8-26-2018

Research on navigation safety evaluation of Jiaxing Port

Chao Meng

WORLD MARITIME UNIVERSITY

Dalian, China

RESEARCH ON NAVIGATON SAFETY EVALUATION OF JIAXING PORT

By

W1701474

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)

2018

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): _________________

(Date): 27 June 2018

Supervised by: Xie Hongbin
Professor
Dalian Maritime University

Assessor: ____________________________

Co-assessor: ____________________________

ACKNOWLEDGEMENTS

First and foremost, I would like to express my most sincere thanks to the Maritime Safety and Environmental Management (MSEM) project of World Maritime University (WMU) and Dalian Maritime University (DMU) for giving me this precious opportunity to study in Dalian.

Secondly, I am thankful to my handsome and gentle supervisor Prof. Xie Hongbin for providing me with invaluable guidance and insightful advice on my research work. I am also grateful to the professors and classmates in MSEM 2018 for their help during my study in Dalian.

Thirdly, sincere thankfulness should be given to Jiaxing Maritime Safety Administration (MSA), whose supports offer me the opportunity to participate in the MSEM project. My sincere thanks should also be given to my colleagues who have provided me with numerous documents and files to support my writing of this research paper.

Last but not least, I am greatly grateful to my wife who is always supporting and encouraging me and taking care of my daughter at all times. The academic journey would not have been possible without her love and everlasting support.

ABSTRACT

Title of research paper: **Research on Navigation Safety Evaluation of Jiaxing Port**

Degree: **MSc**

Jiaxing Port has experienced an unprecedented period of development since the turn of the 21st century. The port throughput continues to increase, a number of modern berths and large hydraulic structures have been built and put into operation and the number of ships in and out of the port is increasing year by year. The navigation environment in the port water area has become more complex, the navigation risks for ships inbound and outbound have been increasing, hence more marine traffic accidents than ever. Therefore, it is necessary to conduct a complete research on the navigation safety assessment to identify risks for Jiaxing Port and comprehensively evaluate the port navigation environment.

This research paper mainly covers the following work: Firstly, it discusses the current situation of navigation environment in Jiaxing Port including natural environment, port environment and traffic environment. Secondly, Fuzzy Comprehensive Evaluation (FCE) is applied as the assessment method through comparison and analysis of several main safety evaluation methods. Thirdly, based on expert consultation and questionnaire investigation, it constructs index system of navigation safety evaluation, calculates the corresponding index weight according to Analytic Hierarchy Process (AHP), and comprehensively assesses the safety level of navigation environment for the port by applying FCE method. Finally, some risk control measures are put forward to the administrations for improving navigation safety of the port in accordance with the evaluation result.

KEY WORDS: Jiaxing port, navigation safety assessment, navigation environment, FCE, AHP, risk control measures

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
CCTV	Closed Circuit Television
CI	Consistency Index
CR	Consistency Ratio
E	East
ENE	East-northeast
ESE	East-southeast
FCE	Fuzzy Comprehensive Evaluation
GST	Grey System Theory
MSA	Maritime Safety Administration
N	North
NE	Northeast
NNE	North-northeast
NNW	North-northwest
NW	Northwest
RI	Average Random Consistency Index
S	South
SE	Southeast
SW	Southwest

SSE	South-southeast
SSW	South-southwest
TEU	Twenty-foot Equivalent Unit
W	West
WNW	West-northwest
WSW	West-southwest
VTS	Vessel Traffic Service

CHAPTER 1

INTRODUCTION

1.1 Background of research

Since the beginning of the 21st century, China's economy has developed dramatically. The increasing import and export trade has promoted the rapid development of the port-based shipping industry. According to the statistics from China Transportation Association, the port's cargo throughput of China has been the world's largest for ten consecutive years since 2004, and breakthroughs have been made in total throughput (Wang, 2016). At the same time, the development of port shipping industry has promoted the continual expansion of port construction in China's coastal areas. The newly-built port construction projects like berths, fairways and anchorages are increasing day by day, the number of inbound and outbound vessels has also increased significantly. The port waters are becoming increasingly busy and crowded and the traffic flow is getting heavier and heavier, which have posed a severe impact on the port navigation safety.

Jiaxing Port is located in the south of Yangtze River Delta and the north of Hangzhou Bay. It is only 53 nautical miles from Yangshan Port and 74 nautical miles from Ningbo Port. It is one of the four major ports along the coast of Zhejiang Province and is also a first-class open port (Fang, 2012). In recent years, Jiaxing Port has experienced rapid development. In 2016, the cargo throughput reached 68.166 million tons, among which the foreign trade cargo throughput was 11.663 million tons with an annual growth of 22 percent. Container throughput reached 1.342 million TEUs with an annual growth of 9.3 percent, and the growth rate ranked first in Zhejiang Province for nine consecutive years (Zhu, 2017). At the same time, the port has achieved great strides in development and construction and a number of modern berths and large hydraulic structures have been built and put into operation. The rapid development of port and the raise in throughput have brought the increase of traffic flow of inbound and outbound vessels, which makes the navigation environment of port waters become more complex and increases the risk of navigation safety for ships entering and leaving the port. Marine traffic accidents have occurred from time to time in port waters, which seriously affects the safety, efficiency and development of Jiaxing Port.

Table 1.1 Statistics of the number of vessels inbound and outbound and cargo throughput in Jiaxing Port

Year	Number of inbound and outbound vessels	Cargo throughput (million tons)
2010	9723	36.638
2011	10626	42.960
2012	11163	47.834
2013	12111	52.663
2014	12883	55.395
2015	11359	57.419
2016	13085	68.166
2017	18165	88.288

Source: Compiled by author based on data from Jiaxing MSA (2018)

Based on the above background, this research paper intends to carry out comprehensive safety evaluation on the navigable waters of Jiaxing Port.

1.2 Objectives of research

The rapid growth of throughput and ship traffic flow is bound to raise higher requirements for the safety of navigation environment of Jiaxing Port and pose a challenge to the safety administrations on how to manage safety production effectively. How to maximize the potential of the port and make greater contribution to the economic development? To solve this problem, the key point is to ensure the safe and orderly navigation of ships in Jiaxing Port. Therefore, it is very important to improve the safety management level of the port, reduce the marine accidents in port waters and avoid unnecessary economic loss. It is essential to use scientific methods to analyze and evaluate the navigation safety of ships in port waters to provide decision-making basis and reasonable suggestions for improving the situation of safety navigation in port waters, raising the management level of the authorities and promoting the full play of port function.

Therefore, the objectives of this research paper are to identify the main factors of navigation environment that influence navigation safety of Jiaxing Port, construct index system of navigation safety evaluation, determine the corresponding index weight and comprehensively assess the safety level for the navigation environment of the port through systematically analyzing the characteristics and safety situation of navigation environment in Jiaxing Port waters. Furthermore, the aim od the research paper is to put forward effective and targeted risk prevention and control measures and safety management suggestions for the competent authorities on the basis of both safety and development, so as to improve the navigation management level of competent authorities, to ensure the safety of navigation and lives and property at sea, and promote the development of local marine economy.

1.3 Structure of the research paper

The research paper is mainly composed of six chapters:

Chapter 1 provide background information,research objectives and methodologies to be used in the following chapters. Chapter 2 introduces and analyses the current situation of navigation environment in Jiaxing Port which includes natural environment, port environment and traffic condition. Chapter 3 determines the use of Fuzzy Comprehensive Evaluation (FCE) to assess the level of navigation safety of Jiaxing Port after discussing several main safety evaluation methods and introduces the methods and procedures of FCE. Chapter 4 constructs index system of navigation safety evaluation according to expert consultation and questionnaire investigation, figures out the corresponding index weight by applying Analytic Hierarchy Process (AHP), determines the evaluation matrix of single factor through questionnaire survey and calculation, and comprehensively assesses the safety level of navigation environment for the port by using the FCE method. Chapter 5 puts forward some risk control measures to the compete authorities of maritime traffic safety of Jiaxing Port for improving navigation safety of the port in accordance with the evaluation result. Chapter 6 summarizes the view and conclusion of the research paper, points out inadequacies, and makes the prospect of the future research.

CHAPTER 2

ANALYSIS OF NAVIGATION ENVIRONMENT IN JIAXING PORT

2.1 Natural environment

2.1.1 Meteorological condition

(1) Wind

Jiaxing Port is located in the East Asian monsoon region with obvious seasonal characteristics. The wind direction is mainly northwest (NW) ~ north (N) from November to the next February with a cumulative frequency of 30% and is mainly east (E) ~ southeast (SE) from March to August with a cumulative frequency of 22%. The direction of strong wind is basically consistent with the direction of prevailing wind. More details are shown in Table 2.1.

Table 2.1 Statistical table of wind conditions in Jiaxing Port (1971-2016)

Wind Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Frequency (%)	6	4	5	5	10	10	10	4	4	4	2	2	3	4	8	8
Maximum wind speed (m/s)	14	13	15	15	17	15	15	10	8	9	13	12	10	14	15	14
Mean wind speed (m/s)	3.1	2.9	2.9	3.2	4.0	4.7	4.3	3.3	3.0	2.7	2.4	2.2	2.4	3.4	4.0	3.7

Source: Wuhan University of Technology, 2018

The mean annual wind speed is 3.2 m/s, and the maximum wind speed was 31.7 m/s (SE direction) occurring on 31 July 1982. E, ESE and SE winds prevail throughout the year and NW wind prevails in winter (China Navy Hydrographic Office,2017). Wind conditions over the years are shown in Table 2.2:

Table 2.2 Summary of wind conditions of Jiaxing Port

Item		**Number of days**	**Year**
＞Force 5 wind	Long-time average annual number	242.1	
	Maximum number in a calendar year	298	1971
	Minimum number in a calendar year	155	2001
＞Force 6 wind	Long-time average annual number	121.1	
	Maximum number in a calendar year	188	1972
	Minimum number in a calendar year	42	2001
＞Force 7 wind	Long-time average annual number	41.5	
	Maximum number in a calendar year	74	1982
	Minimum number in a calendar year	7	2001
＞Force 8 wind	Long-time average annual number	12.1	
	Maximum number in a calendar year	28	1982
	Minimum number in a calendar year	1	2001
＞Force 9 wind	Long-time average annual number	2.1	
	Maximum number in a calendar year	9	1981
	Minimum number in a calendar year	0	1991、1994、1995、2001 and 2002

Source:Compiled by author based on data from Jiaxing MSA(2013)

(2) Air temperature

Mean temperature in a calendar year is 15.8 ℃ ; the mean annual maximum temperature is 19.7 ℃ ; mean annual minimum temperature is 12.4 ℃ ; the highest temperature in a calendar year: 38.4 ℃ (1988.7.17); the lowest temperature in a calendar year is -10.6℃(1977.1.31) (Wuhan University of Technology, 2018).

(3) Fog

Fog days are from March to May in spring and from October to December in winter. There is advection fog in spring and radiation fog in winter in the fog season. The annual average number of foggy days (visibility is less than 2 km) is 38.2. The maximum number of foggy days in a calendar year was 57 (in 1983) and minimum number of foggy days in a calendar year was 13 (in 2003) (Jiaxing MSA, 2013).

(4) Disastrous weather

1) Typhoon

Typhoon is the main disastrous weather that affects Jiaxing Port. According to statistics, the tropical cyclones which affect the region first appears as early as in May and as late as in October, with an average annual occurrence of 1.4 times. The highest number of tropical cyclone appear in July and August. When the tropical cyclone affects the local area, the wind direction is mainly ENE ~ SE, and the maximum wind speed is 31.7m/s. The mean duration is 3 days, with a maximum duration of 5 days and a minimum of 1 day (Jiaxing MSA, 2013).

