8-27-2017

Research on the risk assessment of typhoon preventing for ships in Wenzhou Waters

Kun Yang

WORLD MARITIME UNIVERSITY

Dalian, China

RESEARCH ON THE RISK ASSESSMENT OF TYPHOON PREVENTING FOR SHIPS IN WENZHOU WATERS

By

YANG KUN

The People's Republic of China

A research paper submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2017

DECLARATION

I certify that all the material in this research paper that is not my own work has 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.

(Signature): Yang Kun

(Date): June 29, 2017

Supervised by:

Xie Hongbin

Professor

Dalian Maritime University

Assessor:

Co-assessor:

ACKNOWLEDGEMENTS

It's a great honor for me to spend 18 months studying at WMU and DMU. This is an unforgettable experience in my life, and I am sincerely grateful to all the people who helped and supported me during my study period.

First of all, I am profoundly thankful to my supervisor, Prof. Xie Hongbin, whose valuable guidance and constructive advice helped me complete my research paper.

Secondly, I want to give my sincere thanks to all the professors of MSEM 2017 program, whose rich knowledge and professional teaching broadened my horizons and increased my knowledge.

Thirdly, I must give my heartfelt thanks to Wenzhou Maritime Safety Administration for giving me this learning opportunity, and also deep appreciation to all my colleagues for their supports and encouragement.

Last but not least, I am deeply grateful to my relatives, especially my wife and son, who are always encouraging and supporting me. I will not graduate without their understanding and love.

ABSTRACT

Title of Research Paper: **Research on the Risk Assessment of Typhoon Preventing for Ships in Wenzhou Waters**

Degree: **MSc**

Wenzhou city is located on the southeast coast of China, which is seriously affected by 2-3 typhoons every year, especially for ships in water area. With the rapid development of coastal economy of Wenzhou, the navigational environment and ship condition in Wenzhou water area have become more and more busy and complex. How to ensure the safety of ships in typhoon season has become a hot topic.

In light of the distribution of Wenzhou ports and ships, this paper divides Wenzhou waters into 7 block areas, namely the North-south coastal route waters, Yueqing bay waters, Oujiang estuary and Dongtou waters, Oujiang upstream waters, Feiyun waters, Aojiang waters, and Southern waters of Aojiang river. Five first level evaluation indexes and 18 second level evaluation indexes which affect the safety of ships in each waters are analyzed, and the weight of each factor is determined by using the analytic hierarchy process(AHP). Finally, the safety risk level of 7 waters has been calculated using the fuzzy comprehensive evaluation method.

This paper divides Wenzhou waters into four safety risk levels: low risk, general risk, high risk and extremely high risk. After assessment, the risk level of Yueqing bay waters is low, on the contrary, North-south coastal route waters, Feiyun waters, Aojiang waters and Southern waters of Aojiang River are all in the high risk levels, the risk level of Oujiang estuary and Dongtou waters, in general, is the same as Oujiang upstream waters. It is worth mentioning that the risk level of Aojiang waters is close to extremely high.

Through the division of the risk level of the typhoon preventing for ships in Wenzhou waters, the safety management points of different grades of water areas can be clearly defined. This paper puts forward some suggestions for safety management in several aspects, which can provide reference for the ship preventing typhoon in Wenzhou waters.

KEY WORDS: Ships, Typhoon, Risk level, AHP, Fuzzy Comprehensive Evaluation

TABLE OF CONTENTS

DECLARATION i
ACKNOWLEDGEMENTS ii
ABSTRACT iii
TABLE OF CONTENTS v
LIST OF TABLES vii
LIST OF FIGURES ix
LIST OF ABBREVIATIONS x
CHAPTER 1 Introduction 1
1.1 Research background 1
1.2 Objectives and significance of the research 2
1.3 Research contents and methods 2
1.4 Structure of the paper 3
CHAPTER 2 Status quo of the research 5
2.1 Research status quo of risk assessment of typhoon disasters 5
2.2 Research status quo of risk assessment of navigable waters 6
2.3 Research status quo of typhoon preventing for ships 7
CHAPTER 3 Analysis of risk factors of typhoon preventing for ships in Wenzhou waters 8
3.1 The situation of Wenzhou waters affected by typhoon 8
3.1.1 Introduction to Wenzhou waters 8
3.1.2 Introduction to typhoon 9
3.1.3 The influence of typhoon on Wenzhou 10
3.2 Risk factors analysis of typhoon preventing for ships in Wenzhou waters 11
3.2.1 North-south coastal route waters 11
3.2.2 Yueqing bay waters 15
3.2.3 Oujiang estuary and Dongtou waters 19
3.2.4 Oujiang upstream waters 25
3.2.5 Feiyun waters 31
3.2.6 Aojiang waters 35
3.2.7 Southern waters of Aojiang river 38
CHAPTER 4 Risk assessment of typhoon preventing for ships in Wenzhou waters 43
4.1 Overview of risk assessment system 43
4.2 Selection of risk assessment methods 43
4.2.1 Analytic hierarchy process 43
4.2.2 Gray comprehensive evaluation 44
4.2.3 Fuzzy comprehensive evaluation 44
4.3 Determination of evaluation factors 45

4.3.1 Principles for determining factors....45
4.3.2 Establishment of factor set and comment set....46
4.4 Determinate the weight of factors....49
4.4.1 Establish judgment matrix....49
4.4.2 Consistency test....50
4.5 Risk assessment of each waters based on fuzzy comprehensive evaluation....53
CHAPTER 5 Analysis and countermeasures of risk assessment results....60
5.1 Analysis of results....60
5.2 Countermeasures....61
5.2.1 Strengthen the construction and maintenance of the shelter waters....61
5.2.2 Promote the construction of typhoon warning information center....62
5.2.3 Reasonable deployment of rescue forces....62
5.2.4 Strengthen the protective ability of bridges....62
5.2.5 Revise and improve the typhoon emergency plan....63
5.2.6 Strengthen the safety management of ships....63
5.2.7 Strengthen the maintenance of navigational aids and the clearance of obstructions....64
CHAPTER 6 Conclusions....65
REFERENCES....67
APPENDIX I....71
APPENDIX II....74

LIST OF TABLES

Table 3.1 Ship traffic flow of North-south coastal route waters in the typhoon season 2016.....13
Table 3.2 Accidents and dangerous situations in North-south coastal route waters....................14
Table 3.3 Ship traffic flow of Yueqing Bay waters in the typhoon season 2016.........................17
Table 3.4 Bridges in Yueqing Bay waters.. 17
Table 3.5 Rescue forces in Yueqing bay waters..18
Table 3.6 Accidents and dangerous situations in Yueqing bay waters..19
Table 3.7 Ship traffic flow of Oujiang estuary and Dongtou waters in the typhoon season 2016.. 22
Table 3.8 Bridges in Oujiang estuary and Dongtou waters...22
Table 3.9 Rescue tugs in Oujiang estuary and Dongtou waters..23
Table 3.10 Patrol boats of MSA in Oujiang estuary and Dongtou waters.................................24
Table 3.11 Accidents and dangerous situations in Oujiang estuary and Dongtou waters........... 25
Table 3.12 Ship traffic flow of Oujiang upstream waters in typhoon season 2016.....................27
Table 3.13 Bridges in Oujiang upstream waters... 28
Table 3.14 Rescue tugs in Oujiang upstream waters...29
Table 3.15 Patrol boats of MSA in Oujiang upstream waters...29
Table 3.16 Accidents and dangerous situations in Oujiang upstream waters.............................30
Table 3.17 Ship traffic flow of Feiyun waters in the typhoon season 2016................................32
Table 3.18 Bridges in Feiyun waters...33
Table 3.19 Patrol boats of MSA in Feiyun waters.. 33
Table 3.20 Accidents and dangerous situations in Feiyun waters...34
Table 3.21 Ship traffic flow of Aojiang waters in the typhoon season 2016..............................36
Table 3.22 Bridges in Aojiang waters... 37
Table 3.23 Patrol boats of MSA in Aojiang waters...37
Table 3.24 Accidents and dangerous situations in Aojiang waters... 38
Table3.25 Ship traffic flow of southern waters of Aojiang river in the typhoon season 2016.... 40
Table 3.26 Rescue tugs in southern waters of Aojiang river...40
Table 3.27 Accidents and dangerous situations in southern waters of Aojiang river.................. 41
Table 4.1 Nine scaling ratio table...49
Table 4.2 The value of RI... 51
Table 4.3 Weight and consistency results of first-level factors...51
Table 4.4 Weight and consistency results of secondary factors (natural environment)..............52
Table 4.5 Weight and consistency results of secondary factors (shelter waters)........................52
Table 4.6 Weight and consistency results of secondary factors (navigation environment).........52
Table 4.7 Weight and consistency results of secondary factors (ship).......................................53
Table 4.8 Weight and consistency results of secondary factors (safety management)................53

Table 4.9 Risk assessment results of North-south coastal route waters......................................54
Table 4.10 Risk assessment results of Yueqing bay waters..54
Table 4.11 Risk assessment results of Oujiang estuary and Dongtou waters............................. 55
Table 4.12 Risk assessment results of Oujiang upstream waters..56
Table 4.13 Risk assessment results of Feiyun waters.. 57
Table 4.14 Risk assessment results of Aojiang waters...58
Table 4.15 Risk assessment results of southern waters of Aojiang river....................................59
Table 5.1 Risk assessment results and risk levels of each waters...60

LIST OF FIGURES

Figure 3.1 Contrail of ships in North-south coastal route waters in the typhoon season 2016... 13
Figure 3.2 Contrail of ships in Yueqing bay waters in the typhoon season 2016........................ 16
Figure3.3 Contrail of ships in Oujiang estuary and Dongtou waters in the typhoon season 2016.. 21
Figure 3.4 Contrail of ships in Oujiang upstream waters in the typhoon season 2016............... 27
Figure 3.5 Contrail of ships in Feiyun waters in the typhoon season 2016.................................32
Figure 3.6 Contrail of ships in Aojiang waters in the typhoon season 2016............................... 36
Figure 3.7 Contrail of ships in southern waters of Aojiang river in the typhoon season 2016... 39
Figure 4.1 Risk assessment system for ship preventing typhoon in Wenzhou waters.................48

LIST OF ABBREVIATIONS

GIS	Geographic Information System
AHP	Analytic Hierarchy Process
GRA	Grey Relational Analysis
ECDIS	Electronic Chart Display Information System
BP	Back Propagation
AIS	Automatic Identification System
DWT	Dead Weight Tonnage
MSA	Maritime Safety Administration

CHAPTER 1 Introduction

1.1 Research background

Typhoon cyclone is a strong tropical cyclone produced in the sea. More than 50 countries and nearly more than 500 million of the population are affected by typhoons in different degrees, and the maximum wind force of 83 of them reached 8 or more every year around the world. The rainstorm, gale and storm surge caused by typhoons have a serious impact on infrastructure, human lives, ships and port activities. The research data of typhoon since 1988 shows that approximately 440 deaths and 28.6 billion direct economic losses each year all over the world were caused by typhoon disasters (Lu, 2016). China is one of the countries with the most serious typhoon disasters in the world. Over the years, the coastal areas in southeastern China have suffered heavy casualties and economic losses due to typhoon disasters.

Wenzhou is located on the southeast coast of China, which is affected by typhoon more than 20 times every year. The first threatened by typhoon are the ships operating at sea. If the vessel does not enter the sheltered area in time, it could be in danger, and may cause casualties and the ship to sink. For example, typhoon No. 17 in 1994 caused more than 50 ships to be washed ashore in Wenzhou, killing nearly 1000 people (Zhang, 1996, pp. 34-36); typhoon No. 8 in 2006 caused nearly

800 ships to sink and killed hundreds of people in the Sacheng port of Fujian Province (Lu, 2007, pp. 92-96).

In recent years, with the global climate becoming warm, super typhoon and other extreme weather events occur frequently, and the disasters and impacts are becoming more and more serious.

1.2 Objectives and significance of the research

In addition to 355 kilometers of coastline, there are three great rivers and seven major ports in Wenzhou water area. With the rapid development of economy, port industry, shipping industry, shipbuilding industry are becoming more and more prosperous, so many bridges and large docks are or intend to be built, and the number of ships is still rising. However, the anchorage and sheltered waters for ships preventing typhoon are getting smaller. The contradiction between the development of Wenzhou port economy and the shortage of typhoon shelter waters is becoming more and more obvious.

