World Maritime University

The Maritime Commons: Digital Repository of the World Maritime University

Maritime Safety & Environment Management Dissertations (Dalian)

Maritime Safety & Environment Management (Dalian)

8-27-2021

Optimal scheme of ships’ routeing system in the Yangtze Estuary based on analytical hierarchy process

Yixiang Zhang

Follow this and additional works at: https://commons.wmu.se/msem_dissertations

Part of the Environmental Monitoring Commons, Public Administration Commons, and the Transportation Commons

This Dissertation is brought to you courtesy of Maritime Commons. Open Access items may be downloaded for non-commercial, fair use academic purposes. No items may be hosted on another server or web site without express written permission from the World Maritime University. For more information, please contact library@wmu.se.

WORLD MARITIME UNIVERSITY
Dalian, China

OPTIMAL SCHEME OF SHIPS' ROUTEING SYSTEM IN THE YANGTZE ESTUARY BASED ON ANALYTICAL HIERARCHY PROCESS

By

ZHANG YIXIANG
The People's Republic of China

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

MASTER OF SCIENCE

In

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2021

© Copyright Zhang Yixiang, 2021

DECLARATION

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

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

Signature:

Date:

Supervised by: Professor Cao Yuchi

Dalian Maritime University

Assessor:

Co-assessor:

ACKNOWLEDGEMENT

I am very grateful to WMU and DMU for giving me this precious learning opportunity, and thank the teachers for their hard work. After more than a year of study, my knowledge reserve and learning ability have been improved, which all contribute to my career development.

I am very grateful to my supervisor Prof. Cao Yuchi, for guiding me through this work, and for providing me with valuable suggestions and insights on the subject. His rich knowledge and rigorous research attitude will benefit my future career and life.

I am also very grateful to the leaders and colleagues of the Shanghai Maritime Safety Administration and Wusong Maritime Safety Administration for their strong support for my study. Especially when writing this article, they provided me with a lot of material. At the same time, I am also very grateful to my classmates Wang Zhihao, Zhang Weipeng, Zhang Zhimin and Yujian etc. Their rich social experience, solid theoretical foundation, and rigorous academic spirit have greatly helped me.

Last but not least, I am very grateful to my family and friends for their support and encouragement.

ABSTRACT

Title of Dissertation: **Optimal Scheme of Ships' Routeing System in the Yangtze Estuary Based on Analytical Hierarchy Process**

Degree: **MSc**

The Yangtze Estuary is the intersection of the Yangtze River and the north-south channel along the coast of China. In order to maintain the order of ship traffic, improve the navigation environment, ensure the safety of ships, the national authority has implemented the Ships' Routeing System in the Yangtze Estuary. Since the implementation of the routeing system, it has played a positive role in regulating the traffic order. However, due to the large-scale and high-speed development of ships, and the increasing number of navigable ships, new navigable risks have emerged in the Yangtze Estuary. On the basis of field investigation and data collection, this paper conducts a comprehensive analysis of the traffic environment. Through accident analysis and questionnaire surveys, the risks of the current routeing system are summarized. And based on the theory of ship traffic conflict and the theory of ship domain, the optimization plan of the ships' routeing system in Yangtze Estuary was proposed. In order to further determine the safety and standardization of the optimized routeing system, a combination of expert questionnaire survey and analytic hierarchy process was used to compare and select the existing routeing plan and the optimized plan.

KEY WORDS: Yangtze Estuary; Ships' Routeing System; Traffic conflict； optimization； Analytic Hierarchy Process

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
AM	Access management
CJK	Changjiangkou
cm	Centimeter
COLREGS	International Regulations for Preventing Collisions at Sea
CWM	Comprehensive weighing method
GIS	Geographic Information System
IMO	International Maritime Orgnization
m	Meter
MMSI	Maritime Mobile Service Identify
MOT	Ministry of Transport of the People's Republic of China
MSA	Maritime Safety Administration
PHA	Pre-hazard analysis
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
VCM	Variation coefficient method
VDR	Voyage Data Recorder
VHF	Very High Frequency
VTS	Vessel Traffic Service

CHAPTER 1 INTRODUCTION

1.1 Background

The ships' routeing system is a system that specifies the routes or traffic lanes that ships follow or adopt when navigating in certain areas on the water. It is the main means to implement effective management in areas with heavy water traffic. It is also an important measure to improve the navigation order and navigation environment of ships on the water（International Maritime Orgnization[IMO],1986). In March 1971, IMO put forward a recommendation that all traffic separation systems must be enforced. This recommendation was adopted by the IMO Conference in the same year. Since then, the British, French, and Belgian governments have also submitted from time to time amendments to the ships' routeing system of the Dover Strait to amend various amendments made due to changes in navigable waters(IMO,2021). In 1985, IMO passed the "General Provisions on Ship Routeing System", which marked that the complete framework of the routeing system has been basically established. Since then, every country in the world has continued to strengthen research in this area. Almost every year, new routeing systems and existing routeing system amendments are submitted to IMO for approval. From the perspective of geographical distribution, most important international navigation waters in the world have established routeing systems. In order to safeguard national interests, reduce the risk of pollution from ships, improve the safety of ships in China's coastal waters, and improve the efficiency of water transportation， on the basis of in-depth research, the Ministry of Transport of the People's Republic of China(MOT) promulgated the "National Coastal Ships' routeing system Master Plan" in 2011, and China has promoted and implemented the ships' routeing system in many waters.

The Yangtze Estuary is located in the central part of the coast of China, bordering the Yellow Sea to the north, Zhoushan Islands to the south, the East China Sea to the east, and the Yangtze River to the west. The Yangtze Estuary is the access to the sea for the golden waterway of the Yangtze River. It is the intersection of the Yangtze River and the north-south channel along the coast of China. It plays a vital role in the development of Shanghai Port and even the upper and middle reaches of the Yangtze River. The estuary section of large rivers connects inland rivers and the sea, and is the main throat for ships to enter and exit the rivers and seas. It is often high-density waters with high-density ship traffic, and the waters of the Yangtze Estuary are typical waters with dense traffic. In order to maintain the order of ship traffic, improve the navigation environment, ensure the safety of ships, and promote the development of shipping, the MOT formally implemented the "Yangtze Estuary Ships' routeing system" on June 1, 2008. Since its implementation, the routeing system has played a positive role in regulating the navigation order on the Yangtze Estuary. However, due to the development of large-scale and high-speed ships, coupled with the continuous increase in the number of ships in the Yangtze Estuary, ship traffic accidents still occur in the waters of the Yangtze Estuary.

1.2 Purpose and significance of the study

To sum up, a series of new situations and new problems have emerged in the navigation safety management of the Yangtze Estuary waters. The current management rules and methods can no longer fully meet the needs of traffic. The current ships' routeing system in the Yangtze Estuary has certain risks. In order to improve the traffic safety and efficiency of ships in the waters of the Yangtze Estuary, this paper studies the current risks of the ship' routeing system of Yangtze Estuary in a targeted manner, and proposes an optimized ships' routeing system scheme in

Yangtze Estuary.

1.3 Research status

1.3.1 Domestic research status

In the late 1970s, China began to introduce a ships’ routeing system, and implemented ships’ routeing systems in heavy traffic waters such as Chengshantou, the Yangtze Estuary, the Pearl River Estuary, and the Qiongzhou Strait. Many domestic scholars have conducted a lot of researches on the security of the precautionary area and the implementation effect of the ships’ routeing system from the perspectives of the evaluation and optimization of the ships’ routeing system and the research on the security level of the precautionary area.

In terms of theoretical research on ships’ routeing system design, many scholars have adopted data-driven methods to study the elements of ships’ routeing system design. Liang Qinhua(2008) adopted the AIS-based actual observation method of maritime traffic, combined with the characteristics of maritime traffic accidents in the Bohai Sea, and designed a set of reasonable routeing system plans for the Bohai Sea. Gao Weijie(2009) analyzed the traffic flow data of the Bohai Strait, and proposed an integrated optimization plan for the ships’ routeing system. On the basis of the existing ships’ routeing system, the ships’ routeing system in the Bohai Strait was improved. Based on the statistical data of the constituent elements, Xing Chengyin(2013) conducted a cluster analysis of the traffic separation system in coastal waters, and conducted real-time observations to obtain basic data of various traffic elements, and came up with the design rules of the constituent elements of the traffic separation system. Liu Yihua et al.(2014) used AIS data-based methods to conduct marine traffic surveys in the waters of the jurisdiction, and analyze in detail the data of the shipping routes and crossings in the jurisdiction.They studied the characteristics of ship traffic in this water area from the macro and micro perspectives, and determined the overall design plan of the ship routing system, the setting of warning areas and the width of the waters of the routeing system. Tan Jian(2012) et al. learned from the successful experience of the implementation of the Yangtze River routeing system and discussed the implementation of the ships' routeing system on the Xijiang trunk line, taking Zhaoqing and Yunfu waters as examples to analyze the necessity and feasibility of implementing the routeing system on the Xijiang trunk line. On the basis of investigations on the traffic conditions of the Dangan Waterway and the ships' routeing system, Guo Weibin and Fan Zhongzhou(2014) proposed amendments to the Dangan Waterway ships' routeing system. Sheng Yuxin(2015) used traffic flow model calculations and fuzzy comprehensive evaluation methods to put forward an index to reduce the risk of Laotieshan waterway. He analyzed and calculated the channel widening value respectively, and selected the best calculation plan from it. Zhang Wenjun et al.(2016) analyzed the navigation environment of Caofeidian waters and the routeing system of Caofeidian waters, and put forward suggestions on optimizing the navigation lanes, adjusting the west anchorage and modifying the channel of the second port basin of Caofeidian. Yuan Zhitao et al.(2018) took the Aokou waters of Sandu, Fujian as an example. Based on the calculation and analysis of ship track concentration and ship navigation interference, they proposed a preliminary design plan for ships' routeing system in Sanduaokou waters.