2) Cold wave

Jiaxing Port is affected by cold wave twice a year on average. During a cold wave, the duration of strong winds is usually 2 to 3 days and the maximum wind force is generally grade 7 ~ 8 and some can reach grade 9, and the maximum scale of drop in temperature is 14.3℃ (Jiaxing MSA, 2013).

2.1.2 Hydrological condition

(1) Tide

Jiaxing Port is of typical strong tidal area. The main tidal characteristics in the port area are irregular semi-diurnal tides with large tidal range and rapid tidal current. The tidal current in Jiaxing Port has obvious characteristics of reciprocating flow, and the mean velocity of flood tide is larger than the mean velocity of ebb tide. The current speed is generally 3 ~ 4 knots, and the maximum speed can be 6 ~ 7 knots in the port waters (China Navy Hydrographic Office,2017). More details are shown in Table 2.3.

Table 2.3 Characteristic value of tide (1985 National Elevation Benchmarks)

Hydrologic Station		**Zhapu**	**Ganpu**
Geographic Coordinates		30°36′N 121°05′E	30°23′N 120°53′E
Year		1980～2004	1970～2004
Eigenvalue	Highest Tide Level in a calendar year (m)	5.54	6.56
	Lowest Water Level in a calendar year (m)	-3.62	-4.17
	Long-time Mean Tide Level (m)	0.37	0.25
	Maximum Tidal Range in a calendar year (m)	7.82	9.0
	Minimum Tidal Range in a calendar year (m)	0.96	1.15
	Long-time Mean Tidal Range (m)	4.78	5.71
	Long-time Mean Highest Tide Level (m)	2.65	3.18
	Long-time Mean Lowest Tide Level (m)	-2.13	-2.52

	Mean Duration of Tidal Rise (hours)	5:29	5:24
	Mean Duration of Tidal Fall (hours)	6:56	7:01

Source:Compiled by author based on data from Jiaxing MSA(2013)

(2) Wave

Jiaxing Port is located in the north bank of Hangzhou Bay, in a semi-closed sea area little affected by the sea waves. The waves in Jiaxing Port water area are mainly wind waves, with the frequency accounting for more than 95% of the total number of observation. The normal wave direction is SE and NW with frequencies of 14.7% and 12.8% respectively. The strong wave direction is E,ESE and SE with frequencies of 12%, 9.7% and 14.7% respectively. The maximum wave height in a calendar year is 4.8m (China Navy Hydrographic Office,2017).

Table 2.4 Wave conditions of Jiaxing Port

Wind Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Frequency (%)	6	4	5	5	10	10	10	4	4	4	2	2	3	4	8	8
Maximum wave height (m)	0.7	1.5	1.5	2.0	4.8	3.5	2.6	1.6	1.9	2.8	2.6	2.4	0.9	1.2	1.0	1.2
Mean wave height (m)	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Source: Shanghai Maritime University (2016)

2.2 Port environment

2.2.1 Current situation of Jiaxing Port

Jiaxing Port is located in the south of Yangtze River Delta and the north of Hangzhou Bay which enjoys an advantageous geographic position. It is 53 nautical miles from Yangshan Port and 69 nautical miles from Zhoushan Port. It is the only sea gate in the northern part of Zhejiang Province and is also a first-class open port. The port is composed of Dushan port area, Zhapu port area and Haiyan port area with a coastline of 74.1km. After years of development, the port has gradually developed into a modern, multi-functional and comprehensive coastal port which integrates transporting function, modern logistics function, maritime business service function and port information function. By the end of 2017, there were 48 offshore productive terminals in the port, among which 35 berths for ten-thousand-tonnage ships above to alongside. The designing throughout capacity of the port is 85.54 million tons which is second only to Ningbo-Zhoushan port. According to the 13th Five-Year Plan of Jiaxing Port (Jiaxing Port Administration, 2016), there will be 60 offshore productive berths (45 berths for ten-thousand-tonnage ships above), and the total cargo throughput of the port would exceed 100 million tons by the year of 2020.

Figure2.1 Jiaxing Port

Source: http://image.baidu.com/

2.2.2 Fairway

2.2.2.1 Current condition of fairways

The major fairways in Jiaxing Port and adjacent waters are: Jinshan Fairway, Zhapu Fairway, Dushan Fairway and Qinshan Fairway, shown in Figure 2.2.

(1) Jinshan Fairway

Jinshan Fairway was opened in 1975 with a total length of 75.1 n mile and a sweep width of 2 km. The water depth is above 8 meters in general and the minimum depth is 7.4m. It is the main channel for ships to enter and leave Jiaxing Port.

(2) Zhapu Fairway

Zhapu Fairway is the main channel for ships to enter and leave Zhapu and Haiyan port area. The width of the channel is 2 km and the minimum charted depth is around 9 m. Ships sail 4.27 n mile from the starting point O (30˚33´17.83N/121˚12´35.69) along 266° to point P (30˚33´17.83N/121˚12´35.69), then sail to 332° , after about 2.38 n mile they are in Zhapu port area.

(3) Dushan Fairway

The waterway is originally a special purpose channel for Jiaxing Power Plant with a width of 1.8 km and a minimum depth of about 9m.

(4) Qinshan Fairway

Qinshan Fairway is in Haiyan port area. The water depth in the upper reaches of the fairway is relatively shallow. According to the latest scanning data, the charted depth of the shallowest point in the channel is only 2.7m. Where a ship needs to enter the port by high tide, accurate calculations shall be made to ensure that the ship has sufficient additional depth (China Navy Hydrographic Office,2016).

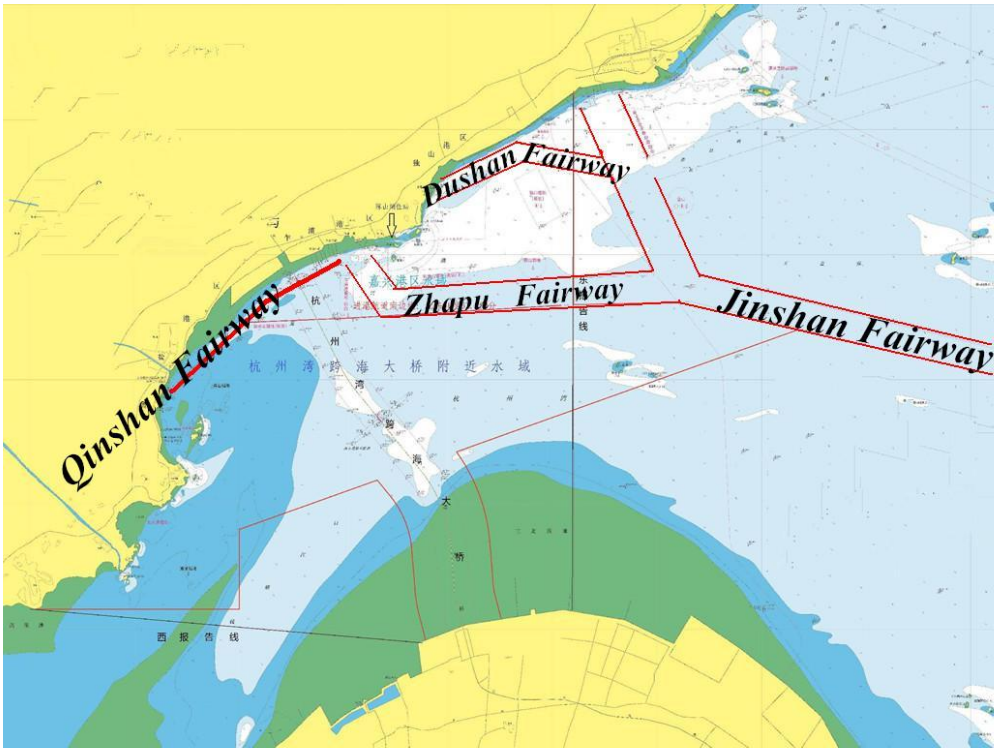


Figure2.2 Fairways of Jiaxing Port

Source: Compiled by author based on pictures of Jiaxing Port chart

2.2.2.2 Characteristics of fairways

Current in the fairways is turbulent. The waters nearby are open and wide and the channels are obviously affected by the wind and current. There are many small fishing boats and fishing stakes near the channel, which are only more than 50 meters away from the fairway and will affect the safe navigation of the large ships entering and leaving the port. There are some shallow waters with a minimum depth of only 7.4 m in the approach channel. Due to the limitation of the water depth of the approach channel, ships of more than 30,000 tonnage with a maximum designing draft of 11.2 m need to reduce the load before entering the port and ships which enter the port by taking high tide shall make accurate calculations to ensure that the ship has sufficient additional depth. The quayside is close to the fairway and ship shall navigate with caution when they are berthing and unberthing.

2.2.3 Anchorages

2.2.3.1 Current condition of anchorages

(1) Dushan Anchorage

The anchorage is within the area bounded by the lines joining the following co-ordinates: A(30° 38′ .0N/121° 13′ .2E); B(30° 36′ .1N/121° 14′ .3E); C(30° 36′ .6N/121° 15′ .4E); D(30° 38′ .5N/121° 14′ .3E). It is an anchorage for ships waiting for berth, joint inspection and pilotage with an area of 11.65 km^2 and water depth of 11.3 ~ 12.3 m, and the bottom is silt. The anchorage can accommodate 24 ships of less than 30,000 gross tonnages for anchoring.

(2) Chenshan Anchorage

The anchorage is in area enclosed within a radius of 1000 m and centered at the point A(30° 34′ .60 N/121° 14′ .00 E). It is a special anchorage for dangerous cargo ships with an area of 3.14 km^2 and water depth of around 12 m. The bottom is muddy and the anchorage can accommodate 2 ships of less than 50,000 gross tonnages for anchoring.

(3) Caiqishan Anchorage

The anchorage is within the area bounded by the lines joining the following co-ordinates: A(30° 34′ .4N/121° 08′ .8E); B(30° 33′ .8N/121° 08′ .5E); C(30° 34′ .0N/121° 11′ .0E); D(30° 34′ .5N/121° 11′ .0E). It is a special anchorage for dangerous cargo ships with an area of 4 km^2 and water depth of 10.6～

12 m. The anchorage can accommodate 6 ships of less than 20,000 gross tonnages for anchoring.

(4) Tangshan Anchorage

The anchorage is within the area bounded by the lines joining the following co-ordinates: A(30°34′11.40"N/121°04′54.69"E)；B(30°34′31.60"N/ 121°05′55.81" E); C(30°32′21.42"N /121°07′13.84"EE); D(30°31′08.27"N /121°06′44.43"E); E(30°32′25.62"N/121°08′49.49"E); F(30°31′12.94"N/121°08′14.5"E).

The anchorage is for ships waiting for berth, joint inspection and pilotage with an area of 14.86 km^2 and water depth of 8.5 ~ 15 m, and the bottom is silt. The anchorage can accommodate 15 ships of less than 20,000 gross tonnages for anchoring.

(5) Baitashan Anchorage

The anchorage is within the area bounded by the lines joining the following co-ordinates: A(30° 31′ .8N/120° 59′ .7E); B(30° 32′ .6N/121° 00′ .7E); C(30° 32′ .4N/121° 00′ .9E); D(30° 31′ .6N/120° 59′ .9E). It is an anchorage for ships waiting for berth and joint inspection with an area of 1.1 km^2 and water depth of 5.9 ~ 7.5 m, and the bottom is mud. The anchorage can accommodate 5 ships of less than 30,00 gross tonnages for anchoring.

