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Risk assessment, study and management on navigational safety in the Yangtze River during dry season

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RISK ASSESSMENT, STUDY AND MANAGEMENT ON NAVIGATIONAL SAFETY IN THE YANGTZE RIVER DURING DRY SEASON

By

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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.

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ABSTRACT

Title of Research Paper: **Risk Assessment, Study and Management on Navigational safety in the Yangtze River During Dry Season**

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As one of the few seasonal large-scale rivers in the world, the depth of the Yangtza river is influenced by many factors, such as season, food discharge by three gorges dam, especially when during dry season, the depth decreases dramatically. The cases of ship running aground and collision accidents happened frequently. Which directly affected the flow and safety inland waterway transport, and brought unfavorable influence to the sustainable development of China's shipping industry.

This paper mainly focuses on navigational risks identified in the dry season, navigational risks assessment in the dry season of Yangtze River, congestion risk modeling and manoeuvring essentials. Moreover, a series of measures were put forward from the point of MSA.

Keywords: Yangtze River, dry season, navigational safety, Bayesian, MSA, management, risk assessment

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
BN	Bayesian Network
CCFs	Congestion Critical Factors
CREAM	Cognitive Reliability Error Analysis Method
DWT	Deadweight
FSA	Formal Safety Assessment
GT	Gross Tonnage
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
MOT	Ministry Of Transport
PMCC	Product Moment Correlation Coefficient
RCOs	Risk Control Options
SCEs	Safety Critical Elements
VHF	Very High Frequency

Chapter 1 Introduction

1.1 Research background

1.1.1 Research background and significance

Inland waterway transport is an important part of integrated transportation system. the characteristics which are of large capacity, less land, low energy consumption, less environmental impact, etc. In the process of breaking the double restriction imposed by both resources and environment and achieving sustainable economic and social development, It is playing an significant role(Yan, 2010, p1). According to the report of work meeting the me in 2014 that the minister Tang Guanjun of Chang Jiang River Administration of Navigational Affairs , MOT reported that:

> *In 2013, the Yangtze River trunk line completed 1.92 billion tons cargo throughput, up to 6.7%,foreign trade cargo throughput 2.49 tons, up to 11.2%, and container throughput 13570000 TEU, up to 9.1% compared with the same period. Transport production continued to maintain rapid growth.*(Tang, 2014)

As China's golden waterway, on which our country's vigorous development relies Yangtze River trunk line has caused extensive attention from governments at different levels from all walks of life in recent years. In May 2010, "the Yangtze River trunk waterway planning outline" which was drawn up by the Ministry of Transport, National Development and Reform Commission, Ministry of Water Resources and Ministry of Finance has gained the approval of the State Council. It formally put forward the construction of ‘open, efficient, safe and green’ modern inland river water transportation system(MOT, 2010, Retrieved 10 October 2010 from the World Wide Web:www.china.com.cn/policy/txt/2009-05/19/content_17796427.htm). In February 2011, the state council also issued ‘suggestions on strengthening the development of the Yangtze River etc. inland waterway transportation’ (Retrieved 15 March 2011 from the World Wide Web: www.gov.cn/zggk/2011-01/30/content_1795360). This marked that the development of inland river shipping had been promoted to the strategic height. In July 2011, the Ministry of Transport and the 9 provincial (city) governments along the Yangtze River under the joint consultation formulated and issued the overall promotion plan of “twelfth five-year” period of the Yangtze golden waterway construction(MOT, 2011, Retrieved 13 August 2011 from the World Wide Web:chinaup.info/2011/07/1472.html), which made clear the implementation schedule of the key projects of Yangtze golden waterway construction during the “twelfth five-year”, at the same time made clear that construction funds of the Yangtze River golden waterway would be not less than 36 billion yuan during the “twelfth five-year”.

Safety and liquidity have always been a key problem in our construction of Yangtze River golden waterway. As one of the world's rare seasonal large rivers, the Yangtze River is affected by seasonal factors, shipping hub water release and many other factors. During dry season, depth of channel is decreasing obviously, navigable waters become more and more narrow, there will be crowded waterway, port congestion, a shallow waterway, etc. events which hinder the sailing. Coupled with a small number of illegal overloaded ships, the situation of the ship running aground and collision accidents happened frequently, which directly affect the inland waterway transport flow and safety, at the same time brought unfavorable influence to the sustainable development of China's shipping. For example, many navigation-unnavigable events occurred in the middle reaches of the Yangtze River YaoJian waterway at the end of 2007, which had resulted in hundreds of ships stagnation for a long time and the

State Council and departments at all levels in begun to pay much attention to these situations (Guangzhou Daily, 2010,Retrieved 11 November 2010from the World Wide Web:gzdaily.dayoo.com/html/2007-12/24/content_101962.htm).

The shallow and dangerous waterway leads to frequent navigation-unnavigable events during the dry season. Although there are external factors for ships overloaded for the economic interests, and there are shortcomings that the competent departments couldn't predict risk according to the changing navigation conditions, it is manifested that inland emergency warning system in our country didn't adapt to the external shipping demand.

Risk assessment and early warning of the navigation environment are the keys to prevent, reduce and avoid water channel obstruction and other water traffic safety accidents during the dry season. This paper focuses on the safety issues of Yangtze River in the dry season for waterway transportation. According the study carried out on navigation risk assessment and forecasting and early warning technology ,we explored the cause mechanism of the Yangtze River navigable risks during the dry season ,and established evaluation index system of the Yangtze River navigable risk during the dry season and put forward relevant measures and suggestions from the perspective of Maritime administration, which are of practical significance to improve safety guarantee ability for dry season in inland waterway traffic

1.1.2 The explanation of related terms

(l) the Yangtze River

In this paper, "the Yangtze River refers to the Yangtze Rivers main river basin, according to the division standard of the Ministry of Transport's "national inland waterway and port layout planning"(MOT, 2010, Retrieved 23 December 2012 from the World Wide Web:www.mot.gov.cn/zhuzhan/jiaotongguihua/guojiaguihua/quangguojiaotong_HYG

H/200709/t20070927_420891). There is totally 2,838km navigable waters from Shuifu to Yangtze River Estuary. Among them, “the upper reaches of the Yangtze River” is 1074km from Shuifu to Yi Chang, “the middle reaches of the Yangtze River” is 900km from Yi Chang to Hu Kou; and the 864km from Hu Kou to Yangtze river estuary is called the lower reaches of the Yangtze River.

(2) Dry season

“Low water” is defined as “river basin in the dry season water supply depends mainly on the hydrological situation” by China National Committee for terms in sciences and technologies. According to the research, the dry season of Yangtze River is from winter to early spring. For the convenience of research work, the paper defined the five months that from November to March of next year as the dry season of Yangtze river.

(3) Navigation risks

In a narrow sense, “navigation risk” can be understood as the risk of ship occurring water traffic safety accident. According to the explanations of “inland water traffic safety management regulations” (Retrieved 16 December 2012 from the World Wide Web:www.gov.cn/banshi/2005-08/23/content_25068.htm), water traffic accident refers to the occurrence of ship, floating facilities in inland navigable waters such as collision, stranding, contact, wave damage, stranding, fire, explosion, sinking etc., caused personal injury and property loss events.

In this paper, we adopt the broader interpretation as the navigation risk. Which Includes the risk of all kind that may cause personal injury, property loss and environmental pollution in the navigable waters.

(4) Impeding navigation

“Impeding navigation” is a general term for a variety of activities and behaviors affecting the ship navigation(Zhang, 2002, p2002). Due to impeding navigation is not the water traffic accident type as the “inland water traffic safety management regulations” defined, therefore, we call this the phenomenon of impeding ship sailing as “impeding navigation event”.

(5) the data

The data in this paper is from the datebase of ChangJiang MSA and Yangtze River waterway administration, even some experts and leaders in the MSA give data which they have gathered and analyzed for many years. Data which the author used are from Wuhu MSA, especially some sensitive date about Yangtze River and navigational safety are only kept in this paper, it is staying away from public access.

1.2 The status quo of Yangtze navigation safety

1.2.1 The basic situation of the Yangtze River waterway

The total length of the Yangtze River is more than 6300km, whose main stream goes from east to west and tributaries goes from north to south. It is China's first, the world third biggest rivers, known as the ‘golden waterway’. Yangtze River waterway starts from Fushui Yunnan, end for the mouth of the Yangtze River. the Yangtze River’s length overall is 2838 km. It flows through Yunnan, Sichuan, Chong Qing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Shanghai seven province and two cities, and is the backbone of the comprehensive transportation system in Yangtze River basin in China (Gaokaichun.2008).

Figure 1- the map of Yangtze River trunk waterway sketch
Source:http://baike.baidu.com/picture/39161/39161/0/4a77b2af5ffe52a97cd92aae?fr=lemma&ct=single#aid=0&pic=4a77b2af5ffe52a97cd92aae

1.2.1.1 the profile of the upper Yangtze River channel

The upper reaches of the Yangtze River is over 4504 km, and watershed area is 100 square kilometers. Jinshajiang river is from Zhimenda to Yi Bin. It’s 3464 kilometers long and typical mountainous river, most of which is rock bed. The characteristics of waterway are rushing, bent, shallow risk. There are more than 200 impeding navigation shoal and reefs. After many years’ systematical governance, at present, there are more than 10 impeding navigation shoals from Shuifu to Yi Bin, more than 30 impeding navigation shoals from Yi Bin to Chong Qing, about 20 in the fluctuating backwater area of three Gorges. At the same time, there are some impeding navigation problems between two dams and Ge Zhou dam.

At present, mountainous waterway is from He Jiangmen Yi Bin to Hong Huazhai, Jiang Jin; Fluctuating backwater area waterway is from Hong Huazhai, Jiang Jin to Feng Du, Chong Qing; the perennial reservoir area waterway is from Feng Du Chong

Qing to three Gorges dam. After the three Gorges reservoir have been constructed, the conditions of perennial reservoir area waterway have been greatly improved. The rapids and shoals disappear below Feng Du, Chong Qing. Ships with 3000GT and more can navigate here yearly.

1.2.1.2 the profile of the middle reaches of the Yangtze River channel

It’s 900km from Yin Chang to Hu Kou, The middle reaches of the Yangtze River waterway belongs to plain river. With frequent and violent development, there are about 20 shoals. The river from Yi Chang to Zhi Cheng flows through the hilly area, and the waterway condition is good. The famous Jing Jiang river is from Zhi Cheng to Cheng Lingji, which is divided into the upper and lower two parts with Ou Chikou as the boundary. The upper of the Jing Jiang river that belongs to slightly curved river, is about 175km. The lower of the river that belongs to meandering river, is 164km. The waterway is with many twists and turns. The main shallow waterways are Lu Jiahe, Zhi Jiang, Jiang Kou, Tai Pingkou, Yao Jian and Wu Qiao etc. the middle reaches of the Yangtze River has always been given the priority in the maintenance of the Yangtze River.

The storage water of three gorges has a great impact on this channel. The main evidence is that the release clear water rushes the riverbed , which lead the new silting change of the channel. At present, the dimension of this channel maintenance is as follows: It’s 2.9m x 80m x 750m from Yi Chang to Cheng Lingji, and 3.2m x 80m x l000m from Cheng Lingji to Wuhan. Navigation shipping tonnage is: It is 1500 dwt from Yi Chang to Cheng Lingji. The largest fleet from Cheng Lingji to Wuhan is the million ton oil tanker fleet composed with 3000 dwt barge.

1.2.1.3 The profile of the lower reaches of the Yangtze River channel

It‘s 864km from Hu Kou to Yangtze River estuary. The waterway is broad in which there are many sandbanks. There are Hanjiang, Duyanghu river system from Wuhan to Nanjing. Due to the fact that the tributary in southern Anhui joins, the riverbed is wide and narrow. The river formats many branches where about 20 reaches exist the impeding navigation shallow area; The river from Nanjing to Liu He Kou was furtherly broadened. Therefore, bottomland spreads everywhere and the channel are changing. The lower reaches of Jiang Yin River are tidal river that is influenced by tides greatly.

The reach from Wuhan to Nanjing can accommodate 10,000 dwt – 30, 000 dwt fleet transiting every year. The 5000 dwt seacraft can directly arrive Wuhan in middle flood period. Seacraft between 20,000 dwt and 24,000 dwt can directly arrive Nanjing from Yangtze River estuary.

1.2.2 The profile of Yangtze River accident risk in recent years

Based on the statistics of the security situation analysis report of Yangtze River Maritime Administration from 2011 to 2013, during the period, 896 all kinds of accidents occurred in the district of Yangtze River Maritime Administration. The number of missing and death is 116, and 85 ships sunk. All these resulted in 81.211 million economic loss.

1.2.2.1 Annual variation of accident and dangerous situation

Four indicators of accident and dangerous situation demonstrate that the number of accident and dangerous situation, the number of death and missing, the number of the sunk ship and annual change in direct economic loss. As figure 2 shows:

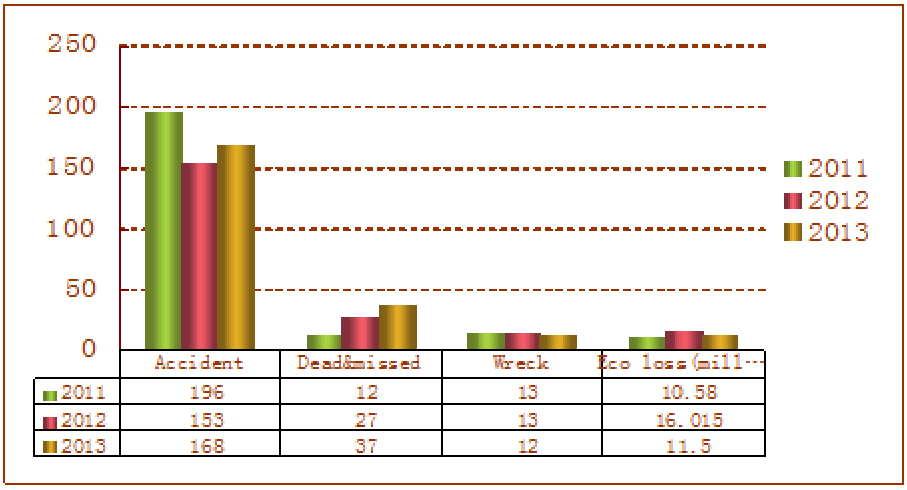

Figure 2 - Annual variations of accident and dangerous situation

Source: ChangJiang MSA, (2011, 2012, 2013). The annual safety analyze of Chang Jiang MSA. Figure is made by author, 2014

We can observe from the figure that every indicator tends to decline in recent years, which reflect the safety status of Yangtze River many gradually improving, but still have further room for improvement.

1.2.2.2 The month variation of accident and dangerous situation

The month variation of the number of accident and dangerous situation from 2011 to 2013 is show in figure 3.

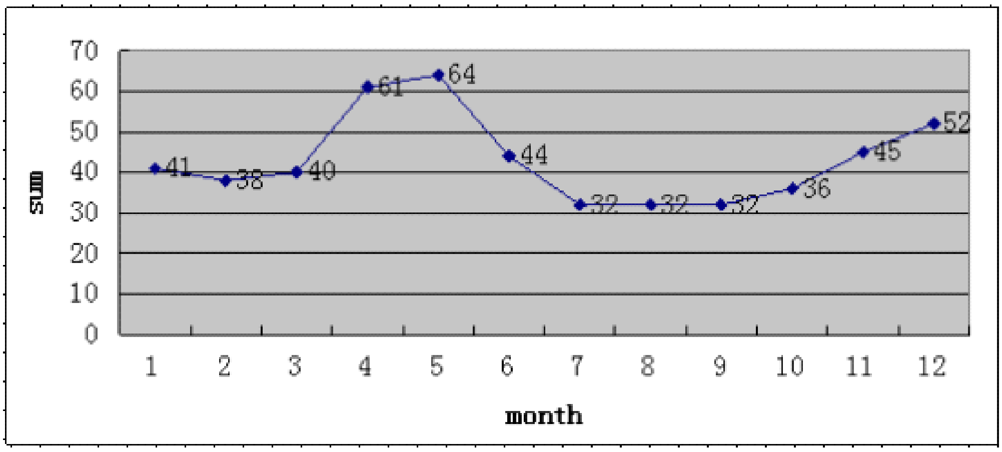

Figure 3 - The month variation of the number of accident and dangerous situation

Source: ChangJiang MSA, (2011, 2012, 2013). the annual safety analyze of Chang Jiang MSA. Figure is completed by author, 2014

We can see in recent years, the high incidence month (number more than 80) of accident and dangerous situation is the six months 1,3,4,6,10,11. In addition to the June in flood season, the other five months belong to or nearby the dry season defined in this study. In particular, the dry season defined in this study is from November to March of the next year. During the past 3 years, 384 accidents and dangerous situation occurred, which accounted for 42.9% of the total. Therefore, the targeted research on the navigation risk of dry season has important significance to the navigation safety of ensuring the navigation safety of the Yangtze River.

1.2.2.3 The type and the distribution of accidents and dangerous situation

The type and the distribution of accidents and dangerous situation in the recent years is shown in figure 4.

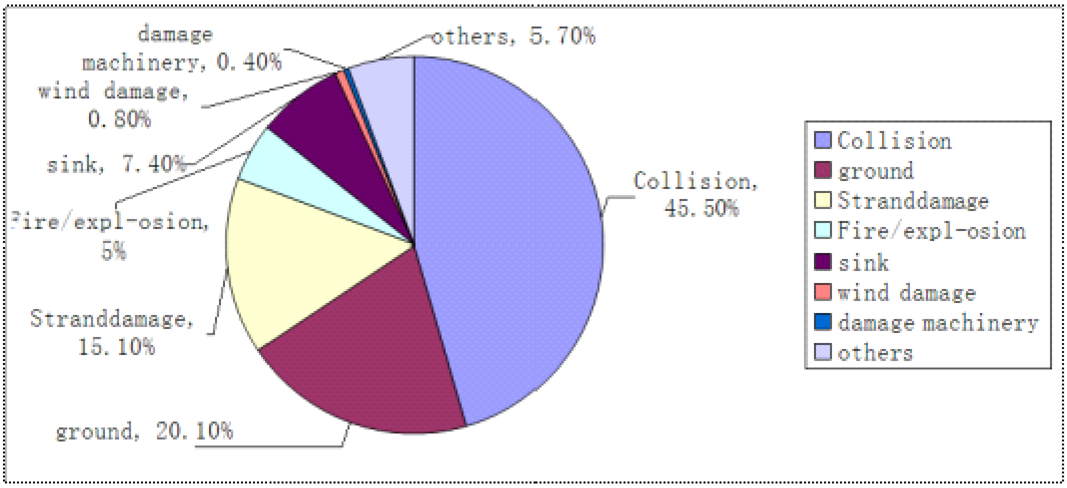

Figure 4 - The type and the distribution of accident and dangerous situation

Source: ChangJiang MSA, (2011, 2012, 2013). The annual safety analyze of Chang Jiang MSA.

Figure is made by author, 2014

The accident and dangerous situations in the district of Yangtze River Maritime Administration are 413, from 2011 to 2013, which account for 46% of the total. Secondly, the y are stranded and wrecked, accounted for 20% and 10% of the total. If we classify the stranding and contact damage as the same type, the collision, grounding, contact damage (reef) account for 82% of the total.

1.2.2.4 The regional distribution of accident and dangerous situation

The regional distribution of the trunk line of the Yangtze River accidents and dangerous situation is shown in figure 5 showing from 2011 to 2013.

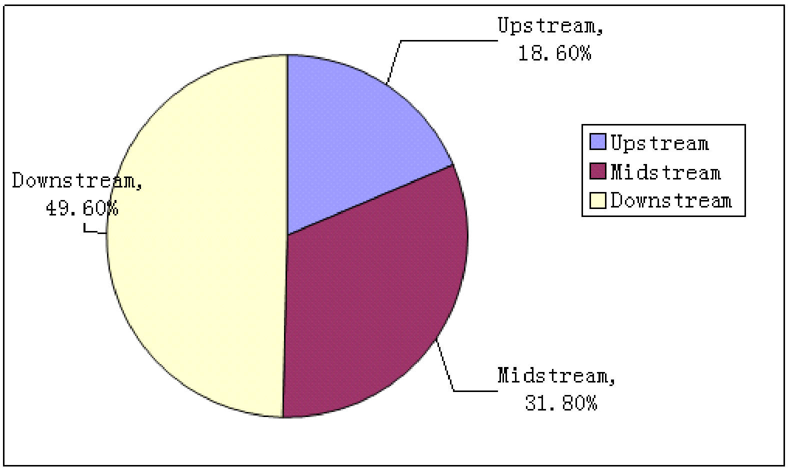

Figure 5 - The regional distribution of the accident and dangerous situation

Source: ChangJiang MSA, (2011, 2012, 2013). The annual safety analyze of Chang Jiang MSA. Figure is made by author, 2014

As shown in The figure above, the number of the lower reaches of the Yangtze River accident danger is the most, accounting for 49,6% of the total; Secondly, it is the middle reaches of the Yangtze River, accounting for 31.8% of the total; However, the accidents and dangerous situation of the upper reaches of the Yangtze River is relatively less, 96 pieces in past 3years, which account for 18.6% of the total. It should be pointed out that the above results are closely related to traffic density. We should not directly judge level of risk of the region by the value of the number of the accident and dangerous situation.

