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WORLD MARITIME UNIVERSITY

Dalian, China

A STUDY ON PILOTAGE RISK ASSESSMENT IN JIANGSU SECTION OF YANGTZE RIVER

By

RAN RUIHONG

The People's Republic of China

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

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL

MANAGEMENT)

2018

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DECLARATION

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

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

Signature: Ran Ruihong

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ABSTRACT

Title of Dissertation: **A Study on Pilotage Risk Assessment in Jiangsu Section of the Yangtze River**

Degree: **MSc**

The Jiangsu section of the Yangtze River covers 75% of the total cargo volume of the Yangtze River by only a 1/7 navigable mileage of the Yangtze River. The annual cargo volume in Jiangsu Section of the Yangtze River is more than 16 million tons, in which the shipping volume exceeds 8 million tons. Since the 1980s, the number of ships sailing on the Yangtze River has increased geometrically. In 2011, the average daily traffic volume of certain cross-section in the Jiangsu section was close to 3,000 ships, and the peak period was nearly 5,000. The hourly flow of ships in some section reached 350 ships. With the extension of the -12.5 m deep-water channel to Nanjing, the 50 thousand DWT ship could reach to Nanjing with full load, which would further exacerbate the risk of navigation safety.

As the basis of production operations, the safety of ships, ports and waters has always been the focus of attention. Dense traffic has already threatened the safety of navigation, as the carrying cargo or passengers on board would not only cause huge economic losses but also directly threaten human life in the event of an accident. In the process of ships entering and leaving the ports, the pilot plays an irreplaceable role. So, it is worth to use mathematical model to reveal and assess the risk of pilotage for further ensure the safety of navigation in Jiangsu Section, so as to achieve an orderly navigational environment in Yangtze River.

In this paper, the risk of ship pilotage in Jiangsu section of the Yangtze River is studied by fuzzy comprehensive evaluation: risk factor identification, risk evaluation and decision making suggestion. First, the expert brainstorming method was used in surveys among the pilots, captains, and other industry-related experts of the Yangtze River; secondly, a safety-risk index system was established; thirdly, a mathematical evaluation model was established based on the AHP method; lastly, some suggestions would give after applying the model in Jiangsu section of Yangtze River.

Based on a comprehensive analysis of the navigation characteristics of the ship in Jiangsu section, the target layer is subdivided into: human operational behavior, ship aspects, and traffic conditions. It is then subdivided into 10 sub-factors, such as berthing operations, the size of ship, and waterways and so on. On this basis, the risk index system and evaluation model are established. At the same time, the judgment matrix was obtained based on the questionnaire survey under the two kinds of weather conditions, and the weight changes of each sub-factor under the corresponding weather conditions were obtained.

This paper lays a theoretical foundation for further improving pilotage safety.

KEY WORDS: Jiangsu section of the Yangtze River; comprehensive evaluation; fuzzy mathematics; pilotage risk

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
BRM	Bridge Resource Management
DEA	Data Envelopment Analysis
FCE	Fuzzy Comprehensive Evaluation
GDP	Gross Domestic Product
MSA	Maritime Safety Administration
WG	Working Group

CHAPTER 1

INTRODUCTION

1.1 Purpose and significance of the study

The Jiangsu section of the Yangtze River, from the west of Cihu estuary to the east of Liuhe estuary, with more than 360 kilometers' length, bears the task of carrying bulk materials related to the national economy and the people's livelihood on water. Relying on the Yangtze River, the region along the river has become the core area of Jiangsu's socio-economic development: this region accounts for only 47% of the province in area, and its regional GDP and total import and export volume account for 80% and 95% of the whole province respectively. The Jiangsu section of the Yangtze River, with only 1/7 of the navigable mileage of whole Yangtze River, transported about 75% of the total cargo volume in Yangtze River and accounted 70% of the port cargo throughput of the whole river and has had 80% of the berths above the 10,000-ton class of the whole river (Sima & Zai, 2011). The annual cargo volume of the section below Nanjing of the Yangtze River is more than 1.6 billion tons, of which the ship carries more than 800 million tons.

With the rapid development of Jiangsu's society and economy, the Jiangsu section of the Yangtze River shows the characteristics of "many ports areas, huge numbers of large ships, many bridges, dense traffic, many chemical enterprises, many construction waters" and "many water function and many traffic risk sources"(There are more than 700 chemical companies and 117 chemical terminals in the water area).

With the development of the regional economy, the shipping industry in Jiangsu has developed rapidly. As a result, there are more and more ships entering into Yangtze River and the size of these ships are becoming larger and larger. In this context, the Yangtze pilots and their pilot ships are facing increasing risks and pressures. As reported, ship pilot is listed as the third most dangerous job in the world after miners and test pilots. The pilotage for ships is a good way to ensure the safe navigation of ships, to improve the traffic efficiency of port areas, to maintain the order of the port security and to protect the waters environment. Therefore, it is necessary to study the pilotage risk and its corresponding prevention and control measures in Jiangsu section of the Yangtze River.

The purpose of this study is to make people understand the actual situation and the developing trend of the pilotage risks in Jiangsu section on the basis of a comprehensive summary and a deep analysis of the present situation of pilotage safety risk in Jiangsu through standardized safety assessment, so as to evaluate the pilotage risk by certain model, especially in two different weather conditions, also to give some suggestions for improving the ship safety.

1.2 The status quo of research

1.2.1 The status quo of domestic research

Wu Yongjun (2013) studied and developed the applicable software about "the safety assessment system for ship’s navigation" to evaluate the pilotage risks by FSA method. Through the analysis of the assessment results, he put forward relevant decision-making suggestions to improve the safety of port pilotage.

Lin Wei (2017) carried out statistics on AIS data of Chengshantou waters, and studied the traffic flow characteristics, such as ship traffic volume, ship density, ship track, speed, ship arrival pattern, ship spacing, traffic flow, traffic capacity, ship field, collision avoidance behavior, and encounter rate, further excavated the ship's risk data for navigation in this particular waters and provided a data support for the establishment of traffic flow theoretical models.

Liu Yuxiao (2014) studied the impacts of waterway congestion on shipping. He used the fractal theory to examine the complexity of the ship's traffic flow system, made predictions based on ship data, waterways, and other information to help the authority make appropriate navigational order management methods and safety supervision measures.

Liang Guangrong (2014), Zhang Zongjing (2016), proceeded from the human factors in a pilot accident case, and analyzed the role of the bridge resources and the relationship between captain and pilot in reducing pilotage risk and defensive pilotage accidents. Bai Jun (2017) and Ge Jianping (2018) explained the importance of implementing effective bridge resource management when pilots were on board by analyzing a ship grounding case. They studied the pilots' participation in the bridge team model, introduced the team mental model to establish team situational awareness, and finally put forward specific measures on how pilots participated in the bridge team.

Xu Jianxin (2017), by using questionnaires and gray correlation in grey models, explored risk factors that affect safe navigation in a restricted water area of Yangtze River, obtained major hazard sources in this waters, and proposed reasonable approaches for safe navigation. Wang Hongjun (2015), on the basis of a comprehensive analysis for the composition of pilotage risk assessment systems, innovatively used unascertained measure pre-evaluation methods for pilotage risk assessment. This calculation method has certain reliability and provides theoretical assurance for pilotage safety.

Yang Junrong (2016) analyzed the pilotage risk in Jiangyin channel by using the fuzzy comprehensive evaluation method, and put forward reasonable suggestions to ensure the safety of pilotage. Fu Jianhua (2017), based on Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation Method, evaluated the Pilotage Risk of Caoxiexia channel. Cai Wenpeng (2013) and Chu Yanfei (2010) based on years of pilotage experience have conducted risk analysis on the Yangtze River ferry waters and the Yangtze River Yingongzhou section respectively, and put forward related safety recommendations.

Hu Shenping et al (2017) analyzed the risk degree of the different pilotage tasks, and quantitatively studied the rule of the risk evolution of the pilotage in the specific waters, and put forward the transfer equation of the ship's pilotage state among the anchorage, the channel and the area near berth. The calculation results show that the transition of the ship's pilotage state is consistent with Markov's steady-state characteristics, and the process variables of the ship's navigational state transfer have a significant impact on the overall ship order in the waters of the port area.

Wang Chen et al (2016) innovatively applied TOPSIS model and entropy weight theory to the risk assessment of navigation environment, and used entropy weight theory to determine the index weight, which effectively avoided the influence of subjective factors on the weight distribution. However, he did not determine the level of pilotage risk based on this model.

Gan Langxiong et al classified pilotage environment safety factors into four first-class indexes: natural environment, channel condition, traffic environment and the condition of the cited ship. By establishing a pilot environment risk assessment index system, Gan et al (2018) used the entropy weight method to determine the weight coefficient of the evaluation index, and established the standard normal cloud element model for the pilot environment risk assessment based on the randomness and fuzziness of the pilot environment environmental risk assessment index. By calculating the correlation degree between the evaluated matter element and the standard normal cloud matter element, they introduced a confidence criterion to identify the risk level.

1.2.2 The status quo of foreign research

In the 1980s, Norway (Ma, 1998) issued a risk assessment rule for maritime transport: Safety analysis and assessment must be performed on petroleum-related offshore facilities and ships.

British scholars, Vldimirem Trboject and Berryj Carre, proposed a safety management system for harbor navigation based on risk. These two scholars first evaluated and analyzed the ship safety, then put forward the corresponding reform plan according to the result. Scholars T.C.Coldwell (1983) and Don T.Phillips (1985) introduced experts in ship safety risk analysis.

According to the characteristics of the chemical industry, Imperial Chemical Corporation of England, Mendsu Branch, put forward the evaluation method on fire, explosion and toxicity index of the company. In 1976, the Ministry of Labor of Japan developed the "six-step safety evaluation method for chemical plants", and introduced the related technology of system engineering in the analysis stage, which made the contents more comprehensive and systematic than the previous methods (Roland, 1985). In 1976, the British Production Safety Authority conducted a hazard assessment on industrial facilities on the islands of Ganvey Island and Thurreck (Hollnagel E, 1992; FINKELAM, 1994). UK Technica Co. Ltd., the Netherlands Institute of Applied Science, and the European Lspra Joint Research Center have conducted in-depth and extensive research on safety evaluation (Wu, 1994).

Scholars Natasha Khalil (1994), H.H. Goh, B.C. Koki (1994), Mincheol Kimn (2013), Alessio Ishizaka (2016) and Juliana Saraj (2015) used AHP to evaluate power systems, waste management decisions, etc.

Japanese scholars have made remarkable achievements in environmental risk assessment of ship navigation.

In the study of the influence of natural environment conditions on navigation safety evaluation, Japanese scholar Nii Ysuo and Fuhu Chun Sijiu (1994) quantified the index values of natural environment elements and distinguished the relationship between the indexes and the subjective feeling of ship operation. It provides a theoretical basis for judging the influence of each element on navigation safety and improving navigation environment. In the study of the influence of ship maneuvering characteristics on the safety evaluation of navigation environment, the Japanese scholar Kobayashi Hiroa (1994) put forward an evaluation method based on the difficulty degree of ship operation. This method quantitatively analyzed the influence of ship type, length, water depth, and wind conditions on the ship handling capacity, and thus evaluates the difficulty of handling the entire sea area.

Inoue Sanshin (1998), in the study of technical criteria for evaluation of maritime traffic safety, carried out a quantitative analysis from two aspects of the potential collision risk in a certain water area: one was how many opportunities the ship had to meet with other ships during the navigation in this waters, and the other was how much additional burden would be placed on the ship's operator when the ship meets other ships, and these two were used as indicators of the potential danger level of a ship sailing in this waters.

In 1998, Lin (1998), Massachusetts Institute of Technology, took the navigable environment factors such as tide, visibility and channel complexity as statistical variables, using Bayesian method to analyze the accident data of five ports, and obtained the quantitative results of ship grounding probability. Marie Lutzen (2000), from the Danish University of Science and Technology, used Bayesian method to analyze the ship collision accidents, forecasted the risks in the ship's navigation, and proposed safety recommendations for navigation. Lin (2010) applied grey theory to analyze the ship's pilotage risk and achieved the best relevance ranking of pilot risk factors. D.Roeleven (1972), according to the traffic condition factors such as visibility, navigable water area and so on, used binomial distribution theory to establish the prediction model of accident probability. The results showed that the environmental factors had greater impact on the safety than the characteristics of the navigable waters.

1.3 The method and structure of this paper

In order to refine the risk factors of the Yangtze River in Jiangsu and complete the risk assessment, this paper mainly uses the following methods to study:

⑴Confirm the research contents and methods through field surveys and WeChat questionnaires.