(6) Qinshan Anchorage

The anchorage is in Haiyan port area and is in waters enclosed within a radius of 500 m and centered at the point A(30° 28′ 00″ N， 120° 57′ 30″ E). It is an anchorage for small ships waiting for berth with an area of 0,78 km^2 and the water depth is limited. The anchorage can accommodate 3 ships of less than 30,00 gross tonnages for anchoring.

(7) Changchuanbei Anchorage

The anchorage is in Haiyan port area and is in waters enclosed within a radius of 500 m and centered at the point A(30° 24′ 40″ N，120° 56′ 00″ E). The water depth is limited. It is an anchorage for small ships waiting for berth with an area of 0,78 km^2. The anchorage can accommodate 3 ships of less than 10,00 gross tonnages for anchoring (Wuhan University of Technology, 2018).

2.2.3.2 Characteristics of anchorages

The bottom of the anchorages in Jiaxing port is poor and the current is rapid, ships at anchor are easy to be dragging. Tangshan Anchorage is close to the Hangzhou Bay Bridge, so vessels are not recommended to drop anchor there. Both Qinshan Anchorage and Changchuanbei Anchorage have a small area and insufficient water depth. They are located in the west of the bridge in Haiyan port area and cannot satisfy the requirement of anchorage for ships entering the port. Only Chenshan Anchorage and Caiqishan Anchorage are for dangerous cargo ships to anchor. There are many dangerous cargo ships entering the port everyday and many of them are anchoring adjacent to the anchorages due to insufficient special anchor

Figure2.3 Layout of anchorages in Jiaxing Port

Source: Compiled by author based on pictures of Jiaxing Port chart position. The insufficient anchorage for dangerous cargo ships has seriously affected the navigation safety of ships and limited the development of the port.

2.2.4 Hangzhou Bay Bridge

Hangzhou Bay Bridge is 36 km long. It has two fairways and four navigable spans from the north to the south. The NO.2 navigable span(north main navigable span) has a free height of 47 m and a navigable clearance width of 325 m, and the designed navigable ship type is 35,000 tonnage. The NO.1 and NO.3 navigable span (north auxiliary navigable span) besides have a free height of 28 m and a navigable clearance width of 110 m, and the designed navigable ship type is 1,000 tonnage. The NO.4 navigable span (south navigable span) has a free height of 31 m and a navigable clearance width of 250 m, and the designed navigable ship type is 3,000 tonnage (Jiaxing MSA, 2017).

Figure2.4 North main navigable span of Hangzhou Bay Bridge

Source: http://image.baidu.com/

2.2.5 Submarine pipeline

The pipeline starts from Baisha Bay of Pinghu City in the north and reaches Cixi City in the south, with a total length of 53.5 km, of which about 5 km is across the waters of Jiaxing Port (Jiaxing MSA, 2017).

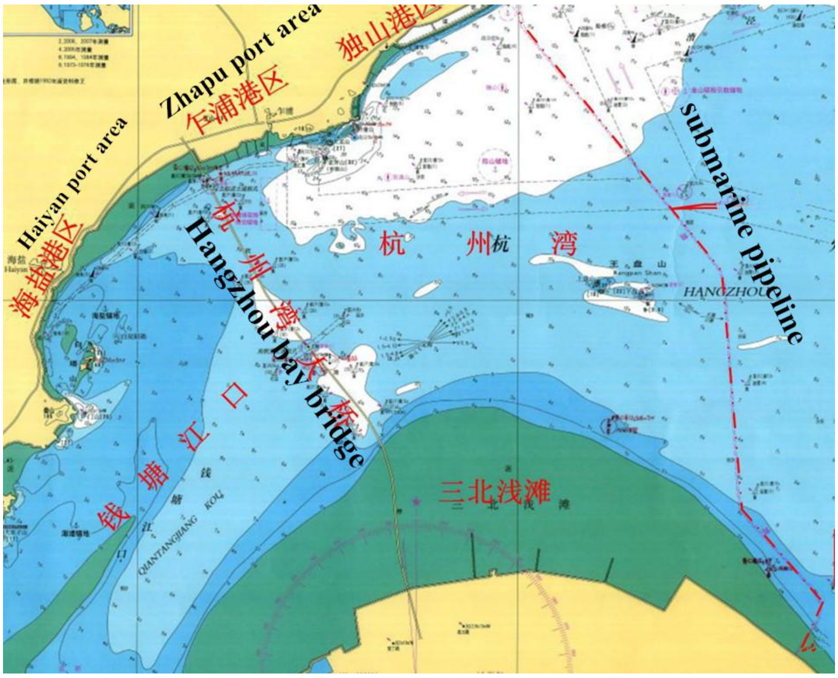


Figure2.4 Hangzhou Bay Bridge and submarine pipeline

Source: Compiled by author based on pictures of Jiaxing Port chart

2.3 Traffic environment

2.3.1 Analysis of traffic flow

According to the statistics from Jiaxing Maritime Safety Administration (MSA), the number of inbound and outbound vessels and foreign ships are shown as the table below:

Table 2.5 Statistics of the number of inbound and outbound vessels and foreign ships in Jiaxing Port

Year	Number of inbound and outbound vessels	Number of foreign ships
2010	9723	969
2011	10626	1205
2012	11163	1507
2013	12111	1768

2014	12883	1564
2015	11359	1438
2016	13085	1762
2017	18165	1721

Source: Compiled by author based on data from Jiaxing MSA (2018)

Through comprehensive analysis of statistics of vessels entering and leaving Jiaxing Port, it can be concluded that the traffic flow of the port every day is about 50, and among them there are 9 dangerous cargo vessels per day (Jiaxing MSA, 2018).

2.3.2 Statistical analysis of marine accidents

According to statistics from Jiaxing MSA, maritime traffic accidents in Jiaxing Port are shown as the following table:

Table 2.6 Statistics of marine accidents from 2008 to 2015

Indicator / Year	Number of accidents	Number of ships sank	Number of dead and missing	Direct economic loss (million RMB)
2008	0	0	0	0
2009	4	1	0	3.941
2010	3	1	0	3.252
2011	5	0	0	5.960
2012	1	0	0	2.930
2013	2	1	1	2.000
2014	1	0	0	0
2015	0	0	0	0
Total	13	2	0	18.083

Source: Jiaxing MSA, 2016

And the types of accidents are shown in Table 2.7:

Table 2.7 Statistics of marine accident type from 2008 to 2015

Year / Type	2008	2009	2010	2011	2012	2013	2014	2015	Total
Collision	0	0	1	1	0	1	0	0	3
Grounding	0	1	0	0	0	0	0	0	1
Stranding	0	0	0	0	0	0	0	0	0
Contact damage	0	3	2	4	1	0	1	0	11
Wave damage	0	0	0	0	0	0	0	0	0
Fire/ explosion	0	0	0	0	0	0	0	0	0
Self sinking	0	0	0	0	0	1	0	0	1
Others	0	0	0	0	0	0	0	0	0

Source: Jiaxing MSA, 2016

It can be seen from the above table that contact damage is the main type of marine accidents in Jiaxing Port, occurring 11 times and accounting for 68.75% of all accidents. 9 contact damage accidents occurring when the ships are berthing or unberthing, accounting for 56.25% of all accidents.

Table 2.8 Distribution of marine accidents

Type / Location	Contact damage	Collision	Grounding	Self sinking	Total
Zhapu port area	8	1	0	0	9
Dushan port area	1	0	1	0	2
Haiyan port area	0	1	0	0	1
Chenshan anchoragr	0	1	0	0	1
Bridge area	1	0	0	0	1
Other areas	1	0	0	1	2

Source: Compiled by author based on data from Jiaxing MSA (2016)

It can be seen from the table that most of the accidents occurring in Zhapu port area, accounting for 56.25% of all accidents.

2.3.3 Aid to navigation

There are 76 visual navigation aids in Jiaxing Port which are composed of 67 light buoys and 9 light beacon. There are also 2 radio beacon in position A(30˚33΄.7N/121˚21΄.5E) and B(30˚30΄.2N/121˚20΄.0E) and signals displayed by radar transponder are G (— ‥)and X (— ‥ —) (Jiaxing MSA, 2013).

2.3.4 Traffic management

The competent authority for maritime supervision and service in the port water area is Jiaxing MSA. In addition to existing international and domestic regulations and regulations on safe navigation of ships, Zhejiang MSA and Jiaxing MSA have formulated some navigation safety management regulations which are suitable for the port waters, including *Regulations on safe navigation of Hangzhou Bay Bridge*, *Regulations on the safety supervision and management for Jiaxing VTS* and so on. Jiaxing MSA has established the Vessel Traffic Service (VTS) system with two radar stations and one VTS center in 2011. Vessels shall report to the VTS on Channel 10 and follow the regulations of Jiaxing Port. Automatic Identification System (AIS) and Closed Circuit Television (CCTV) system are also applied to supervise the marine traffic. Marine patrol vessels can be arranged for on-site surveillance to protect the navigation environment. The construction of maritime supervision and protection facilities is under development to protect the safety of navigation and environment.

CHAPTER 3

NAVIGATION SAFETY EVALUATION METHODS

3.1 Definition of navigation safety evaluation

Navigation safety evaluation is an important subject in the study of marine traffic safety in port waters. By applying the theory and method of system safety evaluation, it analyses and finds out potential risk factors existing in the marine traffic system by using the theory and method of system security assessment, carries out risk assessment on the navigation environment system through adopting appropriate evaluation methods, puts forward the specific security measures to improve the safety of navigation environment system according to the evaluation results, so as to achieve the aim of decreasing the accident rate, reducing the economic loss and maximally enhancing economic performance (Pillay, Wall & Loughran, 1999). The danger level of navigation environment can be expressed by some exact objective evaluation indexes and the corresponding evaluation criteria which are given. The the flow chart of navigation safety evaluation is given in Figure 3.1 .

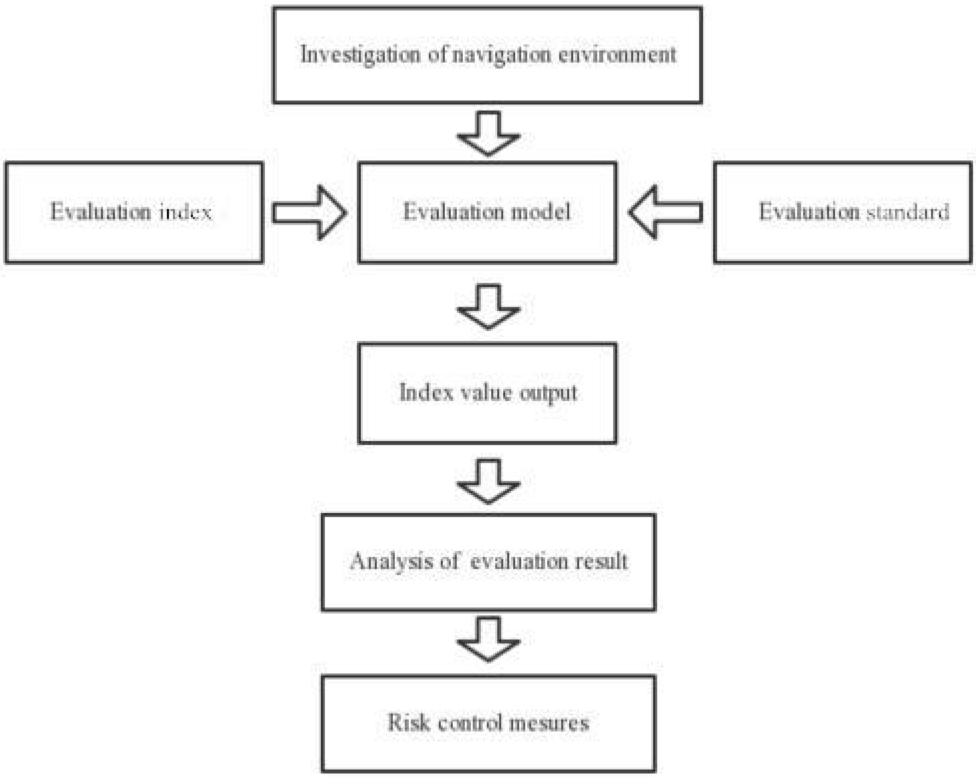


Figure 3.1 Flow chart of navigation safety evaluation

Source:Compiled by the author

3.2 Review of current major evaluation methods

There are many comprehensive safety evaluation methods which are commonly used:

3.2.1 Mathematical statistic method

The general statistical analysis method is to count the number of maritime traffic accidents or weighted accident conversion number (determine the weighting factor according to the accident grade) and to find the percentage of accidents caused by various reasons(Wu, 2001). Mathematical statistical analysis refers to regression analysis, principal component analysis and correlation analysis of accidents caused by various reasons.At present, many scholars and maritime safety administrations have calculated the risk level of navigable waters of inland river based on the number of accidents actually occurring in this water area. A certain amount of sample size is required when applying the mathematical statistics method to analyse and evaluate the system. With the sampling statistics increasing and reaching a certain amount, frequency distribution becomes stable, and the model and the evaluation results are more reliable.