1.2.2.5 The analysis of cause of the accidents and dangerous situation

If we divide the cause of accidents and dangerous situation into 4 categories, such as ship factor, crew factor, the navigation environment and natural disasters and other factors. Based on the statistics on Yangtze River Maritime Administration from 2011 to 2013, the cause distribution of the accidents and dangerous situation is shown in figure 6.

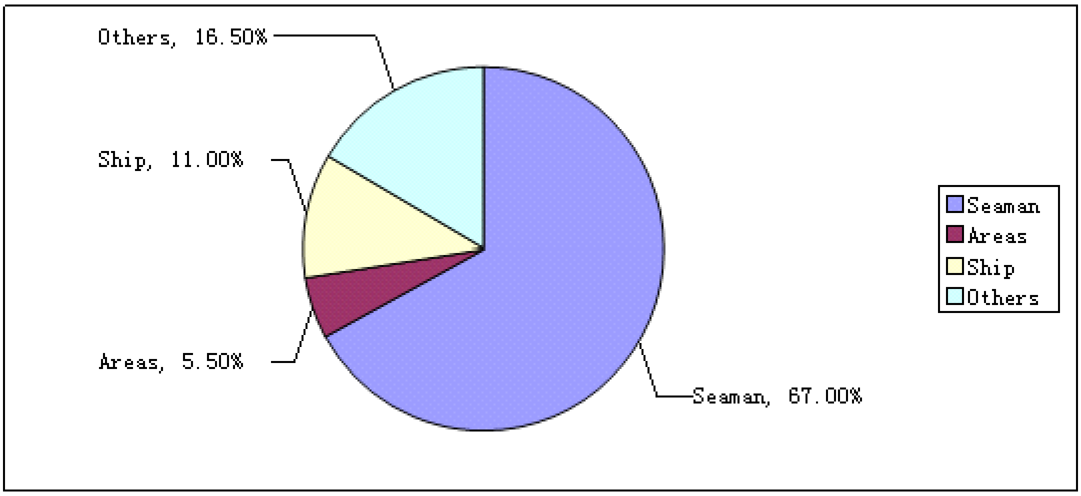

Figure 6 - The cause distribution of the accident and dangerous situation

Source: ChangJiang MSA, (2011, 2012, 2013). The annual safety analyze of ChangJiang MSA. Figure is made by author, 2014

Obviously, human factors are the main cause of the Yangtze River water traffic safety accidents. Therefore, strengthening the crew training and management, and improving the crew's operation level and safety consciousness play important role in promoting the safety navigation level in the Yangtze River.

1.2.3 The profile of impeding navigation of Yangtze river channel

Influenced by the channel dimensions, the Yangtze River channel impeding navigation events mainly occur in the dry season, especially in the middle reach of Yangtze River, which is shallow and risk(Li, 2008, p43). Generally speaking, the channel impeding navigation mainly has following three forms:

1) Simply the reasons of natural conditions lack and other reasons cause the impeding navigation or interruption of shipping happened in a certain period of time.

2) The reasons of ship super draft and other reasons cause the grounding accidents, and the channel stoppage, impeding navigation even interruption of shipping.

3) The reason of the improper operation of the ship operator and others reasons cause

ships collision, waiting and channel congestion.

The Yangtze River waterway Administration and other departments have taken a series of remediation projects, which basically guarantee maintenance dimension of Yangtze River during the dry season. Therefore, the impeding navigation simply caused by navigable dimensions deficiency rarely happen; Relatively, water traffic safety accidents such as stranding, collision etc. have become the main cause of impeding navigation. Especially, the grounding accident may always cause blocking and stoppage for a long time.

1.3 Related research status at home and abroad

1.3.1 The profile of water traffic safety assessment research

The research of water traffic safety begun with the research of the risk on the ship collision at sea. Accident investigation and analysis methods are usually adopted in identifying the cause of the accident, and putting forward the measures to prevent similar accidents. Marine investigation report of this form is still in use in certain scope and field(Wu, 1993, P5). Safety indicators methods belong to the second generation evaluation method that is widely used in the water traffic. Our country has adopted 5 indicators to evaluate the different regional water traffic safety condition for many years, such as “the number of accidents”, “direct economic loss”, “the number of deaths”, “the number of injured”, and “the number of sunk ship”. For example , the Yangtze River Maritime Administration in 1.1.2 still adopt the five indicators to evaluate security situation of Maritime Administration in each jurisdiction district(Changjiang MSA Security situation in 2011,2012,2013). The two methods above focus on the conditions to study the water traffic safety situation, but they consider less the safety situation of systemic risk factors, which make the water traffic safety evaluation stay on the stage of ex-post evaluation(Hu, 2000, p100).

Since the 1990s, with the advanced preventive safety management requirements, domestic and international research of water traffic risk analysis prevailed rapidly. It's a landmark that IMO officially take the formal safety assessment (FSA)method as the guidelines of risk assessment (IMO MSC/Circ.829)(IMO MSC/Circ.1023). The FSA as risk analysis method has get rid of the limitations of the evaluation of the accident since then. Most scholars regarded the dangerous factors of water traffic as the evaluation object. They analyzed the safety state under the particular condition by selecting the evaluation index and establishing the corresponding index system. They obtained the good application result.

1.3.1.1 The research object of water safety assessment

In term of object of water traffic safety assessment, related research at home and abroad can mainly be classified into different types of ships, specific waters, accident type and cause of mechanism, security management etc, several aspects of research.

(1) The study of different types of ships

From the literature review, seeing the degree of the harm of water traffic accidents that may cause, passenger ship, chemical tanker and fishing boat are the research focus of scholars at home and abroad. Among them, Hong Biguang and other scholars evaluated the safety of the Ro-Ro passenger ship. Vanem and other scholar put forward passenger ship design method of risk oriented: HIDEYUKI and Elsayed etc., evaluated the LNG and load and unload risk; Arslan quantitatively analyzed the risk in the operation process of chemical ships(Arslan O, 2009, p113). Piniella and Jensen etc, put forward the suggestions and safety management on the operation and management of the fishing boats.

(2) The research of different navigable waters

Scholars at home and abroad studied the waters of large ship traffic and relatively limited navigable conditions. Therefore, the waters of strait or harbor were the research focus. Ozgecan and Ersan evaluated and analyzed ship traffic of Turkish straits and pointed out the relatively high risk areas. Hehuihua etc, evaluated and analyzed navigation environment of Pearl River mouth waters and pointed out ship navigation suggestions; Gaoyansong etc., quantitatively evaluated the degree of risk of the environmental risk of Xiamen port channel; Zhangdi evaluated and studied the risk of ship collision, stranding, contact loss in Tianjin port waters.

(3) The research on different types of accidents

The research on water traffic accidents has always been the focus of the evaluation on the water safety . For example, foreign scholar Psarms etc(Psarros G, 2012, p619), described the status of water risks according to statistical analysis of accident data to the sea. Celik etc(Celik M, 2010, p18), put forward the accident investigation method of risk assessment; Jun etc., put forward the method of collision risk analysis based on the data of AIS(Jun M, 2010, p483); Cerup etc., put forward the prediction method of grounding risk(Cerup-Simonsen B, 2009, p62).

(4) The research of mechanism of accident causation

The water traffic safety system is considered to be the multi factor complex system of “people”, “ship”, “environment” and “management”. Statistical material showed that the human factor is the most important and direct factor leading to water traffic accidents(Gao, 2007, p65). Therefore, the human factor is the focus on the research of water accident causation mechanism for the scholars at home and abroad. Foreign scholar Konstandinidou etc., studied the human reliability combining with fuzzy logics and CREAM(Konstandinidou, 2006, p706); the scholars of our country also studied the human reliability in the process of ship operation and failure mechanism of human and ship system, such as Liu Zhengjiang(Liu, 2004), , Zeng Hualan(Zeng, 2000).

(5) The research on safety management

The relevant departments and scholars of scientific research institutions of our country extensively discussed and studied strategies and methods for water traffic safety management, and made certain achievements. For example, Zheng Liangdong proposed AHP to evaluate performance of Maritime management(Zheng, 2007, p47); Hao Yuguo proposed Maritime safety evaluation method based on safety management(Hao, 2003, p10).

1.3.1.3 The main method of water transportation system safety assessment

(1) Formal Safety Assessment (FSA)

FSA formally assesses the related project of ship design, testing, operation, navigation by adopting the standardized 5 steps (risk identification, risk assessment, risk control options, cost and benefit assessment, providing decision suggestions) to improve the degree of safety of life at Sea, the crew health, marine environment, and ship and cargo property etc (IMO MSC.Circ,829).

(2) Multi index evaluation method based on the hierarchical model

In recent years, multi-index evaluation system based on the risk factors that put the water traffic system safety or the degree of risk as the research object is the quantitative risk assessment method widely used at home and abroad. At present , it's also the water traffic safety evaluation method that the scholar of ours country mainly adopted.

On the basis of the hierarchical model, in recent years, foreign scholars proposed fuzzy evidential to ratiocinate , using the method of fuzzy comprehensive evaluation etc., to analyze the integrated risk of the system; At the present, the widely used methods are ray system theory, the unascertained measure model, and fuzzy analytic hierarchy process etc.

(3) The evaluation method based on network model

The network model can better reflect the interaction between the various risk factors than hierarchical model. Therefore, in recent years, the scholars at home and abroad paid more attention to them. The Bayesian Network(BN) model that has a good ability to deal with uncertainty problem is the most popular one. The related research achievements of them are most significant, too.

(4) Other water safety evaluation methods

Except the hierarchical model and network model, some scholars evaluated and analyzed the safety status of water traffic system by combining both or integrating into the system simulation technology.

1.4 The main research content of the paper

1.4.1 The main research work in this paper

We put the Yangtze River water traffic safety system as the research object in the paper, studied the system security status and characteristics in the special period of the dry season, identified the key factor of the navigation risk, analyzed the risk distribution in different areas, and put forward suggestions for risk control. This paper will further take impeding navigation as a typical form of Yangtze River navigation risk in the dry season, studied the evaluation index system of navigation risk, and realized the combination of theory with practice from the Maritime supervision. Specifically, the main research work in the paper is as following:

1) The research on Yangtze River navigation risk identification in dry season. We divided the Yangtze River water traffic safety system into several sub-systems, established Yangtze River navigable risk hierarchical evaluation model in dry season based on risk factors, and put forward the optimal risk control scheme on the basis of identifying key risk factors.

2) The research of Yangtze River navigation risk assessment in dry season. It analyzed the case of navigable risk of different areas of the Yangtze River in the dry season , on the basis of the established hierarchy evaluation model, and studied the spatial distribution characteristics of navigable risk in Yangtze River in dry season.

3) The research of prediction and evaluation of impeding navigation risk. Put forward modeling method of impeding navigation risk according to the characteristics of the Yangtze River impeding navigation, and evaluated and predicted impeding navigation risk by using the data from historical water traffic safety accidents combining with the scenario analysis, and studied the key elements causing the impeding navigation.

4) The impact on ship sailing in shallow water during the dry season of the Yangtze

River. The paper analyzed the presented characteristics of the ship in shallow water by starting from the actual operation of the field crew, and pointed out the matters causing attention of the operations in shallow water in the dry season according to the characteristics and complexity of the Yangtze River channel in dry season.

5) Maritime administration in dry season. The various aspects and comprehensive regulatory measures are developed to improve the Maritime management in the dry season, reduced the Yangtze River accidents rate in dry season, making the channel unimpeded from the perspective of the Maritime administrating.

Chapter 2 The research on navigation risk identification based on the fuzzy analytic hierarchy process

Due to the complexity and uncertainty of the Yangtze River transport system, combining with the basis of discrete fuzzy sets and the analytic hierarchy process (AHP), this chapter identified and studied Yangtze River navigation risk comprehensively and scientifically, and put forward the optimal control scheme for the key risk factors, through the analysis of the utility.

2.1 The research background of this chapter

2.1.1 The determination of research methods

Inland water transportation system is a complex large system, involving people, ship, environment, management etc., and other sub-systems. Therefore, it is quite difficult to identify the key risk factors and choose a specific risk control scheme. Analytical hierarchy process is chosen as the main means of risk identification in this chapter, which divided the water traffic system into several subsystems, a child module for step by step research, so as to achieve the purpose of identifying the main risk factors.

There is another difficulty for this study that it is the uncertainty of object and data integrity. Therefore, using expert investigation method and collecting relevant data from the work of Maritime administration itself in this chapter, we deal with the expert judgment results with discrete fuzzy set theory to transform qualitative evaluation into quantitative data, so as to use them to identify key risk factors and evaluate risk control program. With AHP to compare, currently, experts widely adopted the rating scale method to score and confirm the value with the compare results. Although this method is easy to adopt, there will be poorer consistence due to the limitation of the subjective judgment; At the same time, quantitative scoring approach increases the difficulty for the evaluation process of experts. Therefore, this study adopted the method of directly collecting qualitative evaluation results, and transformed quantitative data into discrete fuzzy sets through the establishment of judge term.

2.2 AHP model of the Yangtze River water traffic safety systems

With reference to the existing research results and opinions of experts' survey and combined with the actual situation(Zhang, 2009), the water traffic safety system was divided into 4 subsystems of people, ship, environment and management ,which are of different levels. At last, 14 risk factors are screened, as shown in figure 7.

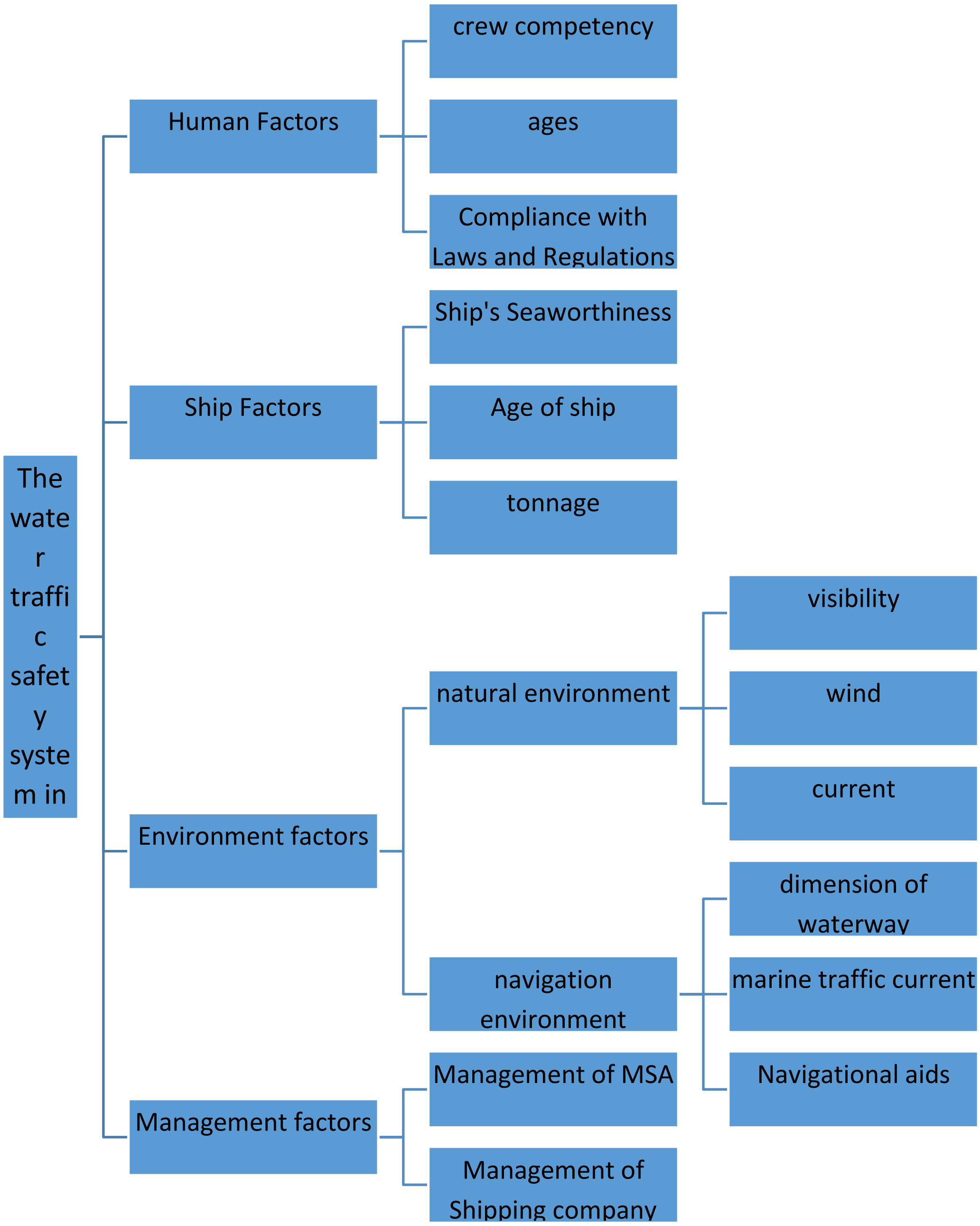

Figure 7 - AHP model of the Yangtze River water traffic safety systems
Source: Compiled by the author, 2014

2.2.1 The human factor

The human is the subject of ship navigation safety. In water traffic safety accident, the human factor is the main direct factor that causes the accident. The age structure of the crew, education and training of crew, the condition of the crew holding the certificate, the crew attributes, and the crew's personality and psychological state etc., have a direct impact on the behavior of the crew, and play a decisive role in the accident. At the same time , the other person such as the pilot, management person, and the docker, etc. can also make mistakes or negligence which cause accidents when they performed their respective duties.

Factors in this model are mainly referring to the crew, including the 3 risk factors of the crew's competency, age and complying with the relevant laws and regulations.

The crew's competency, the education of crew, the crew training, the condition of the crew holding the certificate, etc. These elements reflect the crew's professional and technical level.

The crew's age scale reflects the crew's qualifications and experience level at a certain extent.

Complying with the relevant laws and regulations: reflecting the degree of the crew 's compliance with the relevant laws and regulations .

2.2.2 The ship factors

The ship factors are another possible factor influencing the water traffic safety directly. the ship factors refer to the age of the ship, ship structure, tonnage of ship, ship type, ship load and the ship's technical defects, etc.

The ship factors in this model include 3 risk factors of the condition of ship seaworthiness, the age of the ship, and tonnage of ship.

1) The condition of ship seaworthiness：reflecting the state of the ship suitable for navigation under the effect of the factors of the ship structure, hull maintenance, and ship load, etc.
2) The age of the ship reflects the ship maintenance and the state of equipment.
3) The tonnage of ship reflects the ship's size and scale.

2.2.3 Environmental factors

Except for force majeure, environmental factors are less direct factors of accidents, but they are always the main induced factor that results human error. The navigation environment of the Yangtze River is unfavorable during the dry season. The restricted Navigable dimension is one of the causes of water traffic safety accident.

In this study, environmental factors are divided into the natural environment and the navigation environment to further select the risk factors of water traffic.

2.2.3.1 The natural environment

In this model, the natural environment considered 3 risk factors of the visibility, wind and water flow.

1) the visibility: Mainly influenced by the bad weather of fog, snow, rain, etc., the Officer On Watch's visual is influenced to a certain extent.
2) Wind: Strong wind will increase the difficulty for operating the ship, and the probability of grounding, collision ,etc.
3) Water flow: As in the case of strong winds, water flow can also influence the operative performance of ship, thus may lead to water traffic accidents.

2.2.3.2 The navigation environment

The navigation environment in this model considered the 3 risk factors of navigable dimensions, ship traffic ,and navigational facilities equipped.

1) Navigable dimensions: the channel width, depth, radius of curvature, etc.
2) Ship traffic: reflecting the density of ship navigation.
3) Navigational facilities equipped: reflecting the perfect degree of navigational facilities.

2.2.4 Management factors

Although management factors are not the direct factor causing the water traffic safety accidents, it affects the human factor, ship factor and other environmental factors directly. Therefore, we can consider that the water traffic safety accidents are caused by the inappropriate management to some extent(Yan, 2010).

Management factors in this study include the 2 risk factors of Maritime department management and shipping companies management:

1) Maritime department management: Including all levels of Maritime authorities and waterway department management.
2) Shipping companies management: including the management of shipowner and operations department.

2.3 The research methods of FUZZY-AHP

2.3.1 The procedure of FUZZY-AHP

The fuzzy AHP in this chapter is established on the basis of AHP model. We put forward the targeted optimal risk control scheme according to the results of utility analysis by using the data from the expert judgment of discrete fuzzy sets processing, constructing judgment matrix to calculate the weights of various risk factors. The scheme includes the following 6 steps:

1) Defining as the compared expert judgment term, establish various terms of discrete fuzzy sets and get all the weighted value of judgment terms by normalization process.
2) Transforming the results of experts paired comparison into the value of two-two

comparison by the value of discrete fuzzy sets .

3) Calculating the corresponding weight through each level judgment matrix , and conduct consistency check.

4) Calculating the synthetic weight of each risk factor for the total target, and sequence them.

5) Proposing risk control scheme for representative risk factors based on the sequencing results of risk factors.

6) Establishing discrete fuzzy sets of utility judgment, and get the optimal sequencing of risk scheme for the combined effect of the risk control factors by judging each risk scheme.

2.3.2 Discrete fuzzy set

Discrete fuzzy set is one of the fuzzy set. At present , it is often applied to the quantify conversion of the subjective judgment data(Wang J, 1995, p103).

2.3.2.1 The definition of expert judgment terms

In the cases of discrete fuzzy set of 7 expert judgment terms(Wang J, 1995, p271), we divided the results of two comparison into scales namely, 'equally', 'slightly', 'moderately', 'fairly', 'strongly', 'very strongly' and 'extremely', as shown in table 1.