The purpose of this paper is to determine the safety level of different water areas, by assessing the safety situation of the ship preventing typhoon, and draw up the corresponding typhoon preventing emergency plan so as to ensure the safety of the ships to the utmost extent, and reduce the water traffic accidents which are caused by the typhoon, especially the serious accidents.

1.3 Research contents and methods

Wenzhou waters is divided into 7 block areas, namely the North-south coastal route waters, Yueqing bay waters, Oujiang estuary and Dongtou waters, Oujiang upstream waters, Feiyun waters, Aojiang waters, Southern waters of Aojiang River. This paper chooses the 7 areas as the research objects, analyzing various research methods of preventing typhoon for ships in specific water area both at home and abroad, and finally, adopting the fuzzy comprehensive evaluation method to evaluate the safety risks of typhoon preventing for ships in Wenzhou waters. The specific research methods are as follows.

The navigation environment in Wenzhou waters is combed, and the factors affecting the safety of ship anti typhoon in each water area are summarized. In light of the research results home and abroad as well as the opinions of expert investigations, 5 factors are defined as first level evaluation indexes, natural factors, shelter factors, navigation environment factors, ship factors and safety management factors, and the two-grade index system is established with 18 second level evaluation indexes, using expert scoring method to determine the weight set, and getting the weight of each index factor by using the analytic hierarchy process (AHP). The present research then determines the risk evaluation standards of each index by adopting data analysis and questionnaire survey method, and then confirms the subset of risk evaluation standard so as to establish a fuzzy comprehensive evaluation model, and finally obtains the appraisal results of each water area through the concrete evaluation and calculation.

1.4 Structure of the paper

This paper consists of six chapters followed by two appendices. Chapter one is introduction. The second Chapter is about the present research situation, introduces the research status of typhoon disaster risk assessment at home and abroad, the research status of ship prevent typhoon and the current situation of water traffic safety assessment. Chapter three summarizes and analyzes the situation of Wenzhou waters, the influence of typhoon on Wenzhou waters and risk factors of ship preventing typhoon in each area. In the fourth Chapter, the fuzzy comprehensive evaluation method is used to establish the index system for the risk evaluation of ship preventing typhoon in Wenzhou waters, and calculating the evaluation results in the last. Chapter five analyzes the evaluation results, and puts forward the countermeasures of management. Finally, the last chapter discusses the overall summary and conclusion.

CHAPTER 2 Status quo of the research

2.1 Research status quo of risk assessment of typhoon disasters

The research on risk assessment of typhoon disaster at home and abroad mainly has the following methods: regression analysis method, analytic hierarchy process (AHP), fuzzy comprehensive evaluation method, neural network algorithm, extension method and grey relational analysis method. In recent years, many scholars have carried out a series of studies on typhoon disaster. For example, the studies of Mille (Mille, 1998, pp.184-195), Emanuel (Emanuel, 1988, pp. 1143-1155), and Holland (Holland, 1997, pp.2519-2541) show that rainstorm and gale caused by typhoon are the direct factors causing the disaster, and the severity of the disaster is closely related to the size of typhoon, the greater, the more serious. Kunreuther and Riehard also hold the same view in the article “The status and role of insurance against natural disasters in the united states” (Kunreuther, 1998). Chen Xiang established an assessment model of typhoon disaster, and used the GIS technology, disaster risk index method and weighted evaluation method to classify the risk level of typhoon disaster in Fujian province (Chen, 2007, pp. 6-10). Zhang Lijia selected the gale, 24h rainfall, storm surge and the number of disasters which are caused by typhoon as the evaluation indices, and analyzed the risk of typhoon in the southeastern coastal areas of China (Zhang, 2010, pp. 81-83). Yin Jie analyzed and evaluated the disaster risks of typhoon storm surge in different coastal areas of China based on index system and scenario simulation (Yin, 2011). Wang Zhongdong analyzed and studied 6 different types of Typhoons which affect Wenzhou from 1949 to 2012 (Wang, 2015). Ni Yanbo proposed the methods and measures of anti-typhoon for container ships in Ningbo port (Ni, 2010).

2.2 Research status quo of risk assessment of navigable waters

Scholars at home and abroad have a lot of researches on the risk assessment of navigable waters, of which Japan and Europe have been in a relatively dominant position. Japanese experts have made remarkable achievements in the safety evaluation of ship handling environment and traffic environment, using marine traffic flow simulation, ship handling simulator simulation and other methods (Hiroaki, 1995). Duan Aiyuan proposed a ranking of safety levels of ship traffic environment in different port waters, through the comparison between the unascertained measure model and the fuzzy mathematics evaluation models (Duan, 2006). Zheng Zhongyi and Li Hongxi selected the channel length, the ratio of the ship width and channel width, visibility, wind, flow, traffic volume, traffic density, turning point, VTS management and navigational aids as the evaluation indices, using the grey relational analysis (GRA) method and factor analysis method to determine the weight coefficient of evaluation indices, and finally getting the safety situation of the 10 major ports of China by adopting the fuzzy comprehensive evaluation method (Zheng, 2008, pp.130-134). Hu Shenping and Fang Quangen discussed traffic safety status of Chinese coastal waters by using the FSA method, and suggested a coastal water traffic risk prevention system (Hu, 2010, pp. 50-55). Shi Pingan studied and designed an anti-typhoon intelligent system for a sea area, which is based on VTS, ship information center, typhoon warning center, ECDIS, decision-making system and other hardware devices (Shi, 2010).

2.3 Research status quo of typhoon preventing for ships

Wang Jingquan established a typhoon threat rating model by using BP algorithm of artificial neural network, and then got the data of typhoon preventing by track supplement correction and weather forecast correction (Wang, 2006, pp. 9-12). Ye Zhonghui introduced the measures and key points of the ship's anti-typhoon in the northwest pacific, which has a good reference to other ships (Ye, 2013, pp. 20-23). Pan Weichao proposed typhoon preventing plan, emergency response and other suggestions for inland ships (Pan, 2013, pp. 45-47). This paper is about the analysis of the risk assessment of typhoon preventing, so in addition to the area as a whole to study the topic, it is also necessary to study the influence factors of the ship itself.

CHAPTER 3 Analysis of risk factors of typhoon preventing for ships in Wenzhou waters

3.1 The situation of Wenzhou waters affected by typhoon

3.1.1 Introduction to Wenzhou waters

Wenzhou is located in the southeast coast of China, between the Yangtze River Delta and the Pearl River Delta economic circle. The region is one of China's most economically developed areas. Wenzhou port is one of the important ports along the coast of China and the main port of Zhejiang province for foreign exchanges. After many years of development, Wenzhou port has become an important channel for import and export of marine products.

To the north of Wenzhou waters is the "Wenzhou 8" boundary monument, and the south the junction of Zhejiang and Fujian province, and the western boundary is the coastline. The coastline is 355 kilometers long, while the length of inland waterways is 1135 kilometers, and the area of the sea is 11000 square kilometers. There are 437 islands with an area of more than 500 square meters, such as Dongtou island, Beiji island, Nanji island and Seven star islands. The land area of all islands is about 170 square kilometers and the coastline is about 676 km. Along the coastline, there are large bays and large rivers, such as the Yueqing bay, Wenzhou bay, Oujiang river, Feiyunjiang river and Aojiang river, etc. (WZMSA, 2015)

3.1.2 Introduction to typhoon

Tropical cyclone is a strong cyclone vortex that occurs on a tropical ocean and goes rapidly counterclockwise, with a warm center structure. It is often accompanied by winds, heavy rains and waves, moving from low latitudes to mid-latitudes, with strong destructive power and a great impact on human life. Due to the different generating regions and intensities of tropical cyclones, there are different names in different regions. In the Atlantic, its name is hurricane, and in the Indian ocean and the bay of Bengal it is known as the tropical storm, while in the northwest Pacific it is called typhoon (Duan, 2005, pp. 636-645). Before 2003, China Meteorological Administration stipulated that the tropical cyclones were divided into 4 grades, such as tropical depression, tropical storm, strong tropical storm and typhoon, which was based on the average maximum wind speed per 2 minutes near the tropical cyclone center (CMA, 2003). In 2006, tropical cyclones were re-graded by the China Meteorological Administration, which were divided into six grades, including tropical depression, tropical storm, strong tropical storm, typhoon, strong typhoon and super typhoon (CMA, 2006). The typhoon studied in this paper refers to tropical cyclones with maximum winds greater than or equal to 8, including all tropical cyclones above tropical storms.

Typhoon is a powerful low-pressure system consisting of typhoon eye zone, vortex zone and gale zone. Eye zone is also known as typhoon inner ring, within which the wind speed is very low and the diameter is usually 10-60 kilometers. Vortex zone is also known as the typhoon central circle, which is a maximum wind speed belt located around the typhoon eye zone with strongest convection and precipitation.

The diameter of the vortex zone is usually 200-400 kilometers, which is the most violent and concentrated area of typhoon. The gale zone is also called the typhoon outer ring, which is on the inside of the spiral cloud belt, with the diameter of 400-1000 kilometers (Li, 2003, pp. 152-159).

In marine meteorology, typhoons are divided into dangerous semicircle zone and navigable semicircle zone. The wind direction of the right semicircle in the northern hemisphere is consistent with the typhoon movement path, resulting in wind speed superimposed, which causes the ship to be easily blown into the typhoon moving route or into the typhoon center, and it is difficult to leave. Therefore, in the northern hemisphere, the right semicircle is dangerous semicircle zone, and the left semicircle is the navigable semicircle zone (Liu, 1999, pp. 23-24).

3.1.3 The influence of typhoon on Wenzhou

During the period from 1949 to 2016, there were 196 typhoons affecting Wenzhou. According to the movement path and the landing area, the typhoons which influenced Wenzhou are roughly classified into four categories: The first type of typhoon landed between Xiamen and Wenzhou, which were called the frontal assault typhoon and seriously harmful. Its number reached 105, accounting for 52% of the total. A total of 32 typhoons which landed in the south of Xiamen is the second category. They were known as the south typhoon, which caused the impact of heavy rain in Wenzhou. The third type of the typhoon is north typhoon, which landed in the north of Yueqing. Twenty-one typhoons impacted Wenzhou in the period, accounting for 11% of the total. The last category is called offshore typhoon, which mainly affected Wenzhou waters by gale. It has appeared 38 times, accounting for 20% of the total (WZMNM, 2016).

3.2 Risk factors analysis of typhoon preventing for ships in Wenzhou waters

This section will analyze the seven waters delineated in Chapter 1, respectively, and summarizes the main factors that affect the safety of ship preventing typhoon. The data in this section are from the database of Wenzhou Maritime Safety Administration and Zhejiang Maritime Safety Administration.

3.2.1 North-south coastal route waters

3.2.1.1 Basic profiles

The waters are located in the open sea of Wenzhou, which has 5 north-south routes, such as international route, China eastern road, west road and 2 small ships customary routes.

1. The international route is outside from Beiji island about 25 nautical miles, which can meet all types of ships navigate in all-weather situation. It has the features of wide sea area, straight route, few turning points and unlimited water depth. From the AIS system can be observed that the density of road traffic is very large, and the ships are mostly large and very large types.

2. Eastern route is the common route for 5000-50000 DWT ships transit along the coast of Zhejiang, which crosses with the ships entering and leaving Wenzhou harbor

and the navigation density is very large. The route is relatively straight with few turning points and unlimited water depth.

3. West route is the common route for the ships of 5000 DWT or below to or transit Wenzhou port areas. The route is near the shore and the navigational aids are complete. However, it has many disadvantages such as large density of ships, many turning points in the route, narrow navigable waters and frequent accidents.

4. Two small ship customary routes are suitable for ships of 1000 DWT or below. The waters have many turning points, lots of islands and reefs, many fishing nets and complicated water flow. The navigational aids along the route are not perfect, and some positions indicating marks of the submerged reefs have not been set up.

3.2.1.2 Anchorage

There are no suitable shelters for ships in the area, ships passing through the waters had to look for a suitable anchorage shelter in other places to defend the typhoon.

3.2.1.3 Ship traffic flow

Because the waters is an important part of China's coastal north-south channel, so the ship flow is very large. The contrail and traffic flow data of ships in the typhoon season 2016 (from May 1 to October 31) are calculated in this paper as follows.