Although the above method plays an important role in quantitative analysis of maritime traffic accidents, it has some limitations: First of all, the number of accidents caused by various reasons can only represent the absolute number of accidents, and it does not reflect the degree of correlation between various causes and accidents well. Secondly, the mathematical statistical analysis method require large sample size and a good sample distribution. It is difficult to meet the above requirements for the accumulated accident data in practical work.

3.2.2 Grey System Theory

Grey System Theory (GST) is a discipline initiated by professor Julong Deng in the early 1980s under the influence of Cybernetics, Information Theory and System Theory. The focus of Grey System Theory is on uncertainty problems with small samples and poor information. Many factors are included in the study of a system and the behavior of the system is determined by mutual interactions of the factors. Some of their relations clear and are white and some of their relations are ambiguous which are called grey, such a system belongs to the grey system. Systems with completely known information are white, and those with partially known and partially ambiguous are gray (Liu & Lin, 2010). This theory is a method to whitening process the potential information of the existing data and make predictions or decisions under the condition that the data are sparse and unclear. It is characterized by the quantitative analysis and research on the system with partially known and partly unknown information (Gan, Zhang, Zheng & Peng, 2008).

Navigation environment system is a complex system which is composed of multiple factors, the relationship between the factors of the system is not very clear. In addition, the probability of the marine traffic accident is small and the data are difficult to collect. Thus the system has no simple physical prototype and mathematical prototype, and its internal mechanism relationship is fuzzy and uncertainty. They conform to the concept of grey system in terms of interaction and data collection (Zhang, 2010). Therefore, Grey System Theory is adopted by many scholars in risk analysis of navigation environment.

3.2.3 Probabilistic Risk Assessment

Probability Risk Assessment is a kind of qualitative and quantitative analysis of system safety evaluation method which calculates the accident probability (P) of the system according to the accident probability of the components and subsystems and then figures out the risk probability (R) which reflects the safety level of the system comprehensively in accordance with the formula R=P*S after determining the severity of the consequences (S) (Liao, Wang & Xu, 2010).

This method is an effective method to evaluate navigation safety. However, it is complex which requires accurate and sufficient data, complete analysis process and reasonable judgment and hypothesis. And the navigation environment system is broad which has serious insufficiency in safety data. Thus, the practical application of this method has certain difficulty which needs to invest more manpower, material resources and time.

3.2.4 Analytic Hierarchy Process

AHP was first proposed by the American operational research scientist Saaty in the 1970s (Peng & Qiang, 2004). It is a qualitative and quantitative, systematic and hierarchical analytical method. The basic steps of AHP are: Firstly, set up a hierarchy structure model; Secondly, construct a paired comparison matrix; Thirdly, calculate the weight vector and perform the consistency check; Finally, calculate the combination weight vector along with the consistency check.

AHP is applied to the complex decision-making problems, the nature of the problem, risk factors through deep analysis of the intrinsic nature of the problem, the risk factors influencing the overall objective and their internal relations which use quantitative information to mathematize the decision-making process. It is an effective method to solve complex decision-making problems with multiple criteria and objectives.

3.2.5 Fuzzy Comprehensive Evaluation

FCE is a comprehensive assessment method based on Fuzzy Mathematics which transforms qualitative evaluation into quantitative evaluation and applies Fuzzy Mathematics to make overall evaluation of events or objects restricted by many factors. It is an effective multi-factor evaluation method for the comprehensive evaluation of various influencing factors of system engineering and its evaluation results are generally expressed as fuzzy sets. FCE usually consists of fuzzy factor set, evaluation set and single factor evaluation. And multi-factor synthetic evaluation is carried out on the basis of single factor evaluation.

FCE is applicable to the quantitative evaluation of qualitative indicators through the establishment of factor set, comment set, weight set and evaluation matrix and quantitative processing of complex fuzzy factors. Besides, it can accurately describe the fuzziness of the factors, rather than the arbitrary determination of human, so the evaluation results are more consistent with the objective reality and more reasonable (Wang, 2012). Therefore, FCE can solve problems which are fuzzy and difficult to quantify well and it is also suitable for solving non-deterministic problems.

3.3 Determination of evaluation method

In this paper, FCE is used to comprehensively evaluate the navigation safety of Jiaxing Port. The main reasons are as follows:

3.3.1 Characteristics of navigation safety evaluation

Navigation safety evaluation is a complex problem which is affected by numerous and complicated indicators. The concept of most indicators is ambiguous and unspecific and is difficult to carry out accurate quantitative analysis and evaluation. The main factors affecting navigation safety mainly include natural environment factor, port environment factor and traffic environment factor, human factor and so on. Each factor contains a number of sub-factors which affect and restrict each other. For example, natural environment factor includes indicators of wind, current, visibility and so on. It is difficult to have evaluation standards to carry out objective evaluations of these factors quantitatively. So it is necessary to establish specific mathematical models to refine and quantify these fuzzy factors.

3.3.2 Advantages of FCE

FCE is a very effective multi-factor decision making method to make a comprehensive evaluation of the general objective affected by various factors. It is an effective mathematical tool for quantitative evaluation of qualitative indicators with wide scope of application which can solve the problem of fuzzy evaluation index well and provide a new and effective special way for the evaluation of navigation environment safety. It can not only be used for the comprehensive evaluation of subjective indicators, but also be used for the comprehensive evaluation of objective indicators. The application of FCE can establish a simple, intuitive and easy data-processing mathematical model, which is now used in the field of safety evaluation by more and more people.

3.4 Steps of FCE

FCE is a comprehensive evaluation method which applies fuzzy math and a maximum membership degree principle to assess systems which are affected by various factors (Jiang, Zheng & Shi, 2012). Factor set, evaluation set and single factor evaluation are the three basic elements of FCE, single factor judgement is the basis on which fuzzy comprehensive evaluation of multiple factors can be carried out. The main steps of FCE are:

Step 1: Set up the factor set $U=\{u_1,u_2,\cdots\cdots,u_n\}$. It is composed of evaluation factors (u_i) which affects the system. The selected assessment factors should be able to comprehensively, objectively and practically reflect and evaluate the attributes of the system.

Step 2: Calculate the weight set (A) which is on the basis of the corresponding weight (a_i) of each factors (u_i) in the factor set (U). The weight is determined according to the importance degree of the corresponding factor.

$A=(a_1,a_2,\cdots\cdots,a_n)$; And $\sum_{i=1}^{n} a_i = 1$; $a_i \geqslant 0$.

Step 3: Establish the evaluation set $V=\{v_1,v_2,\cdots\cdots,v_n\}$ which is a discrete set made up of evaluation results, and v_n is the nth evaluation result.

Step 4: Single factor evaluation. It is to evaluate a single factor (u_i) and determine the membership degree of u_i to v_i. So

$f: U \rightarrow F(V)$

$u_i \rightarrow f(u_i)=(r_{i1},r_{i2},\cdots\cdots,r_{im})$

Single factor evaluation is the foundation of multi-factor comprehensive evaluation. And the fuzzy evaluation matrix is:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

And the element $r_{ij} = u_R (u_i ,v_j)$, $0\leq r_{ij}\leq 1$.

Step 5: Fuzzy comprehensive evaluation.

According to the matrix multiplication rule, we can get the comprehensive evaluation set (B) which is a set consists of assessment result (Ding, Chong, Bao, Xue, & Zhang, 2017):

$$B = A \circ R = (a_1,a_2,\cdots\cdots,a_n) \circ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

CHAPTER 4

NAVIGATION SAFETY EVALUATION OF JIAXING PORT

In the previous chapter, we make a comprehensive comparison of the advantages and disadvantages of several main methods of safety assessment, analyze the advantage of FCE applied in navigation safety assessment in detail, and finally select FCE as the safety assessment method for this topic. In this chapter, we are to determine the evaluation index system, weight of factors and membership degree through expert consultation, questionnaires and research findings of scholars, and then establish the model of navigation safety evaluation and assess the navigation environment safety of Jiaxing port.

4.1 Establishment of the evaluation index system of Jiaxing Port

In the whole process of navigation environment safety evaluation, the priority goes to the determination of evaluation index system which is a combination of many factors. These factors seem to be single and independent, but they are actually closely related and interact with each other. In order to complete the evaluation work more effectively and scientifically, it is very important to choose the evaluation factors to establish the index system correctly and reasonably.

4.1.1 Selecting principle of evaluation factors

(1) The establishment of evaluation index system should meet the scientific principle, which can scientifically reflect the system's inner link and objectively reflect the relationship between each subsystem and various factors. Adhering to the scientific principle is an important precondition to ensure the reliability and objectivity of the information obtained and to make the final evaluation results more credible.

(2) The evaluation factors should be able to comprehensively and objectively evaluate the attribute characteristics, advantages and disadvantages of the system and should include many factors that affect the system security to form a relatively complete evaluation index system (Zhang, 2014).

(3) The index should be practical and operable for easier collection of data, and the comprehensive evaluation model can be established conveniently and quickly.

(4) There are many evaluation factors, which should be selected according to the evaluation object, so that the selected factors have a strong purposiveness.

(5) The design of the index system should meet the principle of qualitative and quantitative, that is, on the basis of qualitative analysis, quantitative treatment should be carried out.Only by quantifying can we reveal the essence of things more accurately.

(6) The index system should not only reflect the actual situation of system security in a certain period of time, but also keep track of its changes, so as to timely discover problems and prevent them from happening in the future.

4.1.2 Establishment of the evaluation index system

There are many factors which affect the navigation safety of ports such as natural environment, port environment, traffic condition and so on, and each factor contains several sub-factors. In this research paper, the author conducts a questionnaire survey on the determination of navigation safety evaluation index of Jiaxing Port (The questionnaire is shown in APPENDIX A) . The subjects are all professionals who know the port waters very well, including 8 pilots of Jiaxing Port, 24 senior officers from ships visiting the port frequently, 18 port managers and 15 VTS officers from Jiaxing MSA. 65 questionnaires were issued and 62 valid questionnaires were collected. The survey results are summarized in Table 4.1.