⑵ System analysis method. Based on the results of the questionnaire and pilotage risks in the Jiangsu section of the Yangtze River, a modular division is conducted.

⑶ The method of combining theoretical analysis with mathematical analysis. Using the geometric average mathematics method for quantitative analysis on key issues to find out where the problems are and propose constructive measures.

This paper discusses in detail the risk factors of pilotage in the Jiangsu section of the Yangtze River, and builds a piloting risk assessment index system based on “people”, “ship” and “environment”. Based on this, a pilotage risk assessment model is established. The weights of the pilots’ operational behavior change with visibility, so I try to find out the changing risks associated with different visibility. Finally, according to the result of risk assessment in Jiangsu section of the Yangtze River, combined with expert advice and analysis of water traffic accidents, the corresponding suggestions and measures for mitigating pilotage risk are put forward.

The data source of pilotage risk evaluation comes from expert brainstorming and paper questionnaire, in which the influencing factors of pilotage risk are identified, sorted and graded. The whole pilotage risk index level is divided into three layers: the first layer is the total goal, the middle layer is the decomposition of the total goal, and the bottom layer is the further decomposition of the middle layer.

The first part of the article introduces the background of the research and the current research situation at home and abroad, and introduces the main research roadmap of this article. The second part introduces the general safety situation in Jiangsu section. The third part carries out risk identification and establishes corresponding safety index system. The fourth part uses mathematical method to establish ship pilotage risk assessment model. The fifth part makes an example calculation based on the mathematical model established in the previous part, and proposes some safety suggestions about pilot operating aspect, the ship aspect and the ship traffic conditions aspect respectively.

The route of this study is shown in Fig. 1.1:

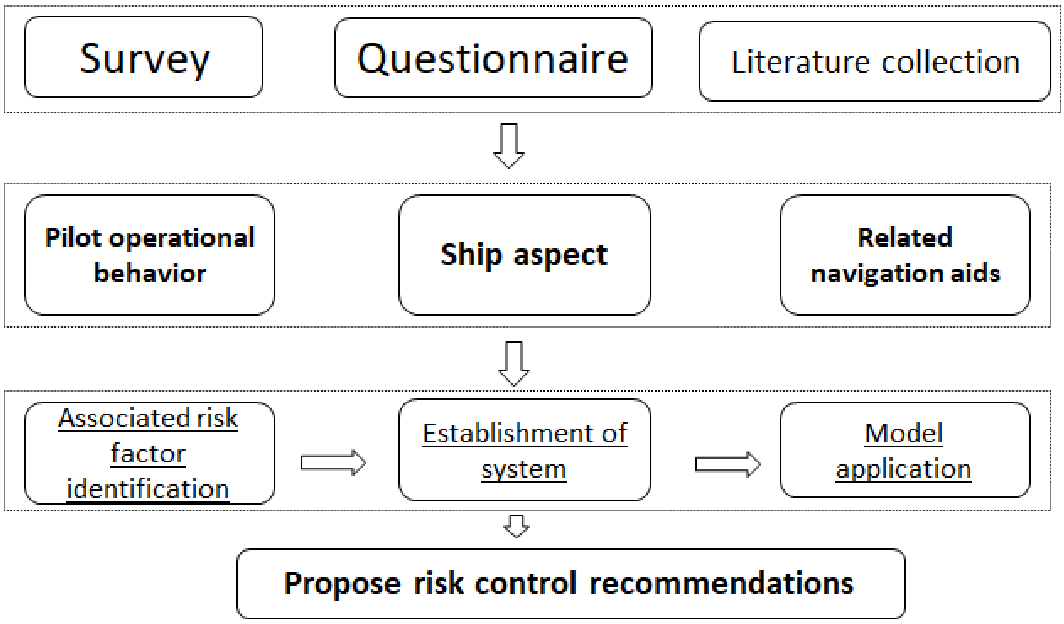

Figure 1.1 Research roadmap
Source: Draw by myself

CHAPTER 2

Navigation status of the Jiangsu section of the Yangtze River

2.1 The status of navigation environment in the Jiangsu section of Yangtze River

The Jiangsu section of the Yangtze River is located at the junction of the Yangtze River basin and the coastal area. The length of the Jiangsu section of the Yangtze River is about 431 km with about 360 km deep water channel. The ports along the river has a relative dense distribution in Jiangsu, and the berths number is relative large, the industrial distribution is rational as well. By the end of 2017, the cargo throughput of 7 ports along the Yangtze River in Jiangsu, Nanjing, Zhenjiang, Taizhou, Jiangyin, Zhangjiagang, Nantong and Taicang exceeded 100 million tons. More than half of the iron ore, timber and coal needed by enterprises in Jiangsu's along river area are transported through the Jiangsu section of the Yangtze River.

2.1.1 Channel profile

The deep-water channel in Jiangsu section of the Yangtze River is divided into 16 channels: Fangjiaji channel, Nanjing channel, Caosxiexia channel, Longtan channel, Yizheng channel, Jiaoshan channel, Dantu channel, Kouanzhi channel, Taixing channel, Jiangyin channel, Fujiangsha channel, Liu Haisha channel, Nantong channel, Tongzhou Shadong channel, Baimao sha channel, Liuhe channel. In addition, there are some special purpose channels and agile channels. Each of these channels has different navigable and hydrological characteristics.

As the volume of incoming water from upper stream of the Yangtze River and the amount of sediment in the water constantly change, the natural water depth of the channel often changes, especially after the summer flood season. In addition, ten cross river bridges have been built in Jiangsu Province, which have changed the nearby water flow and affected the traffic of the waters. According to the regulations of the ship routing system in Jiangsu Province, the maintenance width of deep water route in Jiangsu section of the Yangtze River is minimum 500 meters, and the maintenance depth of channel is -12.5 meters.

Since 1998, the Yangtze River Waterway has started a total of three phases of renovation projects (Zhou, 2012). Since 2011, the Ministry of Transport (Ministry of Transport, 2018) and the Jiangsu Provincial Government have launched a new round of -12.5 meters deep water channel construction project. This project started in August 2012 and the first phase of the project was completed in July 2014 and the -12.5m deep water channel was extended to Nantong at that time. The second phase of this project started in June 2015 and was completed in April 2018 and the 12.5-meter deep-water channel was extended to Nanjing. So far, the -12.5-meter deep-water channel of 431 kilometers from Nanjing to the Changjiang Kou has completed which allows 50,000-ton vessels to reach Nanjing Port directly.

With the improvement of the channel level in the Jiangsu section, the passing capacity of the channel has also increased. The increase of channel depth has brought a series of effects: it has raised the structure grade of the port along the river, greatly increased the number of large-vessel entering and leaving the port along the river, and also promoted the efficiency of loading and unloading of the wharf.

2.1.2 Port profile

The ports along the Yangtze River in Jiangsu are composed of Nanjing, Jiangyin, Zhenjiang, Suzhou (Zhangjiagang, Changshu, Taicang), Yangzhou, Changzhou, Taizhou and Nantong eight ports, of which there are total 11 Category 1 open ports. Most of the cargo transshipment for the upper and middle stream of the Yangtze River depends on these ports. Along with the improvement of navigation conditions in the Jiangsu section, the port construction along the Yangtze River has made remarkable achievements in two aspects (Wu, 2004). The first is the continuous improvement of the modernization level of the port facilities. Traditional port functions mainly focus on loading and unloading, transportation and so on, while modern port functions mainly focus on packaging, circulation, processing, storage, distribution, information processing and so on. The second is the increasing content of port operations, the continuous improvement of port handling efficiency, the increasing scope of port operation, and the upgrading of port structure. Taking Nantong Port as an example, at the end of 2017, Nantong Port has 4166 meters along the Yangtze River shore; 24 berths above 1000 tons, of which 14 have berthing capacity above 10, 000 tons, of which the maximum berthing capacity is 200000 tons; the storage area is 670000 square meters and the warehouse area is 60, 000 square meters. Nantong Port has a navigational relationship with 312 ports in 96 countries and regions of the world. Nantong port group mainly engaged in the construction and operation of port, cargo loading and unloading, storage and logistics distribution, ship agent, tally, ship towing service in port, shipping repair and so on.

At the end of the 11th Five-Year Plan, with the increasing number of berths in Jiangsu, the cargo throughput and container throughput of the ports along the Yangtze River have been greatly improved. According to statistics, the throughput of ports along the Yangtze River at the end of the 11th Five-Year Plan period reached 1.02 billion tons and 7.382 million TEUs respectively, up by 29.3% and 30.2% respectively compared with 2009. At the end of the "11^{th} Five-Year Plan", the throughput of Jiangsu river ports accounted for 13% and 37% of the ports in the country and the Yangtze River Delta respectively (CPY, 2011). The throughput and container throughput of Jiangsu ports along the Yangtze River at the end of the 11th Five-Year Plan are shown in the following Table 2.1.

Table 2.1 The throughput and container throughput at the end of 11^{th} 5 year plan

Port name	Cargo throughput (ten thousand ton)	Year-on-year growth	Container throughput (Ten thousand TEUs)	Year-on-year growth
Nanjing	15825.2	22.4%	145.3	19.9%
Zhenjiang	10600	21.7%	30.26	7.8%
Changzhou	3155.9	15.9%	10.6	62.8%
Jiangyin	12500	15.3%	100.1	33.1%
Suzhou	33000	33.5%	364.4	34.1%

Yangzhou	7384	15%	31.9	37.3%
Taizhou	9971	33.6%	10.0	21.2%
Nantong	15069.8	10.5%	46.2	31.9%

Source: China Port Yearbook 2011

By the end of 2017, there were 402 berths with a capacity of over 10,000 tons in Jiangsu, which accounted for 34.5% of the total number of berths along the river in the province. The comprehensive capacity of the berths reached 780 million tons, accounting for 70.4% of the total capacity of the ports along the river in the province; of which there are 178 berths at or above 50,000 tons, accounting for 15.3% of the total number of berths along the river in the province, with a comprehensive capacity of 475 million tons. According to statistics, in 2017, there were 6685 ships over 50 thousand tons entering into the river, an increase of 43% than last year, in which the proportion of ships above 100 thousand ton increased significantly (Ministry of Transport, 2018).

2.1.3 Meteorological and hydrological profile

The Jiangsu section of the Yangtze River is influenced by both runoff and tide, which is irregular semidiurnal tide. It means that this section would experience two high tides and two low tides each day. Generally speaking, the flood tide lasts more than 3 hours, and the ebb tide lasts more than 8 hours. Every year from June to September is the flood season. During this period, the water level is high and the flow rate is high.

Every year from December to March of the following year, it is the dry season with low water level and low flow rate. In other seasons, it has moderate water level which is good period for navigation.

Jiangsu is located in the middle latitudes, on the eastern and southern coast of Eurasia, and is close to the Pacific Ocean. The geographical environment has a great influence on the climate of the region. Therefore, it has the characteristics of monsoon climate and belongs to the transitional region of subtropical and warm temperate zone. There is more southeast wind in summer and more northwest wind in winter. The wind near the coast is relatively stronger than the wind in the inland area. Tropical cyclones are mostly concentrated in the two seasons of summer and autumn. The Yangtze and Huaihe cyclones occur all the year round. Spring and early summer are the most active periods of cyclones. There are more fog and mist in winter and spring (November to April), resulting in poor visibility in water areas. The largest humidity month is July, and the lowest humidity month is January.

2.1.4 Traffic flow

Since 2007, the Jiangsu Maritime Safety Administration has set up seven observation lines on Nanjing Yangtze River Bridge, Runyang Bridge North & South Line, Zhenjiang Yingongzhou, Jiangyin Yangtze River Bridge, Nantong Langshan Port Area and Taicang Maritime Base, and carried out observations for traffic.

From 2007 to 2014, the daily average vessel flow statistics of 7 observation lines in Jiangsu show as follows Figure 2.1. From this, we can see that the daily average traffic flow of these observation lines is almost kept at 1500-2000 ships. The Yingongzhou section has always maintained a relatively high traffic flow and the Taicang section is relatively low. This is because the Yingongzhou section of

Zhenjiang River is located at the junction of the Beijing-Hangzhou Canal and the Yangtze River, where ships transported from the north to the south of the Beijing-Hangzhou Canal must go through and Taicang Port is located at the downstream of the Jiangsu section of the Yangtze River, where only few barges pass through to inland area.