Table 1- example of discrete fuzzy

Judgment term	disperse subordinate function						
	y_1	y_2	y_3	y_4	y_5	y_6	y_7
Equally(EQ)	x_{EQ1}	x_{EQ2}	x_{EQ3}	x_{EQ4}	x_{EQ5}	x_{EQ6}	x_{EQ7}
Slightly(SL)	x_{SL1}	x_{SL2}	x_{SL3}	x_{SL4}	x_{SL5}	x_{SL6}	x_{SL7}
Moderately(MO)	x_{MO1}	x_{MO2}	x_{MO3}	x_{MO4}	x_{MO5}	x_{MO6}	x_{MO7}

Fairly(FA)	x_{FA1}	x_{FA2}	x_{FA3}	x_{FA4}	x_{FA5}	x_{FA6}	x_{FA7}
Strongly(ST)	x_{ST1}	x_{ST2}	x_{ST3}	x_{ST4}	x_{ST5}	x_{ST6}	x_{ST7}
Very strongly(VS)	x_{VS1}	x_{VS2}	x_{VS3}	x_{VS4}	x_{VS5}	x_{VS6}	x_{VS7}
Extremely(EX)	x_{EX1}	x_{EX2}	x_{EX3}	x_{EX4}	x_{EX5}	x_{EX6}	x_{EX7}

Source: Compiled by the author, 2014

Among them, the district from Y_1 to Y_7 represents 7 discrete subject function in this fuzzy set. It's most important from Y_1 to Y_2. x represents membership grade of each judgment term under every discrete subject function. Thus, the initial value k_x' of the judgment term X in the discrete fuzzy set can be get from the following formula:

$$kx' = \sum_{i=1}^{n} \{ [\frac{x_i}{\sum_{i=1}^{n} x_i}] \times y_i \}$$

(Formula 1)

x_i is membership grade of judgment term X in the discrete subject function i. n is the number of defined discrete subject .

2.3.2.2 Calculation of the weighted value of judgments term

In order to obtain judgment term weighted the value that was applied in the AHP, we need to normalize kx' in formula 1 to get the weighting value k_x' of judgment term x, as the formula 2 showing.

$$kx = \frac{kx'}{\max(k_1', k_2', \ldots k_m')}$$

(Formula 2)

In this formula, m is the number of judgment term, and in this formula 2, m is 7.

2.3.3 AHP

2.3.3.1 The processing of expert judgment results

On the basis of establishing the judgment terms set , experts can give important two-two comparing results according to the corresponding standard. That is the degree of confidence of judgment terms. For example, (0.5EQ,0.5SL) represents that equally important degree of confidence is 50% and slightly important degree of confidence is 50%.

Each expert's comprehensive judgment results (degree of confidence) can be obtained from the following formula 3:

$$\beta = \sum_{i=1}^{l} \beta_i \times c_i$$

(formula 3)

According to weighted value of the results from the formula (1)、(2) and the comprehensive method of expert opinion from formula 3, we can quantify the results of expert judgment for two-two compared the relatively important index N_I, as the following formula:

$$N_I = \sum_{X=1}^{m} \beta_X \times k_X$$

(formula 4)

2.3.3.2 AHP judgment matrix

Assuming that there are n factors in the AHP model, and indicating the I factor with a_{ij} relative to the important comparing results of j factor , the level of judgment matrix A can indicate n×n matrix (Pillay A, 2003):

$$A = (a_{ij}) = \begin{matrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{matrix}$$

(formula 5)

The weights of factor K in the hierarchy can be calculated by the following formula (Ung S, 2006, p73):

$$w_k = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}}$$

(k=1,2,...,n) (formula 6)

2.3.3.3 Consistency check

Consistency check to judge matrix A can guarantee expert's judgment data and the calculated weights have certain reliability and application value. If we could not reach the requirements of consistency check, it's necessary to recollect the expert's judgment data or to adjust the paired comparison of discrete fuzzy set(Anderson D, 2003) .

Consistency check steps are as following:

l) Calculating and judge characteristic values of matrix, and take the λ_{max} value .

2) Calculating the consistency index CI(Consistency Index) ,as the following formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$ (formula 7)

3) Finding corresponding random consistency index RI (Random Index), as table 2.
4) Calculating the proportion of consistency CR(Consistency Ratio), as the following formula showing.

$$CR = \frac{CI}{RI}$$ (formula 8)

When CR <0.1, consider that consistency of judgment matrix is acceptable, and each factor weight calculated can be used; On the contrary, we need to recollect the data or adjust the pairwise comparison discrete fuzzy set, until the judgment matrix can receive the requirements of consistency check.

Random consistency index RI generally adopted the methods of calculating the average of the obtained matrix.

Currently common values are shown in the following table 2(Anderson D, 2003):

Table 2 - the value of RI

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

2.3.3.4 Synthetic weight calculation

Assuming that the k_n factors in the AHP model is in the n layer under target layer, as the figure 7.

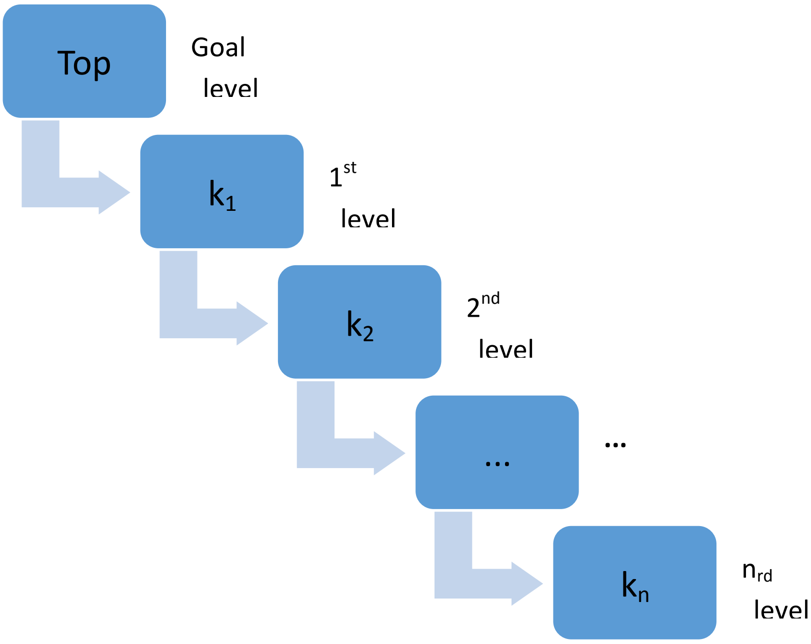

Figure 7 - factors hierarchy in the AHP model showing
Source: Compiled by the author, 2014

Factor k_n relative to the combining weight w_{kn} of target layer can be calculated by following formula:

$$W_{kn} = w_{k1} \times w_{k2} \times \ldots \times w_{kn} \qquad \text{(formula 9)}$$

In formula 9, $w_{kl}, w_{k2}, \ldots, w_{kn}$ are the relative weight of $k_1, k_2, \ldots.\ k_n$ can be obtained through formula 6 in the relative weights of each level.

2.3.4The selection of risk control scheme

The selected SCEs in AHP model can be served as the evaluation criterion to select the RCOs, as shown in the figure 9.

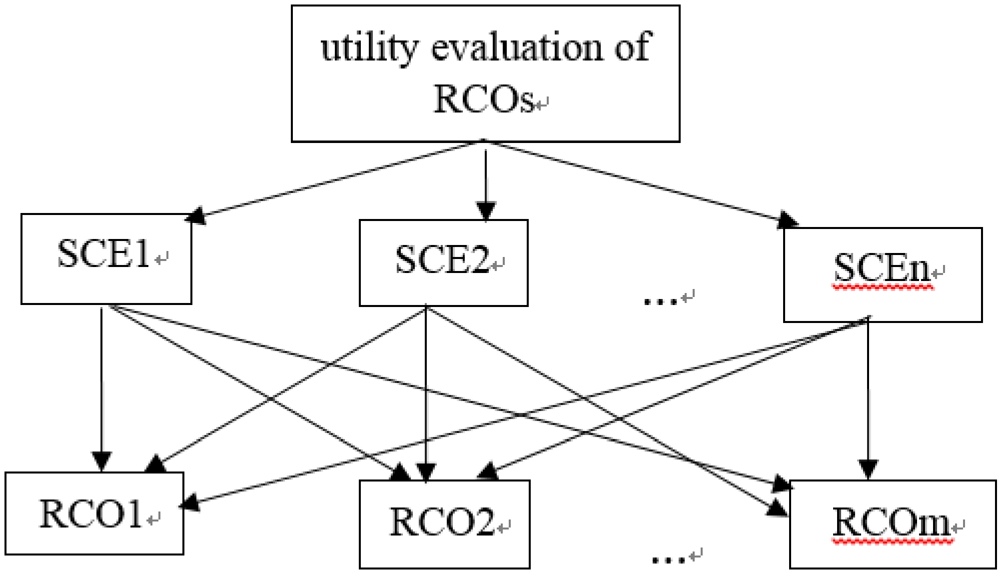

Figure 8 the choose of RCOs
Source: Compiled by the author, 2014

Among the m, SCE_1, SCE_2, ...SCE_Z, SCE are the selected as n risk factors, RCO_1,RCO_2,…,RCO_m are the m RCOs. Assuming K_j is the utility which RCO_i for SCE_j, so RCO_i can be calculated by formula:

$$E_i = \sum_{j=1}^{n} K_j \times W_j \qquad (i=1,2, ..., m) \quad \text{(formula 10)}$$

Among the m, W_j can be obtained from the formula 9, however, K_j can be got by calculating formula 4 with the results of the experts' judgment. Finally, we can conclude the optimal risk control options from the overall utility sequence.

2.4 The cases study on the Yangtze river navigation risk in the dry season

We studied the objects of Yangtze river navigation risk as the case in dry season, compared and evaluated the importance of Yangtze river navigation risk in dry season for each factor in the model in the form of having an informal discussion with expert , according to the AHP model of the built Yangtze river water traffic safety system(figure 6) , and identified the critical factors of Yangtze river navigation risk in the dry season by using the fuzzy analytical hierarchy process as introduced in the 2.3. As described in 2.1.2, considering the three experts in MSA having equivalent qualifications, this chapter gave the same weight for every expert. That is expert standard weight (C_1, C_2, C_3) as (0.34,0.33,0.33) involved in formula 3.

2.4.1 Paired comparison discrete fuzzy set

This study adopted 7 judgments terms as 2.3.2.1 describing by pairwise comparison. They are equally, slightly, moderately, fairly, strongly, very strongly and extremely. Meanwhile, we defined the corresponding pairwise comparison of discrete fuzzy sets as follows.

Table 3 - pairwise comparison of discrete fuzzy set

Judgment term	disperse subordinate function						
	0	1/6	1/3	1/2	2/3	5/6	1
Equally(EQ)	0	0	0	0	0	0.25	1
Slightly(SL)	0	0	0	0	0.75	1	0.25
Moderately(MO)	0	0	0	0.75	1	0.25	0
Fairly(FA)	0	0	0.5	1	0.5	0	0
Strongly(ST)	0	0.25	1	0.75	0	0	0
Very strongly(VS)	0.25	1	0.75	0	0	0	0
Extremely(EX)	1	0.25	0	0	0	0	0

Source: Compiled by the author, 2014

According to the formula1, we can work out the initial value of each judgment term:

$$k'_{EQ} = \left(\frac{0.25}{0.25+1}\right)\times\frac{5}{6}+\left(\frac{1}{0.25+1}\right)\times 1 = 0.967$$

$$k'_{SL}=\left(\frac{0.75}{0.75+1+0.25}\right)\times\frac{2}{3}+\left(\frac{1}{0.75+1+0.25}\right)\times\frac{5}{6}+\left(\frac{0.25}{0.75+1+0.25}\right)\times1=0.792$$

$$k'_{FA}=\left(\frac{0.5}{0.5+1+0.5}\right)\times\frac{1}{3}+\left(\frac{1}{0.5+1+0.5}\right)\times\frac{1}{2}+\left(\frac{0.5}{0.5+1+0.5}\right)\times\frac{2}{3}=0.500$$

$$k'_{ST}=\left(\frac{0.25}{0.25+1+0.75}\right)\times\frac{1}{6}+\left(\frac{1}{0.25+1+0.75}\right)\times\frac{1}{3}+\left(\frac{0.75}{0.25+1+0.75}\right)\times\frac{1}{2}=0.375$$

$$k'_{VS}=\left(\frac{0.25}{0.25+1+0.75}\right)\times0+\left(\frac{1}{0.25+1+0.75}\right)\times\frac{1}{6}+\left(\frac{0.75}{0.25+1+0.75}\right)\times\frac{1}{3}=0.208$$

$$k'_{EX}=\left(\frac{1}{1+0.25}\right)\times0+\left(\frac{0.25}{1+0.25}\right)\times\frac{1}{6}=0.033$$

We can furtherly get the weighted value of each term with the normalization processing from formula 2. The calculation results are shown in table 4:

Table 4 - weighted value of paired comparison judgment terms

k_{EQ}	k_{SL}	k_{MO}	k_{FA}	k_{ST}	k_{VS}	k_{EX}
1	0.82	0.65	0.52	0.39	0.22	0.03

Source: Compiled by the author, 2014

2.4.2 The calculation of weight at each level

2.4.2.1The target layer

There are 4 factors under the target layer in AHP model. They are human ,ship, environment and management. The pairwise comparison results of comprehensive expert investigation are shown in the following table according to the formula 3.

Table 5 - The expert investigation results of target layer

	Management	Environment	Ship	Human
Management	1EQ	0.5FA 0.5ST	0.5SL 0.5MO	0.33ST 0.67VS

Environment		1EQ	0.67EQ 0.33SL	0.5MO 0.5FA
Ship			1EQ	0.5FA 0.5ST
Human				1EQ

Source: Compiled by the author, 2014

Through the table 3 and formula 4,5, we can get this judgment matrix:

	Mangement	*Environment*	*Ship*	*Human*
Management	1.000	0.455	0.735	0.276
Environment	2.198	1.000	0.941	0.585
Ship	1.361	1.063	1.000	0.455
Human	3.622	1.709	2.198	1.000

And through formula 6, we can get the factors weight in this level:

Table 6 factor weight in goal level

Factors	Management	Environment	Ship	Human
weight	0.12	0.24	0.21	0.43
order	4	2	3	1

Source: Compiled by the author.

Use formula 7 and 8 to check the consistency of judgment matrix:

$$CR = \frac{\frac{4.027-4}{4-1}}{0.9} = 0.010 < 0.1$$

Therefore, we can consider this level of judgment matrix is with good consistency. the weight of each factor has a certain credibility.

2.4.2.2 The layer of human factor

There are 3 risk factors in the layer of human factor in AHP model. They are the age, competent, complying with the laws and regulations. Pairwise comparison data that is obtained by expert investigation is shown in the table7.

Table 7 - The expert investigation results of human factor layer

	Age	Competent	Laws and regulations
Age	1EQ	0.5FA 0.5ST	0.33ST 0.67VS
Competent		1EQ	0.33EQ 0.67SL
Laws and regulations			1EQ

Source: Compiled by the author, 2014

So , in this level the judgment matrix is:

$$\begin{array}{l} \\ \text{Age} \\ \text{Competent} \\ \text{Laws and regulations} \end{array} \begin{bmatrix} Age & Competent & Laws \& regulations \\ 1.000 & 0.455 & 0.276 \\ 2.198 & 1.000 & 0.879 \\ 3.622 & 1.137 & 1.000 \end{bmatrix}$$

And each weight of factors are in table 8:

Table 8 - factor weight in human factor

Risk factors	Age	Competent	Laws and regulations
weight	0.15	0.37	0.48
orders	3	2	1

Source: Compiled by the author, 2014

2.4.2.3 The layer of ship factors

This layer is divided into three risk factors, and they are tonnage, vessel age and seaworthiness. Result of Expert in MSA research is listed in table 9:

Table 9 - results of expert in ship factor level.

	Tonnage	Vessel age	seaworthiness
Tonnage	1EQ	0.67EQ 0.33SL	0.5SL 0.5MO
Vessel age		1EQ	0.33SL 0.67MO
seaworthiness			1EQ

Source: compiled by author, 2014

And its judgment matrix is:

$$\begin{array}{lccc} & Tonnage & Vessel-ages & seaworthy \\ \text{Tonnage} & 1.000 & 0.941 & 0.735 \\ \text{Vessel ages} & 1.063 & 1.000 & 0.706 \\ \text{seaworthiness} & 1.361 & 1.416 & 1.000 \end{array}$$

And each weight of factors are in table 10:

Table 10 - factor weight in ship factor layer

Risk factors	Tonnage	Vessel age	seaworthiness
Weight	0.29	0.30	0.41
Orders	3	2	1

Source: compiled by author, 2014

The consistency check for judgment matrix is :

$$CR = \frac{\frac{3.001-3}{3-1}}{0.58} = 0.001 < 0.1$$

2.4.2.4 The layer of environmental factors

This layer is divided into two parts of the natural environment and the navigation environment ,which including six risk factors of wind, stream, visibility and traffic, navigation aids, navigation scale. We need pairwise comparison and weight calculation step by step, according to the method and the AHP theory .

(1) the natural environment and the navigation environment

With respect to the importance of navigation environment, the comparison results of the natural environment obtained through the experts investigation are (0.5FA, 0.5ST). The both weight of this hierarchy that was calculated according to these is (the natural environment 0.31, the navigation environment 0.69).

(2) the layer of natural environment

The expert investigation results of this layer are shown in the table 11 showing.

Table 11- The expert result in environment layer.

	current	Wind	Visibility
current	1EQ	0.67MO 0.33FA	0.5FA 0.5ST
Wind		1EQ	0.67SL 0.33MO
Visibility			1EQ

Source: compiled by author, 2014

And its judgment matrix is:

	Flow	*Wind*	*Visibility*
current	1.000	0.607	0.455
Wind	1.647	1.000	0.764
Visibility	2.198	1.309	1.000

And each weight of factors are in table 12:

Table 12 - actor weight in environment factor layer

Risk factors	current	Wind	Visibility
Weight	0.21	0.34	0.45
Orders	3	2	1

Source: compiled by author

The consistency check for judgment matrix is :

$$CR = \frac{\frac{3.001-3}{3-1}}{0.58} = 0.001 < 0.1$$

Therefore, we can consider that the obtained each factor weights has a certain credibility.

(3)The layer of navigation environment

In this layer, expert investigation result is in table 13:

Table 13 - expert result in navigation environment layer

	Volume of traffic	Navigational aids	Dimension of waterway
Volume of traffic	1EQ	0.67ST 0.33VS	0.5VS 0.5EX
Navigational aids		1EQ	0.33FA 0.67ST
Dimension of waterway			1EQ

Source: compiled by author, 2014

So, the judgment matrix in this layer is:

$$\begin{array}{lccc} & \textit{Volume}-\textit{traffic} & \textit{Navigational}-\textit{aids} & \textit{Dimension} \\ \text{Volume of traffic} & 1.000 & 0.334 & 0.125 \\ \text{Navigational of aids} & 2.995 & 1.000 & 0.433 \\ \text{Dimension of waterway} & 8.000 & 2.310 & 1.000 \end{array}$$

And the weight of factor is shown in table 14:

Table 14 - weight of navigation environment layer

Risk factors	Volume of traffic	Navigational aids	Dimension of waterway
Weight	0.09	0.26	0.65
Orders	3	2	1

Source: compiled by author, 2014

Judgment matrix has a good consistency, and the check result is:

$$CR = \frac{\frac{3.002-3}{3-1}}{0.58} = 0.002 < 0.1$$

2.4.2.5 The layer of management factors

This layer includes two risk factors of the management of Maritime department and shipping companies. With regard to the importance of shipping companies' management, the comparison results of the management of Maritime department obtained through the experts investigation are (0.5EQ, 0.5sL). The both weight of this hierarchy that was calculated according to these is (Maritime department management 0.48, shipping management 0.52).

2.4.3 The Identification of the navigation risk factors in dry season

We use formula 9 in 2.4.2 to work out synthetic weight of 14 risk factors, and the results are in table 15:

Table 15 - synthetic weight of risk factors

Membership level		Risk factors	Synthetic weight	orders
Human factors		Age	0.064906	6
		competence	0.160881	2
		Follow laws and rules	0.206675	1
Ship factors		Tonnage	0.059641	8
		Ship ages	0.0613	7
		seaworthiness	0.083921	4
Environment factors	Natural environment	current	0.015353	13
		Wind	0.02545	12
		Visibility	0.033529	11
	Navigational environment	Volume of traffic	0.013899	14
		Navigational aids	0.043673	10
		Dimension of waterway	0.105796	3
		Management of MSA	0.059543	9
		Management of shipping company	0.065432	5

Source: compiled by author, 2014

We can see that from the sequence of the table above the 4 risk factors of complying with the laws and regulations, competent, Navigable dimensions, and ship's seaworthiness are identified as the key elements of Yangtze river navigation risk in dry season. It’s total contribution rate reaches up more than 55%.

As described in 1.2.3, the navigation risks in Yangtze river during dry season mainly express the ship grounding accident etc., Under the condition of the navigation limited scale. However, these accidents are always caused by ship operator not complying with the relevant laws and regulations and subjective super draft. The objective fact coincides with the above identified risk factors, which verify the scientific and rationality of this method.