In the evaluation of ships' routeing system, Liu Dexin and Yang Shouren(1989) systematically summarized 11 technical factors that should usually be considered in the planning and design of lane separation and navigation, and proposed an evaluation model for lane separation schemes based on the fuzzy analytic hierarchy process. Based on the ships’ routeing system project of the Anhui section of the Yangtze River, Wang Ling(2007) conducted a wide range of social surveys by means of social questionnaire surveys, and put forward the idea of establishing a social evaluation system for the ships’ routeing system project. Xing Yongheng(2008) took the ships’ routeing system in Laotieshan shan waterway as a specific research object, by analyzing the statistics, and evaluating the effects of the Laotieshan shan waterway ship routing system and the problems that existed after implementation. Chu Lihui(2009) investigated the factors affecting the hazard degree of the ship's navigation environment in the waters near the port, used MATLAB software to simulate the membership function, and proposed a fuzzy comprehensive evaluation model for the degree of risk of the ship's routeing system in the waters near the port. Cui Juan(2012) counted and analyzed the number of water traffic accidents before the implementation of the routeing system in the waters of the routeing system waters. This is the first time that time series analysis was applied to the field of safety effect evaluation after the implementation of routeing system. Yin Xianming(2011) proposed a design plan for the ships’ routeing system in Rizhao Port area, and evaluated the proposed plan by using the analytic hierarchy process. He used Autoregressive Integrated Moving Average Model(ARIMA) prediction model and interference prediction model to perform data fitting analysis and effect prediction analysis on the implementation plan to verify the rationality and effectiveness of the planning plan. Fan Zhongzhou et al.(2014) used grey system theory to evaluate the effect of ships’ routeing system in Chengshanjiao with analytic hierarchy process, extension theory evaluation method and fuzzy neural network evaluation method, and analyzed the applicability of the three evaluation methods. In order to test the effect of the ships’ routeing system in the Qiongzhou Strait, Zhuo Yongqiang and Tao Jun(2015) analyzed the effectiveness of the ships’ routeing system from the aspects of traffic efficiency evaluation, safety evaluation and rationality evaluation. And they put forward a plan to further improve the ships' routeing system in Qiongzhou Strait. Sun Hao(2016) used a mathematical model based on the improved mean square error method to conduct a post-evaluation study on the revised ships' routeing system for Dangan waterways, taking into consideration the inherent relationship between the index factors. In the research on the optimization of the ships' routeing system, Hu Zonghua(2012) conducted statistics on ship traffic accidents in the eastern waters of Chengshanjiao, and proceeded from the different perspectives of large ships' routeing system users, managers and design planners. Comprehensive evaluation, traffic flow simulation, traffic environment pressure evaluation, Technique for Order Preference by Similarity to an Ideal Solution(TOPSIS) and other related theories and methods are used to evaluate and select the best routeing system. Li Haijiang(2015) used the set to verify the feasibility of the analysis and evaluation model, and improved the evaluation model based on the entropy weight method, and optimized and evaluated the revised ship routeing scheme. Ai Xiaobo and Hu Youneng(2015) systematically studied the optimal method of ships' routeing system, and comprehensively analyzed the factors that affecting the ships' routeing system plan. Xu Caiyun et al.(2017) put forward several feasible schemes for ships' routeing system in the Minjiang Estuary according to the international norms of the routeing system, and compared and selected these schemes in combination with the traffic conflict technology, and came up with the best recommended scheme.

Feng Zijian(2015) conducted a statistical analysis of the ship traffic flow of the Dahao Waterway and Dangan Waterway through research and questionnaire surveys. Combined with the actual traffic environment, a comprehensive evaluation system was established to have a comprehensive understanding of the implementation of the ships' routeing system, and provided reference for the follow-up management work of relevant agencies. To determine the navigation risk of the ships' routeing system, Huang Changhai et al.(2014) used CWM and VCM to establish a navigation risk rating and ranking model, and test their consistency. The research results proved that the model can be used to solve the uncertainty of many factors in the navigation risk assessment of route-based waters, and it can be popularized and applied in actual projects. In response to the rapid growth of Ningbo and Zhoushan port areas and changes in traffic patterns, Liu Jibo et al.(2013) introduced the navigation characteristics of the ships' routeing system in this water area, analyzed the hidden safety hazards in the routeing system water area, and put forward countermeasures and suggestions. According to the characteristics of high density and complexity of traffic flow in the precautionary area of the ships' routeing system, Li Song et al.(2013) used the research methods of traffic conflict technology to focus on the conflict of traffic flow in the precautionary area. The methods of changing the small-angle oblique channel crossing in the precautionary area to a large angle and the channelized traffic design in the precautionary area are proposed. In response to the rapid increase in traffic in the Bohai Sea, Zhao Chunyang et al.(2013) conducted a statistical analysis of traffic flow patterns and ship traffic accidents in the waters, and proposed an optimization plan. According to the current traffic situation in Luoyuan Bay, Chen Hong et al.(2013) summarized the risk evaluation index system of the water area through statistical analysis of water traffic accidents and traffic data. The fuzzy mathematics theory was used to establish an evaluation model to comprehensively evaluate the risk of the navigation environment of Luoyuan Bay, and propose measures to improve the navigation environment of Luoyuan Bay.

1.3.2 Research status abroad

Jason et al.(2003) conducted a modeling study on the impact of new routes on the safe navigation of ships in the San Francisco Bay area on the west coast of the

United States. He analyzed the degree of traffic congestion in the area through the model, and compared the simulation results with the actual situation for evaluation. Bimur Ozbas Ihan(2007) investigated and modeled the maritime traffic environment in the Istanbul Strait, analyzed the factors affecting navigation safety, and summarized the interrelationship between the factors. Dong et al.(2016) conducted research at Lehigh University in the United States and developed a task-based ship routeing decision support system that considers multiple performance indicators to solve the decision-making problems of smart ships and also provide a reference for the design of routeing systems. Hwang(2016) introduced a new navigation safety zone risk assessment model, and proposed a new algorithm to determine the ship domain to support the management of ships by MSA or VTS Centers. Based on the concept of navigational hazard, Vladimir (2000) analyzed and assessed the safety of ship traffic, and established a navigational safety management system for waterways, and made targeted improvements to ship traffic safety. Toke et al.(2013) took a bridge across the Fehamline Belt between Denmark and Germany as the research object, evaluated the TSS traffic guidance efficiency through the main bridge opening, and calculated the navigation efficiency of ships in the traffic separation area. This method has been well applied in areas with dense ship traffic. In order to solve the multi-ship encounter problem in the waters of ships' routeing system, Szapczynski(2013) adopted evolutionary algorithm to study the optimal trajectory of ships based on the rules of collision avoidance, so as to achieve the purpose of ship collision avoidance. Jun Min Mou et al.(2010) took the European Rotterdam Port TSS as an example, and used AIS data to perform statistical analysis on ships involved in collisions. In order to determine the correlation between the key index CPA for collision avoidance and the size, speed and heading of the ship, a linear regression model was established. In order to assess the risk, a dynamic assessment method based on SAMSON was proposed.

1.3.3 Research status of ships' routeing system in the Yangtze Estuary

In summary, many scholars have done a lot of research in the research of ship' routeing system. Many scholars have mainly adopted a variety of evaluation methods including TOPSIS optimization evaluation model method and analytic hierarchy process, etc., and have made certain contributions to the theoretical research and evaluation and optimization of ships' routeing system. Since the implementation of the ships' routeing system in Yangtze Estuary in 2008, it has played a role in maintaining navigation order and improving navigation safety and efficiency. Scholars have also carried out related research on the routeing system. Aiming at the implementation of the ships' routeing system in Yangtze Estuary and combining the characteristics of the ship flow in the waters, Qian Weizhong and Li Zhiyong(2010) proposed the regular navigation method and appropriate measures for ships in the waters of the routeing system, to ensure the effective implementation of the ships' routeing system in the Yangtze Estuary. Hu Bin and Zhan Haidong refer to the "Entry and Exit Management Strategy" (AM) and put forward optimization suggestions for the precautionary area A in the Yangtze Estuary. Zhang Hao and others combined with the research work on the ships' routeing system of the Yangtze Estuary in recent years, and established a ships' routeing system design plan evaluation model to evaluate the routeing system. In order to improve the navigation safety of the Yangtze Estuary, Bai Xiangen et al.(2016) analyzed the current status of the ships' routeing system in the Yangtze Estuary, analyzed the existing problems, and put forward an optimization plan. And use traffic conflict technology, take a precautionary area as an example, evaluate the optimization plan. However, in the past four years, the number of ships in the Yangtze Estuary has increased, and the trend of large ships has become obvious. The ship' routeing system in Yangtze Estuary has faced new problems. At present, there are few optimization studies on the new problems of the ships' routeing system in the Yangtze Estuary.

1.4 Research method

This paper adopts research methods such as field survey, interviews and discussion and questionnaire survey, big data statistical analysis, ship traffic conflict theory, ship domain, literature analysis method, qualitative and general navigation quantitative analysis. Through the collection and analysis of relevant technical documents such as ship navigation order, traffic organization, navigation efficiency, navigation safety and other related data in the Yangtze Estuary, the problems in the navigation safety and efficiency of the Yangtze Estuary waters are analyzed. The paper optimizes the routeing system based on the problems and risks found.

Specifically, through investigation and analysis of the current status and needs of ship navigation order management in the Yangtze Estuary waters, this paper can sort out the relevant laws and regulations of ship navigation safety and management system guarantee conditions, summarize the characteristics of the navigation environment in the Yangtze Estuary, and sort out the rules of ship traffic flow. Combining the statistical data of ship traffic accidents, this paper analyzes the risk of the Yangtze Estuary to sort out and summarize the problems existing in the current order of ship navigation in the Yangtze Estuary. In view of the existing problems, a reasonable plan for optimizing the routeing system of the Yangtze Estuary was proposed， and based on the Analytic Hierarchy Process(AHP), the optimization plan is evaluated to verify the safety and standardization of the plan.

CHAPTER 2 TRAFFIC ENVIRONMENT AND TRAFFIC MANAGEMENT STATUS IN THE YANGTZE ESTUARY

2.1 General situation of the water area of the Yangtze Estuary

2.1.1 Introduction of the Ship' Routeing System in the Yangtze Estuary

The Yangtze Estuary is the mouth of the Yangtze River. Since 2002, the Yangtze Estuary has implemented the "The Ships' Routeing System in the Yangtze Estuary" for navigation of ships. In order to cooperate with the third phase of the Yangtze Estuary Deepwater Channel Improvement Project, MOT issued a new "The Ships' Routeing system in Yangtze Estuary" in 2008. The ships' routeing system in the Yangtze Estuary seamlessly connects with the Yangtze Estuary Deepwater Channel and the lower section of the South Channel, forming the "gateway" of the Yangtze Estuary and Shanghai Port. Navigation aids in the waters of the Yangtze Estuary are complete, and navigation aid signs are set on each channel. In the Yangtze Estuary, there are lightships in the Yangtze Estuary and South Channel lightships, which can be used for ships to sail day and night.

The ships' routeing system is composed of 2 precautionary areas, 5 traffic separation zones and 5 traffic lanes, and together with its related anchorages and piloting operation points, it forms a complete ship traffic system, as shown in Figure 1.