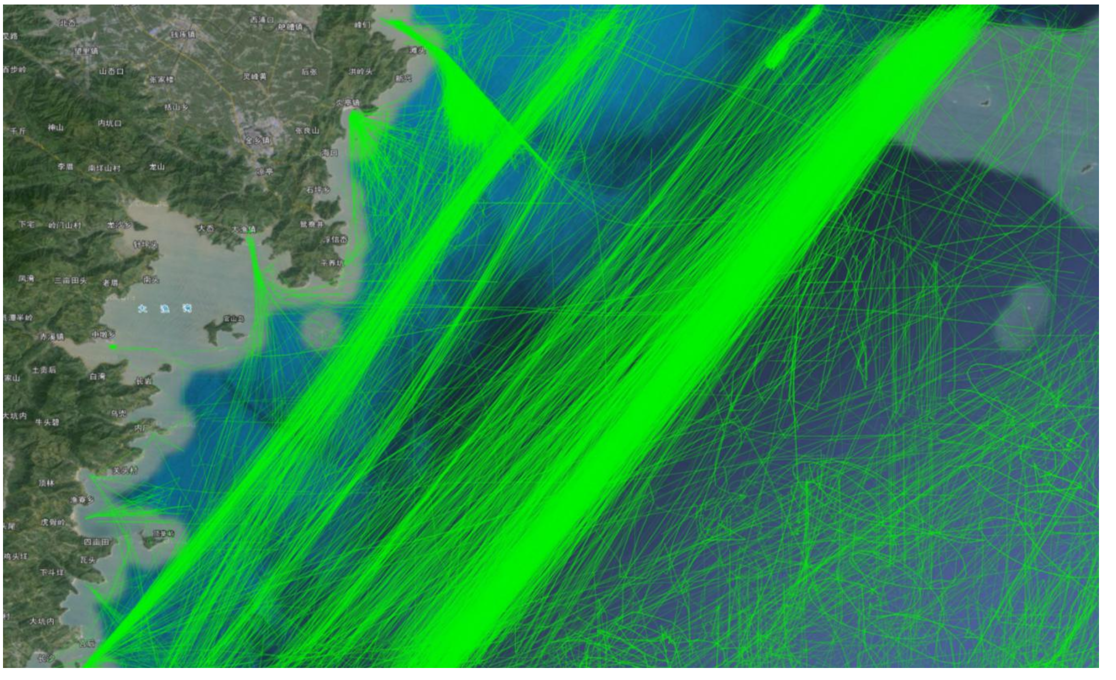

Figure 3.1 Contrail of ships in North-south coastal route waters in the typhoon season 2016

Source: Database of Zhejiang MSA

An observation section is set in this water area. The number and types of ships passing through this section in the typhoon season 2016 are as follows.

Table 3.1 Ship traffic flow of North-south coastal route waters in the typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	49185
2	oil tanker	7203
3	passenger ship	680
4	engineering ship	896
5	fishing boat	64844
6	others	1099
Total number of all ships		123907

Source: Database of Zhejiang MSA

As can be seen from the above figure and table, there are many ships sailing through the waters, and the volume of vessels is intensive. In typhoon season, the number of ships that need to be sheltered is also very large.

3.2.1.4 Bridges

There are no bridges in this water area.

3.2.1.5 Rescue forces

This area does not have emergency rescue power, but there are regular patrols by law enforcement boats of Wenzhou MSA.

3.2.1.6 Accidents and dangerous situations

According to statistics, accidents and dangerous situations caused by typhoon in the waters in typhoon season from 2012 to 2016 are shown in the following table.

Table 3.2 Accidents and dangerous situations in North-south coastal route waters

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualties	Shipwrecks
2012	1	Sunken 1	2	0	1
2013	2	Sunken 1 and dragging anchor 1	15	0	1
2014	0	0	0	0	0
2015	0	0	0	0	0

2016	2	Dragging anchor 2	20	0	0
Sum	5	Sunken 2 and dragging anchor 3	37	0	2

Source: Database of Zhejiang MSA

It can be seen from the table that, from 2012 to 2016, the number of accidents and dangerous situations caused by typhoons in this waters was 5, of which, there were two ship sinking accidents and three anchor dragging dangerous situations, causing a total of 37 people in distress and two wrecks, no casualty. The main reason is that the waves of here are large, and it is easy to cause the sinking of small ships. At the same time, there is no suitable shelter anchorage in this water area, and the probability of ship dragging anchor is higher.

3.2.2 Yueqing bay waters

3.2.2.1 Basic profiles

Yueqing bay is located on the north side of Oujiang river estuary, 47 kilometers long from north to south and east-west width of 15 kilometers, which has 469 square kilometers of sea area and 220 kilometers of coastline. The average water depth in Yueqing bay is between 9-40 meters, and it is suitable for constructing more than 30 berths with a capacity of 10,000-50,000 tons or more, and 4 deep-water berths of 100,000 tons. At present, there are two large ports in the area, Yueqing bay port of Wenzhou city and Yuhuan port of Taizhou city (Bike, 2016).

3.2.2.2 Anchorage

The east of Yueqing bay is Yuhuan island which is at an altitude of 200m-360m; the north is Yandang mountain, whose elevation is between 250m-730m; the west is Yueqing city with a mountain of 110m-250m high; in the south of the bay, there are Damen, Xiaomen islands, which are natural barriers. There are five good anchorages in the bay of Yueqing, No. 1-5, which can meet the requirements of vessels under 20000 tons and below.

3.2.2.3 Ship traffic flow

Yueqing bay is not only an important port area, but also a major anchorage in the south of Zhejiang province. Therefore, the import and export volume of ships is very large. The contrail and traffic flow data of ships in the typhoon season 2016 (from May 1 to October 31) are calculated in this paper as follows.

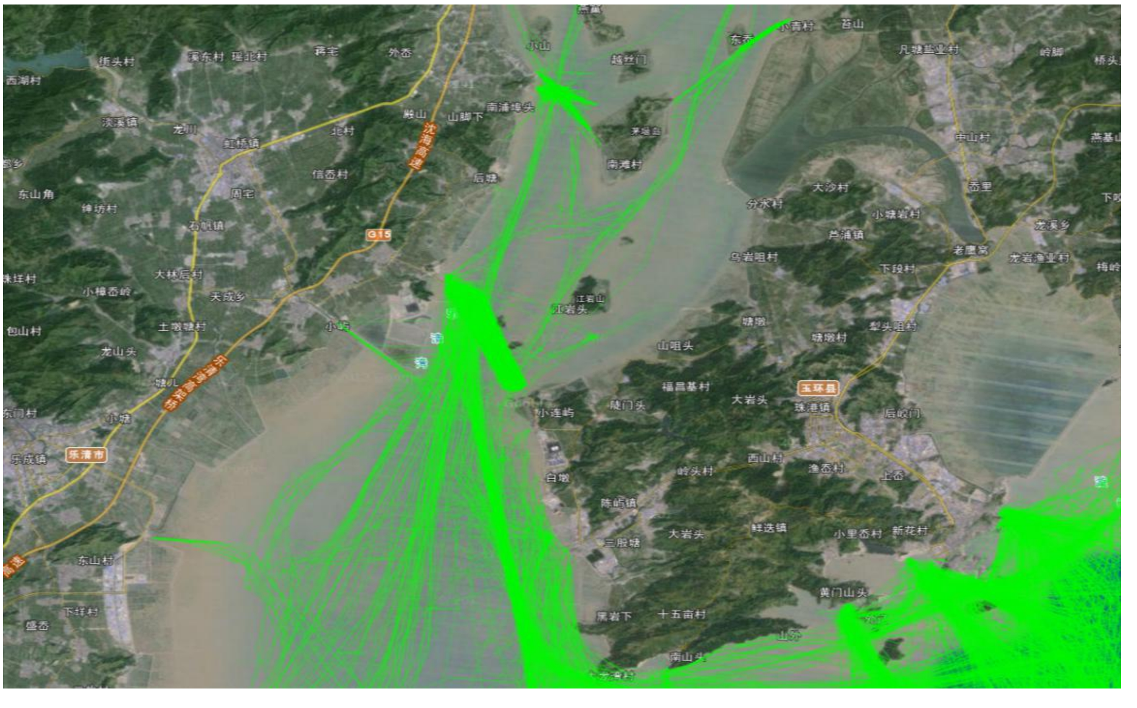

Figure 3.2 Contrail of ships in Yueqing bay waters in the typhoon season 2016

Source: Database of Zhejiang MSA

Choose the mouth of Yueqing bay for the observation section. The number and types of ships passing through this section in the typhoon season 2016 are as follows.

Table 3.3 Ship traffic flow of Yueqing Bay waters in the typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	6309
2	oil tanker	384
3	passenger ship	147
4	engineering ship	358
5	fishing boat	4974
6	others	682
Total number of all ships		12854

Source: Database of Zhejiang MSA

Most of the vessels entering and leaving the waters are bulk cargo ships or fishing boats, which come in for loading and unloading or entering the anchorage for shelter.

3.2.2.4 Bridges

There are 5 bridges in the waters of Yueqing Bay as shown below.

Table 3.4 Bridges in Yueqing Bay waters

No.	Name	Navigation scale (Width * height) m	Navigable grade (T)
1	Qingjiang bridge of 104 national road	30×18	500
2	Shamen island bridge	50×13.5	500
3	Railway bridge (Dingtou)	50×13.5	300
4	Railway bridge (Qingjiang)	30×8.5	

5	Highway bridge (Qingjiang)	30×8	300
6	Yueqing bay bridge	171×35.5	5000

Source: Database of Zhejiang MSA

These bridges are mainly distributed inside the Yueqing Bay and its navigable grade is very small, except the Yueqing bay bridge.

3.2.2.5 Rescue forces

The main rescue forces deployed in the waters are the tugs as shown below. There are also regular patrols of maritime patrol boats.

Table 3.5 Rescue forces in Yueqing bay waters

No.	Name	Types	Power (kw)	Rating of wind resistance
1	Wentuo 1	tug	2352	Force 7 wind

Source: Database of Zhejiang MSA

There is only one tug stationed in the water area. Therefore, the emergency rescue force is obviously insufficient, and it is difficult to meet the emergency rescue needs of more than 100 sheltered ships preventing typhoon.

3.2.2.6 Accidents and dangerous situations

In Yueqing bay waters, accidents and dangerous situations caused by typhoon in the typhoon season from 2012 to 2016 are shown in the following table.

Table 3.6 Accidents and dangerous situations in Yueqing bay waters

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualties	Shipwrecks
2012	0	0	0	0	0
2013	2	Out of control 1 and dragging anchor 1	18	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
Sum	2	Out of control 1 and dragging anchor 1	18	0	0

Source: Database of Zhejiang MSA

From 2012 to 2016, the number of accidents and dangerous situations caused by typhoon in this waters was 2, of which, one ship was out of control and the other ship dragged anchor, causing a total of 18 people in distress. Relatively speaking, this area is a good place for preventing typhoon, but ship dragging cases may happen when typhoon turns direction.

3.2.3 Oujiang estuary and Dongtou waters

3.2.3.1 Basic profiles

The Oujiang estuary and Dongtou waters include Daxiaomen port, Zhuangyuan'ao port, Oujiang port, Oufei reclamation area and the relevant import and export channel. Among them, the Daxiao'men port is located in the Daxiao'men islands, which is a petrochemical port area dominated by petroleum and chemical industry with 4 oil terminals; Zhuangyuan'ao port area is located in the northwest side of the

Zhuangyuan'ao island outside of Oujiang estuary, which mainly engages in container and bulk cargo transport with 2 multi-purpose berths of 50,000 tons and 3 container berths of 50,000 tons under construction; the Ojiang port is located in the Oujiang river, consisting of Longwan operation area, Lingkun operation area and Qili operation area. It mainly engages in domestic container, bulk cargo, and oil transportation with 80 berths; the Oufei reclamation area is a large reclamation project newly launched in recent years. It is located on the coastal beach between the Oujiang river and Feiyunjiang river with more than 100 ships working here at the same time.

3.2.3.2 Anchorage

The area has a total of five anchorges, including Yuanyu anchorage, Qinglingyu anchorage, Wuxingyu anchorage, Dongtou No. 4 anchorage and Banping emergency sheltered waters. Among them, Yuanyu anchorage is located on the north side of the Dabijia island, used as waiting berth or pilotage for ships above 10000 tons, which is rectangular with sediment bottom and 9.9-18.9 meters depth. Qinglingyu anchorage is located between Damen island and Qingshan island, used as waiting berth or pilotage for ships above 10000 tons, which is rectangular with mud bottom and 7.1-10.4 meters depth. Wuxingyu anchorage is located on the north side of the Xiaomen island, used as waiting berth or pilotage for small oil ships, but occupied by fishing nets sometimes. Dongtou No. 4 anchorage is located on the west side of Dongtou island, northwest side of Daqu island, used as waiting berth for ships below 500 tons. Banping emergency sheltered waters is located between Banping island and Dongtou island, used as shelter waters for engineering ships below 500 tons.