2.5 The study on navigable risk in Yangtze River control scheme during dry season

We put forward relevant risk control scheme based on the risk factors that Fuzzy-AHP identifies, and study the optimal scheme for controlling Yangtze River navigable risk in dry season by analyzing the comprehensive utility of each scheme.

2.5.1 Risk control scheme

Combining the 4 risk factors of complying with the laws and regulations, competenty, navigable dimensions, and ship's seaworthiness, with expert survey opinion and the actual situation of Yangtze River, This study proposes the following four control schemes of the navigable risk in Yangtze River during the dry season (RCOs).

1）RCO1: Strengthen the crew training and management

Increase the intensity of the crew training and management from the two sides of Maritime departments at all levels and ship companies, enhance the crew's awareness of law and regulation, and improve their competency.

2）RCO2: Maritime department intensifies the degree of supervision and management

Implement segmented visa system for specific shallow and risk channel in dry season, increase the frequency of on-site cruising; strictly control illegal situation of the crew with false testimony, without carrying identification, and the ship with super draft and unseaworthiness etc.

3）RCO3: Strengthen the hydrologic information collection and release

The channel department should increase the frequency of hydrological information collected for the specific shallow and risk channels, and promptly announce the se to the coming and going ships through the network, notice to navigator, VHF etc.

4）RCO4: the dredging and maintenance for channel

We should adopt the necessary dredging and maintenance for channel to guarantee the navigable dimensions for Yangtze river in dry season ,on the basis of fully collecting the hydrological information.

2.5.2 Discrete fuzzy set of utility evaluation

In order to further assess the utility of risk control scheme, this study established a discrete fuzzy set of utility evaluation. Similar to the pairwise comparison discrete fuzzy set in 2.4.1, utility evaluation also adopts seven judgment terms. They are completely effective, greatly effective, averagely effective, effective, moderately effective, slightly effective, least effective. The definition of the corresponding expert judgment discrete fuzzy set is shown in the table 16.

Table 16 - effectiveness evaluation of discrete fuzzy set

Judgment term	disperse subordinate function						
	0	1/6	1/3	1/2	2/3	5/6	1
Completely effective(CE)	0	0	0	0	0	0.25	1
Greatly effective(GE)	0	0	0	0	0.75	1	0.25
Averagely effective(AE)	0	0	0	0.75	1	0.25	0
Effective(EF)	0	0	0.5	1	0.5	0	0
Moderately effective(ME)	0	0.25	1	0.75	0	0	0
Slightly effective(SE)	0.25	1	0.75	0	0	0	0
Least effective(LE)	1	0.25	0	0	0	0	0

Source: compiled by author, 2014

The weighted value of each utility of judgment term can be get from the calculation by the formula 2. It’s results as the table 17 showing.

Table 17 - the weighted value of each utility of judgment term

k_{CE}	k_{GE}	k_{AE}	k_{EF}	k_{ME}	k_{SE}	k_{LE}
1	0.82	0.65	0.52	0.39	0.22	0.03

Source: compiled by author, 2014

2.5.3 The utility evaluation of risk control scheme

With regard to 4 risk factors complying with the laws and regulations, competent, navigable dimensions, and ship's seaworthiness as the standard, we should use the judgment term of using utility evaluation discrete fuzzy set to evaluate every risk control scheme and get the results of expert judgment. Like2.4, when comprehensively judging the results, we give the same weight to each expert according to the results in table 18 calculated from formula 3.

Table 18 - the utility evaluation of expert judgment

	Effect of control follow rules and laws	Effect of control crew competence	Effect of control Dimension of waterway	Effect of control seaworthiness
RCO1	0.5AE	1EF	1LE	0.5EF
	0.5EF			0.5ME
RCO2	0.5EF	0.5ME	1LE	1EF
	0.5ME	0.5SE		
RCO3	0.5ME	1LE	0.5AE	1LE
	0.5SE		0.5EF	
RCO4	1LE	1LE	0.5CE	1LE
			0.5GE	

Source: compiled by author, 2014

Taking RCO1 ‘strengthen the crew training and management’ as an example, in the table ,the effect that it controls the crew complying the laws and regulations is 0.SAE,0.SEF. the confidence level of averagely effective is 50%. The confidence level of effective is 50%.

The dates of tables 15, 17, 18 applied to formula 4 and 10 were calculated to get each alternative risk control scheme for utility value of each risk factors and combined risk factor synthetic utility value of integrated weights as table 19.

Table 19 - the utility value of risk management scheme

	Follow laws and rules w=0.21	Competent w=0.16	Dimension of waterway w=0.11	seaworthiness w=0.08	Utility function	orders
RCO1	0.585	0.52	0.03	0.455	0.246	1
RCO2	0.455	0.305	0.03	0.52	0.189	2
RCO3	0.305	0.03	0.585	0.03	0.136	3
RCO4	0.03	0.03	0.91	0.03	0.114	4

Source: compiled by author, 2014

Taking the RCO1 as an example, the utility values of RCOI are calculated as the following process, based on expert judgment results in Table 18 and 17 the weighted values of the utility judgment terms.

Control "comply with laws and regulations" utility value: 0.65x0.5+0.52x0.5=0.585

Control " competent " utility value: 0.52xl=0.52

Control "navigable scale" utility value: 0.03xl=0.03

Control " ship seaworthiness" utility value: 0.52x0.5+0.39x0.5=0.455

Combining with relative weight of each risk factor in table 3-14, we get RCOI comprehensive utility value: 0.585X0.21+0.52X0.16+0.03x0.11+0.455X0.08=0.246.

From the comprehensive utility scheme of the each risk control scheme, we can see that it's considered as the most effective way controlling Yangtze river navigation risk in dry season to improve the crew's quality and business level. Secondly, the enhancing supervision and taking effective measuring by Maritime department can suppress the illegal behavior and have good effect on reducing navigation risk.

Chapter 3 The study on navigation safety evaluation based on Fuzzy evidence reason

On the basis of identifying and studying the Yangtze river navigation risk in dry season, this chapter studied the navigation risk of the upper ,middle and lower reaches of Yangtze river as a case, using the method of fuzzy rule base and evidence reasoning, and combining with the historical data and expert survey results. At the same time, we arrange their navigation safety conditions in a sequence by the method of utility value calculation.

3.1 The research background of this chapter

3.1.1 The choice of research method

The related research in chapter 2 puts forward a hierarchical model (figure 6) to evaluate the Yangtze river navigation risk in dry season, analyzed and calculated the relative weights of all levels of the relevant factors using Fuzzy-AHP. However, if we use the hierarchical model to study Yangtze river navigable risk as the specific case in dry season , we are required to establish evaluation grades of each influence factors, evaluation standard and mapping relationship between the each level, and at last get the evaluation results of ultimate goal by combining evaluation results and the hierarchical relationship of each influence factor .

When we define evaluation standard and the theory of multiple domain mapping relations, the fuzzy rule base of fuzzy logic reflects better practicality and has a broad application. When dealing with multi-index evaluation, evidence reasoning also better reflects rationality, and plays an important role in the field of decisions in the field of decision-making.

Therefore, this chapter will use the evidence reasoning method based on fuzzy rule base and study the Yangtze river navigation safety in dry season as a case on the basis of hierarchical model as put forward in the chapter 2.

3.1.2 The data sources

3.1.2.1the objective data

We selected the relevant data of the dry season in 2011-2013(November 2011 to march 2013) as the basis of the study, which come from the Yangtze river Maritime Administration intranet.

3.1.2.2 subjective data

This subjective data collected from chapter 3 come from the domain experts introduced in the 2.1.2. the results of their judgment will complement as objective historical data.

3.2 The hierarchical model of navigation safety in Yangtze River evaluation during dry season

Based on the research results in the second chapter, in this chapter, the hierarchical model of Yangtze River navigation safety evaluation in dry season and the relative weight of each level are shown in table 20.

Table 20 - the hierarchical model of Yangtze river navigation safety evaluation in dry season

Module Goals	first grade assessment indicator	second grade assessment indicator	third grade assessment indicator
Navigation safety of Yangtze river in dry season(1.00)	Human factors (0.43)	Competency of crew(0.37)	
		Age(0.15)	
		Follow laws and rules(0.48)	
	Ship factors (0.21)	seaworthiness(0.41)	
		Age of vessel(0.30)	
		Tonnage(0.29)	
	Environment factors (0.24)	Natural factors(0.31)	Visibility(0.45)
			Wind(0.34)
			current(0.21)
			Dimension of waterway(0.65)
		Navigational environment(0.69)	Volume of traffic
			navigational aids
	Management factors(0.12)	Management of MSA(0.48)	
		Management of shipping company(0.52)	

Source: compiled by author, 2014

On the basis of hierarchical model above , we will establish the evaluation grade of indicators at all levels, evaluation standard, the mapping relationship between the each level index in this chapter to evaluate and analyze navigation safety in Yangtze River evaluation during dry season

3.3 The research methods of FRBER

3.3.1The procedure of FRBER

Fuzzy evidential reasoning used in the chapter is established on the basis of the hierarchical evaluation model by expert judgment to establish fuzzy rule base, and the n determined the evaluation grade of indicators at all levels, evaluation standard, the mapping relationship between the each level index, and achieved the conversion between quantitative and qualitative data. Finally, use evidential reasoning algorithm to fuse each index evaluation results, by calculating the utility values for the quantitative analysis of navigation risk. these include the following 5 steps:

1) Defining the each evaluation index, qualitative or quantitative evaluation grade and evaluation standard through the objective and subjective data.
2) Using the method of fuzzy rule base to transform quantitative data into qualitative evaluation data.
3) Establishing the inferior to superior index mapping relationship by the fuzzy rule base.
4) Using the evidential reasoning algorithm to synthesize evaluation results of each subordinate index, and obtaining the target evaluation results.
5) Analyzing the evaluation results using the calculation method of utility value and getting the navigation risk sequence of each case.

3.3.2 The fuzzy rule base

The fuzzy rule base in this chapter is mainly from expert investigation and relevant literature(Bowles J, 1995, p203). They will be applied to the transformation between the quantitative and qualitative data and the mapping of the superior and inferior index .

3.3.2.1 The conversion of quantitative and qualitative data

In order to facilitate the synthesis of each index evaluation results, it is necessary to transform some indicators of quantitative data by fuzzy rule base into qualitative evaluation results (Yang J, 2002,p289).

Assuming that index e_i is a “efficiency” quantitative index, that is the corresponding value is larger ,it is more ideal. Define the qualitative evaluation grade and the standard (fuzzy rules) of index e_i, as:

$$h_{n,i} \rightarrow Hn(n = 1,2,..., N)$$ (formula 11)

Among the m, the H_n is index e_i. the $h_{n,i}$ is qualitative evaluation grade. $h_{n,i}$ is the ir corresponding quantitative evaluation standard. N is the number of evaluation grades of index e_i.

So, if the fixed date h_j are under the e_i, the fixed express are:

$$S(h_j) = \{(H_n, \beta_{n,j}), n = 1,2,..., N\}$$ (formula 12)

Make $h_{n,i} \le h_i \le h_{n+1,i}$, so:

$$\beta_{n,j} = \frac{h_{n+1,i} - h_i}{h_{n+1,i} - h_n}$$ (formula 13)

$$\beta_{n+1,j} = 1 - \beta_{n,j}$$ (formula 14)

$\beta_{k,j} = 0$, k =1,2,...N, $k \neq n, n+1$

When we determine the actual evaluation grade and standard, the quantitative standards Hn of each grade in formula 11 is difficult to be determined. The two extreme value h_{min}, and h_{max} of this index are relatively easy to determine. In this situation:

We can use fuzzy rules to determine the type of quantitative evaluation standard of every grade:

$$h_{n,i} = h_{\min,i} + \frac{h_{\max,i} - h_{\min,i}}{N-1} \times (n-1)$$ (formula 15)

Hn is the best evaluation grade of index ei, corresponding quantitative standard h_{max}; However, Hl is the most unsatisfactory evaluation grades, corresponding quantitative standard $h_{min,i}$.

When e_i is "consumption" evaluation index, we can accordingly exchange the ir corresponding extrema value .

3.3.2.2 The mapping relationship of superior and inferior index

In order to guarantee the rationality of the mapping relationship of superior and inferior index, this chapter adopts the fuzzy rules based on confidence level IF-THEN. As shown in table 21, evaluation grade in inferior index "navigable dimensions" is "Very Good". The mapping rules of superior index "navigation environment " is defined as "Good", and the confidence level is 0.5, "Very Good" the confidence level 0.5. That is IF" navigable dimensions" ="Very Good", the n "navigation environment " ="50%Good,50%Very Good"。

Table 21- example of fuzzy rules

Rules NO.	Dimension of waterway	Navigational environment
1	Very good	Good 0.5, very good 0.5

Source: compiled by author, 2014

In general, the mapping rules of the inferior index e, corresponding to superiors index e, are defined as follows:

Table 22 - fuzzy rules base of index mapping.

Rules NO.	e_i	e_l
1	H_1	$(L_1, \beta_{k,1}), k = 1,..., M$
...	...	...
n	H_n	$(L_k, \beta_{k,n}), k = 1,..., M$
...	...	...
N	H_N	$(L_k, \beta_{K,N}), k = 1,..., M$

Source: compiled by author, 2014

In table 22, H_1,…, H_n are the N evaluation levels for e_i, L_1,…,L_M is the M evaluation levels for top index e_l, $\beta_{k,n}$ are the number of n evaluation level for confidence of the number of k , and e_i and e_l can make out by formula:

$$e_i \rightarrow e_l = \{(L_{k,} \sum_{n=1}^{N} \beta_{n,j} \times \beta_{k,n}), k = 1,..., M\}$$ (formula 16)

Mapping sample of inferior index are showed:

Table 23 - mapping sample of inferior index

the superior index		0.1	0.4	0.14	0.36	0		Mapping result
Navigation environment		Very good	Good	Average	Poor	Very poor		evaluation rating
		0.5 0.5	1.0	0.7 0.3	1.0	1.0		fuzzy rule sets
Dimension of waterway		Very good	Good	Average	Poor	Very poor		order of evaluation
Junior index		0.2	0.3	0.3	0.3	0		Fuzzy input

Source: compiled by author, 2014

As Table 23 showed, inferior targets "navigable scale" fuzzy input(Very Good0.2, Good0.3, Average0.2, Poor0.3, Very Poor0), the mapping rules of its corresponding to the superior targets 'navigable environment' are shown in table showing:

Table 24 - example of fuzzy rule sets

Rules NO.	Dimension of waterway	Navigational environment
1	Very good	Good 0.5, very good 0.5
2	Good	Good 1.0
3	Average	Average 0.7, Poor 0.3
4	Poor	Poor 1.0
5	Very Poor	Very Poor 1.0

Source: compiled by author, 2014

Using the formula (4-7) to calculate the mapping results as following:

. Navigation environment=confidence level of "Very Good":0.2×0.5=0.1;

. Navigation environment = confidence level of “Good” :0.2×0.5+0.3×l=0.4;

. Navigation environment = confidence level of “Average”:0.2×0.7=0.14;

. Navigation environment = confidence level of “Poor”:0.2×0.3+0.3×l=0.36;

. Navigation environment = confidence level of “very Poor”: 0×1=0；

Therefore, the mapping results of navigable dimensions corresponding to navigation environment are (VeryGood0.1, Good0.4, Average0.14, Poor0.36, VeryPoor0)。

3.3.3 The method of evidential reasoning

We can get each index for the target mapping results through the forenamed index of evaluation and mapping method. However, evidential reasoning has provided effective ways of comprehensive index evaluation results.

3.3.3.1The general procedures for evidential reasoning

Assuming that evaluation target has N evaluation grades Hn (n=l,2,…N) and L evaluation index e_i(1=1,2,…L), the general procedures for using evidential reasoning to integrate each index evaluation results (evidence) as follows [158]:

1) Defining the evidence set E:

$$E = \{e_i, (i = 1,2,..., L)\}$$ (formula 17)

2) Determining the relative normalized weights w of each evidence for evaluation target, and w_i satisfied:

$$\sum_{i=1}^{L} w_i = 1, 0 \le w_i \le 1$$ (formula 18)

3) Defining evaluation grade H of target:

$$H = \{H_n, (n = 1,2,..., N)\}$$ (formula 19)

4) Determining evaluation results $S(e_i)$ of each evaluation index for the target.

$$S(e_i) = \{(H_n, \beta_{n,i}), n = 1,2,..., N\}, i = 1,2, . . L,$$ (formula 20)

Among it, $\beta_{n,i}$ represent evidence e_i,, for the confidence level of evaluation grades Hn.

5) Finally, using the evidential reasoning algorithm to synthesize evaluation results of each indicator , evaluation S (E)

$$S(E)=\{(H_n,\beta_n),n=1,2,\ .\ N\}$$ (formula 21)

3.3.3.2 Evidence synthetical algorithm

The calculation process of evidence synthetical in this chapter is described as follows (Yang J, 2002, p376).

Define the confidence weighting parameters $m_{n,i}$ of evidence e_i:

$$m_{n,i}=w_i\times\beta_{n,i},n=1,2,...,N;i=1,2,...,L$$ (formula 22)

In view of the possible incompleteness evidence e_i, under that case, the definition of incompleteness parameters $m_{H,i}$ as follows:

$$m_{H,i}=1-\sum_{n=1}^{N}m_{n,i}$$, i=1,2,,,,L (formula 23)

We will divide the incompleteness parameters $m_{H,i}$ into incompleteness parameters of weight coefficient caused and data missing caused, respectively are shown as formula 24 and 25:

$$\overline{m}=1-w_i,i=1,2,...,L$$ (formula 24)

$$\tilde{m}_{H,i}=w_i(1-\sum_{n=1}^{N}\beta_{n,i}),i=1,2,...,L$$ (formula 25)

Make $E_{l(i)}$ be the synthetic results of the evidence previous, obviously when i = 1, it satisfies formula26 and 27:

$$m_{n,l(1)}=m_{n,1},n=1,2,...,n$$ (formula26)

$$m_{H,I(1)}=m_{h,1}$$ (formula27)

When I = 2,3,,,, L, the adjustment factor $K_{l(i)}$ is defined as follows:

$$K_{l(i)}=\left[1-\sum_{t=1}^{N}\sum_{j=1_{j\neq t}}^{N}m_{t,l(i-1)}\times m_{j,i}\right]^{-1}$$ (formula28)

The comprehensive weighted confidence parameters and incompleteness parameters of the evidence previous can be obtained by calculation in the following formula:

$$m_{n,I(i)} = K_{I(i)}\left\lfloor m_{n,I(i-1)}m_{n,i} + m_{H,I(i-1)}m_{n,i} + m_{I(i-1)}m_{H,i}\right\rfloor, n = 1,...,N \quad \text{(formula 29)}$$

$$\tilde{m}_{H,I(i)} = K_{I(i)}\left\lfloor \tilde{m}_{H,I(i-1)}\tilde{m}_{H,i} + \overline{m}_{H,I(i-1)}\tilde{m}_{H,i} + \tilde{m}_{H,I(i-1)}\overline{m}_{H,I}\right\rfloor \quad \text{(formula 30)}$$

$$\overline{m}_{H,I(i)} = K_{I(i)}\overline{m}_{H,I(i-1)}\overline{m}_{H,i} \quad \text{(formula 31)}$$

According to make i=2，3，，，L, combining formula 26 to 27, we can obtain L comprehensive evidence weighted confidence parameters $m_{n,I(L)}$ and the corresponding incompleteness parameters.

Finally, the L evidence for each evaluation grade comprehensive confidence level for:

$$\beta_n = \frac{m_{n,I(L)}}{1-\overline{m}_{H,I(L)}}$$

$$n = 1,2,...,N \quad \text{(formula 32)}$$

Integrated language incompleteness confidence level could be calculated through the formula:

$$\beta_H = \frac{\tilde{m}_{H,I(L)}}{1-m_{H,I(L)}} \quad \text{(formula 33)}$$

Obviously, when the each index evaluation results are completed, under the conditions of formula 25 $\sum_{n=1}^{N}\beta_{n,i} = 1$, $\tilde{m}_{H,i} = 0$ the incompleteness parameters are caused by the data missing. It means that the comprehensive evaluation incompleteness confidence level β_H is also 0 in formula 33. Evaluation results will not appear the incompleteness condition; On the contrary, the third larger represents the higher evaluation results incompleteness, and the uncertainty of data missing is greater.

3.3.4 The calculation method of the utility value

When we need to compare the results of more than one case in many groups, the different distribution of confidence level of the evaluation grade always can't directly reflect the superiority of the evaluation results under different situations(Yang, 2001, p31). This chapter introduces calculation methods of utility values to transform the distribution of confidence level into single comprehensive utility value to achieve the purpose of comparing different cases.

Make u (H_n) be utility value of evaluate grade Hn and $u(H_{n+1})>u(H_n)$. H_{n+1} evaluation grade is more ideal than H_n, and the n we can calculate through the formula:

$$u(Hn)=\frac{n-1}{N-1},n=1,2,...N,N\geq 2$$ (formula 34)

N is the number of target evaluation grade, and N should be greater or equal to 2.