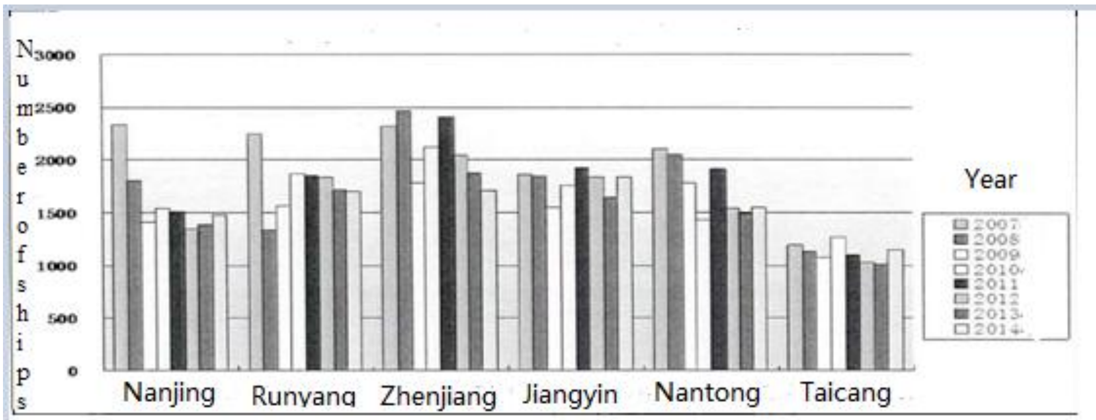

Figure 2.1 Average daily ship traffic volume for each line from 2007 to 2014
Source: Reports on Traffic flow Statistics of Jiangsu MSA 2007-2014

The observed data show that the daily average flow rate of vessels over 90 meters in Jiangsu section of the Yangtze River increases year by year, with the highest cross-section exceeding 300 and the lowest section reaching 100 times. Statistics on the number of ships over 90 meters in each section in 2008-2014 are shown as Figure 2.2.

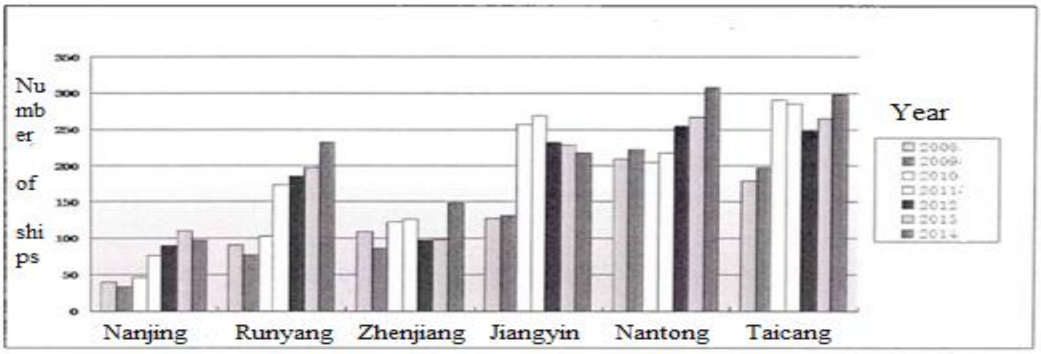

Figure 2.2 Average daily traffic of ships over 90 meters from 2008 to 2014
Source: Reports on Traffic flow Statistics of Jiangsu MSA 2008-2014

From Figure 2.2 we can see that the more ships that sail downstream, the more large ships there are. The daily average traffic of Nantong and Taicang is maintained around 300 ships.

The shipping throughput of the Yangtze River's Jiangsu section has continued to grow rapidly for many years, reaching 1.374 billion tons in 2013, an increase of 14.1% over 2012. According to the statistics (Zhao, 2014), a total of 11,718 super-large vessels entering and leaving Jiangsu province in 2013 were increased by 27% compared with 2012, of which 1135 ships had the capacity over 50,000 tons. According to the statistics of May 2018, the number of ships in and out of Jiangsu increased from 434000 in 2002 to more than 2.2 million in 2017, with a cargo capacity of 1.514 billion tons.

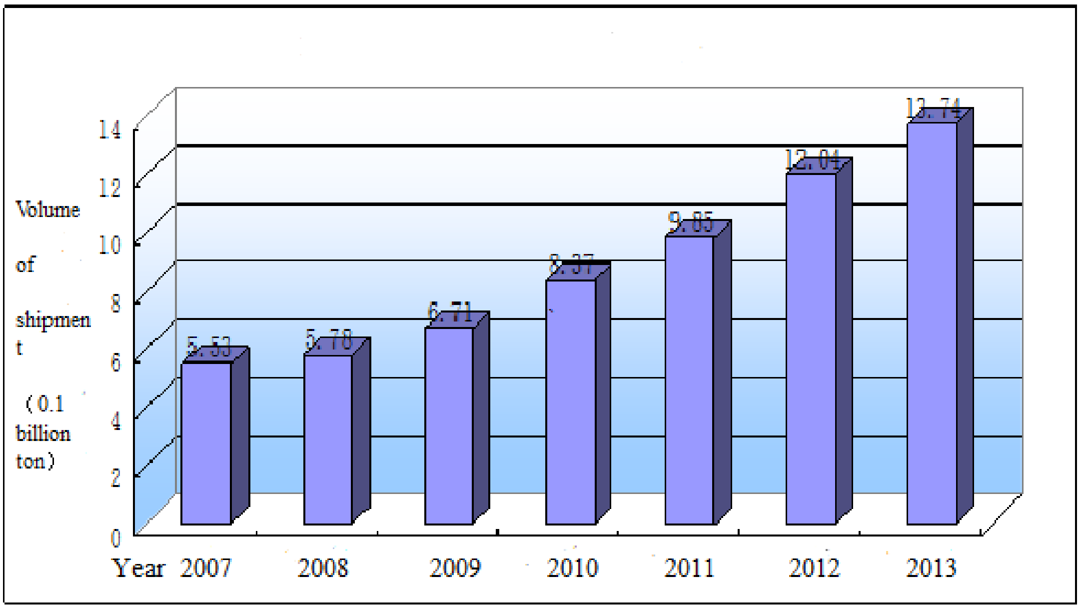

Figure 2.3 Shipment volume in and out of Jiangsu section of the Yangtze River from 2007 to 2013
Source: Statistical data of Jiangsu MSA 2007-2013

2.2 Jiangsu ship's routing system

On July 1, 2003, the "Regulations of the Ship routing System in the Jiangsu Section of the Yangtze River" came into force. This regulation clarifies the navigation method, route setting, and the principle of responsibility determination in the Jiangsu section of the Yangtze River, and delimits the specific bridge area, ferry boat area, and the range of waterway intersections, and sets up different anchorages and berthing areas. This routing system was revised in 2005 and 2013 to better conform to the actual practice of the Yangtze River.

Since the implementation of the ship routing system in Jiangsu section of the Yangtze River, the accident rate has been decreasing year by year, from more than 100 accidents per year in 2003 to about 40 accidents per year in 2017(MoT, 2018).

2.3 Brief introduction to the History and Development of pilotage in the Yangtze River

According to relevant data, since the ancient three kingdoms (AD 983) of China, the Yangtze River has been the seed of pilotage (Wu, 2007). During the period of grain shipping in Yuan Dynasty (About 1291), many ships gathered in the Liuhe of Jiangsu Province to transport grain to Dadu (now Beijing), and there was a standard set of "shallow vessels" to show the way for other ships. The compulsory pilotage system for foreign ships appeared in the Ming Dynasty (About 1684).

In the 1950s, three pilot stations were set up in Yichang Port, Wuhan and Shanghai Yangtze River Shipping Company to be responsible for the pilotage affairs of the upper and middle reaches of the Yangtze River and the lower reaches of the Yangtze River from Wusongkou to Hankou, respectively.

In June 1981, the Port Supervision Bureau of the Ministry of Transport (now the MSA of the Ministry of Transport) decided to set up pilot stations in Nanjing and

Nantong to provide pilotage services for ships entering the river. In 1997, in order to adapt to the further opening of the Yangtze River to the outside world, break the boundaries of the region, and meet the needs of ship operation, the pilot stations scattered along the Yangtze River were merged to form the Yangtze River pilot Center. Now, the Yangtze River pilot center has 10 pilot stations in Wuhan, Wuhu, Zhenjiang, Nantong, Zhangjiagang, Jiangyin, Nanjing, Jingjiang, Changshu, Taicang. The pilotage range from Wusong to Yunnan Shuifu is more than 2800 kilometers, but its main business is concentrated in the Yangtze Jiangsu section.

Table 2.2 Statistics of pilotage vessels in Yangtze River pilot center from 2013 to 2017

Year	Ships	Gross tonnages (0.1 billion ton)	Net tonnages (0.1 billion ton)	Pilot mileage (Kilometers)	Number of super-large vessels
2013	56399	6.72	3.63	7626	6708
2014	54986	7.2	4.00	7360	7257
2015	55127	8.08	4.44	7273	8929
2016	59192	9.24	4.97	7690	10170
2017	62015	10.53	5.82	8281	10603

Source: Yangtze River Pilot Center

2.4 Statistics and characteristics of pilotage accidents

The following Table 2.3 lists the pilotage accidents or near miss in these years (2013-2017).

Table2.3 Accident statics form 2013 to 2017

		Type of accident			Accident grade				
Year	Total number of accidents	Collision	Grounding	Strike damage	Major accident	ordinary accident	Minor accident	Non-grated accident	Out of control
2013	26	22	3	1	1	1	4	20	13
2014	20	15	0	5	1	0	7	12	10
2015	20	20	0	0	0	1	0	19	3
2016	28	21	4	3	1	2	9	16	12
2017	18	13	3	2	1	0	1	16	5
∑	112	91	10	11	4	4	21	83	43

Source: Yangtze River Pilot Center internal report

Statistics show that there were 112 water traffic accidents in the Yangtze River pilot Center from 2013 to 2017 (43 of which were caused by out of control), including 91 collisions (81%), 21 minor accidents (19%), and 83 non-grade accidents (74%). Among these accidents, there were 4 major accidents and 4 general grade accidents. The losses caused by the 4 major accidents exceeded RMB 10 million per case, and the losses caused by 4 general-level accidents were between RMB 1 million to RMB 10 million per case. These higher-level accidents have had a serious impact on local navigation and production. For instance, some have caused short-term suspension of certain channel.

The causes of these accidents were analyzed and the results were as follows: 78% of the total accidents caused by delay to take operation; 42% of total accidents occurred due to poor visibility and its vicinity; 38% of total due to out of control of ships; 9%

of the total accidents, grounding, due to the rapid change of water depth or near berth and the new chart not yet to release.

2.5 Conclusion

This chapter introduces the general situation of Jiangsu section of the Yangtze River from the aspects of channel, hydrometeorology, traffic flow, port, etc. This chapter also introduces the production volume of the Yangtze pilotage Center in 2013-2017 and the statistics of pilotage accidents in the same period. This chapter also makes a brief analysis from the accident size, the main accident type, the accident main characteristic, has made the foundation for the next chapter Yangtze River pilotage risk identification.

CHAPTER 3

Identification of pilotage risk in Jiangsu section of the Yangtze River

Ship pilotage is a systematic project, which is restricted by four aspects: man, ship, environment and management. This paper does not consider the pilot's own physiological and psychological factors, and assume the pilot is competent. The paper only focuses on the following factors: the pilot's operation on the ship, the conditions ship, and the port traffic conditions such as the natural environment for ship's navigation. The purpose of risk identification is to determine the likelihood of accidents and the magnitude of the risk induced by a certain ship or a certain environment or certain operations by pilots. Therefore, this chapter describes these three aspects respectively.

3.1 Pilot's operational behavior

According to statistics, about 80% of accidents at sea are caused by human factors (liu, 2004; liu, 2001). The ability of each pilot to analyze the navigation situation is different, and the key operation in ship avoidance is particularly important because of the limited space of the Yangtze River channel and the unique handling characteristics of some ships. Therefore, it is necessary to carry out research from the human aspect and objectively analyze the pilot's operational behavior for ships. This paper mainly analyzes the pilot's navigational operation, berthing operation and mooring (anchoring) operation.

3.1.1 Yangtze River navigation

The pilotage of the Yangtze River is different from that of the coastal ports. The pilotage of the Yangtze River requires the pilot to assist the captain for navigation certain miles voyage. The voyage ranges from dozens of kilometers to hundreds of kilometers. Due to the narrow curving of the Yangtze River Fairway, the high density of ports along the coast, and the large number of ships entering or leaving the river, the traffic density is relatively high, especially after release the temporary traffic control. Therefore, ships can only keep very close distances to other ship during navigation. This section will focus on analyzing some risks existing in navigation.