Although this area has five anchorages, in addition to Banping emergency sheltered watersr, the rest of the anchorages are only suitable for ships to be berthed or piloted, not suitable for shelter.

3.2.3.3 Ship traffic flow

This water area is the main port area of Wenzhou, and the volume of vessels is also the largest. During the typhoon period, it is the largest area of shelter demands for ships. The contrail and traffic flow data of ships in the typhoon season 2016 (from May 1 to October 31) are calculated in this paper as follows.

Figure3.3 Contrail of ships in Oujiang estuary and Dongtou waters in the typhoon season 2016

Source: Database of Zhejiang MSA

Choose an observation section. The number and types of ships passing through the section in the typhoon season 2016 are as follows.

Table 3.7 Ship traffic flow of Oujiang estuary and Dongtou waters in the typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	10487
2	oil tanker	2090
3	passenger ship	2630
4	engineering ship	421
5	fishing boat	4792
6	others	946
Total number of all ships		21366

Source: Database of Zhejiang MSA

As can be seen from the table, this area is the busiest waters in Wenzhou with dense ship traffic flow. The pressure of the typhoon preventing for ships in this water area is very large.

3.2.3.4 Bridges

There are 9 bridges in the Oujiang estuary and Dongtou waters shown as follows.

Table 3.8 Bridges in Oujiang estuary and Dongtou waters

No.	Name	Navigation scale (Width * height) m	Navigable grade (T)
1	Damen bridge	210×37	3000
2	Sanpan bridge	70×13	500
3	Dongtou bridge	90×21	1000
4	Senmen bridge	70×17	1000
5	Banping bridge	82×13.5	500

6	Dongtou gorge bridge	93×23.5	1000
7	Senmen bridge of 77 provincial road	125×17.5	500
8	Oujiang south bridge	68×12.5	300
9	Oujiang north bridge		

Source: Database of Zhejiang MSA

The bridges of the waters are mainly distributed between the banks of the Oujiang river and the islands of the Dongtou, although the navigable grades of the bridges are relatively high and relatively far away from the anchorage anchors, but there is also some safety risks for the passing of the ships without power and engineering ships with high ship scale, when the wind and waves are rough.

3.2.3.5 Rescue forces

The following tables are about rescue forces deployment in Oujiang estuary and Dongtou waters.

Table 3.9 Rescue tugs in Oujiang estuary and Dongtou waters

No.	Name	Types	Power (kw)	Rating of wind resistance
1	Wentuo 2	Tug	2352	Force 7 wind
2	Wentuo 8	Tug	2942	Force 7 wind
3	Yonggang tuo 7	Tug	2352	Force 7 wind
4	Wentuo 9	Tug	294	Force 7 wind
5	Haigang tuo 9	Tug	1068	Force 7 wind
6	Haigang tuo 7	Tug	721	Force 7 wind

7	Haigang tuo 6	Tug	441	Force 7 wind
8	Haigang tuo 8	Tug	970	Force 8 wind
9	Huachen tuo 1	Tug	2206	Force 10 wind

Source: Database of Zhejiang MSA

Because the waters is the main port of Wenzhou, 9 tugs are deployed here or in the vicinity, which can meet the demands of the emergency rescue forces. In addition, Wenzhou MSA has deployed a number of patrol boats in the waters.

Table 3.10 Patrol boats of MSA in Oujiang estuary and Dongtou waters

No.	Name	Types	Rating of wind resistance
1	Haixun 07678	Patrol boat	Force 6 wind
2	Haixun 07601	Patrol boat	Force 5 wind
3	Haixun 07687	Patrol boat	Force 4 wind
4	Haite 1101	Patrol boat	Force 7 wind
5	Haixun 07679	Patrol boat	Force 5 wind
6	Haixun 0766	Patrol boat	Force 7 wind
7	Haixun 07672	Patrol boat	Force 8 wind
8	Haixun 0761	Patrol boat	Force 10 wind

Source: Database of Wenzhou MSA

3.2.3.6 Accidents and dangerous situations

Accidents and dangerous situations caused by typhoon in the typhoon season from 2012 to 2016 are shown in the following table.

Table 3.11 Accidents and dangerous situations in Oujiang estuary and Dongtou waters

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualties	Shipwrecks
2012	3	Out of control 1, dragging anchor 1 and sickness 1	8	0	0
2013	2	Out of control 1 and sickness 1	3	0	0
2014	2	Out of control 1 and collision 1	14	0	0
2015	8	Anchoring in unsafe waters 8	33	0	0
2016	3	Out of control 2 and anchoring in unsafe waters 8	20	0	0
Sum	18	Out of control 5, dragging anchor 1, sickness 2, collision 1, and anchoring in unsafe waters 9	78	0	0

Source: Database of Zhejiang MSA

From 2012 to 2016, the number of accidents and dangerous situations caused by typhoon in this waters was 18, of which, 5 ships were out of control, 1 ship dragged anchor, 2 sickness, 1 collision accident and 9 ships anchored in unsafe waters, causing a total of 78 people in distress. The waters have many ships, complicated routes and concentrated ports, which are easy to cause accidents or dangerous situations. It is particularly dangerous for ships to anchor in unsafe waters.

3.2.4 Oujiang upstream waters

3.2.4.1 Basic profiles

The upstream of Oujiang river is the old port of Wenzhou city. Most of the waters have been occupied by urban construction, except for some 1000 ton wharves. Most of ships sailing in the waters are small ships, engineering ships and passenger ships. During the typhoon season, a large number of small vessels poured into the water area to shelter from the typhoon.

3.2.4.2 Anchorage

There are four anchorages in the area, but due to the increasing of the bridges construction, anchorages have been shrinking, which cannot meet the requirements of the ship preventing typhoon. Guantou anchorage is located in the north branch of Oujiang river channel, used as shelter waters for ships below 300 tons, which is a natural anchorage with sediment bottom and 2.0-11.0 meters depth. Santiaojiang anchorage is located between Jiangxin island and Meiao, used as shelter waters for ships below 500 tons. However, with the construction of the bridges, the area of the anchorage has been greatly reduced. Meiyuan anchorage is located to the east of Ouyue bridge, used as shelter waters for small ships, which is a new anchorage with sediment bottom and -4.4-2.3 meters depth. The last one is Jiangxin anchorage located in the north of Jiangxin island, which is used as shelter waters for pile driving barges. It is a small anchorage with sediment bottom and 0.6-19.5 meters depth.

3.2.4.3 Ship traffic flow

The main ships in Oujiang upstream waters are small ships, and the flow of ships is low.

Figure 3.4 Contrail of ships in Oujiang upstream waters in the typhoon season 2016

Source: Data base of Zhejiang MSA

Choose an observation section, and check ship traffic flow in the typhoon season 2016 as follows.

Table 3.12 Ship traffic flow of Oujiang upstream waters in typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	936
2	oil tanker	36
3	passenger ship	186
4	engineering ship	13
5	fishing boat	110
6	others	8
Total number of all ships		1289

Source: Database of Zhejiang MSA

Many ships did not install AIS or not normally opened AIS, which may impact the statistical number of ships. Most of the ships sailing in the upstream of Oujiang river engage in sand and gravel transportation.

3.2.4.4 Bridges

There are a lot of bridges in this area, and this paper only discusses the bridges that affect ship's safety. The details are as follows.

Table 3.13 Bridges in Oujiang upstream waters

No.	Name	Navigation scale (Width * height) m	Navigable grade (T)
1	Wenzhou bridge (South)	50×13.5	500
2	Wenzhou bridge (North)	240×31	5000
3	Qidu bridge	50×15.5	500
4	Dongou bridge	91×21	1000
5	Railway bridge (Oujiang)	112×21.5	1000
6	Highway bridge (Oujiang)	109×21.5	1000
7	Oujiang bridge	60×13.5	500
8	Meiao bridge	59×13.8	500
9	Oujiang bridge(No. 5)	45×10	500
10	Ouyue bridge	164×21.5	1000
11	Oujiang bridge of 104 national road	120×21.5	1000
12	Lingkun bridge	No navigation	No navigation
13	Oubei bridge	120×17.5	500

Source: Database of Zhejiang MSA

The most densely distributed place of bridges in Wenzhou waters is the Oujiang upstream waters. The navigable grade of most of the bridges are under 1000 tons, which seriously limits the navigation of the ships, and there will be big risks if large ships navigate in the waters or anchoring near the bridges.

3.2.4.5 Rescue forces

The waters are deployed with official boats, as well as emergency tugs.

Table 3.14 Rescue tugs in Oujiang upstream waters

No.	Name	Types	Power (kw)	Rating of wind resistance
1	Wenhai tuo 1	Tug	2206	Force 7 wind
2	Huaying 399	Tug	713	Force 10 wind

Source: Database of Zhejiang MSA

Although the waters have deployed emergency tugs, limited by the depth of the channel, the navigable grade of bridges and other reasons, it is difficult to meet the emergency needs in typhoon season.

Table 3.15 Patrol boats of MSA in Oujiang upstream waters

No.	Name	Types	Rating of wind resistance
1	Haixun 07673	Patrol boat	Force 5 wind
2	Haixun 07682	Patrol boat	Force 6 wind
3	Haixun 07683	Patrol boat	Force 5 wind
4	Haixun 07675	Patrol boat	Force 5 wind

Source: Database of Wenzhou MSA

This article lists only the patrol boats of MSA, and the rest of the official boats for patrol are not included in the statistics.

3.2.4.6 Accidents and dangerous situations

Accidents and dangerous situations caused by typhoon in the typhoon season from 2012 to 2016 are shown in the following table.

Table 3.16 Accidents and dangerous situations in Oujiang upstream waters

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualtie s	Shipwreck s
2012	0	0	0	0	0
2013	2	Dragging anchor 2	8	0	0
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	7	Dragging anchor 6 and sunken 1	38	2	1
Sum	9	Dragging anchor 8 and sunken 1	46	2	1

Source: Database of Zhejiang MSA

From 2012 to 2016, the number of accidents and dangerous situations caused by typhoon in this waters was 9, of which, 8 ships dragged anchor and 1 ship sank, causing a total of 46 people in distress and the death of 2 people. It is easy to cause many ships to drag anchor together due to the floods and the increasing of the flow speed, which is a serious threat to the safety of the bridges.

3.2.5 Feiyun waters

3.2.5.1 Basic profiles

Feiyun river is the second largest river in Wenzhou, whose main port area is Ruian port. There are a total of 28 berths in the port area, which can berth ships of 2000 tons and below. In addition, two coastal passenger routes operate between the port of Ruian and Nanji island, Beiji island.

3.2.5.2 Anchorages

There are two anchorages in Feiyun waters, Xiaohengshan anchorage and Pandai anchorage. Xiaohengshan anchorage is located between Feiyun bridge (No.5) and Feiyun bridge (No.2), used as shelter waters for ships below 500 tons, which is a small anchorage with sediment bottom and 4.0-6.0 meters depth. Pandai anchorage is located in the upstream of the river with sediment bottom and 0-4.0 meters depth, which is suitable for ships below 300 tons anti-typhoon.

Due to the occupation of bridges and the increasing of the ships, the anchorages in Feiyun waters have been unable to meet the requirement of ships.

3.2.5.3 Ship traffic flow

The contrail and traffic flow data of ships in the typhoon season 2016 (from May 1 to October 31) are calculated as follows.

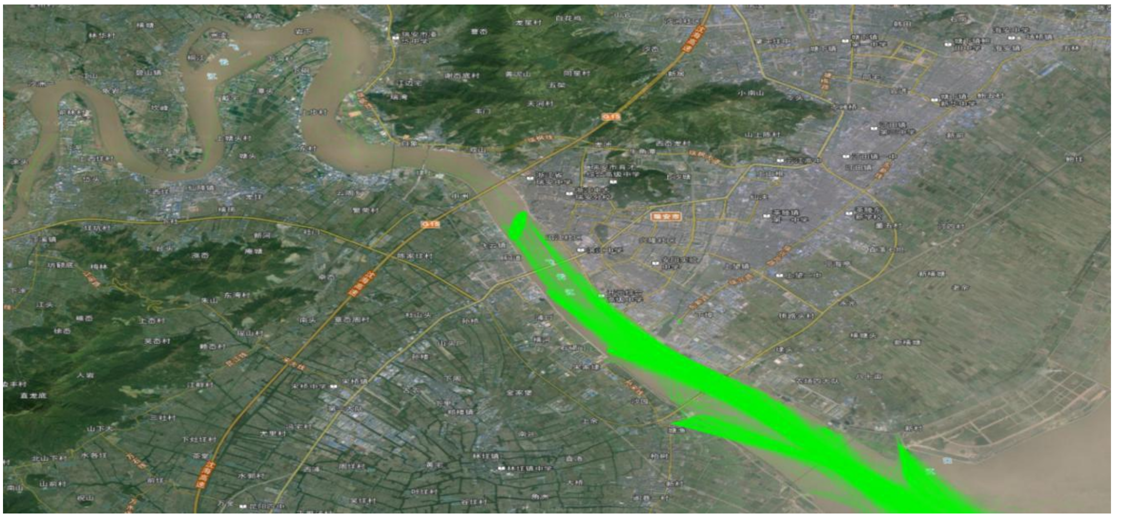

Figure 3.5 Contrail of ships in Feiyun waters in the typhoon season 2016

Source: Database of Zhejiang MSA

Choose an observation section, and calculate ship traffic flow in the typhoon season 2016 as follows.