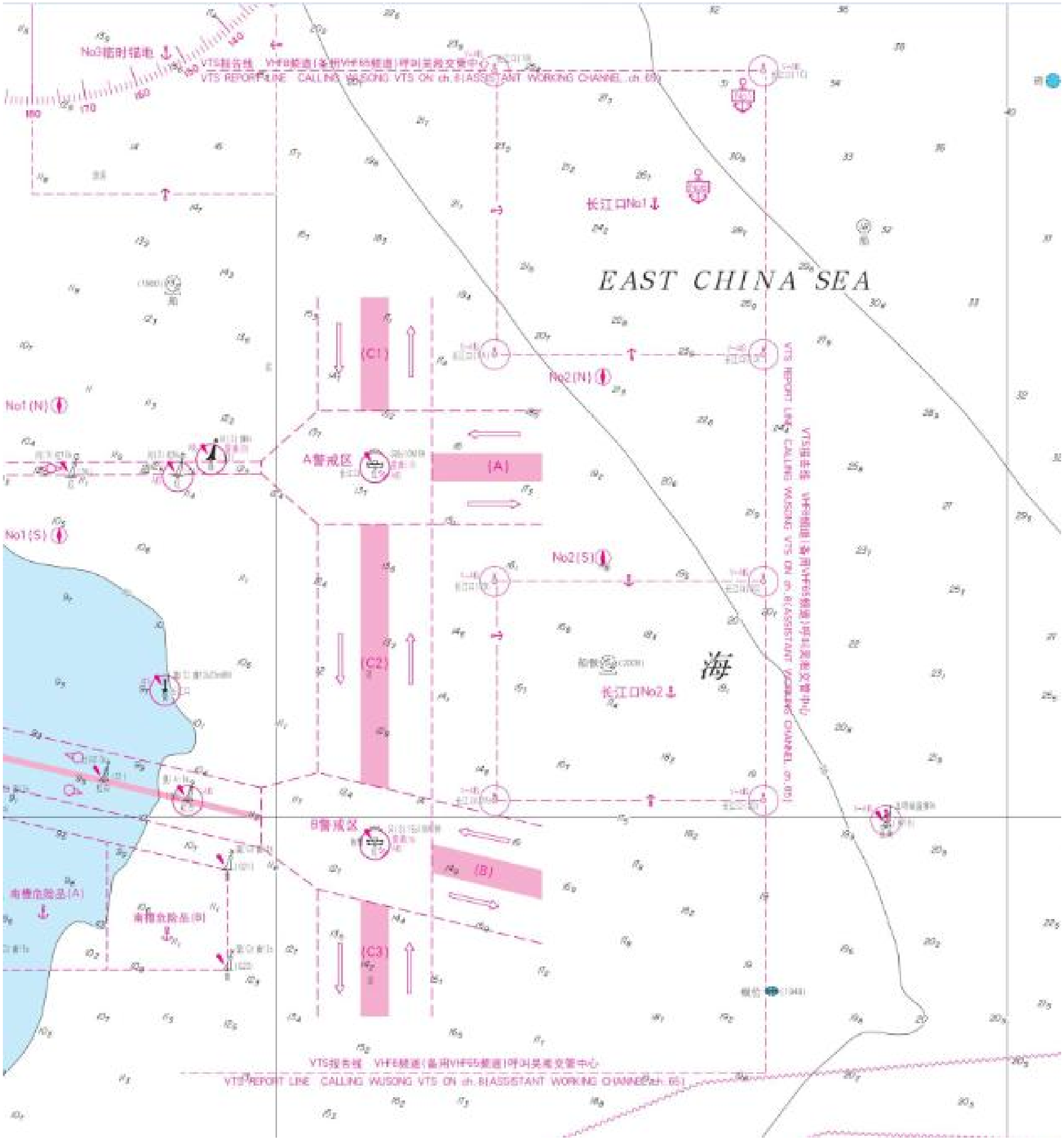

Figure 1. Schematic diagram of ships' routeing system in the Yangtze Estuary

Source: CHINA MSA

(a) Precautionary areas: Precautionary area A and precautionary area B, of which precautionary area A is connected to the Yangtze Estuary deep water channel, and precautionary area B is connected to the South channel.

(b)Traffic separation zones: A and B traffic separation zones and C1, C2, C3 traffic separation zones, of which A traffic separation zone is connected to the east side of the A precautionary area, B traffic separation zone is connected to the east of the B precautionary area, and the C1 traffic separation zone is connected to the north of the precautionary area A. The C2 traffic separation zone connects the precautionary areas A and B, and the C3 traffic separation zone connects the south side of the precautionary area B.

(c) Traffic lanes. A and B traffic lanes and C1, C2, C3 traffic lanes, each traffic lane is arranged corresponding to each separation zone, and a certain width of water on both sides of the separation zone is the traffic lanes.

(d) Anchorages: CJK NO.1 anchorage and CJK NO.2 anchorage.

(e) Pilotage area: No. 1 pilotage area of the Yangtze Estuary and No. 2 pilotage area of the Yangtze Estuary, located on the south side of the CJK No. 1 anchorage and the north side of the CJK No. 2 anchorage respectively.

2.1.2 Introduction to the route in the Yangtze Estuary

According to the "Master Plan for China's Coastal Ship Routes"(MOT, 2011), the Yangtze Estuary has planned two-way routes for ships and two-way branch routes. The planned two-way routes for the main routes are both 6 nautical miles and the two-way branch routes are all 3 nautical miles. In Yangtze Estuary, the main two-way route includes the north-south coastal route (inner route), the outer route of the Yangtze Estuary, the east exit route of the precautionary area A and the east exit route of the precautionary area B. The branch two-way route includes the inner route to the south of the precautionary area and the coastal route to the south of the precautionary area.

The outer route of the Yangtze Estuary is centered on the 123°E line, with a width of 3 nautical miles on both sides. The outer route is mainly for large ships passing north-south. The north-south coast (internal route) of the Yangtze Estuary is mainly for small ships passing north-south.

Table 1. Ship route in the Yangtze Estuary

Water area	Types	Route name	Airway width (nautical mile)
Yangtze Estuary Waters	Main two-way route	North-South Coastal Route (Internal Route)	6
		Outer Route of the Yangtze Estuary	6
		The east exit route of A precautionary area	6
		The east exit route of B precautionary area	6
	Branch routes	The inner route to the south of the precautionary area	3
		The coastal route to the south of the precautionary area	3
		Nancao South Coastal Route	3
		Beigang Airway	3
		In and out of Yangshan Port Airway (Beihang Road, Donghang Road and Nanhang Road)	3

Source: MOT

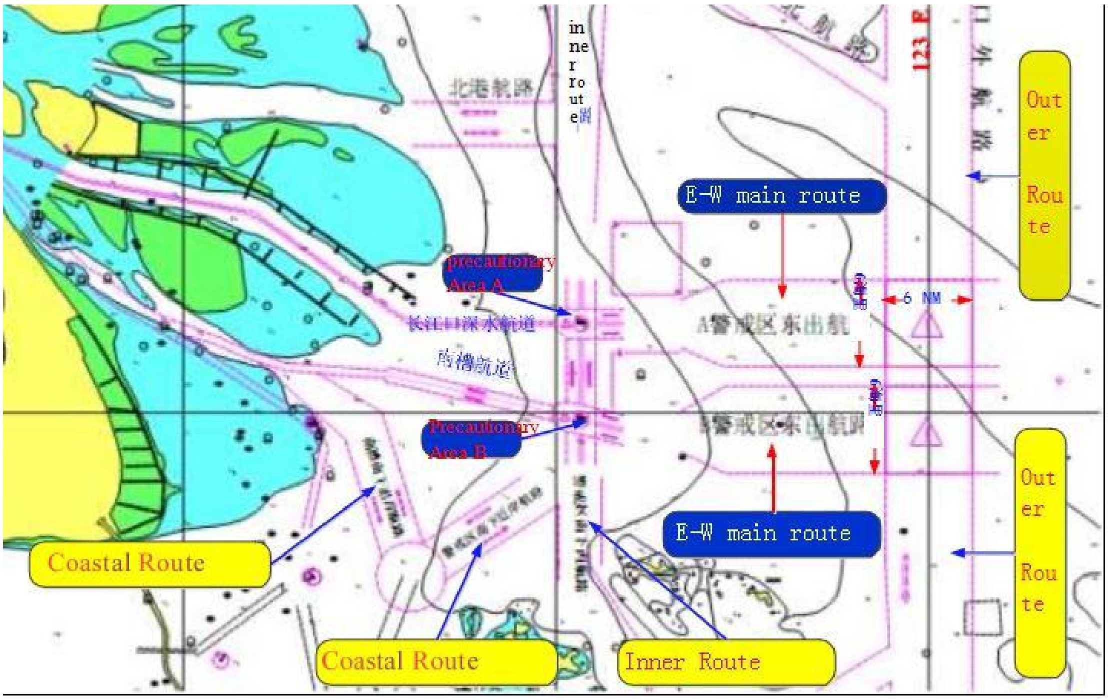

Figure 2. Schematic diagram of the route in the Yangtze Estuary
Source: MOT

In the Yangtze Estuary, there are also some agricultural and fishery areas. According to the "Shanghai Marine Functional Zoning (2011-2020)", there are many fishing areas in the waters of the Yangtze Estuary, as shown in Figure 3.

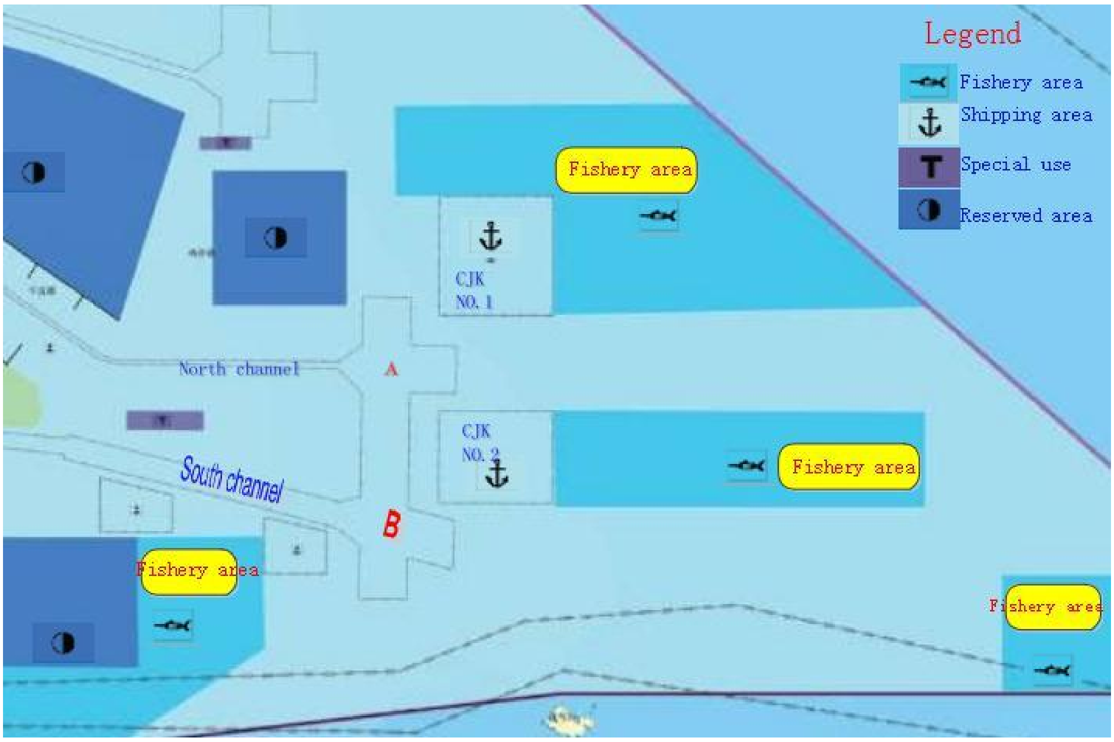

Figure 3. Distribution of fishing areas in the Yangtze Estuary
Source: Wusong VTS

2.2 Basic overview of the traffic environment

2.2.1 Hydrometeorological conditions

(a)Wind and wave conditions: The wind direction in Yangtze Estuary has obvious seasonal changes, with the most southeast wind throughout the year, followed by northwest and northeast winds, and the strong wind is northeast. The month of October of each year and February of the following year is the time when cold air flows southward to form the most strong winds. Every time the cold air moves southward, there is usually a strong wind, mostly from north to northwest. In winter and spring, there are strong north to northeast winds, sometimes reaching force 8 winds. The area around the Yangtze Estuary and Shanghai Port is the cold wave season from October to April each year. When the cold wave crosses the border, it is accompanied by strong northerly winds of level 6 or higher, which lasts for less than 3 days, up to 6 days, and is often accompanied by rain and snow. Researchers from the Shanghai Ocean Meteorological Observatory selected the continuous 6-hour or continuous increase of the Shanghai wave as a wave growth process (Cai,2017). The number of processes in which the waves reached a growth time of more than 6 hours in the waters near the lightship of the Yangtze Estuary from 2011 to 2017 was measured as 149 times. The number of Nancao lightships is 104 times.