According to Article 5 of the Regulations of the People's Republic of China on Inland River Collision Avoidance (MTPRC, 2003), “on the way” means that ships and rafts are not in anchor, tie to the shore or aground. According to the ship routing system in Jiangsu section of the Yangtze River (MTPRC, 2013), the vessel should navigate in the prescribed route with safe speed. Therefore, the upstream and downstream deep-water traffic lanes for large ships were established, and the upper and lower recommended routes for small vessels were established, and the navigational warning zones were established in some crossing areas. It also stipulates that in the deep-water channel, all ships should navigate along the prescribed routes in accordance with the principle of keeping close to their right, and as far as possible away from the separation zone or separation lines. From this point of view, pilotage ships only need to follow the set route and comply with the specific rules of their waters. Next, we will discuss the common navigation conditions of the Yangtze River respectively.

(1) Keep distance

Due to the limitation of the width of the waterway and the restrictions on the surrounding traffic flow, the state of navigation of the rear ship following the front vessel is called trailing. Figure 3.1 shows the ship's shape in the trailing state existing in Jiangsu section.

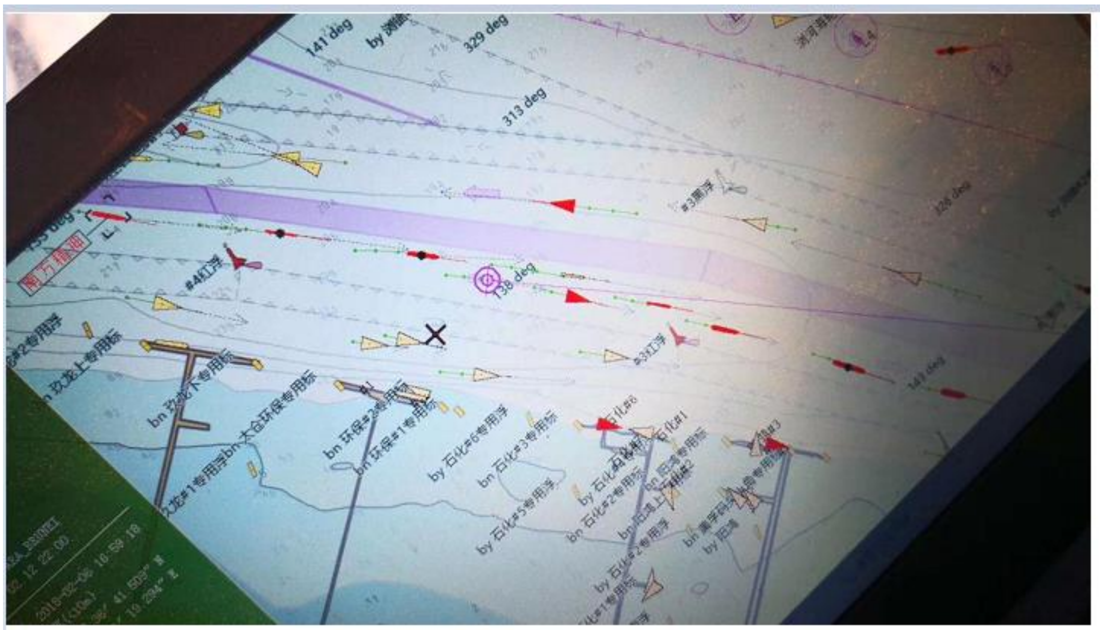

Figure 3.1 The trailing state in Yangtze River on 2018-02-06
Source: Yangtze River Pilot Center e-pilot system

The distance between red buoy No.3 to No. 4 is 1.4 mile. There were 7ships in this buoy. So, we can calculate the distance between two ships is about 0.2 mile. Such a short distance, if the pilot failed to detect the abnormal state of the ship before or in a slow response, would most likely cause rear end collision and other dangers. A typical accident occurred in 2010 when the ship, GLOBAL LEADER, sailing near the No. 27 buoy collided with the small barge ahead. The reason for the accident was that it did not control the speed in advance, and there was no room for evasiveness around it.

⑵Overtaking

There are many kinds of vessels navigating along the Yangtze River, and there are also great differences in the speed of these ships, so the overtaking situation often occurs. Generally speaking, there are not many straight waterways suitable for overtaking in Jiangsu section, and there are many ferry boat crossing areas and bridge areas (forbidden to overtaking), so ships are often forced to overtake at slightly curved sections. The overtaking at the curved fairway means that both the overtaken ship and the overtaken ship turn and overtake simultaneously. This has very high requirements for the cooperation between the two ships and whether the overtaking vessel can grasp the overtaking situation in time. According to the internal statistics of Yangtze River pilot center, about 30% of the accidents occur during overtaking each year.

⑶ Head to head, cross situation and across

Strictly speaking, there is no true head to head in the Jiangsu section, but the cross-encounter situation appears very often, as there are many estuaries and tributaries in the Jiangsu section, and the anchorages along the rivers are also distributed on both sides of the fairway. There is no guideline for head to head situation and cross situation in Jiangsu ship's routing system. It stipulates that vessels not navigating in the navigable lane as prescribed shall take the initiative to avoid vessels navigating in the navigable lane, and vessels in and out of the mouth of the tributaries shall take the initiative to avoid the vessels normally navigating in the prescribed navigable lane; vessels in and out of the anchorage should take the initiative to avoid vessels sailing normally in the prescribed traffic lanes. All along, these points involving the intersection of routes or the convergence of traffic flow are the focus of VTS supervision, and they are also closely followed by the pilots of the Yangtze River.

After studying the accidents in Nantong section of the Yangtze River between 2008 and 2009, Zhang (2009) concluded that the collision is mainly cross collision, accounting for 45% of the total collision, followed by the opposite collision and co-directional collision, accounting for 14% and 11% respectively, in which most of cross collision happened near buoy No.30 and No.25, and opposite collision happened between large ships and barges, and co-directional collision occurred during overtaking.

3.1.2 Berthing and unberthing behavior

Berthing and unberthing are the most dangerous process. At this point, the ship is in a process from a state of motion to a state of rest. Among them, the super large vessels are especially concerned by people as their huge cargo loads. In this point, the pilot must consider the bearing capacity of the berth. This is why many wharves have high requirements for the normal speed of ship berthing. The super large ship has great quality. When it is berthing, even if there is only a little surplus speed, the momentum of the ship will be very great. When it comes into contact with the wharf, it will produce tremendous pressure (Ding & Fan, 2009). In order to avoid damage to ships, wharfs and facilities, it is necessary to strictly control the approaching speed of ships. In addition, the angle of a ship's contact with a pier is also important, and this control runs through the whole berthing process (Sun, 2008; Lv, 2015).

The most serious berthing collision accident in recent years in the Yangtze River was the collision between the "Huang Hai Development" at berthing on September 27, 2013, and the "Wen Qiang Anchorage 1" and another ship, which two docked at the berth. The direct economic loss caused by the accident is as high as 5 million yuan.

3.1.3 Mooring operation (Anchoring operation)

The mooring operation described herein refers to a series of operations when a ship is near the Anchorage, including crossing the channel, entering and leaving the Anchorage, and lifting the anchor (The same goes for next charters). Due to the particularity of Jiangsu section of the Yangtze River, part of the waterway cannot pass at night, so every day there are many ships berthing in Taicang, Changshu and Nantong Port Anchorage.

Guo (2013) pointed out that the risks of vessels in the operation of anchoring in Jiangsu section can be divided into three categories: first, the risk of ships crossing the waterway for entering and leaving the anchorage, is higher, especially during flood tide, the ships have to cross several parallel upstream and downstream flows; the second is the risk of sailing in the Anchorage, which means that the ship has to pass so close to other moored ships; the third is the risk of dragging of anchor. Because the Yangtze River is affected by runoff and tidal reciprocating currents, anchoring ships tend to turn around at the Anchorage. In this process, ships are prone to swing or even anchor dangerous situation.

In addition, due to the limited anchorage waters, under the present conditions, the anchorage of large ships cannot satisfy the mooring requirements of the ships in the Jiangsu section of the Yangtze River. Therefore, crowded Anchorage in Jiangsu has become the norm.

3.2 Attributes of ships under pilotage

The ships entering and leaving the Jiangsu section of the Yangtze River have different ship characteristics. The ship size, draught and maneuverability are different.

This section mainly evaluates the pilotage risk of the Yangtze River from the ship size, draft and type of ship.

3.2.1 The ship size

Ship size directly affects pilotage safety. In general, the larger the size of a ship, the more difficult it is for a ship to operate. The large-scale shipping has greatly increased its risk of navigation at port waters. The high occupancy rate in the channel, the difficulty of maneuverability and the poor braking ability of large ships have restricted and influenced their safe navigation in the port.

I choose Nantong pilotage station as the representative to analyze the specific ship data and ratio, the total number of leading ships in 2017 is 9845, the proportion of different length as the following Table 3.1.

Table 3.1 Statistics of Nantong pilot Station in 2017 (by ship length)

Ship length	LOA ＜ 150 meters	150≤ LOA ＜230	230≤ LOA ＜300	300≤ LOA	Total
Numbers	5451	3749	645	28	9873
Percentage	55.2%	38.0%	6.5%	0.3%	

Source: Nantong Pilot Station 2017 annual report

We can expect that with the development of economy along the Yangtze River and the increasing demand of enterprises, more and more large ships will arrive at the ports of Jiangsu.

3.2.2 Ship draft

For large draught ships, the most important index of navigation safety is the under keel clearance. The ship's routing system of Jiangsu has clear provisions on the under keel clearance of the vessels navigating in River: if the actual draught of the vessel is 9.7-10.5 meters, the clearance shall not be less than 0.8 meters; if the actual draft of the vessel is more than 10.5 meters or more, the clearance is not less than 10% of the actual draft of the ship. The greater of the ship's draught, the greater of the clearance is required.

The Yangtze River channel is mostly a natural channel, and its artificial maintenance depth is only -12.5 meters. The bottom character of Yangtze River channel is dominated by sediment, which is easy to silt as the influence of water flow. Therefore, some larger draught vessels must inbound wit tide, and the pilot must calculate the tide height accurately to ensure the safe passage of large draught ships.

I take the Nantong pilot station as an example to collect the data of 2017 by ship's draft. It shows as follow. Since the water depth of the Yangtze River channel was 10.5 meters before, we categorized the ships by draft 9 and 10.8 meters.

Table 3.2 Statistics of Nantong pilot Station in 2017 (by ship's draft)

Draft	D＜9meters	9≤D＜10.8	10.8≤D	Total
Ship numbers	7863	1103	907	9873
Percentage	79.6%	11.2%	9.2%	

Source: Nantong Pilot Station 2017 annual report

It can be seen that the number of ships with a draft of more than 10.8 metres accounts for about 10 percent of the annual number. With the upgraded of deep-water channel in Jiangsu waterway, the water depth to 12.5 meters, the number of ships with a draught of more than 11.5 meters has risen sharply since 2017, and it could be estimated that the numbers would to be rising continuously.

3.2.3 Type of ships

Different types of ships have different handling characteristics. For example, because of the linearity of container ships, the acceleration of container ships is faster but the speed is slow; the wind area of ro-ro ships and some superstructure ships is large; and the deep draught ships are more affected by the flow.

The pilotage volume of Nantong Pilotage Station in 2017 shows as follows by different types of ships.

Table 3.3 Statistics of Nantong pilot Station in 2017 (by ship types)

	Bulk-cargo ships	General-Cargo ships	Container ships	Dangerous Chemical tankers	Oil tankers	Others	Total
Numbers	4344	1363	228	2360	1542	36	9873
Percentage	44%	13.8%	2.3%	23.9%	15.6%	0.4%	

Source: Nantong Pilot Station 2017 annual report

From it, we can see that the proportion of bulk carriers is 44%, the proportion of dangerous goods ships is 24%, and the proportion of oil vessels is 15%. Therefore, special attention should be paid to the pollution prevention of dangerous goods ships and oil tankers when piloting.

3.3 Traffic conditions

Traffic conditions refer to the ability of a number of ships to pass through a certain waters based on VTS organization and navigational foundation such as fairways and navigational aids. This paper mainly assesses the possible risks on pilotage from the aspects of navigation aids, berth, traffic flow and wind flow.