On the basis of getting each evaluation grade utility value, the comprehensive utility value of evaluation results u(E) can be calculated as the following methods :

1) When the data of evidence E is integrity, that is $\beta_H=0$:

$$u(E)=\sum_{n=1}^{N}\beta_n u(H_n)$$ (formula 35)

2) When evidence is incomplete, that is $\beta_H>0$, $[\beta_n,(\beta_n+\beta_H)]$, we can get the u_{min}(E) AND U_{max}(E) to make sure:

$$u_{min}(E)=\sum_{n=2}^{N}\beta_n u(H_n)+(\beta_1+\beta_H)u(H_1)$$ (formula 35)

$$u_{max}(E)=\sum_{n=1}^{N-1}\beta_n u(H_n)+(\beta_N+\beta_H)u(H_N)$$ (formula 36)

$$u_{mean}(E)=\frac{u_{min}(E)+u_{max}(E)}{2}$$ (formula 37)

3.4 The study on the cases of navigation safety in Yangtze river during dry season

This section will use the methods of fuzzy evidential reasoning to analyze the cases of navigation safety on the upper , middle and lower reaches of Yangtze river in dry season according to the hierarchical model of multiple index. We use the utility value calculation method to make a sequence of navigable risk in dry season. Integrating each expert's opinions, this section adopts the methods in the chapter 2, and gives the same weight coefficients for each expert.

3.4.1 the classification of evaluation index

We divide each level index in the model into qualitative evaluation ranks in table 25 , based on the consideration of expert's surveys opinions and each evaluation grade standardization.

Table 25 - grading of qualitative evaluation index

Top class	Names	Order of evaluation				
Evaluation objective	Navigational safety in dry season	Very poor	Poor	Average	Good	Very good
The first index	Human factors	Very poor	Poor	Average	Good	Very good
	Ship factors	Very poor	Poor	Average	Good	Very good
	Environment factors	Very poor	Poor	Average	Good	Very good
	Management factors	Very poor	Poor	Average	Good	Very good
The second index	Eligibility of sailor	Least Eligible	Slightly Eligible	Moderately Eligible	Fairly Eligible	Very Eligible
	Age	Least Experienced	Slightly Experienced	Moderately Experienced	Fairly Experienced	very Experienced

	Follow laws and rules	Very poor	Poor	Average	Good	Very good
	Seaworthiness	Very poor Seaworthiness	Poor Seaworthiness	Average Seaworthiness	Good Seaworthiness	Very good Seaworthiness
	Vessel age	Very aged	Moderately aged	Average aged	Slightly aged	Least aged
	tonnage	Very large	large	Average	Small	Very small
	Natural Environment	Very poor	Poor	Average	Good	Very good
	Navigational environment	Very poor	Poor	Average	Good	Very good
	Management of MSA	Very poor	Poor	Average	Good	Very good
	Shipping company management	Very poor	Poor	Average	Good	Very good
The third index	Visibility	Very poor	Poor	Average	Good	Very good
	Wind	Very poor	Poor	Average	Good	Very good
	Current	Very poor	Poor	Average	Good	Very good
	Dimension of waterway	Very poor	Poor	Average	Good	Very good
	Volume of vessel traffic	Huge	Large	Moderately	Little	Very little
	Navigational aids	Least complete	Slightly complete	Moderately complete	Fairly complete	Very complete

Source: compiled by author, 2014

Due to the part of evaluation index adopting continuous quantitative data, it is necessary to use the formula 15 to determine quantitative standard of each evaluation grade of these indicators to carry out discrete process.

3.4.1.1 Quantitative standard of complying with laws and regulations

This study reflects the conditions of the crew complying with the laws and regulations with the data of the crew's illegal points. According to collected the data of the crew's illegal points deducted in each district of Yangtze River Maritime Administration from November 2011 to march 2013, we obtain that the crew's illegal points deducted are the most up to 1331, the least 67 in dry season during 11-13 in each residency.

In the formula15 ,we calculated quantification standard of each qualitative evaluation to get the results is shown in table 26.

Table 26 - the quantitative evaluation standard of compliance laws and rules

Assessment Level	Very poor	Poor	Average	Good	Very good
Deduction total	1331	1015	699	383	67

Source: compiled by author, 2014

3.4.1.2 Quantitative standard of navigation scale

This study reflected the different regional navigation scale conditions using minimum navigable water depth of each channel, and collected data of the Yangtze river main channel actual maintenance water depth during the time from November 2011 to march 2013. the min value is 2.7m, and the max is 10.5m. The quantization standard calculated from the formula15 is shown in the table 27.

Table 27 - the quantitative evaluation standard of dimension of waterway

Assessment Level	Very poor	Poor	Average	Good	Very good
Minimum depth	2.6	4.55	6.7	8.65	12

Source: compiled by author, 2014

3.4.1.3 Quantitative standard of ship traffic volume

According to collect the average daily flow of Yangtze river each section during the time from November 2011 to march 2013, we obtained the largest daily flow 1660, the smallest 171. the calculation results are shown in formula 15.

Table 28 - quantitative evaluation standard of the ship traffic

Assessment Level	Huge	Large	Moderate	Little	Very little
Daily marine traffic current	1660	1267.5	903	539	170

Source: compiled by author, 2014

3.4.2The mapping rules of evaluation index

Combining with the opinions of the experts and MSA investigation, this study established corresponding mapping rules base for the evaluation between superiors and subordinates

3.4.2.1 The primary mapping index

The four levels in the evaluation model are 'the human factor', 'ships factor', 'environmental factors' and 'management factors'. These are mapped to the evaluation objectives "dry season Yangtze River navigation safety". Their mapping rules bases are shown in table 29.

Table 29 - the first index of mapping rule base

Navigation safety in dry season						
the first index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Human factors	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0

	Very good	0	0	0	0.2	0.8
Ship factors	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very good	0	0	0	0.5	0.5
Environment factors	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very good	0	0	0	0.5	0.5
Management factors	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very good	0	0	0	0.2	0.8

Source: compiled by author, 2014

3.4.2.2 The mapping of secondary index

Evaluation model consists of ten secondary index. Their corresponding the primary index mapping rules bases are shown as the table 30 to 33.

Table 30 - the secondary index of mapping rule base(1)

Human factors						
The second index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Seaman competency	Least eligible	1	0	0	0	0
	Slightly eligible	0	1	0	0	0
	Moderately eligible	0	0	1	0	0
	Fairly eligible	0	0	0	1	0
	Very eligible	0	0	0	0.5	0.5
Age	Least experienced	1	0	0	0	0
	Slightly experienced	0	1	0	0	0
	Moderately experienced	0	0	1	0	0
	Fairly experienced	0	0	0	1	0
	Very experienced	0	0	0	0.5	0.5
Follow laws and rules	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0

	Good	0	0	0	1	0
	Very good	0	0	0	0.2	0.8

Source: compiled by author, 2014

Table 31- the secondary index of mapping rule base(2)

Ship factors						
The second index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Seaworthiness	Very poor seaworthiness	1	0	0	0	0
	Poor seaworthiness	0	1	0	0	0
	Average seaworthiness	0	0	1	0	0
	Good seaworthiness	0	0	0	1	0
	Very Good seaworthiness	0	0	0	0.5	0.5
Age	Very old	1	0	0	0	0
	Moderately old	0	1	0	0	0
	Averagely old	0	0	1	0	0
	Slightly old	0	0	0	1	0
	Least old	0	0	0	0.5	0.5
Tonnage	Very large	1	0	0	0	0
	large	0	1	0	0	0
	Average	0	0	1	0	0
	small	0	0	0	1	0
	Very small	0	0	0	0.5	0.5

Source: compiled by author, 2014

Table 32 - the secondary index of mapping rule base(3)

Environment factors						
The second index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Natural Environment	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.5	0.5
Navigational	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0

environment	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.2	0.8

Source: compiled by author, 2014

Table 33- the secondary index of mapping rule base(4)

Management factors						
the second index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Management of MSA	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.2	0.8
Management of shipping company	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.2	0.8

Source: compiled by author, 2014

3.4.2.3 The three-level indicators mapping

Evaluation model consists of 6 three-level indicators. They are mapped to the secondary indicators of “natural environment” and “navigation environment”. the mapping rules bases are shown in table 34 and 35.

Table 34 - the three-level index of mapping rule base(1)

Natural environment						
The third index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Wind	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.5	0.5
Current	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0

	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.5	0.5
Visibility	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.5	0.5

Source: compiled by author, 2014

Table 35 - the three-level index of mapping rule base(2)

Navigational environment						
the third index	Order of evaluation	Very poor	Poor	Average	Good	Very good
Volume of vessel traffic	Huge	1	0	0	0	0
	Large	0	1	0	0	0
	Moderate	0	0	1	0	0
	Little	0	0	0	1	0
	Very little	0	0	0	0.5	0.5
Dimension of waterway	Very poor	1	0	0	0	0
	Poor	0	1	0	0	0
	Average	0	0	1	0	0
	Good	0	0	0	1	0
	Very Good	0	0	0	0.2	0.8
Navigational aids	Least complete	1	0	0	0	0
	Slightly complete	0	1	0	0	0
	Moderately complete	0	0	1	0	0
	Fairly complete	0	0	0	1	0
	Very complete	0	0	0	0.5	0.5

Source: compiled by author, 2014

3.4.3 The evaluation analysis based on evidential reasoning

This section selected 3 districts from the upper ,middle and lower in Yangtze River Maritime Administration(the upper CJMSAA, middle CJMSAB and lower CJMSAC) to analyze the Yangtze River navigation safety case. We get the safety navigation evaluation results in each district using evidential reasoning method , according to the qualitative or quantitative evaluation of each index. This study used the IDS software to achieve the process of evidence reasoning calculus. The relative weight of evaluation index at all levels are from the related research results of chapter 2.

3.4.3.1 The selection of evaluation index

We can gradually achieve the target of evaluation from bottom to top based on multi-index evaluation model, evidential reasoning and the methods of superiors and subordinates index mapping. This study selected 12 evaluation index in the hierarchical model of the Yangtze river safety evaluation in the dry season and divided the m into the common and diversity index, which is shown in table 36.

Table 36 - the table of evaluation index

Index code	Index name	Weight	Index classes	Resource
C_1	Seaman competency	0.161	Common index	Expert judgment
C_2	Age	0.065	Common index	Expert judgment
C_3	Compliance with laws and rules	0.207	diversity index	quantitative data
C_4	seaworthiness	0.084	Common index	Expert judgment
C_5	vessel age	0.061	Common index	Expert judgment
C_6	tonnage	0.060	diversity index	Expert judgment
C_7	Natural environment	0.074	Common index	Expert judgment
C_8	Volume of marine traffic	0.014	diversity index	quantitative data
C_9	Dimension of waterway	0.106	diversity index	quantitative data
C_{10}	Navigational aids	0.044	diversity index	Expert judgment
C_{11}	Management of MSA	0.059	diversity index	quantitative data
C_{12}	Management	0.065	Common index	Expert

	of shipping company			judgment

Source: compiled by author, 2014

Among them, the common index is only for this case study. Experts believe that the evaluation results has no obvious differences in the upper, middle and lower reaches on the evaluation index. The index is not applied for other case study in other circumstances.

Additionally, the reason why we did not select this three evaluation of ‘wind’, ‘flow’, and ‘visibility’, because they can be seen as a common index for this case study, selecting the superior index ‘natural environment’ to replace the process that can be simplified. The weight coefficient of each index is taken from the results of the study in chapter 2 table 15. The weight of the natural environment is the sum of weight coefficient of 3 evaluation index as wind, flow and visibility .

3.4.3.2 The collection of evaluation index data

(1) Common index

We classified the qualitative grade of each index according to table 25, and evaluated the general status of Yangtze river in dry season for 6 common index by referring to the methods of experts investigation. the results are shown in table 37 as common index evaluation results.

Table 37 - common index evaluation results

Index code	evaluation results
C1	Moderately eligible 1.0
C2	Moderately experienced 1.0
C4	Average seaworthiness 1.0
C5	Averagely aged 1.0
C7	Average 1.0
C12	Poor 0.2, Average 0.8

Source: compiled by author, 2014

(2) The diversity index

The study collected the data of 6 diversity index. the C3, C8, C9 were collected from the relevant data of this dry season from 9 to 10 : the C3 data is the sum of the crew's illegal deduction during the period in the relevant Maritime Administration management district (unit: minutes). CS data is the average daily ships shiptime (unit: shiptime). The C9 data is the minimum value of actual maintenance water depth in the jurisdiction channel(unit: m) . Qualitative evaluation results of Cl are collected from "the analysis report of security situation and rescue work in2009" of the Yangtze river Maritime Administration. C6 and C10 adopts the experts judgment data. the results are shown in table 38

.

Table 38 - the evaluation results of diversity index

Index code	CJMSA A	CJMSA B	CJMSA C
C_3	285	437	323
C_6	Average 0.5 small 0.5	Average 1.0	Large 0.5 Average 0.5
C_8	195	217	1030
C_9	4.5	2.9	7.5
C_{10}	Moderately complete 0.2	Moderately complete 0.5	Fairly complete 0.7
	Fairly complete 0.8	Fairly complete 0.5	Very complete 0.3
C_{11}	Average 1.0	Poor 0.5 average 0.5	Average 1.0

Source: compiled by author, 2014

3.4.3.3 The conversion of quantitative data

We conversed the quantitative data of the index C3,C8 and C9 into qualitative evaluation using the formula 11 to 15, to facilitate the next step of evidence reasoning established quantitative standard in 3.4.1. The calculated results are shown as follows :

Table 39 - The conversion results of quantitative data

Index code	CJMSA A	CJMSA B	CJMSA C
C_3	Good 0.67 very good 0.33	Average 0.16 Good 0.84	Good 0.81 Very good 0.19
C_8	Little 0.06	Little 0.13	Large 0.31

	Very little 0.94	Very little 0.87	Moderate 0.69
C_9	Very poor 0.08 Poor 0.92	Very poor 0.79 Poor 0.21	Average 0.54 Good 0.46

Source: compiled by author, 2014

3.4.3.4 The evaluation results based on evidence reasoning

According to evidence reasoning to calculate the above each index data , weight coefficient and mapping relationship by IDS software, we obtained Yangtze River navigation safety evaluation results in dry season in the 3 Maritime Administration management district that the upper ,middle and lower of the Yangtze River (figure 4-2 to 4-4)(Zhang, 2011):

CJMSA A=（0.96% very poor, 11.78% poor, 59.45% average, 22.93% good, 4.88% very good）

CJMSA B=(9.18% very poor, 4.95% poor, 56.27% average, 19.49% good, 0.11% very good)

CJMSA C=(0.00% very poor, 2.38% poor, 61.91% average, 33.01% good, 2.70% very good)

3.4.4 Risk sequence based on comprehensive utility value

The evaluation results obtained from evidence reasoning are confidence distribution based on target evaluation grade. Thus, we can’t directly reflect the navigation safety in dry season of each Maritime Administration management districts. In order to further make sequence of navigation safety level of the upper, middle and lower of Yangtze river, this section will apply the methods of calculating the utility value introduced in the 3.3.4 to compare the navigation safety status in dry season in each Maritime Administration management district .

3.4.4.1 The utility value calculation of each level

There are 5 evaluation grades in the target that the section studied “Yangtze river navigation safety in dry season”. We can get the utility value of the evaluation grades according to formula 34. Results are shown in table 40:

Table 40 - the utility value of evaluation target all levels

order of evaluation (Hn)	Very poor	Poor	Moderate	Good	Very good
utility value $u(H_n)$	0	0.25	0.5	0.75	1

Source: compiled by author, 2014

3.4.4.2 The calculation of comprehensive utility value

There is no existing incomplete condition in the data of this case . Therefore, we can use the formula 35 to calculate the comprehensive utility value in Maritime Administration management districts.

$u(A)=0.0096\times0+0.1178\times0.25+0.5945\times0.5+0.2293\times0.75+0.0488\times1=0.5475$

$u(B)=0.0918\times0+0.0495\times0.25+0.6627\times0.5+0.1949\times0.75+0.0011\times1=0.4910$

$u(C)=0\times0+0.0238\times0.25+0.6191\times0.5+0.3301\times0.75+0.0270\times1=0.5900$

Table 41- the sequence of comprehensive utility value in each jurisdictions.

	Very poor	Poor	Moderate	Good	Very good	integrated available value	Order
CJMSA A	0.0096	0.1178	0.5945	0.2293	0.0488	0.5476	2
CJMSA B	0.0918	0.0495	0.6627	0.1949	0.0011	0.4910	3
CJMSA C	0	0.0238	0.6191	0.3301	0.0270	0.5900	1

Source: compiled by author, 2014

As shown in table 41, by calculating the three comprehensive utility value in the Maritime Administration management districts, we can see that the sequence of navigation safety in dry season C is superior to A, and A is superior to B. The results objectively coincide with the fact the ship navigation in the middle reaches of the Yangtze River is greatly influenced by the dry season, however, less in the lower reaches, which prove the fuzzy evidence reasoning methods and the scientific and rationality of hierarchical evaluation model.

3.4.5 discussion and validation

In order to further validate the rationality of the model and the reliability of fuzzy evidence reasoning method, in addition to the comprehensive utility value “Yangtze river Yangtze River navigation safety in dry season” in 3.4.4, this study applies the method to calculate index utility value in the Maritime Administration management districts based on the different level with the preceding methods. The results are shown in table 42.

Table 42 - the order of comprehensive utility value in each jurisdictions

	Human factors		Ship factors		Environment factors		Management factors	
	utility value	Order	utility value	Order	utility value	Order	utility value	Order
CJMSA A	0.6561	1	0.5241	1	0.3590	2	0.4807	2
CJMSA B	0.6010	3	0.5000	2	0.2361	3	0.4224	3
CJMSA C	0.6446	2	0.4759	3	0.5987	1	0.5880	1

Source: compiled by author, 2014

It can be seen that the sequence of utility values based on the first level in Maritime Administration jurisdictions is different from the “Yangtze River navigation safety in dry season “ the sequence of utility values, but the overall trend relatively coincided. In particular, the relatively good navigation safety situation of Maritime Administration C in the lower reaches of Yangtze river is ranked first and has great advantage in these two indicators of the environmental and management factors. Although another two index are ranked second and third , it’s differences are not obvious. On the contrary, the three first level index of the four are the last in the Maritime Administration B which navigation safety in dry season of in the middle of Yangtze river is more worried . Only one ranks second. The utility value results of first level index above verify the reliability and rationality of the research conclusion in 3.4.4. Therefore, we consider that the proposed hierarchical evaluation model, fuzzy evidential reasoning and the method of calculating the utility value are with good scientific rationality.

On the basis of hierarchical model evaluation method, in spite of its wide range of applications, what cannot be avoided is the limitation of extensive contacts between each index. Therefore, the next chapter will use the methods of Bayesian networks to model and study the Yangtze River navigation risk in dry season.

Chapter 4 The modeling research on the navigation risk based on the analysis of accident characteristics

The proposed research for navigation risk aims at Yangtze River navigation status in dry season based on the analysis of accident characteristics. On the basis of fully investigating the historical data of water traffic safety accidents, we study the Yangtze River navigation risk by modeling and combining with the correlation analysis and Bayesian network (BN) ,and use the established network model to analyze and evaluate the Yangtze River navigation factors.

4.1 The research background in this chapter

4.1.1 The definition of navigation

Channel navigation or congestion is generally accepted as the increasing traffic causes the traffic network cannot bear more in the transportation field. The contradiction between traffic demand and through capacity directly reflected that the vehicle speed reducing and the waiting time increasing (Roess, 2011). Due to inland water transport well known it’s large capacity, the scholars at home and broad generally considered that the navigation phenomenon occurs in the port or the dam waters frequently, which seldom occur in the inland water (Lowe, 2005).

Yangtze River as the “golden waterway “that our country rapidly develops is amazing transport volume. According to the data from “Yangtze River Shipping Development Report 2013” which was carried out by Yangtze River Waterway Administration, in 2013, only the trunk line of the Yangtze River completed cargo volume more than 2 billion ton, which ranked the first in the world ‘s inland river. However, the navigation events of the crowded waterway, ship overstock a harbor, a shallow waterway, etc., occurred from time to time in Yangtze River ,especially in dry season, which have a seriously impact on the sustainable development of China's shipping. We can consider that navigation risk in the Yangtze as a typical representative for navigation risks in dry season.

4.1.2 The causes of the blocking in Yangtze River waterway

What is different from too large traffic volume in the general sense is that the cause of subjective super draft etc., which causes the water traffic accidents such as ship grounding, collision, etc. These are particularly prominent, especially in the dry season. For the depth and width of part waterway in Yangtze River are subject to restrictions. Once the water traffic accidents occur, the waterway is likely to completely blocked; Grounding accidents even can block the channel and damage river bed, cause sediment accumulation and lead to channel disable even navigation suspend for long time at the same time(Wu & Cao, 2010, p15).

Based on the data from “Danger report and query system” of Maritime Administration, Ministry of Transport in January 1, 2011 - March 31, 2013, during this period, there are 55 navigation events occurring in Yangtze river in each Maritime Administration management district. All these were caused by water traffic accidents. Running aground are 42 cases, accounting more than 76% of the total. At the same time , data also showed that the Yangtze River navigation events are featured by obvious time and space distribution characteristics. In the middle reaches of the Yangtze River and the dry season, it becomes obvious. Distribution of 41 navigation events in terms of the type of accident, the scene and season are shown in figure 9.