Table 4.1 Survey results of the factors affecting navigation safety of Jiaxing Port

Index		Number of agreed	Number of disagreed
Natural environment	Wind	56	6
	Current	59	3
	Wave	14	48
	Visibility	50	12
	Disaster weather	39	23
Port environment	Fairway depth	40	22
	Fairway length	25	37
	Fairway width	36	26
	Number of turning point of fairway	10	52
	Fairway curvature	12	50
	Obstructions of fairway	41	21
	Anchorage capacity	30	32
	Anchorage depth	22	40
	Quality of the anchorage bottom	15	47
Traffic environment	Traffic flow	50	12
	Number of ships less than 500GT	8	54

	Number of dangerous cargo ship	17	45
	Navigation aids	42	20
	Traffic management	39	23

Source:Compiled by the author based on the questionnaire survey

In order to make evaluation index operable and practicable, through the analysis of the collected questionnaire, the author finally selected 9 factors as evaluation factors according to the survey results, suggestions from experts and the specific situation of Jiaxing Port. And the result is shown in Table 4.2:

Table 4.2 Evaluation index system of navigation safety of Jiaxing Port (U)

First level index	Second level sub-index
Natural environment (U1)	Visibility (U_{11})
	Wind (U_{12})
	Current (U_{13})
	Disaster weather（U_{14})
Port environment (U_2)	Fairway obstacles (U_{21})
	Fairway depth (U_{22})
	Fairway width (U_{23})
Traffic environment (U_3)	Traffic flow (U_{31})
	Navigation aids（U_{32})
	Traffic management (U_{33})

Source:Compiled by the author

The first level index set is constructed as follows:

$U=\{U_1, U_2, U_3\}$;

and the second level index set is expressed as follows:

$U_1=\{U_{11}, U_{12}, U_{13}, U_{14}\}$; $U_2=\{U_{21}, U_{22}, U_{23}\}$; $U_3=\{U_{31}, U_{32}, U_{33}\}$.

4.1.3 Analysis of the evaluation index system

(1) Visibility.

Visibility directly affects the navigation safety of ships at sea, and poor visibility is one of the most important causes of ship collision, stranding and grounding. According to the relevant statistical data analysis, the marine accident rate in restricted visibility is 7 to 10 times of that under the condition of good visibility. Fog, snow, rain and hail are main causes of poor visibility, with fog having the greatest impact. Visibility is an indispensable evaluation index in the navigation safety evaluation of port waters. The annual number of days with poor visibility (visibility is less than 2 km) is usually selected as an evaluation indicator of visibility. And the author set up the evaluation standard of safety level for visibility according to the actual situation of Jiaxing port and research literature of Ma Hui and Wu Zaolin (1998), shown in Table 4.3:

Table 4.3 Evaluation standard of visibility

Annual poor visibility days(N)	N≤15	15< N ≤25	25< N ≤40	40< N ≤50	N>50
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Ma & Wu, 1998)

According to the analysis in Section 2.1.1, the annual poor visibility days of Jiaxing Port is 38.2.

(2) Wind

Wind is a fairly important factor which affects the navigation safety of ships. Wind is one of the main factors causing marine accidents such as capsizing and sinking. According to accident statistics, navigation practice shows that when the wind force reaches Beaufort No.6 or above, the maritime traffic accident rate increases significantly with the increase of wind force. Jiaxing Port is significantly affected by the wind. There are no sheltered anchorages and ships are easy to be dragging and break the mooring lines when there strong wind occurs. Therefore, wind is an indispensable evaluation index in risk assessment. According to the results of some relevant research literature (Kobayashi & Tanaka, 1992), the author selected the “annual standard wind days” as the evaluation criterion of wind factors, and the formula for calculating the annual standard wind days is as follows:

Annual standard wind days=Annual average number of days when the wind force reaches Beaufort No.6 + 1.5*(Annual average number of days when the wind force reaches Beaufort No.8) ;

and then establish the evaluation standard of safety level for wind:

Table 4.4 Evaluation standard of wind

Annual standard wind days (N)	N≤30	30< N ≤58	58< N ≤86	86< N ≤145	N>145
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Ma & Wu, 1998)

According to the analysis in Section 2.1.1, the annual standard wind days of Jiaxing Port is 139.25 (121.1+1.5*12.1).

(3) Current

The current has significant influence on the ship's maneuverability, such as speed, rudder effect and turning performance. For the current in port waters, the influence of tide is mainly considered. The wind and sea current that act together on ships are also of great strength which cannot be ignored for the safe navigation of ships. Under the influence of strong current, it is difficult for the navigating officers to maneuver the ship effectively, and ships are easy to collide with the ships nearby and causing danger. The higher the current velocity, the higher the probability of ship accident. Jiaxing Port is famous for the strong tide in Hangzhou Bay. Therefore, current is an important factor in navigation safety assessment, and the maximum current speed is selected as a standard to assess the safety level of current, as shown in Table 4.5:

Table 4.5 Evaluation standard of current

Maximum current speed (V)	V≤0.5 kn	0.5< V ≤1.5kn	1.5< V ≤2.5kn	2.5< V ≤4kn	V>4kn
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Zhang, 2014)

According to the analysis in Section 2.1.2, the the maximum current speed of Jiaxing Port can reach 7 knots in the port waters.

(4) Disaster weather

Jiaxing Port water area is often affected by disaster weather including typhoon and cold wave and thunderstorm. The port is located in open water area and there are no sheltered anchorages. There are many constructing vessels in the port with low anti-disaster capability. When a natural disaster occurs, it is easy to cause a serious chain reaction, causing significant threat to the navigation safety of ships. In serious cases, it may even cause heavy loss of personnel and property (Gao, 2014). Therefore, disaster weather is taken as the evaluation factor, and the annual disaster weather days is selected as a criterion to assess the safety level of disaster weather.

Table 4.6 Evaluation standard of disaster weather

Annual disaster weather days (N)	N≤12	12< N≤24	24< N≤38	38< N≤50	N>50
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author

According to the analysis in Section 2.1.1, disaster weather of Jiaxing Port is mainly typhoon and cold wave. So the annual disaster weather days of the port is 10.2 (1.4*3+2*3).

(5) Fairway obstacles

When ships are sailing in the fairway, they are easy to deviate from the planning route and fairway if there are positioning errors or improper anti-collision actions. And they may be grounding or stranding if there are obstacles around the fairway. Navigating officers cannot ignore the impact of navigation obstacles near the channel on navigation safety of ships. The influence of obstacles on the navigation safety of ships is mainly reflected in two factors including the number of obstacles and distance from the channel, of which the latter plays a key role. Therefore, this research paper chooses the obstacles near the fairway as one of the evaluation indicators, and takes "the minimum distance between the obstacles and the fairway" as evaluation basis and criterion (Wen, 2015). Then the author established the evaluation standard of safety level for fairway obstacles (see Table 4.7) according to the actual situation of the port and with reference to some relevant research literature.

Table 4.7 Evaluation standard of fairway obstacles

Minimum distance between the obstacles and the fairway (D)	D> 200m	100< D≤200m	50< D≤100m	20< D≤50m	D≤20m
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Ma & Wu, 1998)

According to the analysis in Section 2.2.2.2, the fairway obstacles of Jiaxing Port are mainly small fishing boats and fishing stakes near the channel, and the minimum distance between the obstacles and the fairway is between 50 and 100 meters.

(6) Fairway depth

Fairway depth is an important factor in navigation safety assessment of port waters.

In general, the risk level of this index can be measured by the ratio of channel depth to the maximum designing draft of the vessel. In ship maneuvering, shallow water effect will occur when the channel water depth is less than 4 times of the ship's draft. When the ratio of the channel depth to the ship's draft is less than or equal to 2.5, the ship's maneuverability will be affected. When the ratio of the channel depth to the ship's draft is less than or equal to 1.2, the ship's maneuverability will be significantly affected (Hong, 2009). So the author chooses the ratio of minimum channel depth to the maximum designing draft of vessels entering the port as a standard to evaluate the safety level of fairway depth and the evaluation standard is shown in Table 4.8:

Table 4.8 Evaluation standard of fairway depth

The ratio of minimum channel depth to the maximum designing draft (R)	R> 10	4< R≤10	2.5< R≤4	1.2<R≤2.5	R≤1.2
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on ship maneuvering (Hong, 2009)

According to the analysis in Section 2.2.2, the minimum depth of the main access channels is 7.4 m, and the maximum draft of inbound vessel is 11.2 m, so the ratio of minimum channel depth to the maximum designing draft is 0.66.

(7) Fairway width

When the length of the channel and traffic volume in a certain period of time are fixed, the narrower the channel, the smaller the ship's movement space is, the interaction between ships and bank effect of vessels are more apparent, and the marine traffic accident rate of collision, stranding and grounding is much higher. Therefore, when evaluating the influence of channel width on navigation safety, the ratio of minimum channel width to the maximum breadth of ships designed to pass through the channel is adopted to measure the risk of the channel. And the author established the evaluation standard of safety level for fairway width (see Table 4.8) according to the actual situation of the port and with reference to some relevant research literature, as shown in Table 4.9.

Table 4.9 Evaluation standard of fairway width

The ratio of minimum channel width to the maximum breadth of ships (R)	R> 15	10< R≤15	5< R≤10	2<R≤5	R≤2
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Wen, 2015)

According to the analysis in Section 2.2.2, the minimum channel width of the main access channels is 1800 m, and the maximum breadth of ships designed to pass through the channel is 32 m, so the ratio of minimum channel width to the maximum breadth of ships is 56.25.

(8) Traffic flow

The influence of traffic flow on navigation safety of ships is very obvious. When the traffic is heavy, it means that the number of vessels in and out is large and the water area is more crowded, which not only reduces maneuvering space of the vessel, increases the chances of their encounter, but also causes more risk of collision and increases the probability of marine accidents in the waters. Therefore, the author chose traffic flow as one of the evaluation indicators, and took the average number of ships in and out of the port every day as its evaluation basis and criteria.

Table 4.10 Evaluation standard of traffic flow

The average number of inbound and outbound ships every day(N)	N≤30	30<N≤60	60<N≤110	110<N≤200	N>200
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Xiang, 2007)

According to the analysis in Section 2.3.1, the average number of inbound and outbound ships of the port every day is 50.

(9) Navigation aids

Navigation aids are generally located in the navigable waters to indicate the positions which are closely related to the navigation safety of ships. The perfect degree of navigation aids directly affects the decision-making of officers and the transporting efficiency of the ports and channels, and affects navigation safety of ships to a certain extent. The author chose the perfect rate of navigation aids as an evaluation criteria and established the evaluation standard of safety level for navigation aids (see Table 4.11) according to the consultation with professionals and with reference to the relevant research experience.

Table 4.11 Evaluation standard of navigation aids

The perfect rate of navigation aids (R)	R> 95%	90%< R≤95%	85%< R≤90%	75%<R ≤85%	R≤75%
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Wen, 2015)

Jiaxing Port has established complete navigation aids system to instruct the vessels' safe navigation. Through questionnaire survey and expert consultant the author determines that the perfect rate of navigation aids is above 95%.

(10) Traffic management

Traffic management means that the compete authority (Jiaxing MSA) takes certain supervising measures to monitor the marine traffic condition, maintain the maritime traffic order and ensure the navigation safety of ships. Traffic management factors are subjective and difficult to carry out objective quantitative research. According to the research principles of scholars and combined with the results and opinions of expert investigation, the author also applied the perfect rate of traffic management as the basis and principles for the evaluation of traffic management. The evaluation criteria for the safety level of traffic management is formulated as the following table:

Table 4.12 Evaluation standard of traffic management

The perfect rate of traffic management (R)	R> 95%	90%< R≤95%	85%< R≤90%	75%<R ≤85%	R≤75%
Safety level	Very good	Good	Moderate	Poor	Very poor

Source: Compiled by author based on research literature (Wen, 2015)

According to the analysis in Section 2.3.4 and the result of questionnaire survey and expert consultant, the author determines that the perfect rate of navigation aids is above 95%.