3.3.1 Fairways and navigational aids

A waterway is a passage for safe navigation of ships in inland waters, lakes, harbors, etc. The factors affecting the safety of ships' navigation are mainly navigation aids, turning points, channel lengths, channel widths, depths, channel bends, and obstacles, etc. Channel width, depth and curvature determine channel grade, in which width determines the ship type and whether ships can pass in two-way or not. Channel bending requires the pilot to take into account the new course distance of the ship and the timing of the giving rudder order to ensure that the ship navigate in the center of the waterway.

(1) Curvature

The more curves, the greater the curvature, the more difficult it is to navigate. First, ship lookouts will be affected. When navigating in the curved section, due to the obstruction of sight, the ship is often unable to find the opposite ship in time. Second, the water to avoid collision with other ships is limited. Third, ship needs constant steering to keep on the correct route, so frequent use of the rudder is required.

There is narrower and smaller radius of curvature below Nanjing in Yin Gongzhou section, Sima section, Funan waterway and Nantong waterway. Figure 3.2 shows the Fujiangsha South Waterway.

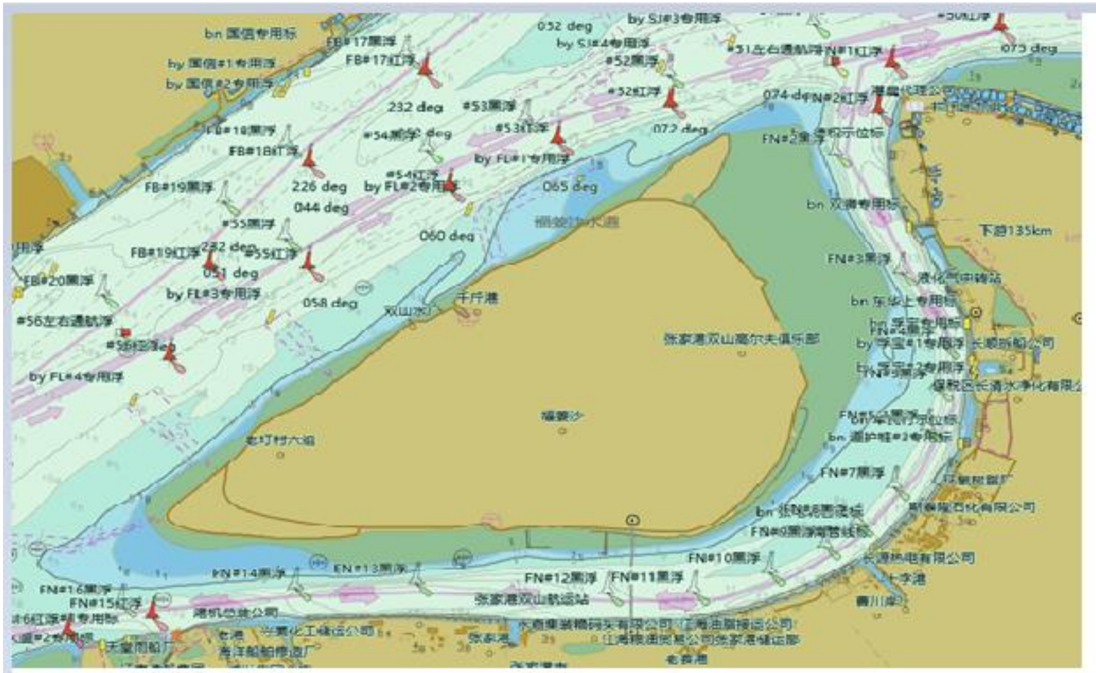

Figure 3.2 The general situation of Fujiangsha south channel

Source: E-pilot system of Yangtze River Pilot Center

There are three sections of Fujiangsha south channel need to turn to 60-90 degrees continuously. In addition, there are lots of quays and estuaries on the south coast, so the navigation risk in this section is great. According to the statistics of the Yangtze River pilot Center, about 5 near miss cases occur in this section every year.

(2) Channel width and depth

When the width of the channel is insufficient, the VTS usually only allows the one-way access of the water area. Similarly, the Yangtze River Channel sets up many turn around areas for ship swing operation. Lack of depth can easily cause ships to run aground and hit reefs.

⑶Navigational aids and other facilities

The maintenance of the navigation marks in Jiangsu section of the Yangtze River is the responsibility of the Nanjing Navigation Bureau of the Yangtze River. The allocation standard of navigation aids in Jiangsu section is: double side setting, the distance between two buoys is about 1800-2500 meters. Some shore markers (some with racon) near key turning points are also established.

Due to the impact of Yangtze River runoff, navigation marks in some waters are prone to displacement, which makes the sailing ship unable to make accurate positioning. For example, in May 2009, the “Huihang” (LOA73.5m, D3.3m) could not find the drift of the buoy in time, eventually causing the ship to ground on the edge of the fairway.

3.3.2 Wharfs

The conditions of wharf, such as berth length, water depth, the scale of the swing-around waters, whether there is other ships on berth and the berth grade, have a great influence on the safety of the ship. When the berthing is at night, the background light affects the pilot's judgement of distance and azimuth. Wharf noise also affects the normal communication between the pilot and the ship, the port terminal captain, and the tugboat crew. The scale of the swing- around waters, the size of the ship, the way chose to swing by ship, and the prevailing wind and current conditions will directly affect the pilotage operation of the ship.

3.3.3 Traffic density

The density of ships basically reflects the frequency and safety of ship traffic in the waters. The results show that the quadratic relation between the number of ship collision and the ship density is corresponding. Ship density distribution refers to the spatial distribution of ships in a certain water area. The density distribution map can not only directly display the intensity of a ship in a certain area, but also clearly reflect its spatial distribution (Gu, 2016). The safety of pilotage will be reduced in the area with high ship density. Considering the difference of ship type, size and cargo carried in waters, it is very important to know the actual distribution of ships by traffic statistics.

3.3.4 Wind, flow and other natural conditions

The natural environment mainly refers to hydrological and meteorological conditions, such as wind, current, wave, surge, temperature, visibility, etc. The following is an analysis of the risk factors affecting pilotage from wind, current and visibility.

Ships are easily deviated from the fairway by wind and current. The strong crosswind and current have a great influence on the ship's course keeping ability. In extreme cases, it will be beyond the control of the ship itself, that is, the ship cannot keep direction by rudder. Wind drift is related to the ratio of freeboard to draft, wind speed, wind angle, heading and speed. The effect of current on ship is mainly reflected in the ship’s speed, the drift induced by current and the effect on rudder efficiency.

When berthing or unberthing, the ship will deflect under the force moment of wind flow.

The difficulty point of berthing or unberthing locates in how to restrain the influence of the wind and current on ship. If the wind is too strong, the speed of ship to downward wind will be quickened, so it is necessary to use tugboat to control the speed as soon as possible. There are many berths in the Jiangsu section that are inconsistent with the front flow field (even with an angle of up to 30). This situation is very dangerous to berthing or unberthing. According to the internal statistics of the Yangtze River pilot Center, in 2017 there were 8 cases in which ships broke lines due to the influence of strong cross-current during berthing and unberthing.

Poor visibility limits the visual observation capability of the pilots. It is difficult for the pilot to locate, navigate, turn, and find the ship as early as possible. Even with Radar, ARPA, AIS and other navigational aids, the pilots need to further process and analyze the relevant information. In addition, navigation aids have some limitations, and their effects are not as direct as the visual lookout. If the avoidance measures adopted by the ship cannot be identified by other ships, it will be very difficult for the pilot to make a correct judgement of the situation.

3.4 Conclusion

This chapter mainly introduces the risk of navigation aids, meteorology, hydrology and traffic flow to pilotage safety in Jiangsu section of the Yangtze River. At the same time, it analyzes the difficulties of different types of ships and their scales and draught for pilotage.

CHAPTER 4

Establishment of pilotage risk assessment model

Risk assessment refers to assessing the danger or safety of the entire system on the basis of hazard identification and analysis, and classifying the degree of danger according to relevant standards and specifications. It also proposes relevant measures for controlling risks in light of current technological and economic levels. It mainly consists of three parts：

⑴Hazard identification, identify unsafe factors, quantify the quantifiable parts, and conduct qualitative analysis of the unquantifiable parts；

⑵Safety assessment, evaluation of risk and possibility of occurrence, and conclusion；

⑶ Put forward improvement measures.

4.1 Common risk assessment methods

There are many commonly used risk assessment methods, including computer simulation method, safety index method, mathematical statistics method, grey theory method, applied extensions evaluation, set pair theory method, fuzzy comprehensive evaluation method, Bayesian network method, artificial neural network method, sub-analysis method, simulator simulation method and so on (Zheng & Wu, 1998).

4.1.1 Grey theory method

Grey Theory is an Applied Mathematics subject. The problem addressed is focused on special areas that contain unknown factors. In the aspect of maritime navigation safety evaluation, every traffic accident occurs under specific conditions. There are many uncertainties in the risk assessment of traffic accidents. The main reason is that it is difficult to collect accident data and many factors are difficult to quantify. Based on these characteristics, it is reasonable to introduce grey theory into maritime navigation safety evaluation.

4.1.2 Artificial neural network theory

In 1943, Neuron Mathematical Model was put forward by W. Mcculloch and W. Pitts, which provides the theoretical basis for the theory of artificial neural network. By imitating the running mechanism of animal neural network, the distributed parallel information processing is carried out, and the mathematical model of artificial neural network is established (Lin & Fang, 2010). A mathematical model of artificial neural network is established by imitating the running mechanism of animal neural network and processing distributed parallel information. By adjusting the connections between nodes within a complex system network, related information would be processed. As an interactive risk evaluation method, this method can modify the weight of evaluation index according to the needs of users, and make the evaluation results more in line with the user's expectations. Its biggest drawback is its implied nature, it can't get an explicit evaluation model, and its algorithm complexity is high.

4.1.3 Mathematical statistical method

The application of mathematical statistical method in the evaluation of maritime navigation safety is mainly based on the statistical analysis of various waterborne traffic accidents and the number of accidents or weighted events caused by a certain cause. Then the percentage of the causes of each accident is obtained. When using this method to evaluate, the number of samples must reach a certain scale, and the reliability of the evaluation results obtained from this method is relatively high. This method also has some limitations: 1) it can only show the absolute value of the percentage of various accident causes, and cannot reflect the correlation degree between each kind of cause and the accident; 2) it requires a lot of statistical sample data.

4.1.4 Computer aided evaluation method

There are two kinds of computer aided evaluation methods: computer simulation evaluation method and computer expert system safety evaluation method. The method of computer simulation and evaluation needs to construct the mathematical model of ship motion, simulate all kinds of ship navigation environment, ship sailing in this environment, collate and analyze the data during navigation, and establish the corresponding evaluation index system. The advantages of this method are: strong controllability and fast simulation speed. The drawback is that the evaluation results are meaningful only if the conditions are the same or similar to those of the simulation experiments, which are restricted by the simulation environment.

4.1.5 Data Envelopment Analysis (DEA)

DEA is an efficiency evaluation method based on relative efficiency. This method can estimate whether the addition of each decision making unit is appropriate or not, and give the direction and degree of the corresponding decision making unit to change the input scale (Yu et al, 2008). The advantage of this method is to evaluate the relative effectiveness of multi-output and multi-input, which is mainly applied in the field of social and cultural economy. The disadvantage is that the development of the unit can only be explained in a relative way, and cannot reflect the overall development.

4.2 The risk Evaluation method chosen in this paper

Ship pilotage risk assessment is a kind of risk assessment, many scholars pay attention to this field (Nuutinen & Noros, 2009; Venkatesh & Wanegas, 1995). They all have their own achievements, and based on these achievements, this paper chooses the fuzzy comprehensive evaluation method to carry out the pilot risk evaluation.

4.2.1 An overview of fuzzy comprehensive evaluation methods

The premise of fuzzy comprehensive evaluation is to determine fuzzy relation, that is, to establish fuzzy set. Fuzzy relation is represented by fuzzy matrix, and fuzzy comprehensive evaluation is carried out through the calculation of fuzzy matrix. The three elements of fuzzy comprehensive evaluation are: factor set, evaluation set and factor evaluation. The steps of establishing the model are: to determine the influencing factors; to establish the evaluation index system; and to evaluate each evaluation index by single factor.

The details of each step of the multifactorial comprehensive evaluation are as follows:

⑴Factor set

The set of influencing factors U is:

$$U = \{u_1, u_{2,} \dots, u_{n,}\} \tag{4.1}$$

Among it, $u_i(i = 1,2,\cdots,n)$ is the influence factor.