Table 3.17 Ship traffic flow of Feiyun waters in the typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	3227
2	oil tanker	987
3	passenger ship	205
4	engineering ship	132
5	fishing boat	7121
6	others	339
Total number of all ships		12011

Source: Database of Zhejiang MSA

According to the analysis, the number of fishing boats in Feiyun waters is large, but the number of merchant ships is not. In addition, it is worth saying that contrail of ships are mainly concentrated in the vicinity of Feiyun river estuary.

3.2.5.4 Bridges

Eight bridges in Feiyun waters are calculated in the paper.

Table 3.18 Bridges in Feiyun waters

No.	Name	Navigation scale (Width * height) m	Navigable grade (T)
1	Feiyun bridge (No.7)	95×8	300
2	Feiyun bridge (No.6)	88×8	300
3	Railway bridge	53×12.5	300
4	Highway bridge	55×17.5	500
5	Feiyun bridge of 104 national road	55×16.5	500
6	Feiyun bridge (No.3)	200×2	3000
7	Feiyun bridge (No.5)	89×12.5	300
8	Highway bridge (Outside)	233×32.5	3000

Source: Database of Zhejiang MSA

In addition to two bridges at Feiyun river estuary are 3,000 tons of navigable grade, the rest of the bridges' grade are less than 500 tons, which limits the volume of ships entering and leaving the Feiyun port, but also limits the ships into the shelter waters.

3.2.5.5 Rescue forces

Feiyun waters does not have rescue tugs, although there are some official boats, these boats cannot bear the tasks of emergency towing.

Table 3.19 Patrol boats of MSA in Feiyun waters

No.	Name	Types	Rating of wind resistance
1	Haixun 07670	Patrol boat	Force 7 wind
2	Haixun 07688	Patrol boat	Force 7 wind
3	Haixun 07677	Patrol boat	Force 5 wind

Source: Database of Wenzhou MSA

3.2.5.6 Accidents and dangerous situations

Accidents and dangerous situations caused by typhoon in the typhoon season from 2012 to 2016 are shown in the following table.

Table 3.20 Accidents and dangerous situations in Feiyun waters

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualties	Shipwrecks
2012	1	Out of control 1	33	0	0
2013	1	Aground 1	14	0	0
2014	2	Dragging anchor 1	6	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
Sum	4	Out of control 1, dragging anchor 2 and aground 1	53	0	0

Source: Database of Zhejiang MSA

From 2012 to 2016, the number of accidents and dangerous situations caused by typhoon in this waters was 4, of which, there was 1 ship out of control, 1 ship dragged anchor and 1 ship ran aground, causing a total of 53 people in distress. The water depth conditions of Feiyun river is not good, which is easy to cause ship aground under the influence of wind and waves.

3.2.6 Aojiang waters

3.2.6.1 Basic profiles

Aojiang river is the third largest river in Wenzhou, and there are 61 terminals which mainly have small wharves below 1,500 tons. Aojiang channel is shallow, which greatly limits the ships in and out of port.

3.2.6.2 Anchorages

Aojiang river does not have shelter anchorages, and a large number of ships moor in the harbor during typhoon season.

3.2.6.3 Ship traffic flow

The contrail and traffic flow data of ships in the typhoon season 2016 (from May 1 to October 31) is shown in the following figure.

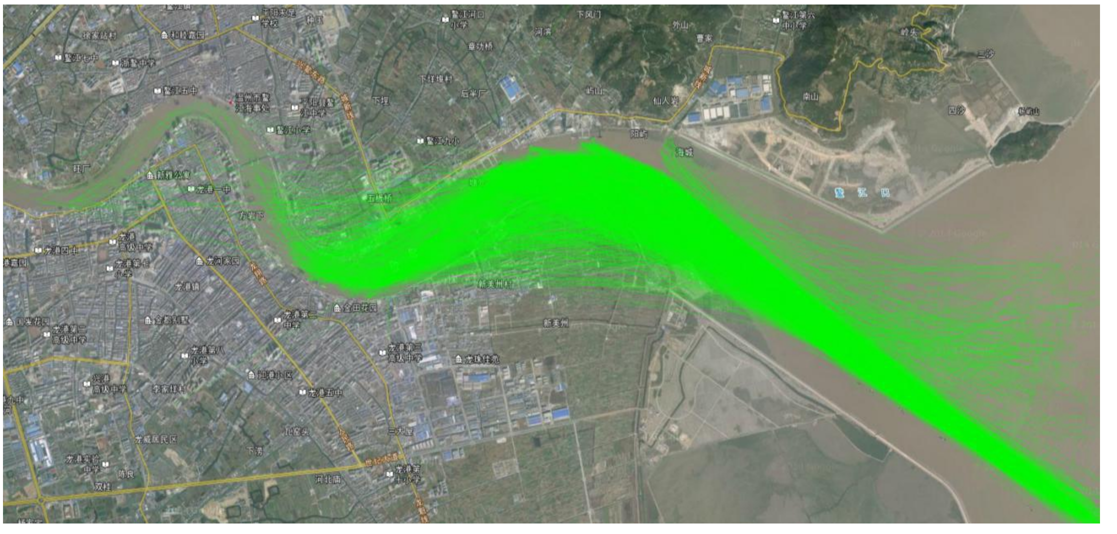

Figure 3.6 Contrail of ships in Aojiang waters in the typhoon season 2016

Source: Database of Zhejiang MSA

Choose an observation section, and calculate ship traffic flow in the typhoon season 2016 as follows.

Table 3.21 Ship traffic flow of Aojiang waters in the typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	4071
2	oil tanker	260
3	passenger ship	920
4	engineering ship	126
5	fishing boat	9580
6	others	657
Total number of all ships		15614

Source: Database of Zhejiang MSA

Aojiang waters and Feiyun waters are somewhat similar to the huge number of fishing boats, but merchant ships are limited by the size of the port, and the number is far less than the fishing boats. In addition, because the typhoon season is also the hot tourist season of Nanji island, passenger ship voyages from Aojiang port to Nanji island are very frequent.

3.2.6.4 Bridges

Table 3.22 Bridges in Aojiang waters

No.	Name	Navigation scale (Width * height) m	Navigable grade (T)
1	Longgang bridge	22×8	200
2	Ounan bridge	64×10	300
3	Railway bridge (Aojiang)	53×12.5	300
4	Aojiang bridge (No.4)	100×12.5	300
5	Aojiang bridge (No.6)	274×23.5	1000

Source: Database of Zhejiang MSA

Except that the navigable grade of Aojiang bridge (No.6) is 1000 tons, other bridges are equal or below 300 tons, which greatly limits the sizes of ships into the harbor.

3.2.6.5 Rescue forces

Aojiang waters does not have any rescue tugs, except some official boats.

Table 3.23 Patrol boats of MSA in Aojiang waters

No.	Name	Types	Rating of wind resistance
1	Haixun 07690	Patrol boat	Force 6 wind
2	Haixun 07696	Patrol boat	Force 6 wind

Source: Database of Wenzhou MSA

3.2.6.6 Accidents and dangerous situations

Accidents and dangerous situations caused by typhoon in the typhoon season from 2012 to 2016 is shown in the following table.

Table 3.24 Accidents and dangerous situations in Aojiang waters

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualties	Shipwrecks
2012	0		0	0	0
2013	14	Out of control 12, aground 1 and sunken 1	29	0	1
2014	1	Out of control 1	105	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
Sum	15	Out of control 13, aground 1 and sunken 1	134	0	1

Source: Database of Zhejiang MSA

From 2012 to 2016, the number of accidents and dangerous situations caused by typhoon in this waters was 15, of which, there were 13 ships out of control, 1 ship sank and 1 ship ran aground, causing a total of 134 people in distress. The water depth conditions of Aojiang river is bad, which is easy to cause ship aground under the influence of wind and waves.

3.2.7 Southern waters of Aojiang river

3.2.7.1 Basic profiles

The area of southern waters of Aojiang river occupies about 1/3 of Wenzhou waters, consisting of Pacao port (Cangnan power plants), Xiaguan port and traditional fishing ground.

3.2.7.2 Anchorages

This area does not have shelter anchorages for ships, except some small fishing ports.

3.2.7.3 Ship traffic flow

The vessels in this water area mainly include the ships that go in and out of Cangnan power plants, as well as ships that pass by and some fishing boats.

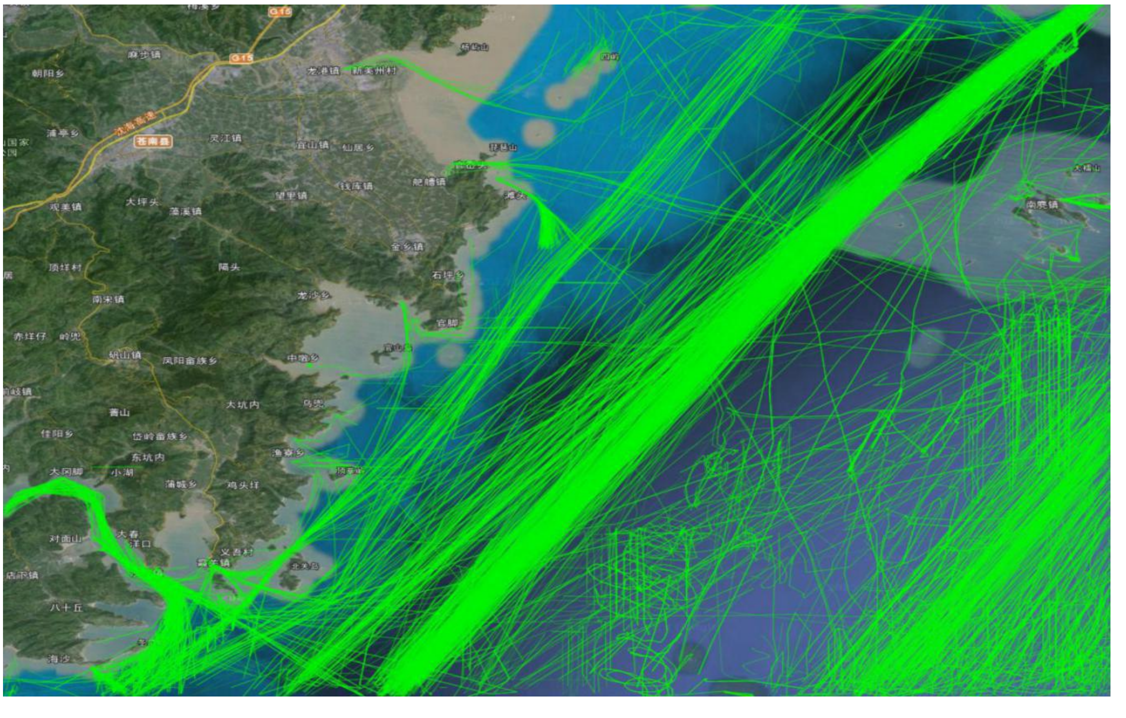

Figure 3.7 Contrail of ships in southern waters of Aojiang river in the typhoon season 2016

Source: Database of Zhejiang MSA

Choose an observation section, and calculate ship traffic flow in the typhoon season 2016, as follows:

Table3.25 Ship traffic flow of southern waters of Aojiang river in the typhoon season 2016

No.	Types of ships	Number of ships
1	cargo ship	20525
2	oil tanker	4819
3	passenger ship	0
4	engineering ship	290
5	fishing boat	18346
6	others	558
Total number of all ships		44538

Source: Database of Zhejiang MSA

3.2.7.4 Bridges

No bridges in this area can impact the safety of ships.