(b)Visibility: The fog in the Yangtze Estuary and its vicinity is mainly advection fog and cover fog. The foggy days vary from month to month. There are more foggy days from March to May. April is the most frequent, followed by February and June. There is almost no fog in August. Approximately 6 days on average. The duration of the fog varies, with 8 consecutive days of fog in April and May. From February to April, thick fog is often generated after the initial rise of the tide. In autumn and winter, it is often affected by radiation fog drifting from the land, which often prevents ships from entering and leaving the port in time, and a large number of ships anchor at the Yangtze Estuary.

(c)Tides: The tides in the waters of the Yangtze Estuary are irregular half-diurnal tides. The high tide and low high tide differ by 0.5-1.5 m in a day. The ebb tide flow time is about 6.5-8.5 hours, which varies with seasons and wind directions. The tide is affected by the wind and changes greatly. When the north-northeast wind is class 6 or above, the tide height increases by 40-50 cm, and the northwest wind decreases by 20-30 cm. The tidal current in the waters of the Yangtze Estuary is usually a rotating flow, and the flow direction changes clockwise. Four hours before the Zhongjun climax, the tide began to rise initially. The tide turned from the south flow to the southwest flow in a clockwise direction, and turned to the northwest flow when it rose sharply. After the high tide, the ebb tide flow from the northwest mountain to the south flow and the southeast flow (Zang,2019).

2.2.2 Traffic situation

The ships' routeing system in the Yangtze Estuary and its nearby waters are more complicated for ship traffic. Because ships within the routeing system need to navigate in accordance with the routeing system requirements, they should not arbitrarily cross the traffic lanes and separation zones, and the traffic flow shows a certain pattern. This article mainly counts the ship flow in the routeing system, and makes a chart of the ship trajectory in order to better analyze the current status of navigation.

(a)Statistically analyze the ship traffic flow in the waters of the routeing system, so as to have an overall intuitive experience and understanding of the ship traffic flow in the Yangtze Estuary. Through the Wusong VTS system, the traffic flow of ships entering and leaving the waters of the Yangtze Estuary from 2017 to 2020 was calculated. The statistics are shown in Table 2.

Table 2. Ship traffic flow in the Yangtze Estuary(Number of ships)

Years	Drive in	Drive out	Total	Average daily volume
2017	273289	270466	543755	1490
2018	241203	240240	481443	1319
2019	236343	238126	474469	1300
2020	276758	279058	555816	1522

Note: Data comes from Wusong VTS

As can be seen from Table 2, the flow of ships entering and exiting is equal in the past two years. There is a slight increase in the number of ships entering and exiting the routed waters. There are about a thousand ships entering and leaving the area every day. There is a large flow of ships entering and leaving the area, and the density of ship traffic is high.

(b) Ship traffic flow in the precautionary area

The flow of ships entering and leaving the prevention zone A from 2017 to 2020 is shown in Table 3.

Table 3. Ship traffic flow in the precautionary area A(Number of ships)

Years	Drive in	Drive out	Total	Average daily volume
2017	103156	103140	206296	565
2018	97437	97598	195035	534
2019	94393	94429	188822	517
2020	108652	108702	217354	595

Source: Data comes from Wusong VTS

It can be seen from Table 3 that, there are more than 500 ships entering and leaving the area every day. There is a large flow of ships entering and leaving the area, and the density of ship traffic is high.

According to the same principle, the statistics of the traffic flow of ships entering and leaving the precaution area B from 2017 to 2020 are shown in Table 4.

Table 4. Ship traffic flow in the precautionary area B(Number of ships)

Years	Drive in	Drive out	Total	Average daily volume
2017	93674	93680	187354	513
2018	83572	83733	167305	458
2019	82556	82637	165193	453
2020	104926	106897	211823	580

Source: Data comes from Wusong VTS

It can be seen from Table 4 that there are more than 500 ships entering and leaving the area every day. There is a large flow of ships entering and leaving the area, and the density of ship traffic is high.

(c) Ship traffic flow of each section

1)Traffic lane A

The VTS system is used to calculate the flow of ships from 2017 to 2020 on the section of traffic lane A. The statistics of the flow of ships passing through the section of traffic lane A in the past four years are shown in Table 5.

Table 5. Ship traffic flow in the traffic lane A(Number of ships)

Years	Inbound	Departures	Total	Average daily volume
2017	14556	13985	28541	78
2018	13978	13297	27275	75
2019	13613	13365	26978	74
2020	14835	14192	29027	80

Source: Data comes from Wusong VTS

It can be seen from Table 5 that the flow of ships entering and leaving the area has not changed much in the past four years. The flow of ships in the traffic lane A is relatively large.

2)Traffic lane B

The statistics of the flow of ships passing through the section of traffic lane A in the past four years are shown in Table 6

Table 6. Ship traffic flow in the traffic lane B(Number of ships)

Years	Inbound	Departures	Total	Average daily volume
2017	13835	10642	24477	67
2018	12871	10056	22927	63
2019	12747	10016	22763	62
2020	14658	11027	25685	70

Source: Data comes from Wusong VTS

It can be seen from Table 6 that the flow of incoming (westbound) ships is more than that of outgoing (eastbound) ships. This is 1.3 times the flow of ships leaving the area. The flow of ships has not changed much in the past four years, and the flow of ships entering and leaving traffic lane B is relatively large.

3)Traffic lane C

The statistics of ship traffic through the traffic lanes of C1, C2 and C3 in the past four years are shown in Table 7, Table 8, and Table 9.

Table 7. Ship traffic flow in the traffic lane C1(Number of ships)

Years	Northward	Southward	Total	Average daily volume
2017	37076	32561	69637	191
2018	37774	35788	73562	202
2019	35828	32570	68398	187
2020	39458	35673	75095	206

Source: Data comes from Wusong VTS

Table 8. Ship traffic flow in the traffic lane C2(Number of ships)

Years	Northward	Southward	Total	Average daily volume
2017	41697	23330	65027	178
2018	42040	24006	66046	181
2019	41561	23208	64769	177
2020	43924	24011	67935	186

Source: Data comes from Wusong VTS

Table 9. Ship traffic flow in the traffic lane C3(Number of ships)

Years	Northward	Southward	Total	Average daily volume
2017	28898	21400	50298	138
2018	28405	19990	48395	133
2019	28689	19123	47812	131
2020	31758	19658	51416	141

Source: Data comes from Wusong VTS

It can be seen from Table 7, Table 8, and Table 9 that the number of ships entering and leaving the C1,C2,C3 traffic lanes is large. The flow of ships going north is about 1.4-1.5 times that of going south. It can be seen from the number that the traffic flow of ships passing through the traffic lanes is very large.

(d) Vessel traffic flow in the outer route of the Yangtze Estuary. Through the AIS system, the flow of ships in the 3 nautical miles section on both sides of the 123°E (outside the Yangtze Estuary) section from 2017 to 2020 is calculated. The ships passing through this area are basically large ships of 3000 tons and above. The statistics of the number of ships that passed through this area each year are shown in Table 10.

Table 10. Ship traffic flow in the outer route of the Yangtze Estuary(Number of ships)

Years	Inbound	Departures	Total	Average daily volume
2017	12890	12980	25870	71
2018	12656	13312	25968	71
2019	12883	12856	25739	71
2020	13032	13075	26107	72

Source: Data comes from Eastern Navigation Service Center

It can be seen from Table 10 that the ship traffic flow has not changed much in the past four years.

The ship's trajectory is a record of the ship's movement route. The tracks of all ships in a certain water area show the characteristics or traffic patterns of the ships' traffic flow routes in the water area. Through the analysis of the trajectory distribution, it is possible to understand the composition and flow direction of the traffic flow and the general conditions of the encounters of the ships, so as to have a grasp of the navigation order of the ship traffic flow in the waters, the distribution of the route and the navigation law.

In order to understand the distribution of ships' trajectories in the Yangtze Estuary and clarify the distribution of habitual routes of ships in the Yangtze Estuary, the AIS system is used to calculate the distribution of ships' trajectories in the Shanghai section of the Yangtze River and the waters of the Yangtze Estuary on a daily, monthly, quarterly and yearly basis. The time period for daily statistics is: November 1, 2019, and the monthly statistics time period is: September 1-7, 2019. The quarterly statistics time period is: the second quarter of 2019, and the annual statistics time period is: 2018. The distribution of ship navigation trajectories in the project study waters based on daily statistics is shown in Figure 4, monthly statistics are shown in Figure 5, quarterly statistics are shown in Figure 6, and annual statistics are shown in Figure 7.

Figure 4. Ship trajectory chart (day)
Source: Wusong VTS

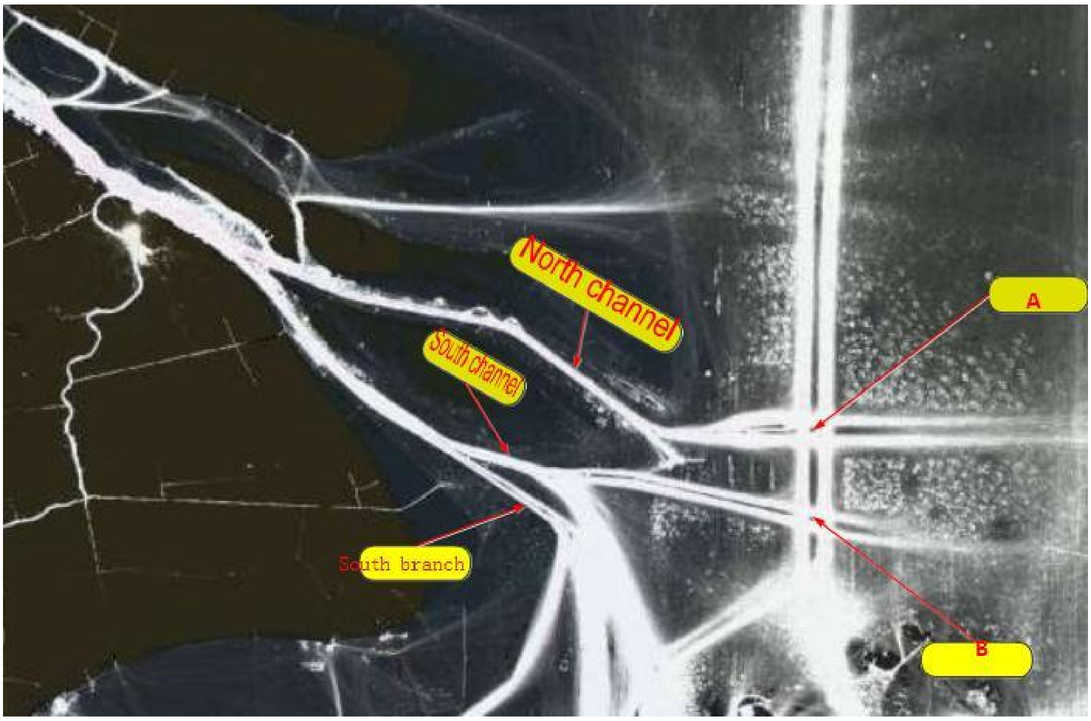

Figure 5. Ship trajectory chart (month)
Source: Wusong VTS

Figure 6. Ship trajectory chart (quarter)
Source: Wusong VTS

Figure 7. Ship trajectory chart (year)
Source: Wusong VTS

It can be seen from the ship trajectory graph that the more trajectory lines, the brighter the trajectory graph. Judging from the distribution of trajectories, in the Yangtze Estuary, ships generally navigate along the waterways, traffic lanes and other navigable waters in accordance with the routeing system, and the overall distribution of ship traffic flow is relatively regular.