⑵Weight set

Determine the weight for each influencing factor and establish the set of factor weights $\widetilde{A}$, that is, the fuzzy subset on U:

$$\widetilde{A} = (a_1, a_2, \cdots, a_n) \tag{4.2}$$

In which, $a_i(i = 1,2,\cdots,n)$ is the degree of membership of the factor U to $\widetilde{A}$, and it reflects the importance of factors, satisfies nonnegative and normalization conditions:

$$\sum_{i=1}^{n} a_i = 1, a_i \geq 0 \tag{4.3}$$

⑶Evaluation set

The set of evaluation results $V = \{v_1, v_2, \cdots, v_m\}$is called evaluation set, in which $v_j(j = 1,2,\cdots,m)$ is a specific evaluation result;

⑷Single factor evaluation

Only one factor is evaluated. The evaluation is as follows: according to $u_j$in U, the degree of membership of v_j in V is r_{ij}, and the result is:

$$\widetilde{R_\imath} = (r_{i1}, r_{i2}, \cdots, r_{im}) \qquad (4.4)$$

Among them: $\widetilde{R_\imath}$ is single factor evaluation set;

⑸Fuzzy comprehensive evaluation

The multi-factor comprehensive evaluation matrix is as follows:

$$\widetilde{R} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{n3} \end{pmatrix} \qquad (4.5)$$

Among them: $r_{ij} = u_R(u_i, v_j)$,$0 \le r_{ij} \le 1$ means under the foundation U_i, get the evaluation result V_j's degree.

When $\widetilde{A}$ and $\widetilde{R}$ are known, the fuzzy comprehensive evaluation set $\widetilde{B}$ is obtained according to the multiplication of fuzzy matrix:

$$\widetilde{B} = A^\circ B = (a_1, a_2, \cdots, a_n) \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix} = (b_1, b_2, \cdots, b_3) \qquad (4.6)$$

Where: b_j is the degree of membership of the object to the j-th element in V.

⑹Evaluation result selection

Usually use the maximum membership method, the weighted average method and the fuzzy distribution method to select the results.

In summary, the establishment of fuzzy comprehensive evaluation model in this paper is as follows: 1, to determine the evaluation index system; 2, to determine the weight value of each index; 3, to determine the membership degree of each index; 4, comprehensive evaluation.

4.2.2 Reasons for choosing Fuzzy Comprehensive Evaluation method

Firstly, the navigation environment of a ship is a complex large system, with many influencing factors. The concept of each factor is not clear enough, difficult to quantify, and the classification standard of each factor is not consistent. These factors restrict and influence each other, and their emphasis is different, and the evaluation results are different. When evaluating a single factor, sometimes even for the same system, there would be two different results. Therefore, it is necessary to make a comprehensive evaluation of the system to solve the problem of the internal relationship between the various factors.

Secondly, the concept of ship pilotage safety itself is rather vague. The expert investigation method is often used in the evaluation, and the expert experience is taken as the main basis. However, the expert experience is summed up from the specific accident, the universality is poor, and it is difficult to quantify.

Thirdly, we choose this method as its advantages and disadvantages. ① It is suitable for quantitative evaluation for qualitative indicators. This method can be used to quantitatively evaluate non-artificial fuzzy factors in complex systems (Lin & Wu, 1998). Its evaluation results are in good agreement with the objective reality.② Its results are usually unique. For a single evaluation object, when the weight is the same and the composition way is the same, the evaluation result is generally unique. ③ The mathematical model is intuitionistic, simple and easy to operate. It can be applied both in objective and subjective evaluation. ④ This method is widely used in the evaluation of maritime navigation safety.

4.3 Establish index system

Through the above analysis and identification of the risk sources of ship pilotage in Jiangsu section of the Yangtze River, the index system is established in this section. The system consists of three first-class indexes and ten second-class indexes, which constitute the index system of ship pilotage risk in Jiangsu section of the Yangtze River.

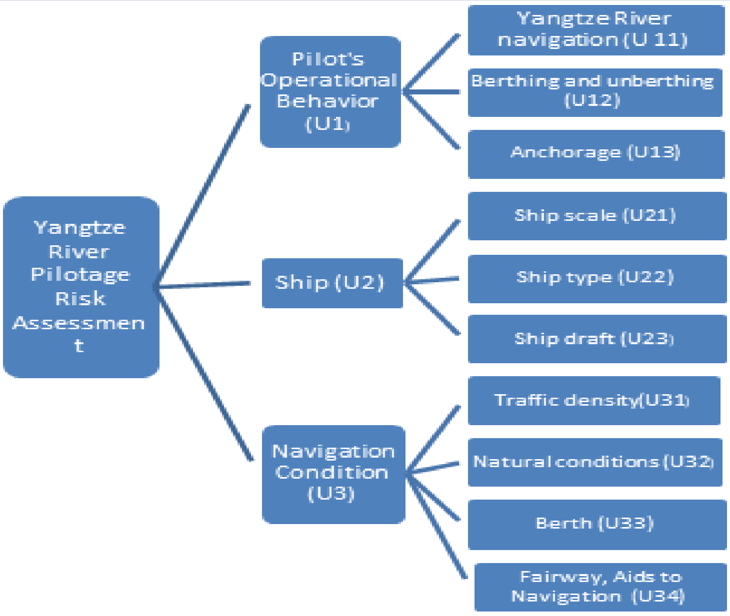

Figure 4.1 Yangtze River pilotage risk index system

Source: Draw by myself

In order to fully understand the influence of pilot on the behavior of pilotage in different conditions, two conditions were introduced into the questionnaire, that is, general weather and poor visibility. The specific questionnaire can be found in Appendix A, and the specific expression is shown in Figure 4-2.

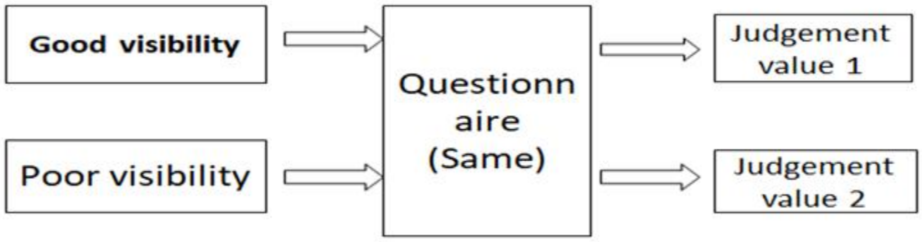

Figure 4.2 Weight determination under different conditions
Source: Draw by myself

In this case, U1, U2, U3, respectively, represent the pilot's operational behaviors, the attributes of the ship, and the conditions of the ship's traffic. U11, U12, U13 represents the three secondary sub factors under U1, which are respectively navigation of the Yangtze River, berthing or unberthing operation and mooring operation of the ship. U21, U22 and U23 represent 3 sub factors of U2: ship size, ship type and ship draught. U31, U32, U33 and U34 represent the four sub-factors under U3 , which are traffic density, natural conditions, wharf or berth, and fairway and aids to navigation. Write in a set as follows:

U = {pilot’s operational behavior U1, ship U2, Navigation condition U3};

U1 = {Yangtze River navigation U11, ship berthing U12, Anchorage operation U13};

U2 = {ship size U21, ship draft U22, ship type U23};

U3 = {traffic density U31, natural conditions U32, wharf U33, navigation aids U34}.

4.4 Verify the consistency of indicators and calculate the weight

In this paper, the analytic hierarchy process is used to determine the weight of each factor. The AHP originated in the 20th century. It was proposed by Professor Thomas L.Saaty of Pisburg University in America based on practical multi-principle decision method. It analyzes the evaluation objects on the basis of layer decomposition, and gives the decision scheme according to the scientific mathematical calculation together with the supervisor's judgement. The AHP is famous for its clarity, simplicity, wide range of application and strong systematicness. Its general working procedures are shown in figure 4.3.

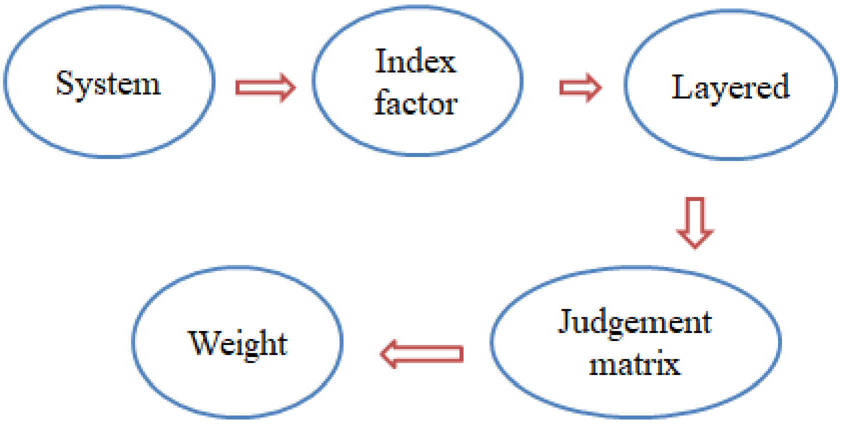

Figure 4.3 Working procedure
Source: Drawing by myself

In this paper, the weights of the third layer factors relative to the second layer and the weight of the second layer factors relative to the first layer are calculated by the hierarchical principle, the comparison principle of the mutual scaling and the sorting principle, and the weight of the lowest (third layers) relative to the target layer is finally determined.

Construction of judgment matrix: through the survey of pilot and related maritime practitioners in the Jiangsu section of the Yangtze River, comparative analysis is made to determine the relative importance of the adjacent level factors, as shown in table 4-1.

Table 4.1　　Judgement matrix

B_k	C_1	C_1	C_1
C_1	C_{11}	C_{12}	C_{13}
C_2	C_{21}	C_{22}	C_{23}
C_3	C_{31}	C_{32}	C_{33}

Source: Hu,S.P.(2014).Risk assessment on Maritime Transportation, p99

The upper-left corner in the judgment matrix represents the target factor of the previous level (Hu, 2014), while the horizontal and vertical column represents the lower level of the target factor. The element c_{ij} indicates the importance of considering the key element c_i relative to element c_j from the judgement criteria B_k, it is the ratio of each element to the weight of the upper level:

$$C_{ij} = \frac{w_i}{w_j} \qquad (4.7)$$

Using 1-9 as an identification to indicate that the former is extremely important compared to the latter, 7 indicates importance, 5 is comparative important, 3 is slightly important, 1 indicates equal importance. Using 1/3, 1/5, 1/7, 1/9 indicates the degree to which the former is less important than the latter. If the relative importance of the two indexes is between the above two adjacent scales, then the two indexes are marked with 8, 6, 4, 2.

The judgment matrix needs to satisfy the following properties:

$$C_{ij}C_{jk} = C_{ik} \qquad (4.8)$$

$$C_{ij}C_{ji} = 1 \qquad (4.9)$$

$$C_{nn} = 1 \qquad (4.10)$$

If there is complete consistency, there is only one non-zero largest characteristic root λ. But in practice, due to the subjectivity of expert scoring, it will not be able to give a judgment without deviation from the facts. To this, the following tests of consistency are performed:

$$\lambda = \frac{C\omega}{\omega} \qquad (4.11)$$

According to the characteristic vectors ω and λ, the consistency is judged by the following formula:

$$\text{C. I.} = \frac{\lambda - n}{n-1} \qquad (4.12)$$

When C.I.=0, the judgment matrix is completely consistent. C.I.<0.1 is generally considered acceptable. When the evaluation indexes are large, it is often difficult to make a large amount of judgement to be consistent. In this case, the consistency index C.I. needs to be corrected according to the order of the judgment matrix. Therefore, the index R.I. is introduced. R.I. As shown in Table 4.2.

Table 4.2 R.I.

Order	1	2	3	4	5	6	7	8	9
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Hu, S.P. (2014). Risk assessment on Maritime Transportation, p99

When the order number is greater than 2, the following formula needs to be used for calculation:

$$\text{C. R.} = \frac{C.I.}{R.I.} \qquad (4.13)$$

When C.R. is less than 0.1, the judgment matrix satisfies the consistency test, otherwise, the judgment value should be adjusted until C. R. less than 0.1.

The eigenvector calculation in this paper will be calculated using the sum-product method as follows.

The first step, normalization treatment:

$$\overline{C}_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \text{(i,j=1,2,….,n)} \qquad (4.14)$$

The second step is to add up the columns of the matrix:

$$\widetilde{\omega_\iota} = \sum_{j=1}^{n} \overline{C_{\iota J}} \ \text{(i=1,2,…n)} \qquad (4.15)$$

The third step is to divide the vector with n after the weight vector is added:

$$\omega_i = \frac{\widetilde{\omega_\iota}}{n} \qquad (4.16)$$

The fourth step, the maximum characteristic root is:

$$\lambda = \frac{\sum_{i=1}^{n} \frac{(A\omega)_i}{\omega_i}}{n} \qquad (4.17)$$

in which A is the judgment matrix.