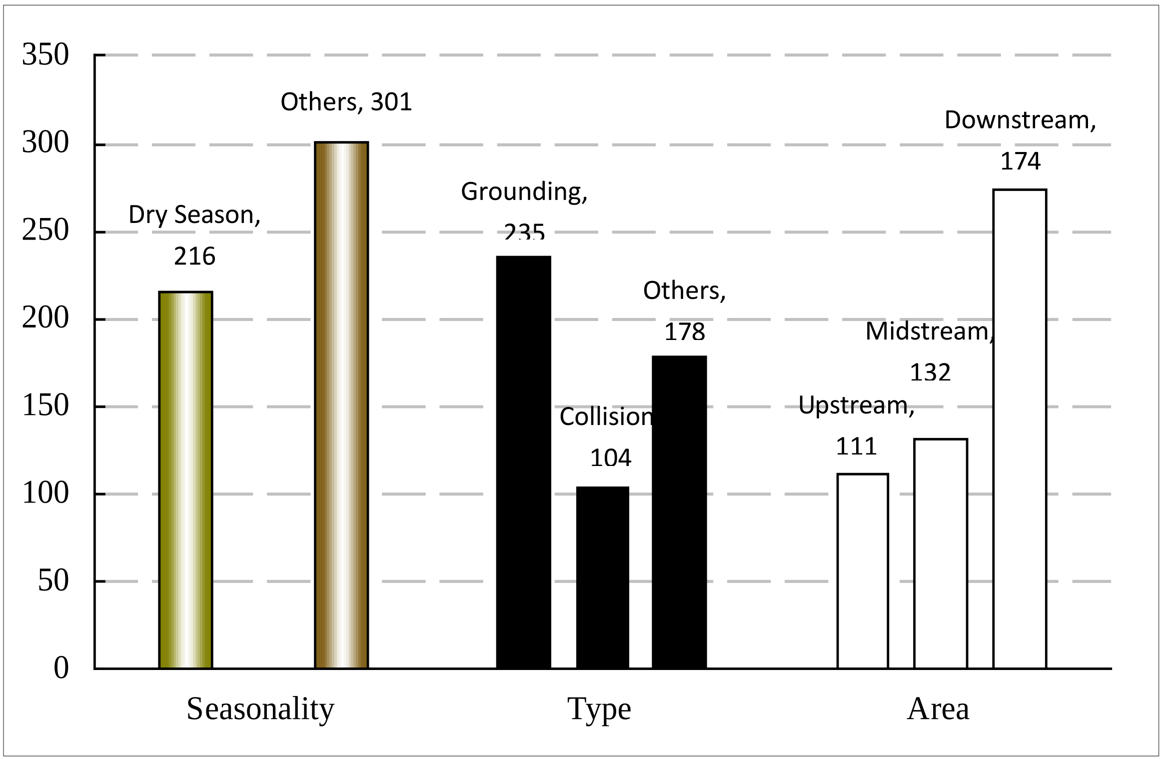

Figure 9 - the characteristics distribution of navigation events

Source: compiled by author, 2014

Therefore, we should start from the navigation events that can cause water traffic accidents to solve Yangtze river marine traffic problem, and put forward the methods to reduce the navigation risk on the basis of analyzing their characteristics.

4.1.3 The selection of research method

Water traffic safety accidents are often the outcomes of combined action of multiple factors, which are of a high uncertainty. If we adopt the hierarchical model to evaluate, we can't obtain the interaction of each influence in the specific issue of navigation, we are likely to put forward higher requirements for collecting the data in the evaluation and analysis process, and cause the difficulty for modeling at the same time .

In order to analyze the characteristics of navigation events from limited data, on the basis of studying the existing historical water traffic safety accident data ,we took the correlation analysis to filtrate each influence factor ,and established the network evaluation model of navigation risk through the Bayesian network. We copied with the ability of uncertainty problem on the condition of making full use of the limited data , so as to achieve the target of the assessment, and to predict Yangtze River navigation risk. As 3.2.4.3 described, the outstanding learning ability of Bayesian network can ensure the model are continuously optimized and improved with the new data obtained.

4.1.4 The data sources

4.1.4.1 Objective data

The study of this chapter is based on the related data of Maritime Administration Ministry of Transport danger reporting system in January 2011 -March 2013. The data on accident danger of general level above that we collected from the Yangtze River trunk lines Maritime Administration jurisdiction were 470, where 41 cases caused the navigation congestion. When an accident hazard involves two or two more ships (such as collision), the research calculated the number of the data according to the number of the offending ship.

Accident hazard data contains the data of the ship in distress, the gross tonnage etc., 11 accident risk characteristics, which are shown in the table 43. The Yangtze River trunk lines accident hazard sample data table.

Table 43 - Sample Table for Data of Accidents in Yangtze River

No.	Ship Type	Gross Tonnage	Ship owner	Time	Area	Accident Severity	Type	Wind Level	Current	Visibility	Congestion Likelihood

1	Bulk-cargo Ship	1456	State-owned	20110316	Downstream	Major	Grounding	3	Minor	Below 2km	Congestion
2	Dry-cargo Ship	554	State-owned	20121212	Upstream	Minor	Collision	3	Minor	4km	No Congestion
3	Bulk-cargo Ship	134	Private	20130408	Midstream	Critical	Fire	4	Minor	3km	Congestion
4	Bulk-cargo Ship	2800	State-owned	20130416	Downstream	Minor	Collision	1	Calm	0.05km	No Congestion

Source: compiled by author, 2014

4.1.4.2 subjective data

The selection of some parameters and adjustments in the process of navigation risk modeling are determined by the experts' opinions.

4.2 The research methods based on the analysis of accident characteristics

4.2.1 Research procedures

The study of this chapter will start from the collection of historical accident data, identify key factor of navigation through correlation analysis , and then establish the network model of navigation risk assessment by using the method of Bayesian network. The research process includes the following 5 steps (shown in figure 11):

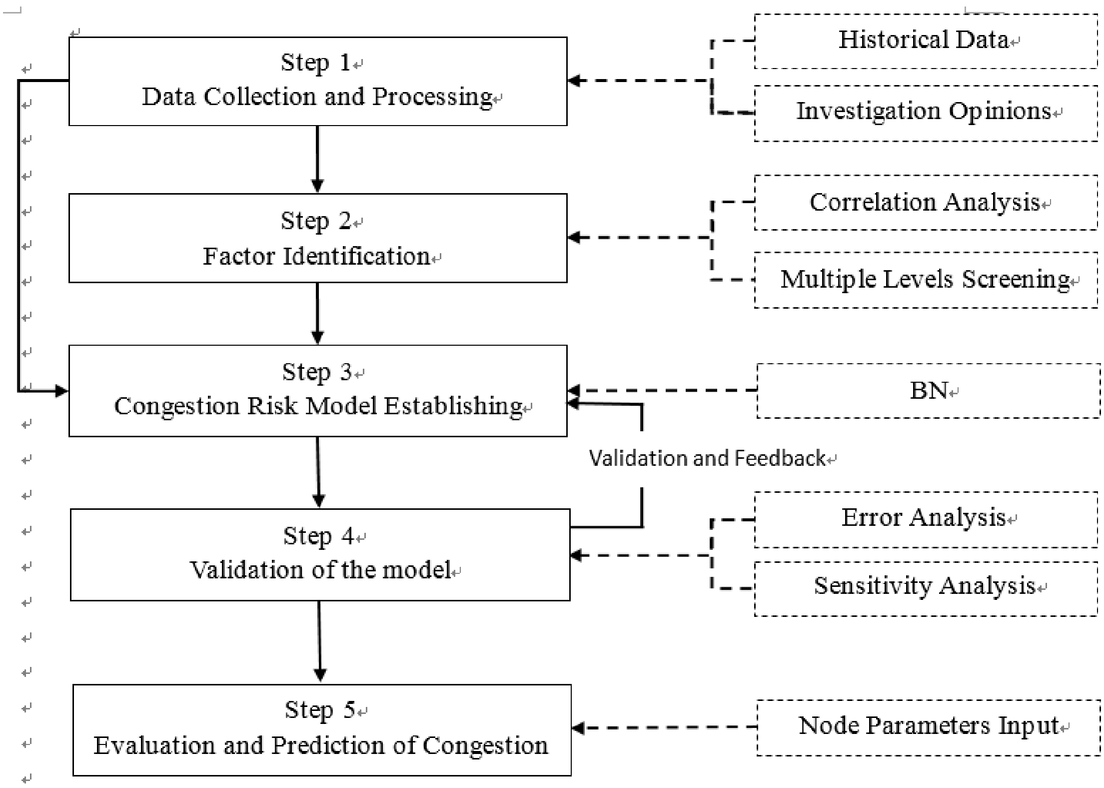

Figure 10 - the procedures of navigation risk modeling

Source: compiled by author, 2014

1) Data collection and processing

Extract navigation factors for sample data and divide discrete levels of each impact factor according to experts investigation opinions , in order to facilitate the establishment of correlation analysis and Bayesian network model.

2) Identification of key factors influencing navigation

Based on two-two result of correlation analysis of each navigation factors, we determined the level of navigation factors according to the multi-level filtrating methods ,and put this as the basis of navigational risk modeling.

3) Congestion Risk Model Establishing

Integrate historical accident data, experts investigation opinions, as well as the results of correlation analysis to determine the parameters in the Bayesian network model.

4) Validation of the model

Investigate the imitative effects of model by comparing the model output with the error of the sample data to get network evaluation model of navigation risk.

5) the evaluation and prediction of navigation risk

Get the evaluation and prediction of navigation risk in different situation by each node the import of different parameters in the Bayesian network model .

4.2.2 Correlation analysis

Common bivariate correlation analysis methods are Pearson correlation coefficient, Spearman's rho, and Kendall's tau-b. This research adopts Pearson's product moment correlation coefficient (PMCC) to determine the significance level of each variable correlation.

4.2.2.1 Pearson's product moment correlation coefficient

In statistics, Pearson's product moment correlation coefficient was developed on the basis of Galton's research in the 1880 s. For many years in academic study it is widely applied to measure the strong and weak of the two variables linear correlation , which is often called "Pearson's r " (Rodgers, 1988, p59) (Stigler, 1989, p73).

If there are N groups of sample data of two variables X and Y , we express as:

$$\{(X_i, Y_i), i = 1,2,...,n)$$

The sample data : can be calculated by the following formula:

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}} \qquad \text{(formula 38)}$$

Among the m $\bar{x}$ and $\overline{Y}$ represent the average of two variable sample data.

The value range of correlation coefficient r is [-1,1]. When r is plus or minus 1, it represents there is fully the linear relationship between the variable X and Y. And Y increases with X increasing (r=1) or decreasing (r=-1); When the correlation coefficient was 0, it represents no linear correlation between two variables.

4.2.2.2 the significance level of the t test

By setting the significance level a, we can judge two variables X and Y whether has significant linear correlation on the transverse based on n groups of sample data(Kendall M, 1973).

$$t^{*} = r\sqrt{\frac{n-2}{1-r^{2}}} \qquad \text{(formula 39)}$$

If $|t^{*}| > t_{\alpha/2}$: Expressing the two variables X and Y in a level has significant linear correlation. Among the m, the test index $t_{\alpha/2}$ can be checked by the t value table. In practice, generally a is set to 0.01 or 0.01, representing the confidence level as 99% and 99% respectively.

4.2.3 A multi-level filtering method based on correlation analysis

On the basis of correlation analysis, this study adopts the method of multi-level filtering to determine key factors of the risk of navigation(Congestion Critieal Factors, CCFs), as shown in Figure 12.

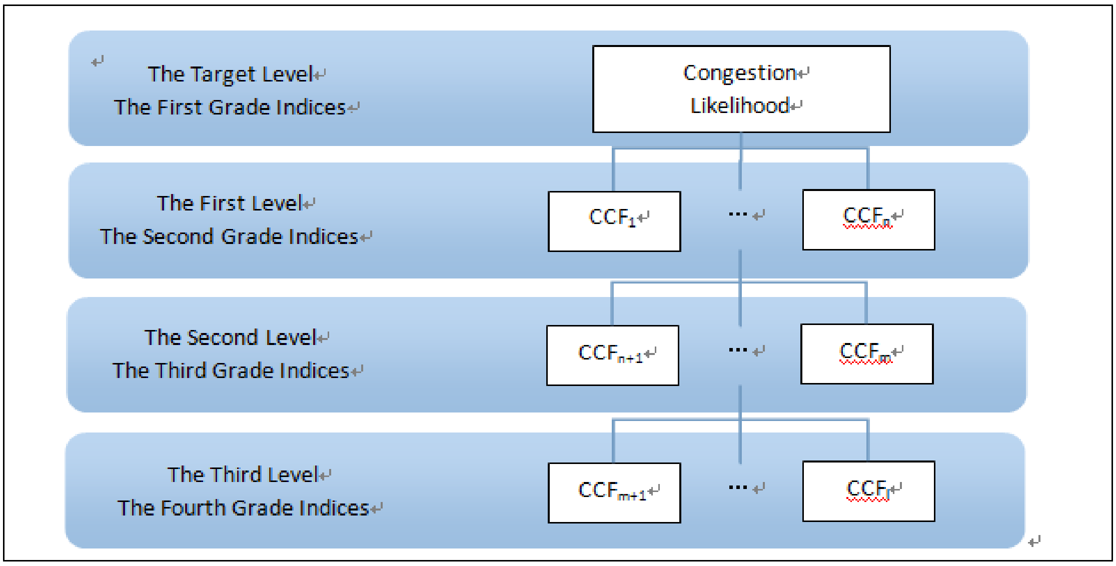

Figure 11 - multi-level filtering of navigation-factor

Source: compiled by author, 2014

1) Put this variable "whether the navigation" as primary goal in the target layer, and at the same time put the two-two correlation between it and other variables as

filtering standard of first navigation factor.

2) Filter the variable that has significant correlation with target layer variable (whether navigation) as the first level of navigation factors.

3) The rest may be deduced by analogy, filtering process of navigation factors is until the remaining variables longer satisfied the current standard of filtering or all of the variables are filtered completely.

Obviously, the level of navigation factors is lower. It shows that the effect on the primary goal of navigation is obscure.

4.2.4 Bayesian network

4.2.4.1 Bayes' theorem

Bayes' theorem, also known as Bayesian theorem, is the formula for calculating the conditional probability proposed by British scholar Bayes in the 18th century. Other scholars conducted a series of future studies on the basis of his study. Especially Bayesian networks developing later have been widely used in areas such as, uncertainty analysis, risk assessment and decision-making., etc. (Eunchang, 2009, p5880) (Uusitalo, 2009, p312).

If there are variables e and observational data x, Bayes' theorem can be expressed in the following formula:

$$p(\theta|x) = \frac{p(x|\theta) \times p(\theta)}{p(x)} \qquad \text{(formula 40)}$$

Among the m, under the condition of x ,p (θ | x) was posteriori probability of variable θ . P (x) is the prior distribution of variable θ and p (x) is the probability of x. When the variable e occurs, p (x | θ) is a conditional probability.

When the x is a set of observations data. That is x=(x_1, ..., x_n). Posteriori probability of variable e can be expressed as:

$$p(\theta|x_1,...x_n) = \frac{p(x_1,...x_n|\theta) \times p(\theta)}{p(x_1,...x_n)} \quad \text{(formula 41)}$$

Therefore, Bayes' theorem allows a posteriori probability which can be constantly updated with new observation data joining. Similar to formula 40, if considering two independent events A and B, the probability of event A on the condition of event B occurring P (A | B) could be calculated through the following formula:

$$P(A|B) = \frac{P(B|A) \times P(A)}{P(B)} \quad \text{(formula 42)}$$

Among the m, P (A) and P (B) are respectively the probability on the condition that event A happens . P (B | A) is the probability of on the condition that event B occurs. When B is a set of events ,it's similar to the same formula 41.

4.2.4.2 the composition of Bayesian networks

Bayesian network is a directed acyclic graph that contains nodes. Correlation and the probability distribute in the three parts.

1) Node

   Nodes in Bayesian network stand for each variable. Each node defines the corresponding states level .

2) Correlation

   The correlation is expressed as each node's direction in Bayesian networks. Primary node pointing subnode represents the influence of primary node influencing to subnode. Each node in the network can be used as other multiple nodes of primary or subordinate nodes, but cannot exist circular pointing. That is the condition of A to B, B to C, C to A .

3) Probability distribution

   In a Bayesian network each subordinate node is endowed with a conditional probability table based on its primary node. No primary node is endowed with the corresponding prior probability distribution. Finally , we calculated posterior probability distribution for each node under different conditions through the Bayesian formula.

4.3 The research on modeling case of navigation risk

4.3.1 Data collection and collation

The research on navigation modeling in this chapter is mainly based on the 470 historical water traffic safety accident data. Combining the experts' opinions, this study extracted 12 variables from the original data (table 43), and the n defined their corresponding discrete state grade (Such as table 44).

The date and time of the accident in the raw data is converted to the two variables of 'whether the dry season', and 'distribution of day and night'. Due to the original data of gross tonnage for ships, visibility, wind, whether the dry season and distribution of day and night are continuous distribution. After referencing the experts , we divide their discrete state grade based on the standards in table 44. The gross tonnage and the visibility shall not include the upper limit. Whether the dry season based on the defined standard in 1.1.2. The dry season is from November to march next year. The days in distribution of day and night is from 0700 to 1900.

Table 44 - variable selection and the division of discrete grade

Variables	**State Level**			
Congestion Likelihood(CL)	Congestion	No Congestion		
Ship Type(ST)	General Cargo Ships	Container Ships	Tankers	Passenger Ships
	Barges&tugs	Others		
Gross Tonnage(GT)	Below 300GT	300~1000GT	1000~2000GT	2000~5000GT
	Above 5000GT			
Shipowner(SO)	State-owned	Private		
Visibility(V)	Below 200m	200~1000m	1000~4000m	Above 4000m
Current(C)	Calm	Minor	Moderate	Heavy
Wind Level(W)	0~3	4~6	Above 6	

Accident Severity (AS)	Minor	Major	Critical	Catastrophic
Seasonality(S)	Dry Season	Non-dry Season		
Time of Day(ToD)	Day	Night		
Area(A)	Upstream	Midstream	Downstream	
Accident Type(AT)	Collision	Contact	Grounding	Fire
	Others			

Source: compiled by author, 2014

4.3.2 The identification of dangerous navigation factors

4.3.2.1The calculation results of PMCC

We calculate the 470 groups of sample data that is discretely processed with formula 38 and 39, and then get two correlation significant levels of evaluation results between each variable. This study realized calculation of PMCC and t test using the software SPSS17.0 to get the two correlation analysis results of 12 variables, as shown in table 44 and 45 Concluding the significant influence factors associated with each variable, according to the results from table 44, correlation analysis results are shown in table 45.

Table 45 - Calculation Results by PMCC

	ST	GT	SO	S	ToD	AT	V	CL	AS	A	W	C
ST	1	0.071	0.057	0.069	-0.015	0.062	.126**	0.025	-0.03	0.018	-0.051	0.01
GT	0.071	1	-.100*	.097*	0.033	-0.053	-0.027	.176**	-.173**	0.063	0.064	0.031
SO	0.057	-.100*	1	-0.002	-0.014	-0.005	0.057	.125**	.186**	-.157**	-0.044	-0.018
S	0.069	.097*	-0.002	1	-0.051	0.04	0.047	.109**	-.136**	-0.014	-0.043	0.018
ToD	-0.015	0.033	-0.014	-0.051	1	-.238**	0.025	-0.04	.116**	0.161	0.061	0.072
AT	0.062	-0.053	-0.005	0.04	-.238**	1	-0.029	-.203**	-.261**	-0.248	.126**	0.057
V	.126**	-0.027	0.057	0.047	0.025	-0.029	1	0.029	-0.027	.082*	-.140**	.112**
CL	0.025	.176**	.125**	.109**	-0.04	-.203**	0.029	1	0.031	-0.054	0.009	0
AS	-0.03	-.173**	.186**	-.136**	.116**	-.261**	-0.027	0.031	1	-.144**	-.095*	-.087*
A	0.018	0.063	-.157**	-0.014	0.161	-0.248	.082*	-0.054	-.144**	1	.098*	.124**
W	-0.051	0.064	-0.044	-0.043	0.061	.126**	-.140**	0.009	-.095*	.098*	1	.387**
C	0.01	0.031	-0.018	0.018	0.072	0.057	.112**	0	-.087*	.124**	.387**	1

Notes:**.Significant Correlation at 0.01 level.

*.Significant Correlation at 0.05 level.

Source: CCS'S calculation(for author doesn't have this soft, so worker who work at CCS calculate it).

From table 45, we can get the influence factors listed in table 46:

Table 46 - Correlation Analysis Results

Variables	**Significant Correlation at 0.01 level**	**Significant Correlation at 0.05 level**
Ship Type	Visibility	
Gross Tonnage	Congestion Likelihood, Accident Severity	Ship Owner, Seasonality
Ship Owner	Congestion Likelihood, Accident Severity, Area	Gross Tonnage
Seasonality	Congestion Likelihood, Accident Severity	Gross Tonnage
Time of Day	Accident Severity, Area, Accident Type	
Accident Type	Congestion Likelihood, Accident Severity, Area, Time of Day, Wind Level	
Visibility	Wind Level, Ship Type, Current	Area
Congestion Likelihood	Accident Type, Ship Owner, Gross Tonnage, Seasonality	
Accident Severity	Area, Accident Type, Time of Day, Gross Tonnage, Seasonality, Ship Owner,	Wind Level, Current
Area	Accident Severity, Ship Owner, Time of Day, Current, Accident Type	Wind Level
Wind Level	Visibility, Accident Type, Current	Accident Severity, Area
Current	Visibility, Area, Wind Level	Accident Severity

Source: compiled by author, 2014

4.3.2.2 the filtering of multilevel navigation factor

On the basis of the multilevel filtering methods of navigation factors in 4.2.3, the study will put "whether Impeding Navigation " as the goal layer, and filter the Impeding Navigation factors step by step by using the standard of the relation and significance level above 0.05, which contains the level above 0.01 and 0.05 significant correlation.