Analysis of the law of ship traffic flow: This paper statistically analyzes the flow of ships in the relevant areas of the Yangtze Estuary routeing system in the past four years, the flow of ships in main sections, and the distribution of AIS ship trajectories, and roughly sorts out the law of ship traffic flow in the Yangtze Estuary waters. The main points are as follows:

(a)Every day, there are thousands of ships entering and leaving the waters of the routeing system. There is a lot of ship flow in and out of this area, and the ship flow density is high. There are a large number of ships entering and exiting the Yangtze Estuary A and B alert areas, and there is a high flow density of ships in the waters of the alert area. The daily average number of ships entering and exiting the Yangtze Estuary A precautionary zone is greater than the number of ships entering and exiting the B precautionary zone.

(b)Among the five traffic lanes, the C1 traffic lane has the largest number of ships per day, followed by the C2 traffic lane, and the B traffic lane is the least. The order of daily average number of ships from largest to smallest is C1>C2>C3>A>B.

(c)The north-south traffic flow accounts for approximately 49% of the total flow of the Yangtze Estuary routeing system. The north-south flow of ships sailing on the outer route of Yangtze Estuary is basically large ships of 3000 tons and above. The average daily flow is about 70 ships, and the flow of ships has not changed much in the past three years.

2.3 Current status of traffic management

2.3.1 Policy requirements

Relevant laws, regulations, rules and regulations concerning the navigation of ships are the main basis for the management of ship navigation order. MOT, Shanghai MSA and other units have successively issued a number of regulations and systems related to the navigation of ships in the Yangtze Estuary and the Shanghai section of the Yangtze River. These include the "Maritime Traffic Safety Law of the People's Republic of China", "Regulations of the People's Republic of China on the Safety Management of Water and Underwater Activities", "Shanghai Safety Supervision Rules", "Traffic Management Rules in Yangtze Estuary of Shanghai Port", "The Ships' routeing System in Yangtze Estuary ", "The Ship Report System in Yangtze Estuary ", "The Ships' routeing System in the Yangtze River of Shanghai Section", "Shanghai Maritime Safety Administration Measures for the Safety Supervision and

Administration of Pilotage Operations", "Wusong VTS User Guide" and other laws and regulations and local rules and regulations.

2.3.2 Management measures

Ships in the Yangtze Estuary shall comply with the following regulations:

(a) Vessels should comply with the provisions of the traffic separation system in the International Regulations for Preventing Collision at Sea(COLREGS, 1972).

(b) Ships navigating in the waters of the routeing system, if there is a risk of collision, shall still comply with the responsibilities and obligations stipulated in the COLREGS,1972.

(c) It is forbidden for ships to anchor or fish in the precautionary areas, the separation zone, the traffic lane and the waters near the ends. Ships that do not use ships' routeing system should stay away from the waters as much as possible.

In order to improve the safety and efficiency of navigation, the Wusong VTS coverage area affairs department completely covers the waters of routeing system. At the same time, the ship reporting system was implemented in the waters of the routeing system. The Ship Reporting System in Yangtze Estuary is a compulsory ship reporting system, applicable to all passenger ships, other ships of 300 gross tonnage and above, and ships below 300 gross tonnage that voluntarily join the reporting system. The reporting system has the following requirements:

(a) When a ship enters the waters of the Ship Reporting System from the north, east or south, it should report to the Wusong VTS. Ships leaving the waters are not required to report.

(b) Ships equipped with AIS equipment should correctly input ship name, call sign and maritime mobile service identification code, port of destination, total length,

gross tonnage and ship type are not required to report.
(c) When the ship breaks down or heaves anchor at the Yangtze Estuary anchorage, it should report to Wusong Ship Traffic Management Center 15 minutes in advance.

The Yangtze Estuary is the main chokeway for ships to enter the Yangtze River. The west side of the routeing system is the two main channels for entering and exiting the Yangtze River, namely the Yangtze Estuary Deep Water Channel (North Channel) and the South Channel. The channel has limited water depth, and ships often need to take advantage of the tide to enter and exit. Especially large ships with drafts greater than 7 meters usually need to enter and exit through the North Channel. In order to ensure the safe and orderly navigation of ships in the channel, the maritime department formulated the "Measures for the Administration of Navigation Safety in the Deepwater Channel of the Yangtze Estuary." The Measures require that the North channel be organized in traffic. Ships that need to enter the North channel between 4 hours before the Changxing climax and 1 hour before the Changxing climax should sail in formation. Wusong VTS conducts traffic control (traffic organization) twice a day for ships intending to enter the North channel according to the navigation safety management measures at various stages and the tide law of Shanghai Port. Each control lasts for 3 hours, from 7.5 hours before the Changxing climax to the Changxing climax. The first 4 hours are the key period. During this period, ships will queue up for import at 6-minute intervals.In other words, there are about 13 hours a day. Large ships need to line up to enter the North channel. These ships will gather entrances in the ships’ routeing system, especially in the precautionary area A, which will affect the traffic flow in the routeing system.

According to Shanghai Port Pilotage Management Regulations, foreign ships entering Shanghai Port need to be compulsory for pilotage, and some ships that are not familiar with Shanghai Port's navigation should also apply for pilotage. There are No.1 and No.2 pilotage areas at the Yangtze Estuary NO.1 and No.2 anchorages respectively. However, because the transport boats used to pick up and drop pilots at the Shanghai Port Pilot Station are small, it is impossible to pick up and drop pilots in the No.1 and No.2 pilotage areas. Pilots can only disembark and disembark the ship in the pilot operation area of the North and South channel. This is why foreign ships and ships that are unfamiliar with the navigation environment need to be piloted to navigate through the waters of the Yangtze River Estuary with complex navigation environment.

CHAPTER 3 TRAFFIC STATUS SURVEY AND RISK ANALYSIS

The investigation of ship traffic conditions is an important research content in the optimization of ships’ routeing system planning. By investigating the history and current situation of ship traffic in the waters of the routeing system, we can grasp the actual traffic conditions and carry out statistical analysis, and provide a scientific basis for the optimization of the ships’ routeing system. This article investigates the current implementation effects and existing problems of the Yangtze Estuary Routeing System through statistical analysis of traffic accidents in the Yangtze Estuary and using questionnaires.

3.1 Accident statistical analysis

According to the overall statistical data of ship accidents in the waters of the Yangtze Estuary from 2006 to 2020, the law of accident changes in this water area can be analyzed, and the positive effects of the Ships’ routeing system (2008 Edition) on the navigation safety of the Yangtze Estuary can be summarized. Aiming at the analysis of ship accidents in the Yangtze Estuary, this paper adopts the reported accidents in the waters of the routeing system as the base. From the number of deaths and missing persons caused by accidents in the past years, the number of shipwrecks and economic losses, the type and level of accidents, the distribution of accidents, and the causes of accidents, a comprehensive analysis of accidents that occurred in the waters of the Yangtze Estuary will be carried out. Identify the water areas where accidents occur frequently, find out the cause of the accident, and put forward more reasonable and effective measures and suggestions to avoid accidents.

3.1.1 Type and distribution of accidents

From 2006 to 2020, a total of 71 ship accidents occurred in the Yangtze Estuary, an average of 4.7 incidents per year. In the 2.5 years (2006-May 2008) before the implementation of the 2008 version of the ships' routeing system, a total of 14 ship accidents occurred, with an annual average of 5.6, which is higher than the average annual number of water accidents in the past 14 years. A total of 57 ship accidents occurred in 12.5 years (June 2008-December 2020) after the implementation of the new ships' routeing system in June 2008, with an average annual rate of 4.5, which is lower than the average annual number of water accidents in the past 15 years, and lower than the annual average number of accidents before the implementation of the 2008 ships' routeing system. However, ship accidents have increased in the past four years, with an average of 6.25 accidents per year, and most of them are collision accidents. The statistics and types of accidents are shown in Table 11 and Table 12.

Table 11. Statistics of ship accidents in the Yangtze Estuary from 2006 to 2020

Time	Number of accidents	Collision number	Shipwreck number	Number of people dead/missing	Direct economic loss(million yuan)
2006	8	7	2	2	9.7
2007	1	1	0	0	0.15
2008.1-5	5	4	1	17	39
2008.6-12	1	0	1	0	7
2009	4	4	0	1	9.1
2010	5	4	1	10	10.3
2011	3	3	0	0	14.1
2012	3	2	1	1	3.545
2013	6	5	3	2	123.8
2014	4	3	0	0	4.70
2015	1	1	0	0	0.3
2016	4	3	0	0	2.03

2017	9	7	0	0	19.1
2018	6	6	0	0	5.14
2019	3	3	0	0	1.93
2020	7	7	1	14	35

Source: Wusong MSA

Table 12. Statistics of accident types

Type of accident	collision	grounding	wind disaster	fire disaster	explosion	sink	other
Quantity	60	0	3	2	1	3	2
proportion	84.6%	0	4.2%	2.8%	1.4%	4.2%	2.8%

Source: Wusong MSA

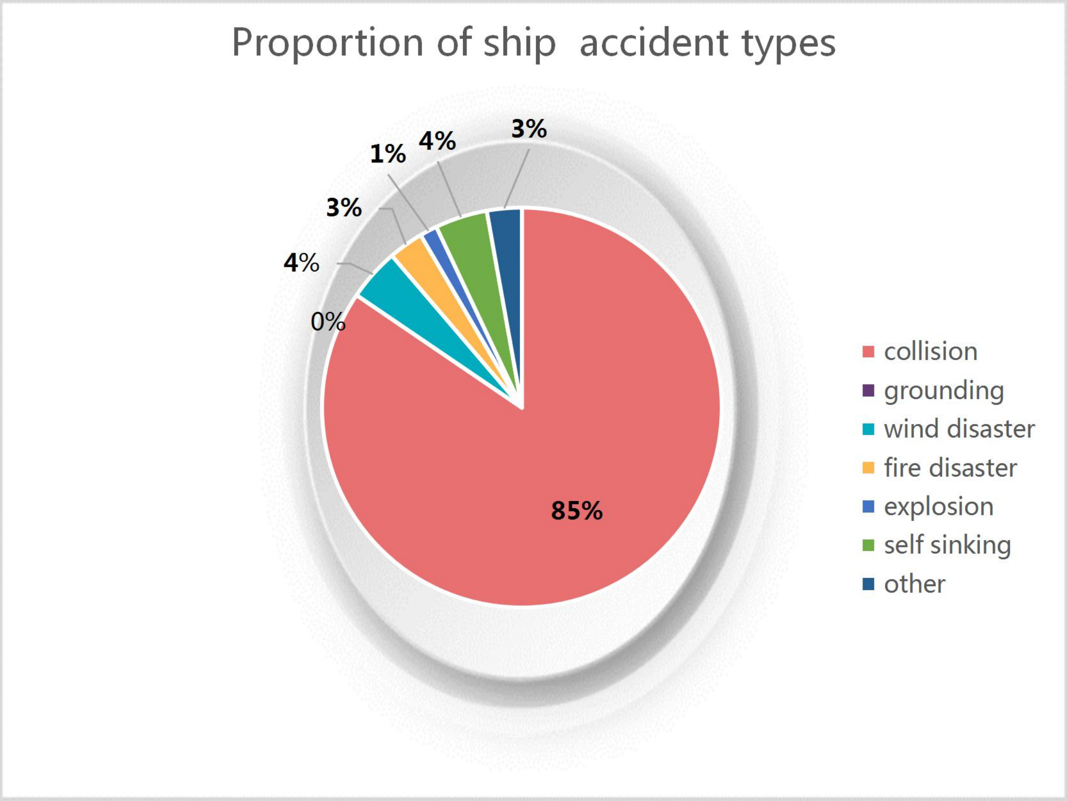

Figure 8. Proportion of ship accident types

Source: Wusong VTS

According to the Table 12 and Figure 8 further analysis of the statistics of accidents in he Yangtze Estuary, collision accidents accounted for a very high proportion of 84.5% of the types of ship accidents in the Yangtze Estuary.