4.5 Determination of membership degree of evaluation index

Delphi method (Yuan et al, 2011) is characterized by the authoritativeness and anonymity of the members of the expert group, the controlled convergence of the prediction process, and the quantitative nature of the prediction statistics. The general steps of the Delphi method are:

(1) Determine the purpose of the investigation and draw up an outline of the survey;

(2) Selecting a group of experts who are familiar with this problem, including experts in theory and practice;

(3) Issue questionnaires to all experts for consultation;

(4) Summarize and statistically analyze the opinions returned, and then send it back to relevant experts. In this way, after several rounds of opinions are concentrated, data processing and comprehensive results are obtained.

In this paper, the factors involved in the evaluation are preliminarily identified by sending questionnaires to pilots, port and maritime experts, and then the membership degree of each factor is obtained by statistical analysis based on the result of expert feedback. According to the statistical results, the membership degree is adjusted appropriately, and the final goal is consistent with the forecast result. The membership degree determination function is:

$$y = \begin{cases} 1 & x \geq x_{max} \\ \frac{x - x_{min}}{x_{max} - x_{min}} & x_{min} < x < x_{max} \\ 0 & x \leq x_{min} \end{cases} \qquad (4.18)$$

in which, X represents the expert score in the questionnaire, $0 \leqslant X \leqslant 100$.

4.6 Create a comment set

The evaluation result constitutes the comment set. The finer the comment set is, the more realistic the prediction will be. However, the amount of calculation will increase exponentially. Therefore, it is necessary to reasonably select the comment set.

There are many factors affecting the pilotage risk of ships in Jiangsu section of the Yangtze River. On the basis of investigation and reference, the evaluation set is divided into five levels:

$$V=\{V_1, V_2, V_3, V_4, V_5\}=\{45,65,75,85,95\} \quad (4.19)$$

In which, 95 means that the corresponding effect is extremely small, 85 is small, 75 is general, 65 is relatively significant, and 45 is extremely significant.

4.7 Establishment of ship pilotage risk Assessment Model in Jiangsu Section of the Yangtze River

After the weight matrix A obtained by AHP and the membership matrix B obtained by the expert questionnaire survey, the weighted evaluation model is used to calculate the comprehensive evaluation model：

$$\tilde{R} = (a_1, a_2, \cdots\cdots, a_n)^\circ \left\{ \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nn} \end{bmatrix} \right\} = (B_1, B_2, \cdots\cdots, B_n) \quad (4.20)$$

Bottom evaluation results will serve as middle level factor membership, combined with the weight coefficient of the middle level, the comprehensive evaluation results of this level will be obtained. In this way, the highest level of evaluation results can be obtained finally.

4.8 Comment set and Anti-fuzzy processing

4.8.1 Anti-fuzzy processing

The largest item b_i in the final comment set $\tilde{B} = (B_1, B_2, \cdots\cdots, B_n)$ is obtained by calculation, and the corresponding evaluation grade V_i is used as the evaluation result. In this case, the evaluation results can only use part of the information in b_i, cannot reflect the true information. In practical applications, each element in the comment set V=$\{V_1, V_2, V_3, V_4, V_5\}$ is usually assigned. After assignment, we get the parameter vector $\mathrm{C} = (C_1, C_2, \cdots\cdots, C_n)^T$ and then consider the final rating $\tilde{B}$. The calculations are as follows:

$$\tilde{P} = \tilde{B} \circ \mathrm{C} = (B_1, B_2, \cdots\cdots, B_n) \circ \begin{pmatrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{pmatrix} \qquad (4.21)$$

The P by calculation fully reflects the information brought by the evaluation set B and the gradation parameter vector C.

4.8.2 Selection of comment sets

This paper divides the comment set into 5 levels, that is, the above-mentioned set V = [extremely significant, relatively significant, general, small, extremely small], and based on the literature and other decisions made comments N = [45, 65, 75, 85, 95] set.

4.9 Conclusion

This chapter briefly summarizes the theory of safety evaluation, and establishes the evaluation index from 10 aspects, such as pilot's operational behavior, and so on, which lays the foundation for model validation of the fifth chapter.

CHAPTER 5

Application of pilotage risk Assessment Model in Jiangsu Section of Yangtze River

According to the risk assessment model of the Jiangsu section of the ship pilotage established in Chapter 4, the survey data after the questionnaire was introduced into the model, and the ship pilotage risk assessment results were calculated to determine the risk status of the Jiangsu section of the Yangtze River under normal weather conditions and poor visibility.

5.1 Model calculation under general weather conditions

The topic of the questionnaire covers all the indicators. According to the questionnaire, the geometric average method is used to get the value of the judgment matrix, so each of the data in the matrix is the geometric average of the questionnaire. In order to improve the quality of the questionnaire, people with maritime background and engaged in shipping for a long time were selected in this questionnaire. The main targets are experts and scholars from the Yangtze River pilot Center, Jiangsu MSA and other shipping related experts along the Yangtze River. In this survey, 85 questionnaires were issued and 80 questionnaires were collected. The formula for the averaging method is as follows:

$$C_{ij} = \sqrt[m]{\prod_{k=1}^{m} C_{ij}^{k}} \qquad (5.1)$$

According to the evaluation index system of pilotage risk in Jiangsu section mentioned in the previous chapter, the weight of each factor is calculated. A sample of the calculated weights will be shown in the following three subfactors of pilot's operational behavior (Yangtze River navigation U11, ship berthing or unbething U12, mooring operation U13). Based on the collected expert questionnaire, the following matrix is obtained:

$$\mathrm{C} = \begin{bmatrix} 1 & 2.0510 & 3.1240 \\ 0.4876 & 1 & 1.2465 \\ 0.3201 & 0.8022 & 1 \end{bmatrix} \qquad (5.2)$$

(1) The normalization of the judgment matrix:

$$\grave{C} = \begin{bmatrix} 0.5532 & 0.5323 & 0.5817 \\ 0.2697 & 0.2595 & 0.2321 \\ 0.1771 & 0.2082 & 0.1862 \end{bmatrix} \qquad (5.3)$$

(2) Add each line:

$$\grave{C}_1 = \sum_{i=1}^{3} \overline{C_{1\iota}} = 1.6672 \qquad (5.4)$$

$$\grave{C}_2 = \sum_{i=1}^{3} \overline{C_{2\iota}} = 0.7613 \qquad (5.5)$$

$$\grave{C}_3 = \sum_{i=1}^{3} \overline{C_{3\iota}} = 0.5715 \qquad (5.6)$$

normalized vector $\mathrm{C} = (1.6672, 0.7613, 0.5715)^T$;

(3) The weight of the calculation is as follows:

$$\omega_1 = \frac{\grave{C}_1}{\sum_{i=1}^{3} \grave{C}_\iota} = 0.5557 \qquad (5.7)$$

$$\omega_2 = \frac{\grave{C}_2}{\sum_{i=1}^{3} \grave{C}_\iota} = 0.2538 \qquad (5.8)$$

$$\omega_3 = \frac{\grave{C}_3}{\sum_{i=1}^{3} \grave{C}_\iota} = 0.1905 \qquad (5.10)$$

(4) Calculation of the maximum eigenvalue:

$$C°W = \begin{bmatrix} 1 & 2.0510 & 3.1240 \\ 0.4876 & 1 & 1.2465 \\ 0.3201 & 0.8022 & 1 \end{bmatrix} ° \begin{bmatrix} 0.5557 \\ 0.2538 \\ 0.1905 \end{bmatrix} = \begin{bmatrix} 1.6713 \\ 0.7622 \\ 0.5720 \end{bmatrix} \quad (5.11)$$

$$\lambda_{max} = \sum_{i=1}^{3} \frac{(C\omega)_i}{n\omega_i} = 3.0045 \quad (5.12)$$

(5) Consistency check of Judgment matrix:

$$\text{C.I.} = \frac{\lambda_{max} - n}{n-1} = 0.0023 \quad (5.13)$$

From Table 4.2, the R.I. value is 0.58, and the C.R. value is 0.0040<0.1, which meets the consistency check. Through the above calculation, the weight values of navigation U11, berthing operation U12 and mooring operation U13 of the Yangtze River are calculated. These three factors are satisfied in consistency and their weights are shown in Table 5.1.

Table 5.1 Weight of sub-factor of pilot's operational behavior

U1	NavigationU11	Berthing and unberthingU12	Anchoring operatioinU13
Weight	0.5557	0.2538	0.1905

Source: Draw by myself

5.2 Calculation of weight of other factors

5.2.1 Target layer weight calculation

Based on the example of U1 weight calculation, the following chapters calculate the weights of other levels respectively, as shown in Table 5.2 to Table 5.4.

Table 5.2 U

	U_1	U_2	U_3	λ_{max}	C.R.	ω
U_1	1.0000	1.3265	1.6547			0.4229
U_2	0.7539	1.0000	1.3854	3.0012	0.0010	0.3302
U_3	0.6043	0.7218	1.0000			0.2469

Source: Draw by myself

Table 5.3 U_2

	U_{21}	U_{22}	U_{23}	λ_{max}	C.R.	ω
U_{21}	1.0000	1.0000	2.0000			0.4111
U_{22}	1.0000	1.0000	1.0000	3.0537	0.0464	0.3278
U_{23}	0.5000	1.0000	1.0000			0.2611

Source: Draw by myself

Table 5.4 U_3

	U_{31}	U_{32}	U_{33}	U_{34}	λ_{max}	C.R.	ω
U_{31}	1.0000	1.2170	2.0513	1.6189			0.3374
U_{32}	0.8217	1.0000	2.1134	1.6851			0.3113
U_{33}	0.4875	0.4732	1.0000	1.0916	4.0194	0.0074	0.1694
U_{34}	0.6177	0.5934	0.9161	1.0000			0.1819

Source: Draw by myself

5.2.2 Comprehensive weight calculation

The comprehensive weight calculation table is shown in Table 5-5.

Table 5.5 Comprehensive weight calculation

	layer one	U_1	U_2	U_3	
sublayer		0.4229	0.3302	0.2469	CWV
U_{11}	0.5557	0	0	0	0.2350

U_{12}	0.2538	0	0	0	0.1073
U_{13}	0.1905	0	0	0	0.0806
U_{21}	0	0.4111	0	0	0.1357
U_{22}	0	0.3278	0	0	0.1082
U_{23}	0	0.2611	0	0	0.0862
U_{31}	0	0	0.3374	0	0.0833
U_{32}	0	0	0.3113	0	0.0769
U_{33}	0	0	0.1694	0	0.0418
U_{34}	0	0	0.1819	0	0.0449

CWV is short for Comprehensive weight value.

Source: Draw by myself

According to statistics, the comprehensive weight of ship pilotage safety in Jiangsu section of the Yangtze River is as follows:

W=[0.2350, 0.1073, 0.0806, 0.1357, 0.1082, 0.0862, 0.0833, 0.0769, 0.0418, 0.0449].

The weights range from small to large, that is, the degree of impact from small to large is: [U_{33}, U_{34}, U_{32}, U_{13}, U_{31}, U_{23}, U_{12}, U_{22}, U_{21}, U_{11}].

It can be seen that the navigation maneuvers (U11) of the Yangtze River pilots are the most important factors affecting the pilotage safety of the Jiangsu section of the Yangtze River. The size of ships is also a more important factor, especially when big draught ships are berthing or unberthing and passing the dense traffic areas.

According to the questionnaire score, the evaluation membership matrix R:

$$
R = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0.25 & 0.25 & 0.5 & 0 & 0 \\ 0 & 0.25 & 0.5 & 0.25 & 0 \\ 0 & 0 & 0.67 & 0 & 0.33 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0.75 & 0.25 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0.75 & 0.25 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0.33 & 0.67 & 0 & 0 \end{bmatrix} \quad (5.14)
$$

Calculation results B:

$$
B = W{\circ}R = [0.0268, \quad 0.0618, \quad 0.8056, \quad 0.0609, \quad 0.0448] \quad (5.15)
$$

Comment set assignment vector N= $[45，65，75，85，95]^T$, defuzzification calculation based on formula (4.21), P=B ° N=75.0755. Final evaluation score P=75.0755. The results show that the effect is general.

5.3 Calculation of the weight of pilot's Behavioral factors under the condition of poor visibility

According to the calculation of comprehensive weights, taking into account the criticality of human operations, an expert survey questionnaire is conducted on the sub-factor U1 of the behavioral factors of pilots under poor visibility conditions. Calculate and analyze the weights of pilots’ behavior in pilots under poor visibility, with other factors unchanged. Its judgment matrix and weight are shown in Table 5.6.