3.2.7.5 Rescue forces

The main rescue forces deployed in the waters are the tugs shown in the table below.

Table 3.26 Rescue tugs in southern waters of Aojiang river

No.	Name	Types	Power (kw)	Rating of wind resistance
1	Wentuo 5	Tug	4000	Force 8 wind
2	Wentuo 6	Tug	2942	Force 7 wind

Source: Database of Zhejiang MSA

Although the waters area is large, the number of ships is huge, but only two tugs are deployed here, which is difficult to meet the demands of rescue.

3.2.7.6 Accidents and dangerous situations

Accidents and dangerous situations caused by typhoon in the typhoon season from 2012 to 2016 is shown in the following table.

Table 3.27 Accidents and dangerous situations in southern waters of Aojiang river

Year	Number	Types of accidents or dangerous situation	Number of people in distress	Casualties	Shipwrecks
2012	0	0	0	0	0
2013	3	Out of control 1, dragging anchor 1 and sunken 1	18	2	1
2014	0	0	0	0	0
2015	0	0	0	0	0
2016	0	0	0	0	0
Sum	3	Out of control 1, dragging anchor 1 and sunken 1	18	2	1

Source: Database of Zhejiang MSA

From 2012 to 2016, the number of accidents and dangerous situations caused by typhoon in this waters was 3, of which, there was 1 ship out of control, 1 ship dragged anchor and 1 ship sank, causing a total of 18 people in distress and the death of 2 people. All ships involved in the accidents in the area were fishing boats.

CHAPTER 4 Risk assessment of typhoon preventing for ships in Wenzhou waters

4.1 Overview of risk assessment system

Risk assessment refers to the use of computing methods to analyze and identify known and unknown risk factors in the system, and then determine the probability of the occurrence of the accidents and the possible consequences of the accidents. (Masuda, 2017)

Risk assessment of waters is an important subject in ship traffic safety researches, which is used to provide scientific basis for waters safety, by the investigation and analysis of the risk factors, the possibility of accidents and the degree of damages according to the scientific procedures and methods. (Zhao, 1991)

4.2 Selection of risk assessment methods

4.2.1 Analytic hierarchy process

According to the theory of system engineering, a target of system is divided into several different levels of objectives, then the qualitative and quantitative analysis is carried out on the different levels of the sub-goals by using the method of mathematical modeling to obtain the ranks of different sub-goals at last. The analysis method is AHP (Saaty, 2013, pp. 109-121). The AHP method combines the qualitative analysis of uncertainty with the quantitative analysis of certainty, which effectively absorbs the results of qualitative analysis and the advantages of quantitative analysis. The method includes subjective logic judgment and scientific calculations, which has a wide range of applications. In this paper, the AHP method is used to determine the weight of the index.

4.2.2 Gray comprehensive evaluation

Under the influence of cybernetics, information theory and system theory, grey system theory is a subject initiated by Professor Deng Julong in China in 1980s, which can make quantitative analysis of a system with some known information and unknown information (Deng, 1985). In the correlation analysis of the gray system theory, the "measure" which describes the degree of influence of each factor on the system is called the degree of correlation. The essence is the analysis and comparison of the difference between the factor curve and the result curve in geometric shape, that is, the closer the geometric shape is, the closer the development trend is and the greater the degree of association. (Guo, 2005) However, because of some of the problems of the method, such as the definition of gray correlation coefficient, and there are some similarities with the fuzzy mathematics method, it is not selected as the assessment method.

4.2.3 Fuzzy comprehensive evaluation

The creator of fuzzy mathematics theory is the American scholar La. Zadeh. He introduced the concept of membership degree, and established a mathematical model by using fuzzy set theory, which makes the fuzzy information quantitative and formal. (Mordeson, 2001) In scientific research, there are often many uncertain factors in the objective situation, so the use of traditional methods will not be able to analyze and judge whether La.zadeh's theory can solve this problem, making the mathematical model able to deal with fuzzy information. Fuzzy theory has promoted the development of mathematical model, which has been widely used in scientific research.(Jin, 2004, pp. 65-70)

Assessment is a behavior based on the known purpose to determine the object system properties, and translates the properties into an objective quantitative value or subjective utility. In practice, because the influence factors for evaluation of the objects are fuzzy, the introduction of fuzzy theory to assess the problem is very necessary. Its aim is to sort out the objects in the discourse domain according to their merits, or to choose an optimal solution from the discourse domain (Buckley, 2002). Fuzzy comprehensive evaluation is the application of fuzzy mathematics theory and methods to help people make multi-factors decision-making. It is a kind of important and simple comprehensive evaluation method, which has the advantages of simple digital model and suitable for multi-level problem evaluation. In this paper, the method will be used to assess the risks of ship preventing typhoon in seven waters of Wenzhou.

4.3 Determination of evaluation factors

4.3.1 Principles for determining factors

From the previous analysis we can see that there are many factors that affect the safety of ships preventing typhoon in Wenzhou waters, and these factors are often interacting with each other. Therefore, in the establishment of risk evaluation factors system, we need to focus on the following principles (Han, 2003).

(1) Scientific principle, that is, to define the concept and calculation method of index according to scientific theory;
(2) The combination of qualitative and quantitative principles, the index system should try to choose quantifiable factors, and the important factors which are difficult to quantify can use qualitative description indicators;
(3) The principle of independence, factors, as far as possible, have relative independence and avoid repetition;
(4) The principle of operability, factors should take full account of the source of information and practical possibilities.

4.3.2 Establishment of factor set and comment set

(1) Establish factor set "U"

The set of factors can be expressed by U = {U1, U2, ..., Un}, where U = {i = 1,2,3 ..., n} represents a single influencing factor and n represents the number of factors. (Ren, 2006, pp.8-9) Based on the research results of scholars at home and abroad and the opinions of experts, five factors such as natural environment factors, shelter waters factors, navigation environment factors, ship factors and safety management factors are identified as first-level evaluation factors, and 26 secondary factors are identified after discussion of experts. The first-level evaluation factor set is denoted by U = {i = 1, 2, 3, ..., n}, and the secondary factor set is denoted by $U_i = \{ U_{i1}, U_{i2} \ldots, U_{in} \}$.

In this paper, the factor set U is defined as: U = {U1 (natural environment factor), U2 (shelter waters factor), U3 (navigation environment factor), U4 (ship factor), U5 (safety management factor)}, and there are: U1 = {U11 (location), U12 (hydrological condition), U13 (typhoon intensity)}; U2= {U21 (shelter anchorage), U22 (rescue forces)}; U3 = {U31 (bridge), U32 (fairway), U33 (navigation aids), U34 (obstruction)}; U4 = {U41 (ship size), U42 (ship type), U43 (seaworthy conditions), U44 (ship traffic flow), U45 (crew quality)}; U5 = {U51 (accidents), U52 (typhoon emergency plan), U53 (shipping company management)}. Risk assessment system for ship preventing typhoon in Wenzhou waters is shown in Figure 4.1

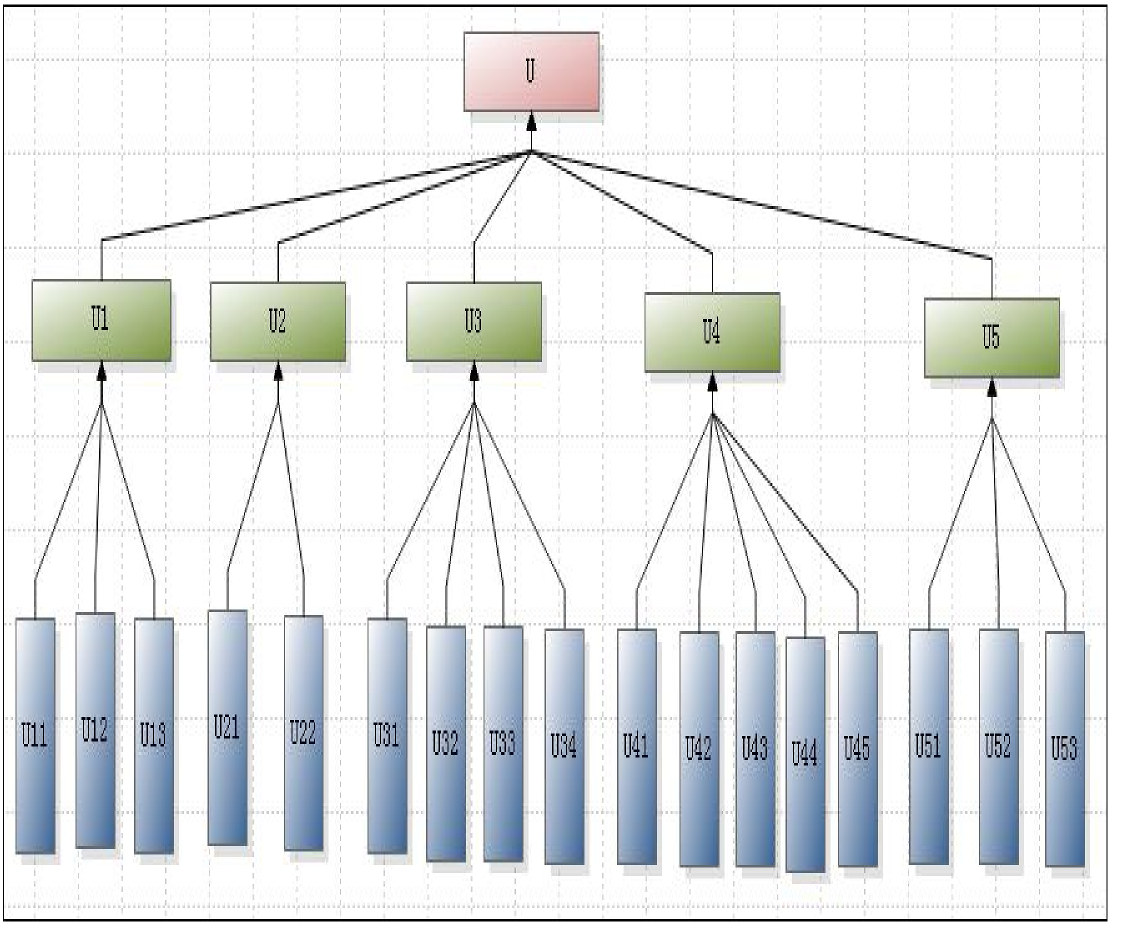

Figure 4.1 Risk assessment system for ship preventing typhoon in Wenzhou waters
Source: Compiled by the author, 2017

（2）Establish comment set

The comment set can be represented by V={V1, V2, ..., Vn}, which determines the extent to which the rated matter belongs to each rating level, and each level can correspond to a fuzzy subset. In practice, the grade can be described in the appropriate language according to the expert's evaluation. For example, the comment set of academic performance can be expressed by V = {excellent, good, medium, poor, poor}. (Wang, 2008)

This paper divides the risks into four grades: low, general, high and extremely high. Therefore, the comment set of the risks can be expressed as: V = {risk is low, risk is general, risk is high and risk is extremely high}. The corresponding values are V = {3-4,2-3, 1-2, 0-1}.

4.4 Determinate the weight of factors

Weight refers to the relative importance of the indicator in the overall evaluation, and is the quantitative allocation of the importance of the different aspects of the object being evaluated. The methods of weight determination are mainly shown as follows: analytic hierarchy process (AHP), subjective experience method, expert investigation method, etc. (Deng, 2012, pp. 93-100) In this paper, AHP is used to determine the weight of each index.

4.4.1 Establish judgment matrix

At each level, the factors of the layer are compared and formed the judgment matrix after quantized according to the prescribed scale. The specified scale is a measure of the degree of importance between each factor. In this paper, 9 scale method is used.

Table 4.1 Nine scaling ratio table

Scale	Definition
1	The factor i is as important as the factor j
3	The factor i is slightly more important than the factor j
5	Factor i is more important than the factor j
7	Factor i is very important than the factor j
9	Factor i is absolutely important than the factor j

2，4，6，8	For the above two judgments between the intermediate state of the corresponding scale value
Reciprocal	If the factor j is compared with the factor i, the value is $a_{ji} = 1/a_{ij}$

Source: from professor Saaty.

4.4.2 Consistency test

This paper conducted a questionnaire survey on experts in the field of Wenzhou water for typhoon preventing (see Appendix Ⅰ for the survey) and conducted a consistency testing on the results.