Since 2008, the total number of collision accidents each year has shown an overall downward trend. However, there were more collision accidents after 2016. A total of 23 collision accidents occurred from 2017 to 2020, with an average annual rate of 5.75. Especially in 2017 and 2020, there were 7 collision accidents. Although basically all accidents occurred at the level of minor accidents, a major accident in 2020 caused 14 deaths and missing.

From the time point of view, ship accidents in the waters of the routeing system showed an overall trend of first decline and then rise. According to the specific locations of ship accidents in Yangtze Estuary, the distribution of ship accidents in the waters of the Yangtze Estuary after the implementation of the 2008 version of the Yangtze Estuary is drawn in Figure 9.

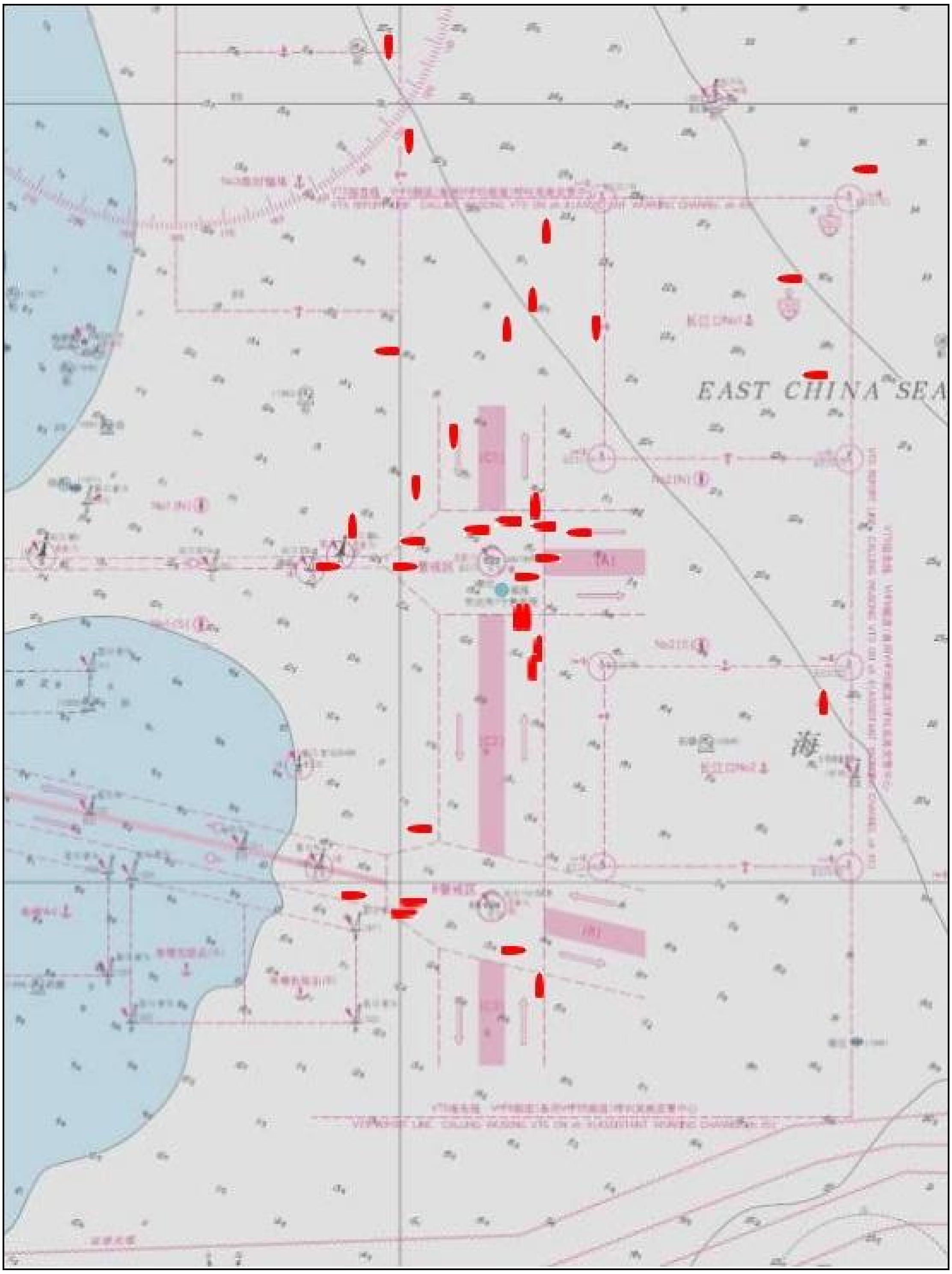

Figure 9. Schematic diagram of the accident location

Source: Wusong VTS

Since the implementation of the ships' routeing system in the Yangtze Estuary in June 2008, a total of 71 ship accidents have occurred in the waters of the routeing system by the end of 2020. A total of 43 accidents occurred in warning areas, navigable lanes and anchorage waters, accounting for about 61%; 28 accidents occurred in other waters, accounting for about 39%. Among them, 17 incidents occurred in and near the A precautionary area, 8 incidents occurred in the B precautionary area and nearby, 1 incident occurred in the navigation lane A, 4 incidents occurred in the C1 navigation lane, and occurred in 3 cases of C2 navigation lanes, 4 cases of CJK No. 1 anchorage, 3 cases of CJL No. 2 anchorage, 3 cases of CJK temporary anchorage of No. 3 and nearby, 28 cases occurred in other waters. The proportion of the accident distribution area is shown in Figure 10.

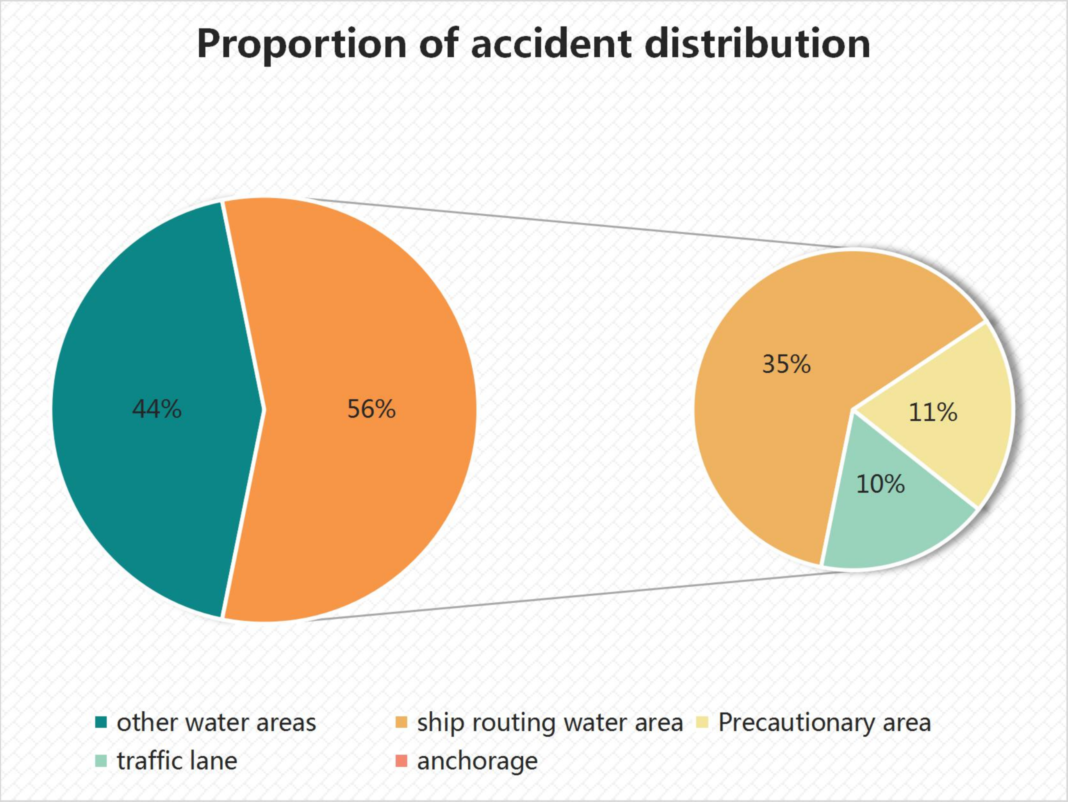

Figure 10. Schematic diagram of the accident location

Source: Author

3.1.2 Analysis of the cause of the accident

(a)Machine reason. Ship accidents caused by mechanical factors account for a certain proportion. The main reason for such accidents is that the overall quality of the crew directly leads to inadequate maintenance of the ship’s machinery, which increases the probability of machine failure and the ship’s poor fuel oil. On May 20, 2016, the northbound ship "XIANGJING EXPRESS" sailing in the C1 traffic lane of the Yangtze Estuary's routeing system, due to the sudden failure of the steering gear, collided with the overtaking ship "Guodian 32" at its rear left position. It is a typical case of ship accidents caused by mechanical factors in the waters of the Yangtze Estuary.

(b)Human Factors. According to incomplete statistics, ship accidents caused by human factors account for more than 80% of maritime ship accidents. The statistics of ship accidents that have occurred in Yangtze Estuary over the years basically conform to this law. To sum up, the human factors mainly include the following items. The overall quality of the crew has declined. As the shipping cycle and the global economy continue to hover at the bottom, in order to save operating costs, the number of flags of convenience ships has increased, ship conditions have deteriorated, and the overall quality of crews has declined. In particular, shipowners tend to hire senior crew members from cheaper areas, which results in some ship pilots lacking in manoeuvring skills, language barriers, and insufficient experience, and unable to adapt to the complex sailing environment. Moreover, due to the reduction of ship manning, the fatigue problem of the crew has become more serious, which is also an important cause of accidents.