4.1.4 Determining the value of evaluation indexes of Jiaxing Port

According to the discussion in Section 4.1.3, the author determines the value of each index in Table 4.13:

Table 4.13 Value of navigation safety evaluation indexes for Jiaxing Port

Index	Evaluation standard	Value
Visibility	Annual poor visibility days	38.2 days
Wind	Annual standard wind days	139.25 days
Current	Maximum current speed	7 knots
Disaster weather	Annual disaster weather days	10.2 days
Fairway obstacles	Minimum distance between the obstacles and the fairway	between 50 and 100 m
Fairway depth	The ratio of minimum channel depth to the maximum designing draft	0.66

Fairway width	The ratio of minimum channel width to the maximum breadth of ships	56.25
Traffic flow	The average number of ships in and out of the port	50
Navigation aids	The perfect rate of navigation aids	> 95%
Traffic management	The perfect rate of traffic management	> 95%

Source: Compiled by author

4.2 Calculation of the weight of evaluation indexes for Jiaxing Port

It is very important to determine the weight of evaluation index which can directly influence the result of comprehensive evaluation. In order to make the weight of evaluation index reflect the objective reality, this paper applies AHP method to determine the weight of each evaluation index.

4.2.1 Steps of AHP

Step 1: Construct a pairwise comparison judgement matrix. The pairwise comparison of the target elements is a qualitative evaluation. In specific applications, we introduce Satty's 1-9 scale method (see in Table 4.14) to transform qualitative evaluation into quantitative evaluation. To obtain the compare results, the 1-9 scale method is applied to indicate the relative importance of each pair of elements in the same hierarchy (Jiao, Ren & Sun, 2016).

Table 4.14 The table for 1-9 scale method

Score	Meaning(One element compares with the other)
1	The two elements are equal important
3	One element is slightly important than the other
5	One element is clearly important than the other
7	One element is strongly important than the other

9	One element is extremely important than the other
2,4,6,8	The median of the above adjacent judgements
Reciprocal	If the judgement value of element i compares with j is a_{jj}, and the judgement value of element j compares with i is $a_{ji}=1/a_{jj}$

Source: Compiled by author based on research literature (Cheng & Tao, 2010)

The judgement matrix is expressed as:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

In the judgement matrix, the characteristics of the elements are:

$a_{ii}=1$ (i=1,2,3,⋯,n);

$a_{ij}=1/a_{ji}$ (i,j=1,2,3,⋯,n);

$a_{i}=a_{ik}/a_{jk}$ (i,j,k=1,2,3,⋯,n).

Step 2: Calculate the maximum eigenvalue of the judgement matrix (λ_{max}) and its corresponding eigenvector by applying normalization method or root method. The corresponding eigenvector (W_0) is the relative importance ranking weights of corresponding elements in the same hierarchy to some elements in the superior hierarchy. And by normalizing the corresponding eigenvector we can get the weight of the element (W).

Step 3: Consistency checking.

Suppose the maximum eigenvalue of the n dimensional judgement matrix is λ max, Consistency Index (CI) is introduced, and $CI = \frac{\lambda_{max} - n}{n - 1}$.

We introduce the Average Random Consistency Index of the matrix (RI), and the standard value of RI is shown in Table 4.15:

Table 4.15 Standard values of Average Random Consistency Index (RI)

Dimension	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Cheng & Tao, 2010

In practise, we apply Consistency Ratio (CR) to check whether the matrix has satisfactory consistency.And $CR = \frac{CI}{RI}$;

When CR<0.1, it is considered that the judgment matrix has satisfactory consistency. Otherwise the judgment matrix needs to re-adjust until satisfied.

4.2.2 Calculate the weight of evaluation index

The author conducts a questionnaire survey on the determination of navigation safety evaluation index of Jiaxing Port. The questionnaires (see in APPENDIX B) are sent out to professionals who know the port waters very well, including 8 pilots of Jiaxing Port, 24 senior officers from ships visiting the port frequently, 18 port managers and 15 VTS officers from Jiaxing MSA. The weights of the indexes are figured out by analyzing the survey results and applying AHP.

The judgement matrix of the first level index (natural environment factors, port environment factors and traffic environment factors) is：

$$A=\begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}$$

And the weight of each index in the first level is shown in Table 4.16:

Table 4.16 Weight of each index in the first level (W)

Index	Natural environment	Port environment	Traffic environment

Weight	0.5390	0.2972	0.1638

Source: Compiled by author

The judgement matrix of the second level sub-index (visibility, wind, current and disaster weather) is：

$$A=\begin{bmatrix} 1 & 1/2 & 1/2 & 2 \\ 2 & 1 & 1 & 2 \\ 2 & 1 & 1 & 3 \\ 1/2 & 1/2 & 1/3 & 1 \end{bmatrix}$$

the weight of each index is shown in Table 4.17:

Table 4.17 Weight of sub-index in natural environment (W_1)

Index	Visibility	Wind	Current	Disaster weather
Weight	0.1937	0.3562	0.3250	0.1251

Source: Compiled by author

The judgement matrix of the second level sub-index (fairway obstacles, fairway depth and fairway width) is：

$$A=\begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}$$

the weight of each index is shown in Table 4.18:

Table 4.18 Weight of sub-index in port environment (W_2)

Index	Fairway obstacles	Fairway depth	Fairway width
Weight	0.5390	0.2972	0.1638

Source: Compiled by author

The judgement matrix of the second level sub-index (traffic flow, navigation aids, traffic management) is：

$$A=\begin{bmatrix} 1 & 2 & 4 \\ 1/2 & 1 & 2 \\ 1/4 & 1/2 & 1 \end{bmatrix}$$

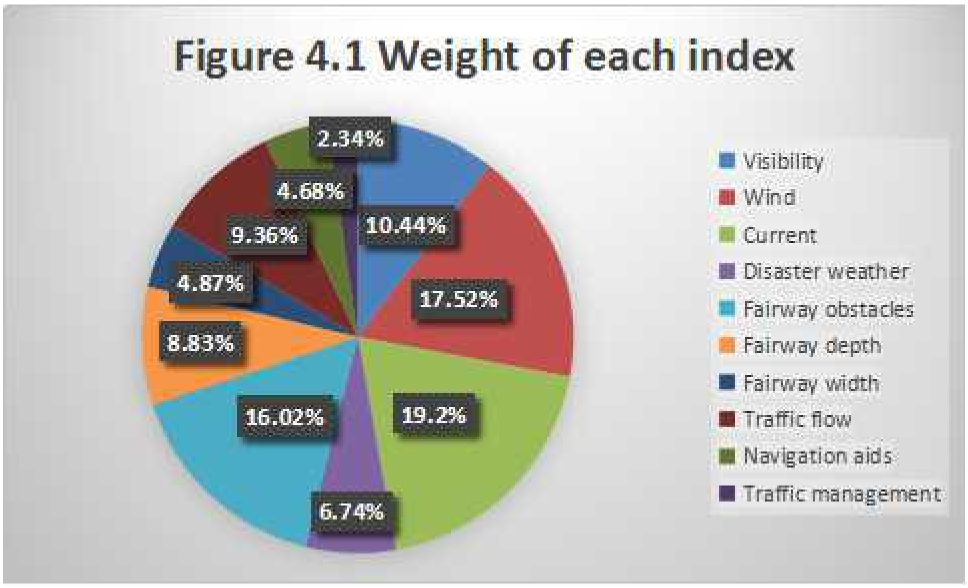
the weight of each index is shown in Table 4.19:

Table 4.19 Weight of sub-index in traffic environment (W_3)

Index	Traffic flow	Navigation aids	Traffic management
Weight	0.5714	0.2857	0.1429

Source: Compiled by author

After calculation, we can get the values of CR of each judgement matrix are 0.008, 0.0345, 0.008 and 0.0169 respectively which are smaller than 0.1, and each judgment matrix has satisfactory consistency. And the weight of each sub-index is shown in the figure below:



Source: Compiled by author

4.3 Establishment of the evaluation set of the index system

In this research paper, the safety level of each navigation safety evaluation index of Jiaxing Port is divided into 5 levels from high to low: Very good (very low risk), Good (low risk), Moderate (moderate risk), Poor (rather high risk), Very poor (very high risk). The evaluation set is:

V={Very good, Good, Moderate, Poor, Very poor}={1, 2, 3, 4, 5}, and 1,2,3,4,5 represent the fuzzy numbers with the purpose to facilitate the calculation and to reflect the results directly.

4.4 Determination of the membership degree of the evaluation index

In the research paper, the author applied the expert scoring method and sent out questionnaires (see in APPENDIX C) to professionals who know the port waters very well, including 8 pilots of Jiaxing Port, 24 senior officers from ships visiting the port frequently, 18 port managers and 15 VTS officers from Jiaxing MSA. 65 questionnaires were issued and 60 valid questionnaires were recovered. After analysis, summary and normalization of the experts' opinions, the membership degree of each evaluation factor corresponding to different safety levels can be obtained (as shown in Table 4.20)

Table 4.20 Membership degree of each factor

Index	Index value	Membership degree				
		Very good	Good	Moderate	Poor	Very poor
Visibility (Annual poor visibility days:N)	N≤15	0.6667	0.2333	0.0833	0.0167	0
	15< N≤25	0.2	0.5333	0.2	0.0667	0
	25< N≤40	0.0667	0.2333	0.5333	0.1333	0.0333
	40< N≤50	0.0167	0.2	0.1833	0.4833	0.1167
	N>50	0	0.0333	0.0667	0.2833	0.6167
	N≤30	0.7	0.2	0.0667	0.0167	0.0167

Wind (Annual standard wind days: N)	30< N≤58	0.2	0.55	0.2	0.05	0
	58< N≤86	0.1167	0.1833	0.5333	0.1333	0.0333
	86< N≤145	0	0.2667	0.2833	0.4333	0.0167
	N>145	0	0	0.0667	0.25	0.6833
Current (Maximum current speed: V)	V≤0.5 kn	0.7167	0.1667	0.0667	0.0333	0.0167
	0.5< V≤1.5kn	0.1667	0.5833	0.15	0.0833	0.0167
	1.5< V≤2.5kn	0.1	0.2	0.4667	0.1667	0.0667
	2.5< V≤4kn	0	0.1667	0.1833	0.5167	0.1333
	V>4kn	0	0.1	0.1667	0.1667	0.5667
Disaster weather (Annual disaster weather days: N)	N≤12	0.5667	0.3167	0.1167	0	0
	12< N≤24	0.2167	0.5	0.2	0.0833	0
	24< N≤38	0.1667	0.2	0.4	0.15	0.0833
	38< N≤50	0.0333	0.1667	0.2	0.4667	0.1333
	N>50	0.0167	0.0167	0.1333	0.2167	0.6167
Fairway obstacles (Minimum distance between the obstacles and the fairway: D)	D> 200m	0.5833	0.3167	0.1	0	0
	100<D ≤200m	0.1667	0.5167	0.0833	0.2	0.0333
	50< D≤100m	0.0833	0.25	0.55	0.1	0.0167
	20< D≤50m	0	0.1667	0.2333	0.5	0.1
	D≤20m	0.0333	0.0333	0.1	0.2833	0.55
Fairway depth (The ratio of minimum channel depth to the maximum	R> 10	0.75	0.1333	0.0833	0.0167	0.0167
	4< R≤10	0.15	0.6	0.2	0.05	0
	2.5< R ≤4	0.2	0.2	0.4167	0.1667	0.0167
	1.2<R ≤2.5	0.0667	0.1333	0.2667	0.4667	0.0667

