right sound/light signal when the visibility is poor or when changing the ships' course/ speed for preventing collision.

(6) The seafarers on duty should reflect self-boat motivation and intention early through sound/light signal properly even if there is no dense fog and strong wind when there is risk of collision. As a complementary measure, the VHF equipment should be kept in use at any time.

(7) Vessels should adopt the safe speed at any time according to regulation 6 of COLREGS. The safe speed should be determined according to the visibility, traffic density， the ship's maneuverability, wind force, the ship's draft and so on in order to stop the vessel within the distance appropriate under the prevailing circumstance and condition. Therefore， the duty officer on bridge should give a comprehensive consideration on all factors to decide the ships' speed. Furthermore, it is better for seafarers to slow down the vessels' speed when the situation is not clear and slower speed can save more time for assessing the situation when collision risk exists.

Given that the fog weather emerges in the 2nd quarter of a year and fog usually rises in the morning, vessels navigating in Hainan jurisdiction during this time are recommended to standby main engine. Meanwhile, standby engine is the prerequisite of stop engine and decrease speed when there is risk of collision. Generally speaking, when the visibility is less than 5 n-miles, the officer on bridge should require the engineer to stand by the main engine because the process of stand by engine will cost a few minutes (Yao, Ren & Li, 2010).

The duty officer should arrange sufficient persons for lookout according to the environment. When ship navigates in Qiongzhou strait, it is suggested that add additional persons for lookout for the high density of ship traffic in the strait. When the visibility is poor, the duty officer should also add persons for lookout and sound signal too.

When there is risk of collision, the duty officer should contact with the coming vessel actively as early as possible through VHF or demonstrate self-vessels' intention/motivation through sound/light signal.

(8) Although the seafarers may be careful enough by adopting safe speed, standby the main engine, arranging sufficient persons for keeping lookout and keeping good seamanship in coordinating with other vessels, it is better to avoid shipping in strong wind. Vessels in Hainan jurisdiction are recommended to stop navigation and take shelter from the wind temporally when the typhoon is coming.

(9) The best way of preventing collision accident is avoiding collision risk initially at the first stage—free action stage. If proper actions have been adopted, the risk of collision may be avoided and the risk of collision exists stage will not be formed. Therefore, duty officer could contact the coming vessel actively and change the ship's course properly to make sure the passing distance is safe. Of course this situation also requires the ship's propulsion and steering system to be in good status at the same time.

(10) When there is rough weather, active measures for preventing collision in the free action stage adopted by ship would be more important. It is hard to maneuver the ship under adverse weather especially in strong wind. So the officer on duty should take action as early as possible to reduce the possibility of collision risk when confronting rough weather such as dense fog and strong wind.

(11) Deemed as the eye of seafarer, RADAR has been widely used in helping prevent

collision accidents especially when the visibility is poor. RADAR can detect the coming vessels from a long distance and also can provide the coming ship's track. Therefore, ships should be equipped with sufficient RADAR according to the requirement of SOLAS as well as keep them in good condition. When the ship is already in the risk of collision, the officer should make sure that the RADAR has been turned on for detecting risk targets around the ship and set the DCPA and TCPA properly for sufficient assessment to the collision risk as well as keep continuous observation on the RADAR with plotting for collecting sufficient RADAR information.

As a supplementary means of detecting the risk targets, officer on the bridge should take the advantage of VTS for obtaining sufficient traffic information through the means of reporting the ships' position and motivation when entering into the SRS, and the means of keeping listening on the VHF channel 16 (channel 25 should be kept on watch too by the domestic voyage vessels when shipping in the Hainan jurisdiction).

(12) Although the propulsion and steering system is in good condition, seafarers should keep cautious and take anti-collision measures as early as possible and as large as possible when the risk of collision already exists. After determined the motivation and intention of coming vessel, seafarers on duty should avoid a series of small changes on course and speed. Meanwhile, the meaning of "as early as possible" is in connection with both time and distance. Seafarers should take anti-collision measures early to save time for coordinating each other and preventing the situation of no time for correcting uncoordinated behavior during the collision-avoidance process. Furthermore, actions for preventing collision accident should comply with the COLREGS and blind change on course should be avoided.

(13) Seafarers should adopt all effective and sufficient measures to detect the risk targets and collect traffic information through RADAR, VTS, visual& audio lookout, as well as assess the risk of collision correctly especially when navigating in the dense

fog. As to the range of RADAR of 10,000DWT vessels with 15kn speed, the RADAR range may be set with 12 n-miles normally and should change to 24 n-miles & 6 n-miles every 5-10 min for detecting other vessels with a wide scope. Meanwhile, one could deem that the close-quarter situation has been formed when detecting the sound signal of other vessel in the dense fog environment (Zhao & Wang, 1999, P51, P1124).

(14) Seafarers should take anti-collision measures as early as possible and as large as possible with the purpose of such action being detected by the coming ship when the risk of collision already exists. Such anti-collision action should be taken even if the weather is good.

5.4 Suggestions for the Local Marine Safety Administration

It has been previously noted that the system of collision accident is one sub-system of navigation system; therefore it needs to take other sub-system of navigation system that may impact the vessel collision into consideration when studying the mechanism of collision accidents. As the safety supervision and management authority in Hainan jurisdiction, the Hainan MSA may consider the following suggestions to promote the effective implementation of anti-collision measures that has been formulated in section 5.3.

(1) Through the seafarer-certification system, the Hainan MSA could increase the proportion of test pertaining to the knowledge of sound& light signal, the knowledge of SRS, the knowledge of RADAR and the knowledge of SMCP, etc in the examination. The routine supervision to seafarers' maneuvering ability should be emerged into the Port State Control (PSC) and the Flag State Control (FSC).

(2) Through the ship-certification system, the MSA could pay closer attention to the

quality and quantity of navigation ads such as the RADAR and attention to the ship's propulsion/ steering system, etc. the routine regular supervision to the maintenance of such equipments could be implemented in the PSC and FSC.

(3) Through the audit process to the shipping companies, the MSA could strengthen the inspection to the companies' PMS as well as the plan for training seafarers when conducting ISM audit.

(4) In order to enlarge the scope of supervision on sea, the local MSA could consider building more VHF and RADAR stations especially in the area with high traffic density and in the area of shelter anchorage. The Qionzhou VTS as part of Hainan MSA should broadcast the information on weather and traffic to the vessels timely and give safety suggestions to coordinate the vessels' motivation properly in order to decrease the possibility of marine accident.

CHAPTER 6 CONCLUSION

The causes of marine accident are various and complicated. At present, the analysis of marine accidents has become one of the important research projects for experts and scholars around the world, which is helpful for navigation safety and marine environment protection. FTA as the technique of risk analysis could be used as an effective method to analyze the main contributing factors of the marine accident comprehensively as well as present their logic relationship, and formulate anti-accident measures easily for avoiding the occurrence of accidents. The FTA includes qualitative and quantitative analysis. Due to the difficulty in collecting the actual data on human error, FTA only uses qualitative analysis in the marine accident generally in the practical application. It has been proved that the qualitative analysis can also produce good results and be a guide for the seafarers, marine safety managers and marine accident investigators to some extent.

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