According to the matrix theory, if the judgment matrix is completely consistent, λ_{max}=n, and the other characteristic roots are zero. In order to ensure the rationality of the analysis, it is necessary to check the consistency of the judgment matrix. The steps are as follows:

(1) Calculate consistency index (CI)

CI= $\dfrac{\lambda_{max} - n}{n-1}$;

(2) Lookup the random index(RI)

Table 4.2 The value of RI

n	1	2	3	4	5	6	7
RI	0	0	0.52	0.89	1.12	1.24	1.36
n	8	9	10	11	12	13	14
RI	1.41	1.46	1.49	1.52	1.54	1.56	1.58

Source: Anderson D., An Introduction to Management Science: Quantitative Approaches to Decision Making. Melissa Accuna, 10th Edition,2003. Among them, n is the number of paired comparison factors.

(3) Calculate consistency random index (CR)

CR=$\frac{CI}{RI}$**;**

When CR <0.10, it is considered that the single order result has satisfactory consistency. Otherwise, you need to adjust the factor scale value. Finally, the weight and consistency of the risk assessment factors of ship preventing typhoon in Wenzhou waters are shown in the following tables.

Table 4.3 Weight and consistency results of first-level factors

U	U1	U2	U3	U4	U5	Wi
U1	1	0.25	2	0.5	0.3333	0.098
U2	4	1	4	3	2	0.4027
U3	0.5	0.25	1	0.3333	0.3333	0.0701
U4	2	0.3333	3	1	0.3333	0.1515
U5	3	0.5	3	3	1	0.2777
CR=0.0395<0.10; weight to “U”=1.0000; λmax=5.1771						

Source: Compiled by the author, 2017

Table 4.4 Weight and consistency results of secondary factors (natural environment)

U1	U11	U12	U13	Wi
U11	1	1	0.25	0.1504
U12	1	1	0.1429	0.1248
U13	4	7	1	0.7248
CR=0.0336<0.10; weight to "U"=0.0980; λmax=3.0349				

Source: Compiled by the author, 2017

Table 4.5 Weight and consistency results of secondary factors (shelter waters)

U2	U21	U22	Wi
U21	1	2	0.7500
U22	0.5	1	0.2500
CR=0<0.10; weight to "U"=0.4027; λmax=2.000			

Source: Compiled by the author, 2017

Table 4.6 Weight and consistency results of secondary factors (navigation environment)

U3	U31	U32	U33	U34	Wi
U31	1	3	3	5	0.5229
U32	0.3333	1	3	3	0.2626
U33	0.3333	0.3333	1	1	0.1158
U34	0.2	0.3333	1	1	0.0988
CR=0.0432<0.10; weight to "U"=0.0701; λmax=4.1155					

Source: Compiled by the author, 2017

Table 4.7 Weight and consistency results of secondary factors (ship)

U4	U41	U42	U43	U44	U45	Wi
U41	1	3	0.1429	0.3333	0.3333	0.079
U42	0.3333	1	0.1429	0.3333	0.2	0.0454
U43	7	7	1	3	3	0.4819
U44	3	3	0.3333	1	0.3333	0.1449
U45	3	5	0.3333	3	1	0.2488
CR=0.0574<0.10; weight to "U"=0.1515; λmax=5.2750						

Source: Compiled by the author, 2017

Table 4.8 Weight and consistency results of secondary factors (safety management)

U5	U51	U52	U53	Wi
U51	1	3	7	0.6491
U52	0.3333	1	5	0.279
U53	0.1429	0.2	1	0.0719
CR=0.0624<0.10; weight to "U"=0.2777; λmax=3.0649				

Source: Compiled by the author, 2017

From the above, we can see that all the factors have passed the consistency testing, which meets the requirements.

4.5 Risk assessment of each waters based on fuzzy comprehensive evaluation

After scoring by experts (see Appendix II), this article identified the evaluation scores of various factors of each waters. The risk assessment results of each water area are as follows.

Table 4.9 Risk assessment results of North-south coastal route waters

Factors	Wi	Scores
U11	0.0147	1.8
U12	0.0122	1.2
U13	0.0710	1.5
U21	0.3020	1.6
U22	0.1007	0.9
U31	0.0366	4
U32	0.0184	3.5
U33	0.0081	3.0
U34	0.0069	2.7
U41	0.0120	1.0
U42	0.0069	3.1
U43	0.0730	3.3
U44	0.0220	1.8
U45	0.0377	2.6
U51	0.1803	1.2
U52	0.0775	2.5
U53	0.0200	2.3

Source: Compiled by the author, 2017

After weighted sum operations, get: V= $\sum a_{ij} w_{ij}$ =1.8433

Table 4.10 Risk assessment results of Yueqing bay waters

Factors	Wi	Scores

U11	0.0147	3.8
U12	0.0122	3.1
U13	0.0710	3.6
U21	0.3020	4
U22	0.1007	2.8
U31	0.0366	2.3
U32	0.0184	3.0
U33	0.0081	2.9
U34	0.0069	3.3
U41	0.0120	1.7
U42	0.0069	2.7
U43	0.0730	3.0
U44	0.0220	1.9
U45	0.0377	2.8
U51	0.1803	2.6
U52	0.0775	2.3
U53	0.0200	2.1

Source: Compiled by the author, 2017

After weighted sum operations, get: V= $\sum a_{ij} w_{ij}$ =3.1195

Table 4.11 Risk assessment results of Oujiang estuary and Dongtou waters

Factors	Wi	Scores
U11	0.0147	2.6
U12	0.0122	1.9
U13	0.0710	2.1
U21	0.3020	3.0
U22	0.1007	4.0
U31	0.0366	1.6

U32	0.0184	2.4
U33	0.0081	3.3
U34	0.0069	2.9
U41	0.0120	2.7
U42	0.0069	0.9
U43	0.0730	2.4
U44	0.0220	1.0
U45	0.0377	2.1
U51	0.1803	0.7
U52	0.0775	3.5
U53	0.0200	1.9

Source: Compiled by the author, 2017

After weighted sum operations, get: V= $\sum a_{ij} w_{ij}$ =2.4193

Table 4.12 Risk assessment results of Oujiang upstream waters

Factors	Wi	Scores
U11	0.0147	3.2
U12	0.0122	1.5
U13	0.0710	3.0
U21	0.3020	2.7
U22	0.1007	1.2
U31	0.0366	0.8
U32	0.0184	1.8
U33	0.0081	2.6
U34	0.0069	2.3
U41	0.0120	3.1
U42	0.0069	1.0
U43	0.0730	1.8

U44	0.0220	2.1
U45	0.0377	1.2
U51	0.1803	1.7
U52	0.0775	1.8
U53	0.0200	1.5

Source: Compiled by the author, 2017

After weighted sum operations, get: V= $\sum a_{ij}w_{ij}$ =2.0569

Table 4.13 Risk assessment results of Feiyun waters

Factor	Wi	Scores
U11	0.0147	1.6
U12	0.0122	1.5
U13	0.0710	1.8
U21	0.3020	1.7
U22	0.1007	0.5
U31	0.0366	0.9
U32	0.0184	1.3
U33	0.0081	2.8
U34	0.0069	2.5
U41	0.0120	3.2
U42	0.0069	0.9
U43	0.0730	1.9
U44	0.0220	2.7
U45	0.0377	1.5
U51	0.1803	2.1
U52	0.0775	2.3
U53	0.0200	1.9

Source: Compiled by the author, 2017

After weighted sum operations, get: V= $\sum a_{ij}w_{ij}$ =1.7242

Table 4.14 Risk assessment results of Aojiang waters

Factor	Wi	Scores
U11	0.0147	0.6
U12	0.0122	0.9
U13	0.0710	1.2
U21	0.3020	0.5
U22	0.1007	0.7
U31	0.0366	0.9
U32	0.0184	1.4
U33	0.0081	2.5
U34	0.0069	2.0
U41	0.0120	3.7
U42	0.0069	0.8
U43	0.0730	1.1
U44	0.0220	3.2
U45	0.0377	1.0
U51	0.1803	1.1
U52	0.0775	1.7
U53	0.0200	1.5

Source: Compiled by the author, 2017

After weighted sum operations, get: V= $\sum a_{ij}w_{ij}$ =1.0174

Table 4.15 Risk assessment results of southern waters of Aojiang river

Factor	Wi	Scores
U11	0.0147	0.5
U12	0.0122	2.7
U13	0.0710	1.0
U21	0.3020	0.8
U22	0.1007	1.8
U31	0.0366	4
U32	0.0184	1.3
U33	0.0081	1.1
U34	0.0069	1.9
U41	0.0120	2.6
U42	0.0069	1.7
U43	0.0730	1.9
U44	0.0220	2.0
U45	0.0377	1.7
U51	0.1803	3.1
U52	0.0775	1.7
U53	0.0200	2.3

Source: Compiled by the author, 2017

After weighted sum operations, get: $V=\sum a_{ij}w_{ij}=1.7528$

CHAPTER 5 Analysis and countermeasures of risk assessment results

5.1 Analysis of results

According to the calculations in Chapter 4, we have obtained the comprehensive evaluation results for each of the waters, as shown in the following table.

Table 5.1 Risk assessment results and risk levels of each waters

Area	Scores	Level of risks
North-south coastal route waters	1.8433	High
Yueqing bay waters	3.1195	Low
Oujiang estuary and Dongtou waters	2.4193	General
Oujiang upstream waters	2.0569	General
Feiyun waters	1.7242	High
Aojiang waters,	1.0174	High
Southern waters of Aojiang river	1.7528	High

Source: Compiled by the author, 2017

For the risks of ships preventing typhoon, the level of Yueqing bay waters is low; Oujiang estuary and Dongtou waters is general as well as Oujiang upstream waters; the risks of North-south coastal route waters are in high level, the same as the last 3 waters. However, the risk level of Aojiang waters is close to extremely high.

The risk rating of each waters is as follows: Yueqing bay waters> Oujiang estuary and Dongtou waters> Oujiang upstream waters> North-south coastal route waters> Southern waters of Aojiang river> Feiyun waters> Aojiang waters.

5.2 Countermeasures

After the analysis above, we can see that the situation of typhoon preventing for ships in Wenzhou waters is not optimistic, especially in the Feiyun waters, Aojiang waters and southern waters of Aojiang river. There is a shortage of anchorages, lack of rescue forces and serious contradictions between ships and bridges. In order to improve the safety situation of Wenzhou waters in typhoon season, the following safety recommendations are proposed.

5.2.1 Strengthen the construction and maintenance of the shelter waters

Shelter waters are the indispensable regions for ships in typhoon season, which are non-renewable resources and should be used rationally and scientifically. At present, in the north of Wenzhou waters, only the Yueqing bay shelter anchorages are suitable for large ships, whose capacity is close to saturation; in the southern waters, there is no suitable shelter waters for ships, except two small anchorages in Feiyun waters. The construction of anchorages is very urgent.

In addition, the existing anchorages are narrowing due to reclamation and bridge construction. For example, the area of Santiaojiang anchorage in the Oujiang upstream waters has reduced significantly due to the construction of Oujiang bridge of 104 national road, which increases the probability of accidents. Therefore, it is necessary to maintain the anchorages that are affected, and develop appropriate countermeasures.

5.2.2 Promote the construction of typhoon warning information center

Early receipt of typhoon warning information and making preparation is the key to ensuring the safety of the ships during typhoon season. Through the establishment of typhoon warning information center, tracking the typhoon trends and releasing typhoon warning information, the safety of ships will be greatly promoted on the prevention of typhoon.

5.2.3 Reasonable deployment of rescue forces

The professional emergency rescue forces are the guarantee for the ships to be rescued, when accidents or dangerous situations occur. Wenzhou waters is badly short of rescue forces except Oujiang estuary and Dongtou waters, especially in the Feiyun waters and Aojiang waters, and there are almost no emergency rescue forces. It is recommended that the professional rescue department should increase the construction of Wenzhou emergency capability, invest in the construction of high-powered tugs and increase the deployment of rescue forces in typhoon season.

5.2.4 Strengthen the protective ability of bridges

In recent years, with the acceleration of bridge construction, more and more bridges have occupied the original sheltered anchorage or habitual shelter waters, resulting in the occurrence of the bridge collision in the typhoon season. Therefore, we should attach great importance to safety management of bridges, and if the protective ability of bridges does not meet the design requirements, it should be promptly repaired and corrected.

5.2.5 Revise and improve the typhoon emergency plan

There are a lot of typhoon emergency plans in Wenzhou waters, such as the "Typhoon emergency plan of Wenzhou MSA", "Typhoon emergency plan of Wenzhou City", etc. But in daily works, it is difficult to deal with the new problems by using current plans. Therefore, the revision of the typhoon emergency plans is a dynamic and long-term work， which needs a scientific and reasonable method, and the revision should be closely integrated with the actual conditions of the waters.