designing draft: R)	R≤1.2	0	0.1333	0.15	0.2167	0.5
Fairway width (The ratio of minimum channel width to the maximum breadth of ships: R)	R> 15	0.5333	0.3500	0.1167	0	0
	10< R ≤15	0.3333	0.5333	0.1333	0	0
	5< R ≤10	0.1333	0.1833	0.5333	0.15	0
	2<R≤5	0.0167	0.1667	0.2167	0.5167	0.0833
	R≤2	0	0	0.0667	0.3	0.6333
Traffic flow (The average number of ships in and out of the port: N)	N≤30	0.5833	0.3	0.1167	0	0
	30<N≤60	0.2333	0.4667	0.2333	0.0667	0
	60<N≤110	0.0833	0.2167	0.5167	0.15	0.0333
	110<N ≤200	0	0.2667	0.2500	0.4500	0.0333
	N>200	0	0.0833	0.15	0.1833	0.5833
Navigation aids (The perfect rate of navigation aids: R)	R> 95%	0.55	0.35	0.1	0	0
	90%<R ≤95%	0.2167	0.5	0.2833	0	0
	85%<R ≤90%	0.15	0.2333	0.5	0.1	0.0167
	75%<R ≤85%	0.0667	0.2167	0.2	0.4333	0.0833
	R≤75%	0.05	0.05	0.0833	0.2833	0.5333
Traffic management (The perfect rate of traffic management: R)	R> 95%	0.5333	0.3667	0.1	0	0
	90%<R ≤95%	0.2667	0.5	0.1833	0.05	0
	85%<R ≤90%	0.15	0.2	0.4667	0.1667	0.0167
	75%<R ≤85%	0.0667	0.15	0.1667	0.5167	0.1
	R≤75%	0	0.1333	0.1667	0.15	0.55

Source: Compiled by the author

According to the value of each evaluation index discussed in Section 4.1.4, we can get the conclusion that the fuzzy evaluation matrix of natural environment factor (R_1) is:

$$R_1 = \begin{bmatrix} 0.0667 & 0.2333 & 0.5333 & 0.1333 & 0.0333 \\ 0 & 0.2677 & 0.2833 & 0.4333 & 0.0167 \\ 0 & 0.1000 & 0.1667 & 0.1667 & 0.5667 \\ 0.5667 & 0.3167 & 0.1167 & 0 & 0 \end{bmatrix}$$

the fuzzy evaluation matrix of port environment factor (R_2) is:

$$R_2 = \begin{bmatrix} 0.0833 & 0.2500 & 0.5500 & 0.1000 & 0.0167 \\ 0 & 0.1333 & 0.1500 & 0.2167 & 0.5000 \\ 0.5333 & 0.3500 & 0.1167 & 0 & 0 \end{bmatrix}$$

the fuzzy evaluation matrix of traffic environment factor (R_3) is:

$$R_3 = \begin{bmatrix} 0.2333 & 0.4667 & 0.2333 & 0.0667 & 0 \\ 0.5500 & 0.3500 & 0.1000 & 0 & 0 \\ 0.5333 & 0.3667 & 0.1000 & 0 & 0 \end{bmatrix}$$

4.5 Fuzzy comprehensive evaluation of navigation safety of Jiaxing Port

According to the above discussion, the evaluation vector for natural environment factor (B_1) is:

$B_1 = W_1 \text{ o } R_1$

$$=(0.1937, 0.3562, 0.3250, 0.1251)\text{o}\begin{bmatrix} 0.0667 & 0.2333 & 0.5333 & 0.1333 & 0.0333 \\ 0 & 0.2677 & 0.2833 & 0.4333 & 0.0167 \\ 0 & 0.1000 & 0.1667 & 0.1667 & 0.5667 \\ 0.5667 & 0.3167 & 0.1167 & 0 & 0 \end{bmatrix}$$

=(0.0838, 0.2123, 0.2730, 0.2343, 0.1966);

The evaluation vector for port environment factor (B_2) is:

$B_2 = W_2 \text{ o } R_2$

$$=(0.5390, 0.2972, 0.1638) \circ \begin{bmatrix} 0.0833 & 0.2500 & 0.5500 & 0.1000 & 0.0167 \\ 0 & 0.1333 & 0.1500 & 0.2167 & 0.5000 \\ 0.5333 & 0.3500 & 0.1167 & 0 & 0 \end{bmatrix}$$

=(0.1323, 0.2327, 0.3601, 0.1183, 0.1576);

The evaluation vector for traffic environment factor (B_3) is:

$B_3=W_3 \circ R_3$

$$=(0.5714, 0.2857, 0.1429) \circ \begin{bmatrix} 0.2333 & 0.4667 & 0.2333 & 0.0667 & 0 \\ 0.5500 & 0.3500 & 0.1000 & 0 & 0 \\ 0.5333 & 0.3667 & 0.1000 & 0 & 0 \end{bmatrix}$$

=(0.3667, 0.4191, 0.1762, 0.0381, 0);

The final comprehensive evaluation matrix (B) is:

$B=W \circ R$

$$=(0.5390, 0.2972, 0.1638) \circ \begin{bmatrix} 0.0838 & 0.2123 & 0.2730 & 0.2343 & 0.1966 \\ 0.1323 & 0.2317 & 0.3601 & 0.1183 & 0.1576 \\ 0.3667 & 0.4191 & 0.1762 & 0.0381 & 0 \end{bmatrix}$$

=(0.1446, 0.2519, 0.2830, 0.1677, 0.1528)

Then we get the result of navigation safety evaluation of Jiaxing Port according to weighted average method:

$$V=\frac{\sum_{i=1}^{5} B_i V_i}{\sum_{i=1}^{5} B_i}=\frac{0.1446\times 1+0.2519\times 2+0.2830\times 3+0.1677\times 4+0.1528\times 5}{0.1446+0.2519+0.2830+0.1677+0.1528}=2.9322;$$

According to the evaluation set V={1, 2, 3, 4, 5}={Very good, Good, Moderate, Poor, Very poor}, we conclude the judgement that the navigation safety level of Jiaxing Port is between good and moderate.

CHAPTER 5

MEASURES TO IMPROVE NAVIGATION SAFETY OF JIAXING PORT

From the above evaluation process and result, it can be concluded that although the navigation safety level of Jiaxing Port is between good and moderate, the risk of navigation still exists. It should be noticed that some factors with large weight have great influence on navigation safety of ships such as wind and current. This chapter will put forward some corresponding measures to the compete authorities for improving maritime traffic safety of Jiaxing Port from three aspects: natural environment, port environment and traffic environment.

5.1 Measures on natural environment

The compete authorities for maritime traffic safety of Jiaxing Port shall:

- strengthen the cooperation with the weather bureau and other units, establish the severe weather early-warning and forecast system of Jiaxing port to improve the level of early warning for strong wind, strong tide, heavy fog with terrible visibility and disaster weather like typhoon and cold wave, so as to quickly obtain meteorological information at an early date and achieve a rapid and relatively accurate response to meteorological conditions.

- strictly implement the early-warning and pre-control system for severe weather and sea conditions including strong wind, strong tide, heavy wave, heavy fog with poor visibility and disaster weather like typhoon and cold wave that seriously threaten the navigation safety of ships, and take different traffic control measures including requirement of ships berthing with tug assistance, suspension of pilotage, suspension of berthing operations and so on according to the severity of weather and sea conditions.
- carry out anti-typhoon work under the guidance of the regulations on the supervision and administration of anti-typhoon in coastal waters of Jiaxing. Typhoon is the most disastrous weather with serious impact on the navigation safety of ships. In addition to taking preventive measures such as timely releasing meteorological safety information, the construction process of anti-typhoon anchorage should also be accelerated to ensure that ships in the port can shelter from typhoon in a timely and safe manner (Zhou, 2015).
- strengthen maritime traffic safety monitoring under the condition of bad weather, and sea conditions including strong wind, strong tide, heavy fog with terrible visibility and disaster weather like typhoon and cold wave through various means such as AIS, VTS, CCTV and on-site inspection. Special attention should be paid to the safety of navigation and anchorage operations of ships during strong wind and tide.

5.2 Measures on port environment

The compete authorities for maritime traffic safety of Jiaxing Port shall:

- strengthen communication and cooperation with the fishery management departments, keep abreast of the fishery production and navigation hindrances in the port area and actively carry out education activities for promoting maritime safety operation of fishing vessels. They shall also step up oversight of fishing operations near the fairways, anchorages and navigable waters to prevent marine fishery from obstructing navigation, improve the navigation safety of merchant ships and ensure a stable security situation for commercial and fishing vessels in areas under their jurisdiction.

- actively coordinate with local governments and functional departments of fisheries to carry out joint actions to strengthen the management of unordered operations and random anchorage of fishing vessels, and intensify efforts to clean up and control fishing nets and stakes that hinder navigation.
- improve the navigable conditions of approach channels. With the rapid development of the port, the number of ships in and out of Jiaxing port is rising sharply year by year, which is affecting the navigation safety of some large ships with deep draught entering the port by taking the tide. The maintenance, dredging, construction and scanning and surveying of fairway shall be strengthened. The latest information about channel with surveying data including water depth and width shall be released timely and accurately. The dredging operation of shallow water in the fairway shall be carried out when conditions permit to improve the depth of channel.

5.3 Measures on traffic environment

- The management of the traffic control department is one of the important factors to control the traffic flow of the port waters. The compete authorities shall give full play to the role of VTS in maritime safety management and strengthen tracking management for ships in areas with heavy traffic flow. It is necessary to make statistics on the traffic flow of ships entering and leaving the port, predict the peak traffic flow in advance, take good control measures in advance, and control the flow and density of ships in the port waters in an appropriate range.

- The compete authorities shall strengthen the management of navigation aids, carry out daily inspection and maintenance to ensure the effectiveness of these facilities, and comprehensively utilize a variety of means and ways to check the working condition of the navigation aids such as beacons, marks and so on. If any abnormal situation is found, it shall be repaired in time to avoid the damage and loss of navigation aids to affect the navigation safety of ships.
- The compete authorities shall formulate a scientific and effective traffic management system to carry out marine traffic management and control work. They shall provide the maritime administrative staff with excellent education and training to improve the control level of them, increase input in the construction of maritime supervision facilities and equipment to offer good material guarantee for marine traffic management, make full use of supervising means including VTS, AIS, CCTV and on-site inspection to strengthen monitoring of key waters and focusing on key risk sources, and cooperate with other administrations such as the coast guard to crack down on marine traffic violations so as to maintain good navigation order in the port waters.

CHAPTER 6

CONCLUSIONS

In this research paper, the author constructed index system of navigation safety evaluation, figured out the corresponding index weight and comprehensively assessed the safety level of navigation environment of Jiaxing Port by applying the FCE based on field investigation, expert consultation, questionnaire investigation and referring to relevant literature and materials. The evaluation result is that the safety level of Jiaxing Port is between good and moderate and can basically meet the requirement of navigation safety in the poet waters. This research paper also puts forward some risk control measures to the compete authorities of maritime safety for improving navigation safety of the port in accordance with the evaluation result. Evaluation of navigation safety is a complicated and comprehensive task involving various factors and this paper provides scientific and reasonable research ideas and methods for solving this problem. The research result may provide a reliable decision basis for the relevant authorities on the navigation safety management of Jiaxing Port。

As the author exploratively applies the method of FCE to the navigation safety evaluation of Jiaxing port waters , and limited by the personal knowledge and time, there are still many limitations in this paper. In this paper, there is still a certain degree of subjectivity in determining the evaluation standard for the safety level of index and the weight of each index. It is also a subject to be further studied in the future to improve the objectivity of evaluation and reduce the influence of subjective and biased human behaviors of experts. And with the rapid development of Jiaxing port, navigation environment of the port will also be changed correspondingly. The evaluation result will be influenced by these changes such as the increasingly more number of inbound and outbound ships, the dredging and widen of approach channels, the improvement of navigation aids and traffic management and so on. Therefore, the continuous attention shall be given to this water area, the latest data should be collected and the evaluation methods shall be improved, so as to obtain more objective, accurate and practical evaluation result.