1) the first level of Impeding navigation factors

   Filtering the first level of Impeding navigation factors for "ships gross tonnage"" everyone nature"" whether the dry season" and"" accident types", according to the significant correlation of "whether Impeding navigation".

2) the second level of Impeding navigation factors

   Filtering the second level of Impeding navigation factors for" accidents grade" "the distress area" " distribution of day and night" and " wind" based on the significant correlation of the first level of Impeding navigation factors.

3) the third level of Impeding navigation factors

   Filtering the third level of Impeding navigation factors for" the ice condition" and "visibility" , based on the significant correlation of the second level of Impeding navigation factors.

If we further put correlation of "the ice condition" and "visibility" as the index to filter ,and then can get the "visibility" in the fourth level that is relative to "ship" type. In general sense , they don't have obvious correlation, and the influence of target layer for the fourth filtered factors is little. So after this study, the navigation risk modeling will discard the "ship" factor.

Thus, the study identifies 10 obstacle factors based on the filtering method of correlation analysis and multiple level . They are "gross tonnage", "everyone nature", "whether dry season", "accident types", "accident grade", "distress area", " distribution of day and night ", "wind", "water" and "visibility".

4.3.3 Bayesian network model of impeding navigation risk

4.3.3.1 Definition of nodes and state grade

Bayesian network model of navigation risk will select "whether navigation " and ten navigation factors as the nodes of network based on the results of identification of navigation factors. Their classification standard of each state grade are shown in table 43.

4.3.3.2 the determination of correlation between the nodes

The dependency relationships between different nodes can be obtained by the methods of historical data and expert investigation. This study will determine the relationship between nodes based on the results in table 45, and adjust the partial correlation combining with expert judgment opinion .

Comparing to the results in table 45, the study supplementarily amended the following correlation results to make the model more favorable and in accordance with the actual situation:

l) In view of the actual situation of the Yangtze River navigation, remove the correlation of “distress area” and “distribution of day and night”, “wind” and “visibility”;

2) Considering the differences of visibility of the day and night, increase the “distribution of day and night “to be “the primary node visibility”;

3) For stranding accidents and etc., often occur in dry season, increase the “whether dry season” to be “accident type” primary node.

The nodes correlation that expert opinion revised is shown in table 47:

Table 47 - Correlations of BN Nodes

Node	**Parent Node**			
Congestion Likelihood	Gross Tonnage	Ship Owner	Accident Type	Seasonality
Gross Tonnage	Seasonality	Ship Owner		
Ship Owner	Area			
Visibility	Area	Current	Time of Day	
Current	Area	Wind Level		
Wind Level	Area			
Accident Severity	Gross Tonnage	Ship Owner	Accident Type	Seasonality
Seasonality	Area	Wind Level	Current	Time of Day
Time of Day				
Area				
Accident Type	Area	Wind Level		Seasonality

Source: compiled by author, 2014

This study regards the Hugin Lite7.3 as Bayesian network modeling software platform. After defining the completing node and correlation, the network structure of navigation risk assessment model in the graphical user interface of Hugin software is shown in figure 13.

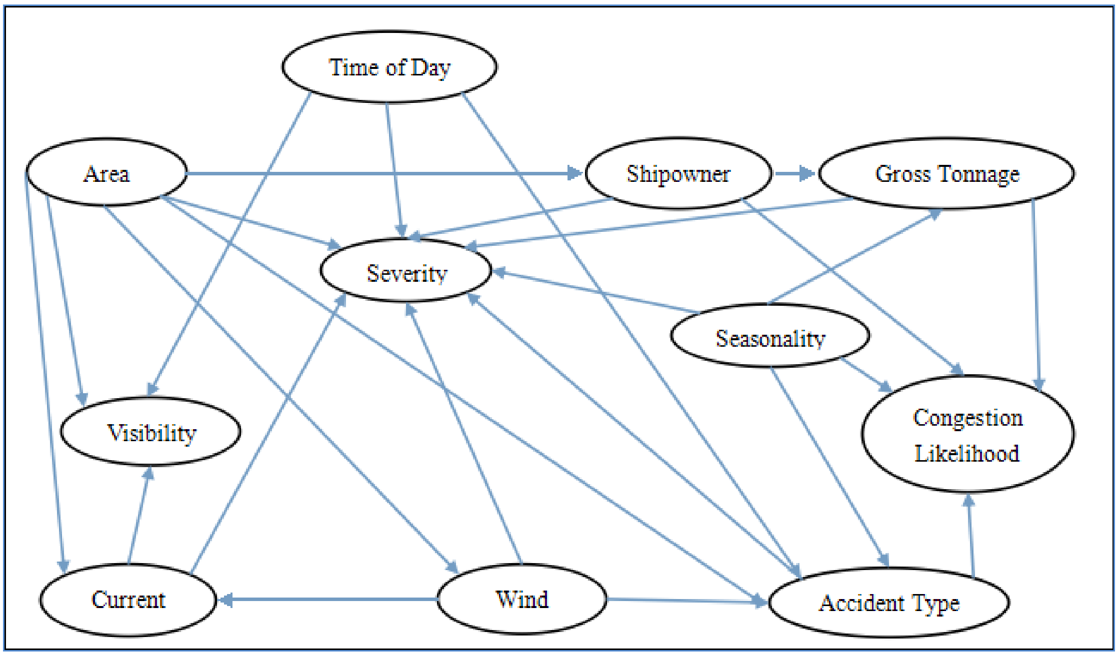

Figure 12 - Structure of navigation risk Bayesian network model

Source: Calculated by Hugin Lite.

4.3.4 Verification of the impeding navigation risk evaluation model

4.3.4.1 error analysis

In order to investigate the condition of the data fitting of the existing Bayesian network model, we conducted the error analysis for the sample probability and posterior probability distribution of the target node. The error analysis results of the target nodes "whether navigation "of navigation risk evaluation model are shown in table 48, the target node of error analysis.

Table 48 - the target node of error analysis

Congestion Likelihood	Congestion	No Congestion
Frequency of the Sample Data	45	472
Probability Distribution of Sample（%）	8.70	91.30
Posteriori Probability Distribution（%）	9.31	90.69
Error	0.061	-0.006

Source: compiled by author, 2014

It can be seen that the error of navigation model is smaller, which means the fitting condition of sample data is better. Based on the theory of bayes' theorem in 4.2.4 , with the increase of sample data and the improvement of conditional probability table in each subnodes, the precision of the model will be further improved.

4.4 The application research based on impeding navigation risk model

We can get a different state of probability of the Yangtze River navigation events, through the nodes parameter set in the Bayesian network model. This section takes the primary nodes of “whether navigation” as the example, studies the influence of each navigation factor for the navigation probability through the condition parameters set to get control of the key elements of navigation events.

4.4.1 The season influence on impeding navigation

In the model, the season is divided into “the dry season” and “non-drought period”. Which is based on the posterior probability of navigation of Bayesian network. Obviously, the navigation probability of dry season is significantly higher than that of non-drought period. This conclusion is consistent with the current situation of the Yangtze River navigation. therefore, ship officers need to be careful operating ship during this period to ensure enough under keel clearance. the relevant departments should also guarantee waterway maintenance scale at the same time to strengthen the supervision and administration of the Yangtze River navigation to avoid navigation incidents.

4.4.2 The influence of accident type on impeding navigation

Based on the existing Bayesian network model, the probability of different types of accidents causing impeding navigation are shown in table 49, the probability of different types of accidents impeding navigation.

Table 49 - the probability of different types of accidents impeding navigation.

Accident Type	Collision	Grounding	Contact
Congestion Probability(%)	2.84	17.47	2.71
Rank	2	1	3

Source: compiled by author, 2014

We can know that from the above table on impeding navigation the posterior probability, three kinds of typical water traffic safety accident shows obvious distribution characteristics. The probability of grounding accident causing the impeding navigation event is far greater than the collision and contact damage (reef) accidents. These coincide with the status of Yangtze River. Decreasing the grounding accidents is important for reducing critical impeding navigation risks.

4.4.3 The influence of ship's ownership on impeding navigation

Shipowner's character can reflect the level of safety management at a certain extent. This study will divide them into the "individual ship in operation" and "state or local enterprises in operation". their posterior probability of impeding navigation is shown in table 50, different impeding navigation probability shipowner nature .

Table 50 - different impeding navigation probability shipowner nature

Ship Owner	Private	State-owned
Congestion Probability(%)	11.25	6.61
Rank	1	2

Source: compiled by author, 2014

Impeding navigation model shows that the impeding navigation probability that caused by individual ship is close to the twice the state or local enterprises, to a certain extent which also reflects the shortcomings of individual ships in operation at the level of security awareness and management. As described previously, the ship's draft is the main reason that cause grounding accidents even the impeding navigation in Yangtze river during the dry season. However, the poor individual private ship crew's operation level , blind pursuit of interests, and safety awareness are the origin causing these problems.

4.4.4 The influence of ship tonnage on impeding navigation

Based on the actual situation of ships on the Yangtze river, the research divided the tonnages of the ships into the 5 discrete grades: "300GT below", "300 to 1000GT", "1000 to 2000GT", "2000 to 5000GT", and"5000GT". Their impeding navigation posterior probability is shown in figure 14.

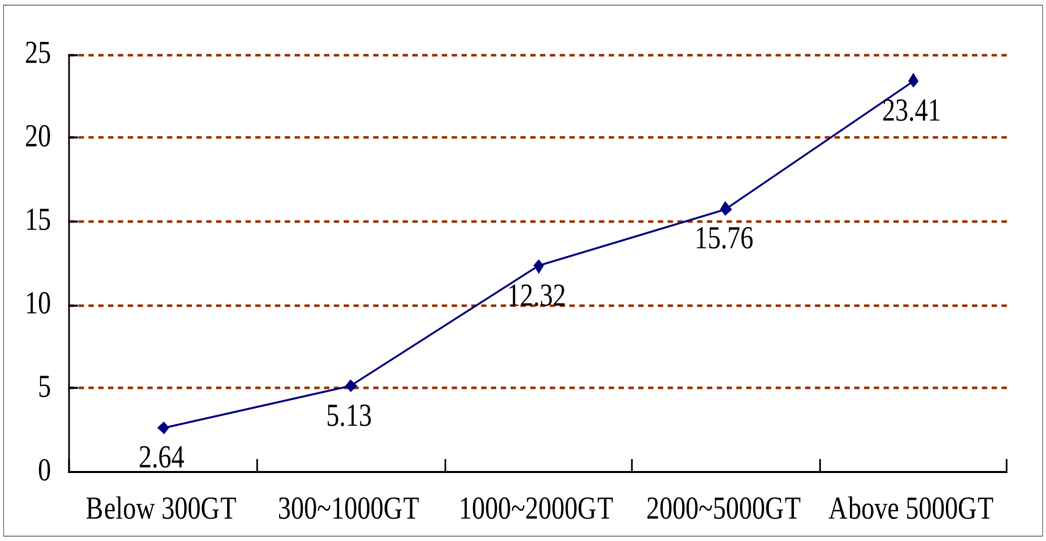

Figure 13 - the impeding navigation of the ship tonnage probability distribution (%)

Source: compiled by author, 2014

Impeding navigation model shows that the posterior probability of impeding navigation increases with the increasing of ship's tonnage grade , gradually increasing up to 23.41% ship more than 5000 GT from 2.64% the ship “below the 300 GT”. What we should point out is that this result is not to prove the ship’s safety level decreases with the increasing of the tonnage, but to show that the large-tonnage ships cause the run stranding accidents more easily, and lead the channel impeding navigation ,because of the navigation scales.

4.4.5 The comprehensive analysis of the key elements of the impeding navigation

On the basis of the research results, the posterior probability ranking of the impeding navigation factors state level is as the table are shown in 51, navigation key elements ranking.

Table 51- navigation key elements ranking

Congestion Factor	State Level	Congestion Probability(%)	D-value with the Initial Probability	Rank
Gross Tonnage	Below 300GT	2.64	-6.67	12
	300~1000GT	5.13	-4.18	9
	1000~2000GT	12.32	3.01	4
	2000~5000GT	15.76	6.45	3
	Above 5000GT	23.41	14.1	1
Seasonality	Dry Season	11.65	2.34	5
	Non-dry Season	6.91	-2.4	7
Accident Type	Collision	2.84	-6.47	10
	Grounding	2.71	-6.6	11
	Contact	17.47	8.16	2
Ship Owner	State-owned	6.61	-2.7	8
	Private	11.25	1.94	6

Source: compiled by author, 2014

Putting the initial value (9.31%)of impeding navigation probability as the standard to get the key elements of impeding navigation: the tonnage more than 1000GT, dry season, grounding accident and individual operation ships.

We can use the following 4 evaluation index to evaluate the benefits of impeding navigation control schemes:

1) Enhance the effect of large tonnage ship safety;

   Guarantee navigable dimensions in dry season and improve the effect of the supervision during the period;

2) Reduce the grounding accident effect;

   Improve the effect of the management level under individual operating the ship safety .

4.5 Chapter conclusion

This chapter takes the more typical impeding navigation in Yangtze river navigation risk in dry season as the research object, puts forward the targeted research ideas based on the analysis of the characteristics of the accident, combining with the navigation risk correlation analysis and the Bayesian network to study the Yangtze River impeding navigation by modeling, and further analyzed the effect of each impeding navigation factors by using the model. We verified its rationality and reliability according to the built model analyzing the error and sensibility to apply it in the evaluation and prediction of impeding navigation. Although limitations of sample data lead the model having less error, the Bayes' theorem decided that it can constantly improve with sample data updated. Therefore it has a good application prospect. In this chapter the impeding navigation risk assessment model and relevant conclusions will be the foundation and basis of impeding navigation risk countermeasures and impeding navigation risk forecasting, early warning and decision support system.

Chapter 5 The Yangtze river influence on manoeuvring

According to the actual situation of the Yangtze River, the ship is the most actual contact thing with the Yangtze River, while the crew is the ship driver. It is a very important to know how to handle the ship stranded in the Yangtze River shallow water during dry season. It is a comprehensive art to handle the ship, which not only requires the crew's good command of ship, favorable performance of ship handling, as well as the knowledge on external factors influencing the ship handling performance. The Yangtze River water level varied with the four seasons, especially in the dry season the waterway depth decreased obviously. Especially in the middle and lower reaches, hydrometeorology is complex and parts of channel water depth even is only 5 meters. If the ship sailed improperly, the ships are very likely to occur stranding impeding navigation and so on. According to the analysis in the third chapter, the crew competency is one of major risk factors to be controlled in Yangtze river navigation in dry season. Especially, the Yangtze River crew quality is uneven, even many crew did not have been properly trained. They started work without certificates, depending on their operating experience, without a bit of theoretical knowledge as the basis. This chapter focuses on the analysis of influence on ship maneuvering in shallow water.

Due to the fact that the flow field around the hull and wave conditions change all the time, when the ship sailed from deep water to low water channel or in shallow water , the ship showed different situations in deep water, which brings some difficulty to the ship maneuvering. The shallow water effect is mainly related to depth-draft ratio H/ T and depth Froude number $Fh = V / gH$.

5.1 Lateral resistance increasing and ship speed declining

5.1.1 Lateral resistance increasing

When the ship sailed in shallow water, the water around and the hull are relatively moving, which is quite different from that in the deep water. When the ship sailed in deep water, regardless of the bow or stern part the water flow has the characteristics of the three-dimensional flow. The bow slant (both to the sides, and below) backward has obvious downward characteristics. The stern slant (from both sides to the vertical cross-section, and to the above) backward has obvious upward characteristic. But when the ship sailed in the shallow water, water flow of the bow or stern part was limited due to the space. The flow of the original 3 d space had to become the flow that flew to the two sides or the two sides flew to the inward two-dimensional planar. In this way, there is new situation of pressure distribution around the hull different from in deep waters.

It shows the changing situation of bottom velocity, as a barge at low speed in shallow water the sailed. There is narrow waterway between the bottom of the ship and river bed, which lead the velocity to increase at the bottom; Because of the stickiness of water, it should form the boundary surface at the river bed and the ship bottom , which leaded the flow cross-section to decrease, and the bottom velocity increase. Due to the restricted water depth, the relative speed of the hull and water increased compared with the condition of deep water. We called the increasing speed as back-flow velocity. The existence of back-flow velocity leaded the bottom velocity to increase, the pressure reduce, which result in that the sinking of ships to increase. There is obvious increase compared to deep water. And the boundary layer thickness of the ship bottom and river bed is gradually increasing from bow to stern, making the flow cross-section smaller compared to the bow part. Therefore, the flow velocity increased more and the pressure declined more dramatically, so that the stern sunk more than the bow and produce the phenomenon of down by the stern. The existence of the return flow velocity make the flow velocity of shallow water around the ship larger than the ship in deep waters, and its broadside wet area increased with the hull sinking, so it enlarges the friction resistance. At the same time, for relative velocity between water flow and the hull increased, the pressure declines is dramatically. Therefore, the pressure difference of bow and stern would increase. The vortex easily occurred in interval between the stern and river bed. The vortex resistance can also increase. When the ship sailed in shallow water, it’s viscosity resistance will increase. In shallow water, lateral resistance increased, and rotary head moment increased, which had a significant effect on manoeuvring. In the mooring manoeuvring , lateral coming flow influences the ship or in calm water, the ship moved laterally when it is pulled into the shore. The value of lateral resistance and rotary head moment of the ship will be doubled with the shallow depth of the water .

5.1.2 Ship speed declining

The ships in Yangtze River are mainly bulk cargo ship, and most of the m are sand carrier. The phenomenon of overloading of sand carrier is more conspicuous. Because the boat carries heavy goods, the navigational speed are slow. When the ship is sailing in shallow water, compared with deep water, the pressure around hull changes dramatically, and the bottom flow accelerated leading the friction resistance increasing. Due to the main the relationship of the ratio of water depth h and draft T , water depth is shallow. The friction resistance bigger ; A low pressure area of the ship extends towards the stern, causing the ship to sink, vertical direction incline increasing; the shallow water waves appear in the shallow area, thus wave-making resistance increases compared with in the deep waters; the side flow and vortex near the propeller disk increasing reduce the propeller efficiency, so there will be the phenomenon of ship's speed decline.

5.2 The ship sinking and the changes of vertical direction incline

5.2.1 The water pressure distribution around the hull and the change of water flow

When the ship is sailing, the surrounding water pressure distribution is shown in figure 4. the changes of pressure distribution and distribution situation along the length of the ship is closely related to the ship type and relative water depth, speed and other factors. If the ship is huge, speed high, relatively water depth shallower ,the changes will be more dramatic. The ship's body should obtain the balance of gravity and flotage in the fluctuating water. There is the performance of the sinking ship body when in the calm water. Because of the different deflection in the bow and stern , draft difference changes are expressed in the voyage.

Due to the small interval of bottom water, when the ship sails in shallow waters, three-dimensional movement of the water only become plane flow, and at the same the increasing velocity (water more shallow, the velocity more increasing) not only causes the violent pressure changes, but also pressure fluctuation to the stern. Therefore, when the wave increases, the ship body sunk more seriously. When the ship sails into the narrow waterway or near the other ship, owing to the reduction of shipboard interval, the pressure change can be further intensified, even causes the phenomenon of instability of sailing directions or deflection balancing difficultly.

5.2.2 The ship body sinks and vertical inclines in shallow water

In fact, even if the ship sails in the deep waters the changes of pressure distribution around the hull will lead the water level decline. The results will lead the ship sink thoroughly, meanwhile vertical incline state will change with them. The degree of this sinking changes will be more intense with the speed increasing of the mast ship. The ship body sunk and the changes of vertical incline in the shallow waters will be more intense than in the deep waters. Therefore, it has greater influence on the ship maneuvering, even causing the accidents of the bottom of ship touching the bottom of the sea. The problem is what we should pay attention when the ship sails into the shallow water area. Within the scope of the merchant ship speed, the ship body sinking will appear when the speed is low in the shallow waters. the increase rate of sinking is more quick with the speed increasing and the bow will come up earlier. Moreover, the water more shallow, the ship speed more minimum what achieving largest the bow vertical incline and the stern vertical incline need. Therefore, when a ship sails through the shallow waters, we should pay attention to the phenomenon of the ship body sinking and vertical incline, and according to estimation, calculate the remaining water depth to prevent the ship from trimming running aground. For safety, we should reduce speed . In actual ship manoeuvring, most of the ships that sail in the shallow waters adopt preparation ship for navigation. At the same time, switch on echo sounder, calculate the remaining water depth to ensure the safety of the ship.

5.3 The influence of the shallow water on maneuverability and cyclicity

When the ship sails into the shallow waters, the two-dimensional flow growth enlarges the ship body sinking. With the vertical incline increasing, it sharply diffuse from the stern, which intensifies vortex near the rudder, enhance the stern side flow and ship virtual mass. The result is the sailing directions stability tend to be good, rudder force decreasing, so the cyclicity goes bad.

5.3.1 Rudder force slowing down

Due to the fact that ships sail in shallow waters, they slow down, which makes the water section of ship bottom decreases, the effect of side flow strengthens the effect of high pressure area of the stern. These above damage the rudder force. Rudder force decline is mainly caused by the increase of the side flow. Rotary angular velocity is obvious decline when we operate the rudder in shallow water. The model test shows that when h/T = 2, rotary angular velocity is about 85% of the deep water; When h/T = 1125, rotary angular velocity is about 50% of the deep water.