5.2.6 Strengthen the safety management of ships

First of all, the competent authority should increase the inspection of ships, and request rectification for vessels that do not meet the requirements. For those unable to meet the standards, measures should be taken to eliminate them from the shipping market. Secondly, the internal safety management of shipping companies should be strengthened, so as to enhance ship company's management level of ship safety. In addition, it is necessary to strengthen the operational inspection of the crew, so as to improve the technical level of the ship navigation and emergency response capabilities.

5.2.7 Strengthen the maintenance of navigational aids and the clearance of obstructions

The overall situation of navigational aids in Wenzhou waters is good, but some waters is poor, such as coastal routes for small vessels. Competent authorities should strengthen the deployment and maintenance of the navigational aids and make them work properly. In addition, some waters are covered with reefs, sunken ships, fishing nets and other obstructions, which should be cleared in time.

CHAPTER 6   Conclusions

In the history, typhoons have caused heavy losses to the ships in the Wenzhou waters, and the works of preventing typhoon for ships has always been a priority issue in the area.   It is an important and meaningful thing to evaluate the risk status of the ships to prevent typhoon in the waters and formulate corresponding countermeasures.

In this paper, Wenzhou waters are divided into seven parts, and the risk assessment system for ship preventing typhoon is established by selecting the factors such as natural environment factors, shelter waters factors, navigation environment factors, ship factors and safety management factors. By using fuzzy comprehensive evaluation method and analytic hierarchy process, the risk factors of each waters were evaluated, and finally the risk level of each waters was graded.   In light of the risk status of Wenzhou waters, this paper puts forward some countermeasures, such as the construction and maintenance of the shelter waters, establishment of typhoon warning information center, deployment of rescue forces, revision of the typhoon emergency plan, maintenance of navigational aids, etc.   The evaluation results are consistent with the actual situation of Wenzhou waters, which has a certain reference value for the typhoon preventing works in the future.

Despite the efforts put in this research, there are still some shortcomings.   For example, the selection of risk factors and the determination of evaluation scores have been taken by expert scoring methods, which are easily disturbed by human factors.

With the development of marine economy in Wenzhou, great changes will take place in the navigation environment, and the situation of typhoon preventing for ships in Wenzhou waters will also be changed. Therefore, I hope more experts and scholars can study the risks of typhoon preventing for ships in Wenzhou waters by using better assessment methods and detailed data, so as to ensure the safety of ships in Wenzhou waters in typhoon season.

REFERENCES

Baike. (2015). *Brief introduction of Yueqing bay*. Retrieved May 19, 2017 from the World Wide Web: http://baike.baidu.com/link?url=_oaKUQA2tApWWWMsw8mXOer4yhNfUchnX6QaihwyUICkft7t0OYR3TW143eDItgcYyaOVBgbD444TRMXlmfE4c8CTtsx2RPRNqJS64ivR0kP_4ih--TVctYE7SGn4295

Buckley, J. J., Eslami, E., & Feuring, T. (2002). Fuzzy mathematics in economics and engineering. *Studies in Fuzziness & Soft Computing,* 91.

Chen, X. (2007). Diagnosis and assessment of the vulnerability process of typhoon disaster system in coastal areas -- a case study of Fujian Province,China. *Science of Disaster,22*(3), 6-10.

Deng, J. L. (1985). *Gray system*. Beijing: National Defense Industry Press.

Deng, X., Li, J. M., & Zhao, J. F. (2012). AHP weight analysis method and its application. *The understanding and practice of Mathematics, 42*(7), 93-100.

Duan, A. Y. (2006). *Application of FSA in vessel traffic safety management in port waters.* Unpublished doctoral dissertation. Huazhong University of Science and Technology, Wuhan, China.

Duan, Y. H., & Wu, R. S. (2005). Study on intensity change of tropical cyclone. *Acta Meteorologica Sinica, 63*(5), 636-645.

Emanuel, K. A. (1988). The maximum intensity of hurricanes. *Journal of the Atmospheric Sciences, 45*(7), 1143-1155.

Guo, P., & Shi, P. G. (2005). Research on fuzzy comprehensive evaluation method of project risks. *Journal of Xi'an University of Technology, 21*(1), 106-109.

Han, Y. P.,& Ruan, B. Q. (2003). Preliminary study on evaluation index system of regional water security. *Journal of Environmental Science, 23*(2), 267-272.

Hiroaki, K. (1995). Development of maritime route system design technology. *Symposium of Japan navigation society, 93*.

Holland, G. J. (1997). The maximum potential intensity of tropical cyclones. *Journal of Atmospheric Sciences, 54*(21), 2519-2541.

Hu, S. P., Fang, Q. G., Zhang, J. P., & Cai, C. Q. (2010). Research on risk assessment of the marine traffic safety in coastal water area. *Navigation of China, 33*(1), 50-55.

Jin, J. L., Wei, Y. M., & Ding, J. (2004). Fuzzy comprehensive evaluation model based on Improved Analytic Hierarchy Process. *Journal of hydraulic engineering, 35*(3), 65-70.

Kunreuther, H., & Richard, J. (1998). *The status and role of insurance against natural disasters in the united states*. Washington: Joseph Henry Press.

Li, J. N., Wang, A. Y., Yang, Z. L., & Li, G. L. (2003). Research progress of the typhoon rainstorm. *Journal of Tropical Meteorology, 19*(1), 152-159.

Liu, Z. H. (1999). Reasonable judgement and avoidance of Typhoon. *Navigational technology, 5*, 23-24.

Lu, Y. (2016). *Risk assessment and regionalization of tropical cyclone disasters in Zhejiang.* Unpublished doctoral dissertation, Nanjing University of Information Science & Technology, Nanjing, China.

Lu, Y. B., & Ma, L. F. (2007). Analysis of the main characteristics of Typhoon "Saomai" and the impact of storm surge. *Marine prediction, 24(*4), 92-96.

Masuda, M., & Harada, F. (2017). Safety evaluation. *Cosmetic Science & Technology,* 785-792.

Mille, B. I. (1958). On the maximum intensity of hurricanes. *Journal of the Atmospheric Sciences, 72*, 184-195.

Mordeson, J. N. (2001). *Fuzzy Mathematics*. Beijing: Physica-Verlag Press.

National standards for tropical cyclone grades(GB/T 19201)2003, China meteorological administration(CMA),（2003).

National standards for tropical cyclone grades(GB/T 19201)2006, China meteorological administration(CMA), (2006).

Ni, Y. B. (201O). *Study on the anti typhoon for container ship in Ningbo port.* Unpublished doctoral dissertation, Dalian Maritime University, Dalian, China.

Pan, W. C. (2013). Analysis and response to the influence of typhoon to inland vessels within Jiangsu jurisdiction of the Yangtze river. *China Maritime Safety, 6*, 45-47.

Ren, L. H. (2006). Brief introduction of mathematical modeling method of fuzzy comprehensive evaluation method. *Market Modernization,20*, 8-9.

Saaty, T. L. (2013). Analytic Hierarchy Process. *Encyclopedia of Biostatistics,* 19-28.

Shi, P. A., Wu, X., & Chen, J. F. (2010). The preliminary design of the regional anti-typhoon intelligence system. *Ship Navigation and Berthing Research Conference 2010*. Shanghai:China Institute of Navigation.

Wang, B. T. (2008). *Study on regional risk assessment based on fuzzy mathematics.* Unpublished doctoral dissertation, Dalian Jiaotong University, Dalian, China.

Wang, J. Q., Shi, P. A., & Xiong, C. C. (2006). Design and research on intelligent typhoon avoidance system for ships. *Journal of Guangzhou Maritime College, 14*(2), 9-12.

Wang, Z. D. (2015). *Study on distribution characteristics of typhoon gale in Wenzhou and typical case analysis*. Unpublished doctoral dissertation, Lanzhou University, Lanzhou, China.

Wenzhou Maritime Safety Administration (WZMSA). (2015). *Brief introduction of Wenzhou Maritime Safety Administration*. Retrieved May 15, 2017 from the World Wide Web:
http://wz.cnzjmsa.gov.cn/xxgk/xxgkml/zzjg/jgjj/201503/t20150325_379747.html

Wenzhou Municipal Bureau of Meteorology（WZMBM), 2016. *Historical typhoon affecting Wenzhou*. Retrieved May 16, 2017 from the World Wide Web:
http://www.wztf121.com/history.html

Ye, Z. H. (2013). How do ships prevent typhoon in Northwest Pacific. *China Water Transport, 3*, 20-23.

Yin, J. (2011). *Risk assessment of typhoon storm surge disaster in China's coastal areas.* Unpublished doctoral dissertation, East China Normal University, Shanghai, China.

Zhang, L. J., Liu, M., Lu, M., & Quan, R. S. (2010). Typhoon risk assessment in southeastern coastal areas of China. *Yangtze River, 41*(6), 81-83.

Zhang, Y. F., & Xu, H. T. (1996). Disaster and reflection of Typhoon No. 9417 in Wenzhou. *Zhejiang Hydrotechnics, 2*, 34-36.

Zhao, J. S., & Wu, Z. L. (1991). A mathematical model for comprehensive evaluation of ship navigation safety. *Journal of Dalian Maritime University, 3*, 25-29.

Zheng, Z. Y., & Li, H. X. (2008). Study on navigation safety evaluation of navigable waters. *Navigation of China, 31*(2), 130-134.

APPENDIX I

Questionnaire of risk assessment factors weight of typhoon preventing for ships in Wenzhou waters

The first-level factors are as follows:

U={U1 (natural environment factors), U2 (shelter waters factors), U3 (navigation environment factor), U4 (ship factor), U5 (safety management factor)},

The secondary factors are as follows:

U1={U11 (location), U12 (hydrological condition), U13 (typhoon intensity)}; U2={U21 (shelter anchorage), U22 (rescue forces)}; U3={U31 (bridge), U32 (fairway), U33 (navigation aids), U34 (obstruction)}; U4={U41 (ship size), U42 (ship type), U43 (seaworthy conditions), U44 (ship traffic flow), U45 (crew quality)}; U5={U51 (accidents), U52 (typhoon emergency plan), U53 (shipping company management)}.

The scoring principles are as follows:

Scale	Definition
1	The factor i is as important as the factor j
3	The factor i is slightly more important than the factor j
5	Factor i is more important than the factor j
7	Factor i is very important than the factor j
9	Factor i is absolutely important than the factor j

2，4，6，8	For the above two judgments between the intermediate state of the corresponding scale value
Reciprocal	If the factor j is compared with the factor i, the value is $a_{ji} = 1/a_{ij}$

Table 1 Questionnaire of first-level factors

U	U1	U2	U3	U4	U5
U1	1				
U2		1			
U3			1		
U4				1	
U5					1

Table 2 Questionnaire of secondary factors (natural environment)

U1	U11	U12	U13
U11	1		
U12		1	
U13			1

Table 3 Questionnaire of secondary factors (shelter waters)

U2	U21	U22
U21	1	
U22		1

Table 4 Questionnaire of secondary factors (navigation environment)

U3	U31	U32	U33	U34
U31	1			
U32		1		
U33			1	
U34				1

Table 5　Questionnaire of secondary factors (ship)

U4	U41	U42	U43	U44	U45
U41	1				
U42		1			
U43			1		
U44				1	
U45					1

Table 6　Questionnaire of secondary factors (safety management)

U5	U51	U52	U53
U51	1		
U52		1	
U53			1

APPENDIX II

Expert scoring standard for risk assessment factors

Standard / Scores / Factors	3-4	2-3	1-2	0-1
Location	Excellent	Good	General	Poor
Hydrological condition	Excellent	Good	General	Poor
Typhoon intensity	Tropical storm	Typhoon	Severe typhoon	Supper typhoon
Shelter anchorage	Excellent	Good	General	No anchorage
Rescue forces	Adequate	Good	General	Lack
Bridges	No effect to ships	Little effect to ships	Great effect to ships	Seriously affect to ships
Fairway	Excellent	Good	General	Poor
Navigation aids	Excellent	Good	General	Poor
Obstruction	No effect to ships	Little effect to ships	Great effect to ships	Seriously affect to ships
Ship size	Small ships	Medium ships	Large ship	Super large ships
Ship type	less types	Little more types	Much types	Complex types
Seaworthy conditions	Excellent	Good	General	Poor
Ship traffic flow	Wee	Less	General	Large
Crew quality	Excellent	Good	General	Poor
Accidents	No	Less	General	Much
Typhoon emergency plan	Excellent	Good	General	Poor
Shipping company management	Excellent	Good	General	Poor