REFERENCES

Cheng, J. & Tao, J. P. (2010). Fuzzy comprehensive evaluation of drought vulnerability based on the analytic hierarchy process : —an empirical study from Xiaogan city in Hubei province. *Agriculture and Agricultural Science Procedia, 1(4), 126-135.*

China Navy Hydrographic Office. (2016). *China Sailing Directions (East China Sea)*. Tianjin: China navigation publications press.

China Navy Hydrographic Office. (2017). *Guide to China ports (East China Sea)*. Tianjin: China navigation publications press.

Ding, X., Chong, X., Bao, Z., Xue, Y., & Zhang, S.H. (2017). Fuzzy Comprehensive Assessment Method Based on the EntropyWeight Method and Its Application in the Water Environmental Safety Evaluation of the Heshangshan Drinking Water Source Area, Three Gorges Reservoir Area, China. *Water, 2017(9),329.*

Fang, J. (2012). Introduction of Binhai District. Retrieved May 24th, 2018 from the World Wide Web: http://www.cnjxol.com/topic/content/2012-10/30/content_2194815.htm

Gan, L.X., Zhang, B.G., Zheng, Y.Z. & Peng, J.M. (2008). Application of the Grey Model Theory to Forecast Maritime Traffic Accident. *Ship & Ocean Engineering, 2008 , 37 (6) :99-102.*

Gao, X. L. (2014). Navigation Safety Assessment of Dongjiakou Port in Qingdao City. Master's thesis, Dalian Maritime University, Dalian, China.

Hong, B.G. (2009). Ship maneuvering. Dalian: Dalian Maritime University Press.

Jiang, F., Zheng, Q. & Shi, W. (2012). The applied research of fuzzy comprehensive evaluation on talent training mode of safety engineering. *Procedia Engineering, 43(43), 425-430.*

Jiao, J., Ren, H., & Sun, S. (2016). Assessment of surface ship environment adaptability in seaways: a fuzzy comprehensive evaluation method. *International Journal of Naval Architecture & Ocean Engineering , 2016,8(4), 344-359.*

Jiaxing MSA. (2013). Report of the influence of some important factors on navigating in Jiaxing Port. (Unpublished report)

Jiaxing MSA. (2016). Statistical report of water traffic accidents in Jiaxing Port water area. (Unpublished report)

Jiaxing MSA. (2017). Publicity manual of marine traffic safety knowledge about Jiaxing Port .

Jiaxing MSA. (2018). Analysis report of maritime safety situation in Jiaxing Port water area.(Unpublished report)

Jiaxing Port Administration. (2016). The 13th Five-Year Plan of Jiaxing Port. Retrieved May 24th, 2018 from the World Wide Web: http://www.jiaxing.gov.cn/sbhbgwjkab/ghjh_7222/ghxx_7224/201612/P020161221399748143688.pdf

Kobayashi, H., & Tanaka, K. (1992). A study on the evaluation of ship handling ability under the disturbance (part 2) : consideration of wind effect for evaluation of ship handling ability and application to an actual route. *Journal of Japan Institute of Navigation, 1992, 86(86), 179-187.*

Liao, S.C., Wang, W. & Xu, Z.S. (2010). Fire risk assessment model based on evidence theory for long-highway tunnel. *Journal of Railway Science and Engineering, 2010 , 07 (6) :80-85.*

Liu, S. & Lin, Y. (2010). Introduction to grey systems theory. *Understanding Complex Systems, 68(2), 1-18.*

Ma, H. & Wu, Z. L. (1998). Comprehensive assessment of the environmental risk of operating ships in port waterway. *Journal of Dalian Maritime University, 1998 (3) :15-18.*

Peng, K. & Qiang, M. (2004). Study on application of Fuzzy-AHP in risk evaluation and bidding decision-making of Duber Khwar hydropower project. *Journal of Hydroelectric Engineering,2004-03.*

Pillay, A., Wall, A. & Loughran, C. G. (1999). The latest development in ship safety assessment. Pa*int & Coatings Industry(August), 328.*

Shanghai Maritime University. (2016). Verification report on the impact of E4 berth in Jiaxing port on navigation safety. (Unpublished report)

Wang, F.J. (2012). Research on navigation risk assessment model of channel waters. Master's thesis, Dalian Maritime University, Dalian, China.

Wang, H. B. (2016). Research on Navigation Safety Evaluation of Qinhuangdao Port based on Cloud Theory. Master's thesis, Dalian Maritime University, Dalian, China.

Wen, Q. H. (2015). Safety Evaluation of Navigation Environment in Channel Waters of Meizhou Bay. Master's thesis, Jimei University, Xiamen, China.

Wuhan University of Technology. (2018). Navigation safety assessment report of E4 berth in Jiaxing port area. (Unpublished report)

Wu, Z. L. (2001). *Research on marine collision avoidance and traffic safety* (pp. 394-407). Dalian: Dalian Maritime University Press.

Xiang, F. (2007). Study on Navigation Safety Assessment of Humen Port. Master's thesis, Wuhan University of Technology, Wuhan, China.

Zhang, B.G. (2010). Research on navigation environment of Lianyungang port approach channel based on matter-element analysis method． Master's thesis, Wuhan University of Technology, Wuhan, China.

Zhang, S.L. (2014). Fuzzy Comprehensive Evaluation of Navigation Safety on Ships in and out Qinhuangdao Port. Master's thesis, Dalian Maritime University, Dalian, China.

Zhou, Z. Y. (2015). Research on the Safety Assessment and Countermeasures of Hangzhou Bay Bridge Navigation Environment. Master's thesis, Dalian Maritime University, Dalian, China.

Zhu, H. (2017). The growth rate of container throughput in Jiaxxing Port ranks the first in Zhejiang Province for nine consecutive years. Retrieved May 27th, 2018 from the World Wide Web:
http://zjnews.zjol.com.cn/zjnews/jxnews/201702/t20170206_3035141.shtml

APPENDIX A:Questionnaire of establishing navigation safety evaluation index system of Jiaxing Port

There are various factors which affect the navigation safety of ports such as wind, visibility, wave and so on. According to the actual situation of Jiaxing Port and combining with your work experience and professional knowledge, please select the factors listed in the following table that you think are suitable for the navigation safety evaluation of Jiaxing Port and tick the corresponding options, and cross the options that you think are not suitable for evaluation. If there are additional evaluation factors, please write them down and state the reasons.

Index		Suitable	Not suitable	Reason
Natural environment	Wind			
	Current			
	Wave			
	Visibility			
	Disaster weather			
Port environment	Fairway depth			
	Fairway length			
	Fairway width			
	Number of turning point of fairway			

	Fairway curvature			
	Obstructions of fairway			
	Anchorage capacity			
	Anchorage depth			
	Quality of the anchorage bottom			
Traffic environment	Traffic flow			
	Navigation aids			
	Number of ships less than 500GT			
	Number of dangerous cargo ship			
	Traffic management			

Additional evaluation factors and reasons: ____

____

____

____

____

APPENDIX B: Questionnaire of determining navigation safety evaluation index weight of Jiaxing Port

The questionnaire is developed to objectively and scientifically determine the navigation evaluation index weight of Jiaxing Port. According to the actual situation of Jiaxing Port and combining with your work experience and professional knowledge, please pairwise compare Index 1 and Index 2 list in Tables 1,2,3,4 and write the scores in the tables. To obtain the compare results, the 1-9 scale method (as shown in the following table) is applied to indicate the relative importance of each pair of indexes in the same hierarchy .

Score	Meaning (Index 1 compares with Index 2)
1	The two indexes are equal important
3	Index 1 is slightly important than Index 2
5	Index 1 is clearly important than Index 2
7	Index 1 is strongly important than Index 2
9	Index 1 is extremely important than Index 2
2,4,6,8	The median of the above adjacent judgement
Reciprocal	If the score of Index 1 compares with Index 2 is a_{jj} , the score of Index 2 compares with Index 1 is $a_{ji}=1/a_{jj}$

Table 1 Pairwise comparison of indexes in the first level

Index 2 / Index 1	Natural environment	Port environment	Traffic environment
Natural environment	1		
Port environment		1	
Traffic environment			1

Table 2 Pairwise comparison of sub-indexes of natural environment

Index 1 \ Index 2	Visibility	Wind	Current	Disaster weather
Visibility	1			
Wind		1		
Current			1	
Disaster weather				1

Table 3 Pairwise comparison of sub-indexes of port environment

Index 1 \ Index 2	Fairway obstacles	Fairway depth	Fairway width
Fairway obstacles	1		
Fairway depth		1	
Fairway width			1

Table 4 Pairwise comparison of sub-indexes of traffic environment

Index 1 \ Index 2	Traffic flow	Navigation aids	Traffic management
Traffic flow	1		
Navigation aids		1	
Traffic management			1

APPENDIX C: Questionnaire of determining safety level of navigation safety evaluation index of Jiaxing Port

The questionnaire is developed to objectively and scientifically determine the membership degree of each evaluation index corresponding to different safety levels . According to the actual situation of Jiaxing Port and combining with your work experience and professional knowledge, please tick the corresponding safety level of each index in accordance with the index value.

Index	Index value	Membership degree				
		Very good	Good	Moderate	Poor	Very poor
Visibility (Annual poor visibility days:N)	N≤15					
	15< N≤25					
	25< N≤40					
	40< N≤50					
	N>50					
Wind (Annual standard wind days: N)	N≤30					
	30< N≤58					
	58< N≤86					
	86< N≤145					
	N>145					
Current (Maximum current speed: V)	V≤0.5 kn					
	0.5< V≤1.5kn					
	1.5< V≤2.5kn					
	2.5< V≤4kn					
	V>4kn					

Disaster weather (Annual disaster weather days: N)	N≤12					
	12< N≤24					
	24< N≤38					
	38< N≤50					
	N>50					
Fairway obstacles (Minimum distance between the obstacles and the fairway: D)	D> 200m					
	100<D ≤200m					
	50< D≤100m					
	20< D≤50m					
	D≤20m					
Fairway depth (The ratio of minimum channel depth to the maximum designing draft: R)	R> 10					
	4< R≤10					
	2.5< R ≤4					
	1.2<R ≤2.5					
	R≤1.2					
Fairway width (The ratio of minimum channel width to the maximum breadth of ships: R)	R> 15					
	10< R ≤15					
	5< R ≤10					
	2<R≤5					
	R≤2					
Traffic flow (The average number of	N≤30					
	30<N≤60					
	60<N≤110					

ships in and out of the port: N)	110<N ≤200					
	N>200					
Navigation aids (The perfect rate of navigation aids: R)	R> 95%					
	90%<R ≤95%					
	85%<R ≤90%					
	75%<R ≤85%					
	R≤75%					
Traffic management (The perfect rate of traffic management: R)	R> 95%					
	90%<R ≤95%					
	85%<R ≤90%					
	75%<R ≤85%					
	R≤75%					