The crew did not have sufficient knowledge of the tidal currents in the Yangtze

Estuary. The crew's lack of understanding of the tides and tidal currents in the Yangtze Estuary can easily lead to accidents of ships dropping anchors during high tides and collisions with normally anchored ships during navigation. A typical maritime case is that on April 12, 2020, the “Huaxuda 1” that was going to enter the channel after the anchor was lifted in the CJK No. 3 anchorage collided with the normal anchored ship “Yongfeng 58” on its right side.

Accidents caused by poor sailing habits. Some ships have poor navigation habits. For example, when navigating in Yangtze Estuary, they habitually use sea speed to sail at a fixed speed, and in a dense flow of ships, no speed reduction measures are used to avoid other ships, which is likely to lead to an urgent situation and cause accidents. Another example is that the pilots fail to strictly abide by the regulations, causing the ship's position to be abnormal, causing other ships to misjudge the situation and the intention of meeting the ship, which in turn leads to accidents. An example is the collision between the "ANL WANGARATTA" and the "Fuxinshan" ship in the precautionary area A on February 22, 2009.

(c)Influence of environmental factors. Frequent severe weather and complicated navigation environment are the objective factors leading to this occurrence. The environmental factors leading to ship accidents in Yangtze Estuary mainly include the following aspects. The density of ship traffic flow is high. The Yangtze Estuary is the area where ships enter and exit the Yangtze River and the north-south coastal navigation meets. Starting from 5 hours before the Changxing high tide, ships sailed into the Changjiang Estuary Deep Water Channel and South Channel by tide from the east, south, and north directions. During this period of time, the density of ships is high and the traffic flow is complicated. Most ships slow down or stop to avoid, control the time of entry and the time of arrival at the pilot operation area. The situation where ships entering and exiting the Yangtze River meet with ships sailing north-south is a prominent problem, which is prone to form a dangerous situation. At approximately 0330 on August 1, 2020, the collision between the bulk carrier "SANTA LUCIA" and the tanker "SONANGOL GIRASSOL" in the C2 navigable lane is a typical case.At that time, the “SANTA LUCIA” and “KOTA LIHAT” were heading eastward from the exit of the deep water channel of the Yangtze Estuary, but there were many ships going north near the precautionary area A, including the ship “ONANGOL GIRASSOL”. According to COLREGS, the “SANTA LUCIA” and “KOTA LIHAT” should avoid ships heading north. However, in the general navigation environment at that time, there was not enough room for maneuvering, and finally “SANTA LUCIA” collided with “ONANGOL GIRASSOL” . See the Figure 11-13 for the AIS trajectory of the accident.

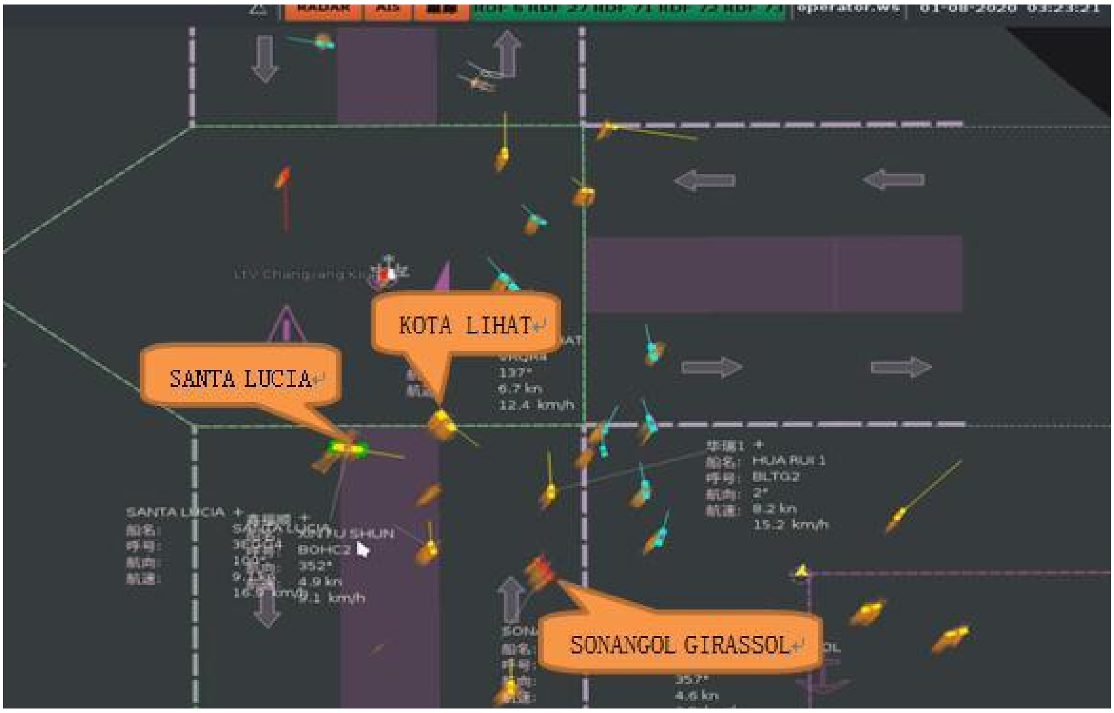

Figure 11. Wusong VTS monitoring screen at 0320 on August 1, 2020
Source: WusongVTS

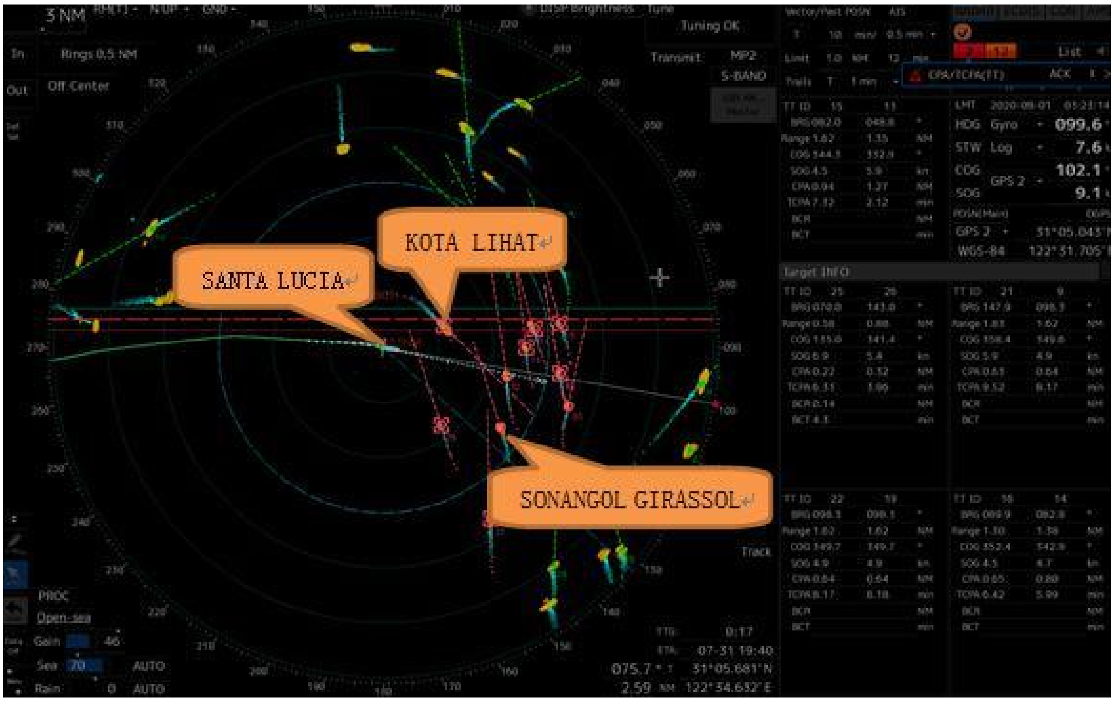

Figure 12. VDR screenshot at 0320 on August 1, 2020
Source: SANTA LUCIA

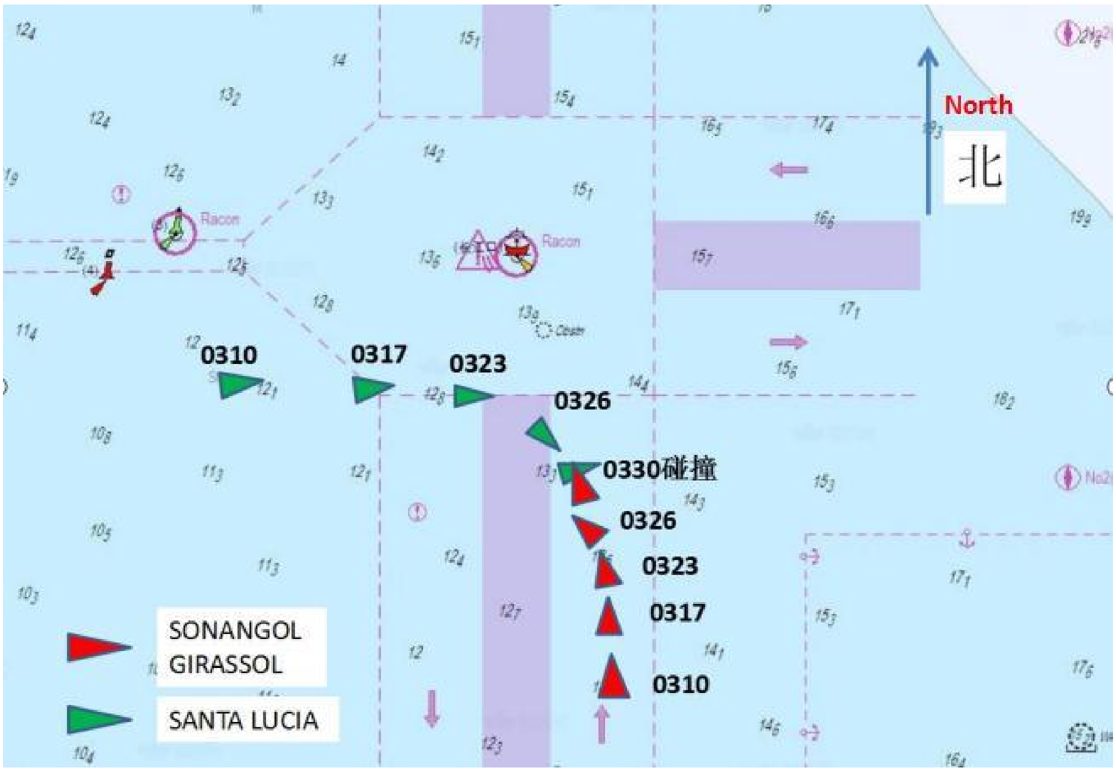

Figure 13. Schematic diagram of ship collision
Source: Author

The ships’ routeing system of the Yangtze Estuary and the coastal merchant ships' customary shipping routes overlap with fishing areas in nearby waters, and the conflict between navigable resources and fishery resources has intensified. It is difficult for merchant ships to adapt to fishing boats' navigational operations and habits, effective communication cannot be established between merchant ships and fishing vessels, and accidents of ship sinking due to collisions between merchant ships and fishing vessels occasionally occur. For example, at about 0302LT on March 6, 2020, the Chinese bulk carrier "Chonghe" was on its way from Zhoushan to Jingtang and collided with the fishing boat "Zhepu Yu 23911" about 26 nautical miles northeast of the Yangtze Estuary. The accident caused the "Zhepu Yu 23911" ship to sink and 7 people were missing.