Table5.6 Weights of pilots' operation factors under poor visibility

	U_{11}	U_{12}	U_{13}	λ_{max}	C.R.	ω
U_{11}	1.0000	2.5372	3.5252			0.5952
U_{12}	0.3941	1.0000	1.4658	3.0004	0.0002	0.2389
U_{13}	0.2837	0.6822	1.0000			0.1659

Source: Draw by myself

In the case of poor visibility, the navigational behavior weight is 0.5952, which is the subordinate factor of pilot's operational behavior. Compared with the normal weather, the risk of navigational behavior is obviously increased, which has the greatest influence on pilotage safety. The same goes for berthing or unberthing operations, while increasing little. It can also be seen that the weight of mooring (anchoring) operations is relatively small, so it can be regarded as the relatively safe behavior under poor visibility.

The main reason for poor visibility in the Jiangsu section of the Yangtze River is fog and haze and severe convective weather. November to March of next year is the main fog season in Jiangsu. Most of the fogs in Jiangsu Province are radiation fog and advection fog coming from the sea after March. Heavy rain often occurs in spring and summer, which is also the cause of poor visibility. The heavy rain in summer brought the visibility down to zero in an instant, which caused great harm to the safety of ship navigation, though it lasts a short time, and it usually takes about 10 minutes.

Poor visibility limits the visual observation range of ship stewards, which makes it difficult for them to find buoys and shore markers in time to determine the ship's position, thus affecting the ship's navigation, avoidance and other operations. At the same time, the propagation of acoustic signals in the fog is affected. It is difficult to clearly distinguish the acoustic signals of other ships even at close distances. The most dangerous thing is that the avoidance measures adopted by the ship cannot be recognized by the other ship in time because of the poor visibility, thus affecting the judgment of the situation by both pilots and bringing great difficulties to the decision-making of the ship operation. When the visibility is poor, the speed of the ship is generally reduced, which also prolongs the time of navigation in the ship, and increases the psychological pressure of pilot, which is easy to cause the fatigue of the pilot.

5.4 Suggestions on ship pilotage safety decision in Jiangsu section of the Yangtze River

It is the ultimate purpose of this study to put forward reasonable decision suggestions based on the evaluation results. According to the weight of each index factor in 5.2 and 5.3, the following decision-making suggestions are put forward.

5.4.1 Pilot’s operational behavior

According to the above calculation, the weight of pilot's operation factor is 0.4229, in which the weight of navigational is 0.5557, the weight of berthing or unberthing is 0.2538, and the weight of mooring operation is 0.1905. The navigation operation weight is 0.5952 under poor visibility. The influence of navigation behavior on pilotage safety becomes more serious under bad weather conditions.

Based on the above analysis, this paper puts forward the following suggestions from the aspects of training the safety consciousness of pilots, improving the skills of ship handling, the utilization of bridge resources and the use of navigator navigation aid system.

(1) Strengthening the training of Pilots' Safety Awareness.

In the pilotage practice, the cultivation of safety awareness comes from two aspects: initiative and passivity. The initiative depends on the pilot itself, and the passive depends on the environment. Active acquisition means that pilots themselves verify on the basis of existing knowledge, or enrich in practice, or learn from practice. Passive acquisition is through the guidance of others, advice, these others pointed out the shortcomings are gains.

⑵ Improvement of ship handling skills.

The Yangtze River pilot Center can make full use of simulators and other ways to strengthen the training of pilots' professional skills, especially in dense traffic waters. The simulator can simulate a variety of ship types (full load tanker, ore ship, container ship, etc.) for pilots to be familiar, and can simulate different ships and situations as their needs. It can improve the ability of pilot to operate and use electronic navigation aids, such as VHF, radar, etc., can improve the ability of pilot to dock, and can improve the ability about emergency response handling skills.

⑶ Strengthening the Utilization of Bridge Resources.

Pilot bridge resource management can make pilots integrate into the ship team, make them clear their responsibilities and division of labor in the work of the bridge group, give full play to the team role of all the crew, improve the ability to correctly judge and deal with the complex situation, so as to ensure the safe navigation of the ship. Therefore, the pilot must communicate effectively with the crew on the bridge, and the other members of the bridge team must inform the pilot in time of the relevant information, such as position information, dynamic information of other ships, etc. After joining the bridge team, the pilot must try their best to enhance situational and team awareness of whole bridge team.

⑷ E-Pilot aid system.

Further increase pilotage safety by equipping the corresponding portable navigation aids with sufficient information. At present, the Yangtze River pilot has been equipped with the "e-pilot" navigation system. At present, the system can only be an information supply mode, and the information feedback mode has not been developed. If a feedback interface can be added to the navigation system, all pilots can more easily obtain information on nearby or upcoming waters. For example, if the upstream pilot finds that visibility is getting poor, the pilot can immediately send the message to other pilots by clicking on feedback.

5.4.2 Ship aspect

According to the weight calculation, the weight of ship aspect is 0.3302, in which the ship size weight is 0.4111, the ship draft weight is 0.3278, and the ship type weight is 0.2611. It can be seen that ship size is the most important factor, ship draught second.

Therefore, it is suggested that the pilot should fully know about the ship information before embarking, and after boarding, he should check the operational performance of the ship by means of Pilot card and ship's particular, as well as by seeking confirmation from the captain, such as the ship's changing direction performance, changing speed performance, and so on. It is necessary for pilot to master the inertia of the ship, the response time of the main engine, the stopping distance the ship, the minimal steering speed.

5.4.3 Traffic condition factor

The weight of traffic condition factor is 0.2469, the weight of navigation mark is 0.3113, the weight of ship traffic density is 0.3374, the weight of wharf is 0.1694, and the weight of natural condition such as wind current is 0.1819. According to the above data, the factor of traffic density is the most important one, followed by other factors. So, the suggestions list following:

⑴ Strengthening Information and Resource sharing between pilot Station and Traffic Control departments. The pilot should make full use of the traffic flow information resources of VTS in special waters and special time period to analyze the traffic situation of the navigation and the related waters around the ship, so as to adjust the pilot scheme accurately. On the one hand, it enables the pilot to keep abreast of the vessel flow data or congestion in the forward waters(if congestion occurs, the pilot can apply for VTS for traffic organization); on the other hand, the pilot can ask for VTS to guide the small vessels who navigate in an abnormal way.

⑵ The waterway department and other units are required to timely scan the Yangtze River waterway and the waters near berth. By comparing the old and new charts, the pilot can know about the water depth changes.

⑶ Pilot stations should obtain the latest meteorological data in time. Meanwhile, pilots should carefully check the natural conditions such as wind, flow, visibility and so on before embark the ship, especially in poor visibility or crowded waters.

5.5 Conclusion

In this chapter, the pilotage risk of the whole Jiangsu section is evaluated under the two conditions of normal visibility and poor visibility, and the comparison and analysis of the actual situation are carried out. Finally, based on the evaluation results, some suggestions and measures are put forward to improve the pilotage safety.

CHAPTER 6

Conclusion and Prospect

6.1 Conclusion

This paper uses fuzzy comprehensive evaluation to study the pilotage risk of ships in Jiangsu section of the Yangtze River. The main research contents are as follows:

⑴ In this paper, fuzzy comprehensive evaluation is used as the mathematical evaluation method, and the classical process of fuzzy comprehensive evaluation is continued: risk factor identification, risk evaluation and decision suggestion. In the stage of risk factor identification, the expert brainstorming method is used to investigate the pilot, captain and other experts in the Yangtze River pilot Center.

⑵ On the basis of synthetically analyzing the characteristics of Jiangsu section, the target layer is subdivided into 3 sub-factors, such as pilot behavior, ship aspect, traffic condition, and then subdivided into 10 sub-factors, such as berthing behavior, the size of ship, the traffic density and so on. According to "man", "ship" and "environment", this paper constructs pilotage risk evaluation index system, calculates the weight, and determines the dangerous degree of each index system.

⑶ This paper establishes the risk index system and evaluation model of the pilotage in Jiangsu section, and compares the changed weights under different environmental factors through the questionnaire. The change of pilotage risk with visibility factors is also identified.

⑷ According to the weight calculation and fuzzy comprehensive evaluation of pilotage risk evaluation index system, the dangerous degree of each index is determined, and the pilotage risk grade of Jiangsu section port is close to good. On this basis, some safety suggestions on pilotage operational behavior, ship aspect and traffic conditions are given respectively, such as the training of pilot safety consciousness, the improvement of ship handling skills, the utilization of bridge team resources, and the mastery of ship performance, improving pilotage aid equipment and share information with VTS.

6.2 Insufficiency and outlook

When establishing the assessment model, the pilot behavioral factors were separately investigated under the two kinds of weather conditions, and corresponding conclusions and recommendations were obtained based on the model.

This paper only discusses the influence of a sub-factor of pilot operational behavior on pilotage safety under poor visibility and normal visibility. However, due to the time factor, the factors are not divided into two factors.

In view of the above shortcomings, in future research, we will consider the change of weight values under different weather conditions and the change of evaluation results at all index levels.

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APPENDIX

Distinguished experts:

In order to complete the graduation design, a questionnaire is made to evaluate the pilotage risk of ships in the waters of Jiangsu section of the Yangtze River by using the evaluation model. I hope you will give me some valuable advice during your busy schedule.

Thanks for your help.

1. What is the influence degree of ship berthing or unberthing on Pilotage risk in Jiangsu section of Yangtze River? [single choice]

A extremely small　　B small　　C general

D relatively significant　　E extremely significant

2. What is the impact of navigational behavior in the waters on pilotage risk? [single choice]

A extremely small　　B small　　C general

D relatively significant　　E extremely significant

3. What is the influence of cross-encounter behavior on pilotage risk in this water area? [single choice]

A extremely small　　B small　　C general

D relatively significant　　E extremely significant

4. What is the influence of ship Anchorage manipulation on pilotage risk in this water? [single choice]

A extremely small　　B small　　C general

D relatively significant　　E extremely significant

5. What is the influence degree of pilotage ship size on Pilotage risk in the water? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

6. What is the influence degree of the draught of the drawn vessel on the pilotage risk in this water? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

7. What is the influence level of pilotage ship type on Pilotage risk in this water? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

8. What is the influence grade of navigational aids and navigation aids on Pilotage risk? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

9. What is the influence grade of wharf condition on pilotage risk? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

10. What is the influence of natural conditions such as wind and current on pilotage risk in this water? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

11. What is the influence degree of traffic flow density on Pilotage risk in this area? [single choice]

A extremely small B small C general

D relatively significant E extremely significant

The following topics please assign a value to the importance of the two in relation to the pilotage risk of a ship. For example, the pilot's operational behavior / the ship aspect can take 1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, 9. You can also go to the intermediate values like 1/8, 1/6, 1/4, 1/2, 2, 4, 6, 8.

12. What is the value of "pilot's operational behavior" in pilotage risk compared with "ship aspect" in this water?

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13. What is the value of "pilot's operational behavior" in pilotage risk compared with "traffic condition" in this water?

----

14. What is the value of "berthing or unberthing operation" in pilotage risk compared with "mooring operation" in this water?

----

15. What is the value of "ship aspects" in pilotage risk compared with "traffic condition" in this water?

----

16. What is the value of "berthing or unberthing operation" in pilotage risk compared with "navigational operation" in this water?

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17. What is the value of "mooring operation" in pilotage risk compared with "navigational operation" in this water?

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18. What is the value of "ship size" in pilotage risk compared with "ship draft" in this water?

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19. What is the value of "ship size" in pilotage risk compared with "ship type" in this water?

----

20. What is the value of "ship draft" in pilotage risk compared with "ship type" in this water?

----

21. What is the value of "navigational aids or other facilities" in pilotage risk compared with "wharfs or berths" in this water?

----

22. What is the value of "navigational aids or other facilities" in pilotage risk compared with "natural conditions, such as wind, flow" in this water?

----

23. What is the value of "navigational aids or other facilities" in pilotage risk compared with "traffic density" in this water?

----

24. What is the value of "wharfs or berths" in pilotage risk compared with "traffic density" in this water?

----

25. What is the value of "wharfs or berths" in pilotage risk compared with "natural conditions, such as wind, flow" in this water?

----

26. What is the value of “natural conditions, such as wind, flow” in pilotage risk compared with “traffic density” in this water?

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27. What other factors do you think affect pilotage risk in this waters?