5.3.2 Cyclicity decline

After entering into shallow waters, the initial cycle moment produced by the rudder declines. The increasing of hull cycle resistance moment makes the index K of cyclicity be small, and cyclicity performance decline. Diameter of cyclicity in shallow water is larger than that in deep waters. According to the test results, when the water depth draft ratio is below 2 (h/T), cyclicity diameter will increase sharply; when the water depth draft ratio is greater than 4, there will be less influence. Therefore, when the ship sails into the shallow water, although we use a rudder or increase the rudder angle, the bow is often reluctant to turn. Once there is the rotation, it's hard to control.

5.3.3 The improvement of the stability of sailing direction

When the ship sails into the shallow waters, there will be two-dimensional flow growth and the ship body sinking etc., which furtherly increases the rotary head moment and makes the stability of sailing direction in deep water improve.

5.3.4 Running rudder

The phenomenon of the bow automatically deflects to one shipboard is called "running rudder"(wall effect). When the ship sails along the shallow water, the bow goes forward and drains away water to both sides , forming high pressure area in the front. Because of the different condition of water depth on both sides, water discharged to the outside can be freely diffused. But there is high water surface on one side of the shallow water, which produces an additional pressure making the counter-acting force on the both sides different. It's action spot before the center of gravity, forming the deflection moment, pushing the bow deflecting to the outside .
Therefore, the depth of shallow water side is smaller, running rudder more significantly. In practice, when running rudder is observed, the person who operates the rudder should not use the counter rudder and press the rudder tightly. These will be the benefits for the ship back to the deep waters and avoid the running aground.

5.3.5 The influence on stroke of shallow water

Due to the intense pressure change around the hull, the ship sailing in shallow waters can cause the ship body sinking, vertical incline , wave and two-dimensional flow rate increasing, which increase the resistance that the hull bears. At the same time, reduction of some of the propulsion efficiency, in general, will make the ship's stroke in shallow water decrease of stroke at a certain extent. Especially during the period of the ship just stopping, the leaving velocity is faster. Shallow water resistance increases more greatly, which plays an important role on reducing the speed and stroke; When the speed reduces to a lower speed, because of the weakening of above influencing factors, deceleration slows down. Therefore, the function of reducing the stroke will be declined. Therefore, in order to adapt to the Yangtze River waterway and the actual requirement of operating the ship stopping and leaving the dock , the ship's operators should not only understand this ship's deep stroke performance, but also be aware of this stroke performance in shallow water.

5.4 additional depth in navigation

5.4.1 additional depth and their significance

There often appears the dramatic reduction of rudder effect extremely reducing, even without rudder effect. That is out of the control of the situation within own strength. The excessive increase of lateral resistance relies on larger external support. Command and control are more complex; the hull in sailing further sinking will endanger the safety of the hull, propeller and rudder's safety, and even endanger the normal work of the host; Therefore, in order to ensure the navigation safety in shallow water, we should make the depth of the water be more than the actual water depth, and keep certain safety margin. These margin are usually called the additional depth.

the additional depth can be calculated by the following formula:

H = charted depth+ when and where height of tide - resting the draft of the ship

5.4.2 Determining the factors of additional depth that should be considered

1. The ship sinking and vertical incline changes, pay attention to sinking volume of the bow.
2. The swing of hull in the waves, including rolling, pitching and the possible changes of the actual draft caused by heave.
3. Icon depth accuracy. The ship operators should remember to use the international standards to measure the water depth. The Maritime map of figure on water depth may have the error as the following:

In the range of figure note standard water depth permissible error

0 — 20m 0.3m

20 — 100m 1.0m

At the same time, the operation should consider impeding navigation object, submarine topography and its changes.

In the Yangtze River, the Yangtze River Maritime Administration stipulate the jurisdiction ship additional depth in detail in dry season:

(1) Inland river ships: additional depth of the river in sichuang shouldn’t be less than 0.3m; additional depth of the middle and lower reaches shouldn’t be less than 0.2m; plus 0.1m as loading the dangerous goods .

(2) Seacrafts into river

Table 52 - the draft of ship

T	Δh	T	Δh
T<4 ,L≤80	≥0.3	5≤T<7	≥0.5
T<4 ,L>80	≥0.4	7≤T<9.5	≥0.7
4≤T<5	≥0.4	T≥9.5	≥0.8

L ---ship total length, T---fresh water draft, Δh--- additional depth

Source: The ship navigation Yangtze River additional depth fixation (try out) in 1988 issued by the Yangtze River port and waterway supervision Administration of ministry of transport.

4. Other aspects:

①the water declines 1cm,as the air pressure rise per 1 KPA.

② Using actual tide level to calculate the changes of height of tide

③the changes of proportion of water in waters will lead to changes in the draft

④Host cooling water entrance, if using the sea entrance at the bottom, cooling water entrance diameter is required at least 1.5-2 times of additional depth at the bottom of the bottom.

5.5 The operation matters worth noticing in shallow water

The ships should sail at low speed in shallow waters. Especially when determining the additional depth of large ship, we should pay attention to solving the problems of ship body sinking and vertical incline changes in the shallow waters .

Prevent suction bottom and the damage of propeller. When the ship sails through the waters that the remain water depth is not big , the operators must proceed at low speed. The water depth less than 1.5 times of drafts the shallow water effect is very significant, especially for the flat and linear plump ships. If the speed is too fast, that squat may appear.

The ship operators should grasp the shallow water effect on ship maneuvering to effectively utilize equipment for ship maneuvering, such as rudder, anchor, cable, to improve the safety of the ship.

5.6 Other matters

Pay close attention to mariners and channel notification, grasp the channel changes, navigation mark adjustment information, carry out the operation on the graph according to above information to ensure Maritime map, and navigation chart reference available.

During the voyage, we should keep lookout seriously, pay attention to adjustment of navigation mark shifting and the lights extinguishing, find exceptions to promptly report to the competent authority and take corresponding measures. Especially two terminals of the part of central bar extends more open, which makes the effective navigation wide be narrow. Therefore, the ship operators should pay attention to position fixing. For some development tendency marginal bank, we should keep an appropriate safe distance during the navigation process.

The water level will decline in dry season. Black bar south waterway and Tuqiao waterway etc., easily appear the shallow leading impeding navigation. The ship should keep additional depth to prevent stranding; When the ship sails through ,the operators should keep slow speed and watching out the shallow signs at any time .

It's windy and foggy in dry season, thus the ship operators should timely listen to the weather reports. Firstly, we should pay attention to cold wind, keep the big wind wave region in heart; Second, we must grasp fog forming rule, understand the dangerous fog area. If the visibility is bad, we should not sail with risk and pay close attention to safety information issued by the competent authority.

During the period of special permission river crab fishing period in Yangtze river, the Yangtze River in Anhui section of ships routing system regulation (2010)， when the Hankou water level has dropped below 4 meters, some of the separation navigation scheme channel turn into a two-way navigable scheme channel. Some channels are carried out one-way navigation. Therefore, the driving and guiding staff should be familiar with these changes, and comply with the relevant provisions.

The operators should choose safe berth, pay attention to the depth and draw close one side of waterway as far as possible. It's important to strengthen duty after anchorage. If it's foggy, the related personnel should drop anchor according to the signal requirements of "Internal regulation" to ring the fog bell. Engine room is ready for at any time.

The related personnel should rigorously comply with the requirements that ships routing stipulates under the jurisdiction of each Maritime Administration and select the correct route. The ferryboat that sails across river should actively avoid the ships that sail along the route. Low water period is the "golden period" for the water engineering under the construction. All ships should pay close attention to the construction notices. When approaching the area, the relevant personnel should pay close attention to construction trends, and pass through carefully.

Chapter 6 Maritime Management in Low Water Period

Maritime Administration is the competent authorities for water shipping. In order to strengthen the safety management of ships sailing through the shallow area in dry season, on the basis of the analysis by previous discussion and according to the characteristics of the Yangtze River section, the Maritime Administration should take the measures in the following aspects:

6.1 implementation of law and active response

Maritime Administration in each jurisdiction should visit the local waterways to master meteorological, and hydrological factors of its jurisdiction etc., other units to grasp the changing characteristics of channel in dry season, the change trend of water level and winter weather trend in jurisdiction. Especially, the related personnel should keep the negative influence of navigation environment in dry season and winter severe weather in heart, analyze carefully jurisdiction accident characteristics and laws in recent years in the winter spring dry season, clarify the key point of regulation, identify weak links of safety management, formulate and improve the emergency pre-arranged planning, together with the characteristics of jurisdiction, the ship seaworthy condition, management of shipping companies, crew quality, navigation environment and Maritime supervision etc.

6.2 Strengthening early warning, prevention and control

Administration of the relevant functional departments，each marine department, law enforcement detachment should arrange professional personnel to collect information on cold wave, wind, rain, snow, fog and haze severe weather etc. and safety information of water regimen water level, channel depth changes etc., and timely grasp the jurisdiction key shallow area segment measured water level, to inform shipping company, ship and crew by the ways of the scene cruise, VTS, mobile short message, water safety information platform, etc. At the same time , related personnel and units should integrate the actual situation of each jurisdiction, reasonably adjust and deploy emergency rescue force to make emergency preparation preventing fog, wind and ship resistance navigation, carry out the fast search and contingency plan practice according to the season feature , make everyone strictly comply with the obligations, execute 24 hours emergency awaiting orders system in holidays, the major safety activities and emergency to make orders and information of government smooth ,dispose dangerous case at first time and report the se to superiors timely and truthfully.

6.3 Examining comprehensively to eliminate potential

Maritime competent authority in each jurisdiction should further carry out jurisdiction potential safety hazard removal and inspection on ferry ferryboat, vessel carrying dangerous goods, vessel carry bulk sand cargo, bridge area and bend narrow shallow risks navigation segment etc., timely update perfect hazard database, use listed supervisory measures to find out the major production safety hidden, urge the relevant units to rectify and reform the potential work.

Strengthen the ship safety inspection, focus on the inspection on ship navigation equipment, manning and emergency equipment, forbid the ship depart from port once finding serious defects; At the same time , strengthen the crew's actual operation ability, grasp of meteorological water level and the checking the situation on performing their duties, constantly improve the crew safety awareness responsibility awareness and operate skill.

The Maritime Administration Authority along the Yangtze river should timely put up the jurisdiction and Yangtze River waterway each section maintenance water depth and water level of the main port, meteorological information in service window and keep it under continuous update, strictly execute the system of “the captain’s declaration before sailing”, perfect the related content according to the navigation requirements, and submitted by ship must be personally signed by the captain.

6.4 Strengthening the ferryboat management

Strictly carry out the long-term management mechanism of ferryboat 116, do a good job of prohibited measures under the bad weather condition, urge the ferry crew to carry out the “the safety of the Yangtze River navigation and guidelines on preventative measures”, execute the report system of the first and the last navigation , deeply push the system of passengers wearing (holding) lifejackets (float) on the ferryboat within 30m, strictly carry out the prohibited measures under the bad weather condition ,fully play the monitoring equipment function of AIS, CCTV, electronic cruise etc., strengthen the monitoring over the whole process of ferry, normalized the ferryboat sailing route, increase the dealing with ferryboat illegal behavior, strengthen inspection of key ferry site staring prevention maintenance during the period of Spring Festival, transportation of Spring Festival, holiday, etc., key time, do a good job of Spring Festival on-line inspection of ferryboat, severely crack down illegal behavior of boat for agricultural purpose, fishing boat, private boat illegal carrying passenger.

6.5 Strengthening the supervision of dangerous chemical ships

Strictly carry out “1+6” the long-term management mechanism of dangerous chemical ships, continue to actualize dynamic tracking maintenance measures for class A dangerous cargo ships, enhance site safety maintenance of dangerous cargo ships entering and leaving port and loading and unloading operation , especially strengthen the supervision of single shell liquid cargo ship, strictly normalize the safety operation procedures of ship to shore to prevent the occurrence of major ship pollution accidents .

6.6 Strengthening the navigation order management

Strengthen the on-site inspection and warning propaganda for Tuqiao, Heinan waterway etc., main meandering shallow and dangerous waterway and accident prone area of Three dam area and Qiaoqu, construction operation zone, do a good job of prohibited sailing under government regulations in the bad weather, and the on-site counseling work of normal peak of the ship flow, the fog dispersion, the wind off etc. If it’s necessary, coast guard boats should stay in site of navigation compact district, crossing area, traffic control area to investigate and treat the behavior of the ships run which disobey the stipulation of regulation line system, the ships which break rules and regulations on sailing with dense fog, and crack down illegal act of sand mining that disrupt the order of navigation, further increase the intensity of night navigation to prevent overloading, super draft ship concentrating at night from washing off and ensure jurisdiction the night navigation order smooth; Based on the illegal act rectification base, severely crack down the ships overload, super draft navigation behavior, force the ships reduce load, let the ships through after the scene examination to ensure they meet the requirements.

6.7 Strict control of ship draft

The ship draft control is one of the most important links for the Yangtze River Maritime authorities supervision during low water period. Therefore, we should severely carry out every management requirements in dry season, enhance ships visa management to further improve the quality of ship visas, strengthen on-site inspection and spot checks to mainly on-site measure the condition of the ships' draft, severely control the ships' draft that come in or leave the shallow navigation section to do well in visa information source. If the inspection declaration information is not true ,we will punish them with "four unities": All these ships will be denied of port entry and exit visas. All these will be included in the "black list". These ships must be checked, when they entry and leave the port. Cancel agent qualification , once the particular authorized visa is obtained by the agent. There are the following several management measures as follows.

6.7.1 Implementation of piecewise visa and addition and subtraction load

When some shallow area sections in jurisdiction are up to the dry season standards, the relevant personnel will implement piecewise visa to the ships that sail through the shallow navigation section and meet the ship draft control standard. For the ships sailing in the middle reaches of Yangtze River from Wuhan to Cheng Lingji, the draft standard will be 4.0m and below for ships carrying dangerous goods. Other ships' are controlled with 4.1m or blow. For the ships sailing in the middle reaches of Yangtze river from Yichan to Cheng Lingji, the ships' draft standards are 2.7m or below as the dangerous goods ships. Other ships' are controlled with 2.8m or below. the ships exceeding the standard will be given visa to pass.

Specifically, the Maritime authorities should set up a ship visa pot and plus (minus) load base at key segment ends. The ships not satisfying the segment navigable dimensions requirements need to be handled procedures at the ship visa pot before entering this segment and downloading goods to pass this section. The goods that are downloaded from the ship should be transported to the loading base at the other end by the way of road transport to reload to the ship. With the implementation of this mechanism, the part ship that didn't satisfying the navigation dimensions requirements can also safety sail through the shallow channel.

Piecewise visa and plus (minus) mechanisms can reduce the ship dragging accidents at a certain extent caused by super draft to increase the upper vision for large scale ship of Maritime law enforcement. What must be pointed out is that implementing risk control scheme can increase the expense of construction of supervision department and maintenance plus (minus) base ,meanwhile can increase the ships' running cost and reduce the efficiency of the transport of goods.

6.7.2 On-site check draft

When a segment goes into low water period, piecewise visa will be implemented. Ships carrying dangerous goods are checked on draft and signed the visa through the following the principles: For the ships intended to directly sail through the shallow waters and the load draft over the shallow waters draft control standard, the Maritime administration signed visa should check the draft on site; For the ship that implemented the piecewise visa then through the shallow waters, the Maritime administration of repeated area should check the draft on site after the goods check again to the base.

When the navigation area is implemented the traffic control in every low water level , for all the ships intended to directly sail through the shallow waters and the load draft over the shallow waters draft control standard, the Maritime administration should check the draft on site; For all the ships that implemented the piecewise visa the n through the shallow waters, the Maritime administration of repetitive area should check the draft on site after the goods reproduced to the base.

6.8 Implementation of management

The ships in the company conferred the safety integrity by the Ministry of transport, Ministry of Maritime Administration, ChangJiang navigation Administration and Maritime Administration along the Yangtze River can be exempt from the on-site check ship draft. The branch of Maritime Administration can implement integrity management for the ships that belonged to the shipping companies that have better safety integrity. Principal of the company signs a pledge for the port of registry branch Maritime Administration, and guarantee the y strictly control the ship draft in strict accordance with the requirements. After the Branch Maritime Administration censors and agrees, the y will report the se to the Yangtze River Maritime Administration. then the ships sailing through the shallow waters in the Yangtze River jurisdiction can be exempt from the on-site check the draft.

6.9 Expert argumentation

The opinions on the expert's demonstration are the examination and approval basis of visa and in and out of the port. Application demonstration shall be accepted by the origin port marine department, which after the initial check will be reported to the ship management office. The application materials include “the application form of demonstration on ship through shallow waters” and related safety measures. After receiving the application documents, the relevant departments of Maritime Administration should organize expert groups to demonstrate as soon as possible. the expert groups consist of professional and technical personnel on channel, shipping, pilotage, Maritime and so on. After the argumentation, the expert groups shall issue a certificate to “ship sails through shallow waters with expert groups argumentation opinion”.

Table 53 - ship sails through shallow waters expert groups argumentation opinion table

Ship name				Nationality	
The shipowner				ship operator	
The captain		the ship width		Before freshwater draft/after	
Gross tonnage		Net tonnage		Load ton	
The host type and quantity		the host power		ship speed	
Previous port		Destination port and arrival time		Pre- berth and design load	
Cargo names and quantity			the agent		
Demonstration meeting time			Place		

The expert groups argumentation opinion					
Expert leader （sign）					
Member of the expert groups （sign）					

Source: compiled by author, 2014

6.10 The preparatory work of preventing stoppage and keeping smooth in advance

According to the characteristics of waterways in jurisdiction and ship navigation, and practical work of navigation in dry season, each Maritime administration authority finds out the easy stoppage navigation section, revises and improves in advance contingency plan of preventing stoppage and keeping smooth, draws up the ship navigation order maintenance scheme in jurisdiction, implements the plan of early arrangement, assignment and enforcement. At the same time, do a good job in the maintenance work of boats ,cars, and communications equipment to ensure them in the seaworthy, effective state; In addition, keep the communication with the relevant departments of salvage company in jurisdiction, fishery industry etc., and do a good job in the emergency preparedness work to ensure that the preparatory work of preventing stoppage and keeping smooth are in good practice.

Chapter 7 Conclusions

Ensuring the safety and smooth navigation of Yangtze River “golden waterway “ is core problem and long-term goal to vigorously develop the inland river transportation system. The Yangtze River water traffic safety system has always been the focal point of research object of scholar, college, shipping enterprise and Maritime management agencies, especially the Yangtze River trunk line navigation safety state in the special period of dry season. In this paper, I put forward targeted navigation risk control scheme by analyzing the risk characteristics identification and evaluation and comprehensively analyzed the property of ships in shallow waters through the actual operating level of Yangtze river shallow waters in dry season, provided reliable theoretical knowledge and basic in the process of the crew’s actual operation. At last, combining with the actual situation of the line of the Yangtze River, proposed regulatory measures from the perspective of Maritime Administration.

The main research work in this paper is summarized as follows:

1) Discussion on the characteristics and limitations of various risk analysis and decision method. On the one hand, the paper pointed out the limitations of traditional risk assessment method P in the study of traffic safety in the Yangtze River. On the other hand, the paper also compared many uncertainty analysis methods in terms of the adaptability specific issues, such as fuzzy logic, evidence reasoning, Bayesian network, etc., Finally the paper analyzed multi attribute decision making method such as AHP, TOPsls ,etc., advantages and disadvantages and applicable situation in handling multiple objectives, and decision problem of multi scheme.

2) Establishing multiple level, multiple index Yangtze River navigation risk

evaluation model of many risk affect factors involving people, ship, environment, management etc., The paper and identified risk factors of Yangtze River navigation safety in dry season based on the data of experts' investigation, using analytic hierarchy process that combining discrete fuzzy sets, proposed 4 risk factors of comply with laws and regulations, crew competency navigation dimensions, the ship seaworthiness etc., obtained controlling risk factors the best countermeasures as "strengthening the crew training and management" and "Maritime authorities intensifying supervision and management" according to utility analysis of alternative risk control scheme.

3) Carrying out the case study on navigation safety in the upper, middle and lower reaches of Yangtze River in dry season. On the basis of multiple levels, multiple index the navigation safety evaluation model, using the evidence reasoning methods based on fuzzy rule base, the research effectively combined the subjective and objective data. Results show that the degree of risk of the lower reaches of Yangtze River is minimum, however, navigation safety status of the middle reaches of Yangtze River in dry season is the most worrying.

4) We proposed the targeted impeding navigation research ideas based on the analysis of characteristics of accident, on the basis of analyzing the cause of the Yangtze River waterway impeding navigation, and made the modeling study on the impeding navigation risk in Yangtze River, according to the collected historical accident data, using the method of correlation analysis and Bayesian network, and further verified the rationality and scientific nature of the impeding navigation model according to error analysis and sensitivity analysis, and finally key factors causing the Yangtze River trunk impeding navigation events ,such as "more than 1000 GT ship ", "grounding accident", "dry season ", and " the individual operating ships" , based on the influence on impeding navigation probability of impeding navigation in Bayesian network model.

5) The research made the detailed analysis of the dynamic of ship in shallow waters , targeted with actual conditions of the Yangtze River channel ,and pointed out the main point for actual controlling and the matters that needed out attention, which provided the theoretical basis for handling the ship in shallow waters, and is the important for improve the quality of crew in Yangtze River to reduce risk.

6) Corresponding management measures are proposed from the perspective of management of Yangtze River in dry season and each management sectors which focused on the Maritime Administration regulations, which helped the Maritime Administration Spervision in dry season .

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