Extreme weather such as strong winds and poor visibility frequently occurs, which brings practical difficulties to ship operations and maritime management services.

(d) Management factors. VHF communication between ships interferes with each other and the sound is noisy, and there are coexistence of VHF16, VHF08, VHF09, VHF69 channels in Yangtze Estuary, and the use of VHF channels is not clear for some ships. This leads to the phenomenon that ships that coordinate avoidance use different VHF channels to call each other. On February 27, 2013, before the collision between "Jin Hairong" and "Ziyun 1", "Ziyun 1" used channel 16 to call "Jin Hairong", and "Jin Hairong" used channel 06 to call "Ziyun 1", the two ships failed to establish effective contact until the time of the accident.

3.2 Risk investigation

In order to further investigate the safety status of the ships’ routeing system in

Yangtze Estuary, and to understand the implementation effect of the routing system and the existing problems, this paeper also adopts the research method of questionnaire survey. Considering that the majority of crew members are the users of the waters and are familiar with the conditions of the waters, the survey objects are those who have rich sailing experience in Yangtze Estuary.

3.2.1 Questionnaire survey

(a)The object of the questionnaire

The 83 questionnaires were all filled out by front-line crews. The captain filled the most with 28 questionnaires. The number of questionnaires filled out by chief officer, second officer and third officer was close, about 20 each. The job status of crew members participating in the questionnaire as shown in Table 13.

Table 13. Job status of crew members participating in the questionnaire

Crew duties	Captain	Chief officer	Second officer	Third office
Number of questionnaires filled	28	18	19	18
Percentage	33.7%	21.7%	22.9%	21.7%

Source: Author

(b)The general traffic order in Yangtze Estuary

The overall navigation order statistics of the Yangtze Estuary waters are shown in Table 14.

Table 14. Overall ship traffic order

Ship traffic order	Good order	Slightly chaotic	Chaotic	Rather chaotic	Very chaotic
Quantity	32	36	4	8	3
Percentage	38.6%	43.4%	4.8%	9.6%	3.6%

Source: Author

(c)The overall degree of danger in Yangtze Estuary

The statistics of the overall navigation order in the Yangtze Estuary are shown in Table 15.

Table 15. The overall degree of danger in Yangtze Estuary

Degree of danger	No danger	Slightly dangerous	Danger	More dangerous	very dangerous
Quantity	9	45	18	9	2
Percentage	10.8%	54.2%	21.7%	10.8%	2.4%

Source: Author

(d)The degree of influence of various traffic conditions on the order of ship traffic

Through investigation, combined with the current status and existing problems of the traffic order in Yangtze Estuary, the questionnaire lists 10 traffic condition factors that may affect the traffic order. The statistics of the degree of influence of various traffic conditions on the order of ship traffic are shown in the table 16.

Table 16. The influence of various traffic conditions on the order of ship traffic

Influencing factors	Summary	influence level				
		no	slight	moderate	increased	great
Traffic density	Quantity	1	16	25	33	8
	Percentage	1.2%	19.3%	30.1%	39.8%	9.6%
intersection of ships	Quantity	1	17	15	40	10
	Percentage	1.2%	20.5%	18.1%	48.2%	12.0%
ships in the North-South corridor Traffic flow	Quantity	4	22	24	24	9
	Percentage	4.8%	26.5%	28.9%	28.9%	10.8%

disorderly navigation	Quantity	2	4	9	41	27
	Percentage	2.4%	4.8%	10.8%	49.4%	32.5%
overtaking	Quantity	0	11	11	41	20
	Percentage	0.0%	13.3%	13.3%	49.4%	24.1%
Sail side by side	Quantity	0	17	22	34	10
	Percentage	0.0%	20.5%	26.5%	41.0%	12.0%
Piloting operations	Quantity	11	32	22	16	2
	Percentage	13.3%	38.6%	26.5%	19.3%	2.4%
Formation sailing	Quantity	26	19	27	10	1
	Percentage	31.3%	22.9%	32.5%	12.0%	1.2%
VHF communication	Quantity	12	31	19	15	6
	Percentage	14.5%	37.3%	22.9%	18.1%	7.2%
Fishing operations	Quantity	0	3	7	45	28
	Percentage	0.0%	3.6%	8.4%	54.2%	33.7%

Source: Author

The statistics of the degree of influence of various geographical factors on the order of ship traffic are shown in Table 17.

Table 17. The influence of various geographical factors on the order of ship traffic

Geographical conditions	Summary	influence level				
		no	slight	moderate	increased	great
Water depth	Quantity	8	16	17	28	14
	Percentage	9.6%	19.3%	20.5%	33.7%	16.9%
Navigation aids	Quantity	20	34	21	8	0
	Percentage	24.1%	41.0%	25.3%	9.6%	0.0%
Channel width	Quantity	14	29	18	22	0

and length	Percentage	16.9%	34.9%	21.7%	26.5%	0.0%
Anchorage resources	Quantity	11	17	35	17	3
	Percentage	13.3%	20.5%	42.2%	20.5%	3.6%
Distance between piloting area and channel	Quantity	9	22	41	7	4
	Percentage	10.8%	26.5%	49.4%	8.4%	4.8%

Source: Author

The influence of various hydrological and meteorological factors on the order of ship navigation is shown in Table 18.

Table 18. The influence of various hydro-meteorological factors on the order of ship traffic

Hydrometeorology	Summary	influence level				
		no	slight	moderate	increased	great
Tide	Quantity	0	7	14	47	15
	Percentage	0.0%	8.4%	16.9%	56.6%	18.1%
Wind	Quantity	1	9	15	50	8
	Percentage	1.2%	10.8%	18.1%	60.2%	9.6%
visibility	Quantity	0	6	11	37	29
	Percentage	0.0%	7.2%	13.3%	44.6%	34.9%
wave	Quantity	0	8	20	47	8
	Percentage	0.0%	9.6%	24.1%	56.6%	9.6%

Source: Author

3.2.2 Summary of survey results

Based on questionnaire survey and accident analysis, it can be concluded that the following navigation risks exist in Yangtze Estuary.

(a) The risks of crossing and encountering ships. The Yangtze Estuary is the area where ships enter and exit the Yangtze River and the north-south coastal navigation meets. At present, ships entering and leaving the Yangtze River and ships in the north-south channel have a large number of intersections and convergences in Yangtze Estuary. In the A and B precautionary areas, there is a high density of ship traffic and the characteristics of multiple sea lanes intersecting. Especially near the precautionary area A, the width of the channel on the west side of the precautionary area A has been sharply reduced, which has increased the density of ships in the area to a certain extent. This also exacerbated the conflict between east-west ship traffic and north-south ship traffic in precautionary area A.

(b) The risk of ships chasing and navigating side by side in the traffic lanes. At present, the width of separation zone in Yangtze Estuary is 0.5 nautical miles, the traffic lanes on both sides of the partition are 0.75 nautical miles, and the ratio of traffic lanes to partitions is a "3-2-3" model. Compared with the density of ship traffic in the waters of ships' routeing system and the increased actual demand in the ship domain due to the large-scale ships, the current channel width of the Yangtze Estuary's ships' routeing system is still slightly insufficient. In particular, the separation zone is too wide, which directly affects the width of the traffic lanes in the routeing system. In this case, there is a risk of collision between ships chasing and multi-ship sailing side by side.

(c) The risk of anchoring ships. Due to the large flow of ships in the Yangtze Estuary and the deep-water channel of the Yangtze Estuary, there are many ships that need to be anchored waiting to enter the port. The current anchorage resources are still insufficient, and a large number of ships are often anchored in the waters outside the anchorage. Random anchoring outside the anchorage increases the difficulty of anchorage management, which is detrimental to the navigation order and safety of ships. The current anchorage resources cannot fully meet the anchoring needs of ships.

(d)The risk of disorderly navigation of ships is mainly small ships and fishing vessels, as well as foreign ships heading to the pilotage area. Disorderly navigation of ships is the main cause of many water traffic accidents and dangers. Especially at night, some small ships shut down AIS navigation, which makes it impossible to communicate and coordinate with them, which can easily increase the navigation pressure of normal ships, trigger urgent and dangerous situations, and even accidents. In addition, once an accident occurs, this type of small ship often takes the approach of shutting down the AIS system and escaping, which has a greater impact on the navigation order and navigation safety of the ship, and also brings great difficulty to the supervision of the maritime department. Irregular fishing operations by fishing boats in the waters of the routeing system occasionally occur, which seriously affects the navigation order and navigation safety of ships. Usually, small fishing boats do not display the signal type normally, nor are they on duty at VHF, and cannot communicate and coordinate. When the fishing boats are dense, they often collide with other underway ships while trying to avoid fishing boats.

CHAPTER 4 OPTIMAL SCHEME OF SHIPS' ROUTEING SYSTEM IN THE YANGTZE ESTUARY

4.1 Optimal design ideas and principles

According to the previous analysis, it can be seen that there is a high density of ship traffic flow in Yangtze Estuary. Therefore, combined with the above analysis results of the traffic risk characteristics, the main objectives that need to be achieved for the optimization of the routeing system in the Yangtze Estuary waters are:

(a) Straighten out and simplify the form of ship traffic flow in the precautionary area and nearby route collection points, so as to reduce the risk of collision caused by ships crossing.

(b) Reduce the navigation hazard between the passing ship and the normal sailing ship. (c)Separate traffic flows of opposite directions in Yangtze Estuary so as to reduce the occurrence of encounters between north-south ships.

(c) Make the traffic flow organization safer and more efficient.

In order to achieve the purposes mentioned above, according to the relevant IMO regulations and the specific measures of the routeing system that have been determined to be adopted, the following optimization principles are proposed:

(a) As far as possible, follow the existing traffic flow patterns within the water area and conform to the sailing habits of seafarers.

(b) Consider all the positioning methods and positioning accuracy available within the water area as effectively as possible.

(c) The length of the traffic separation system should be designed to be short rather than long, but it should be as effective as possible to separate the traffic flow in the opposite direction from north-south ships.

(d) Make the ship turn as little as possible, especially at the intersection of the route and the dense traffic area, and avoid turning at a large angle as much as possible.

(e) Set up Precautionary areas in the areas where there is dense ship traffic to improve the vigilance of ships in this area.

4.2 Optimize specific plans

4.2.1 Location optimization plan for routeing system

(a)Cancel the original traffic lanes C1 and C2. Extend the traffic lane A to the east by 10 nautical miles, and increase the precautionary area C and traffic lanes C1, C2, and C3 accordingly.

(b)Extend the traffic lane B by 10 nautical miles in the direction of due east, and rename the traffic lane B2 accordingly; increase the precautionary area D and the D1 and D2 traffic lanes accordingly, and retain the precautionary area B and the original C3 traffic lane.

(c)Extend CJK NO.1 anchorage 1 nautical mile to the due east direction, extend CJK NO.2 anchorage 1 nautical mile to the due east direction, and the temporary CJK 3 NO.3anchorage remains unchanged.

(d)Restricted navigation is implemented between the A and B precautionary areas and the waters north of the A precautionary area, that is, ships navigating in North channel and ports near Jiangsu and Zhejiang can use the restricted lanes. However, these ships must reporte in advance, drive cautiously, and at the same time must obtain the consent of VTS.

(e)The other corresponding lightships and virtual floats are added.

The optimization situation is shown in Figure 14.

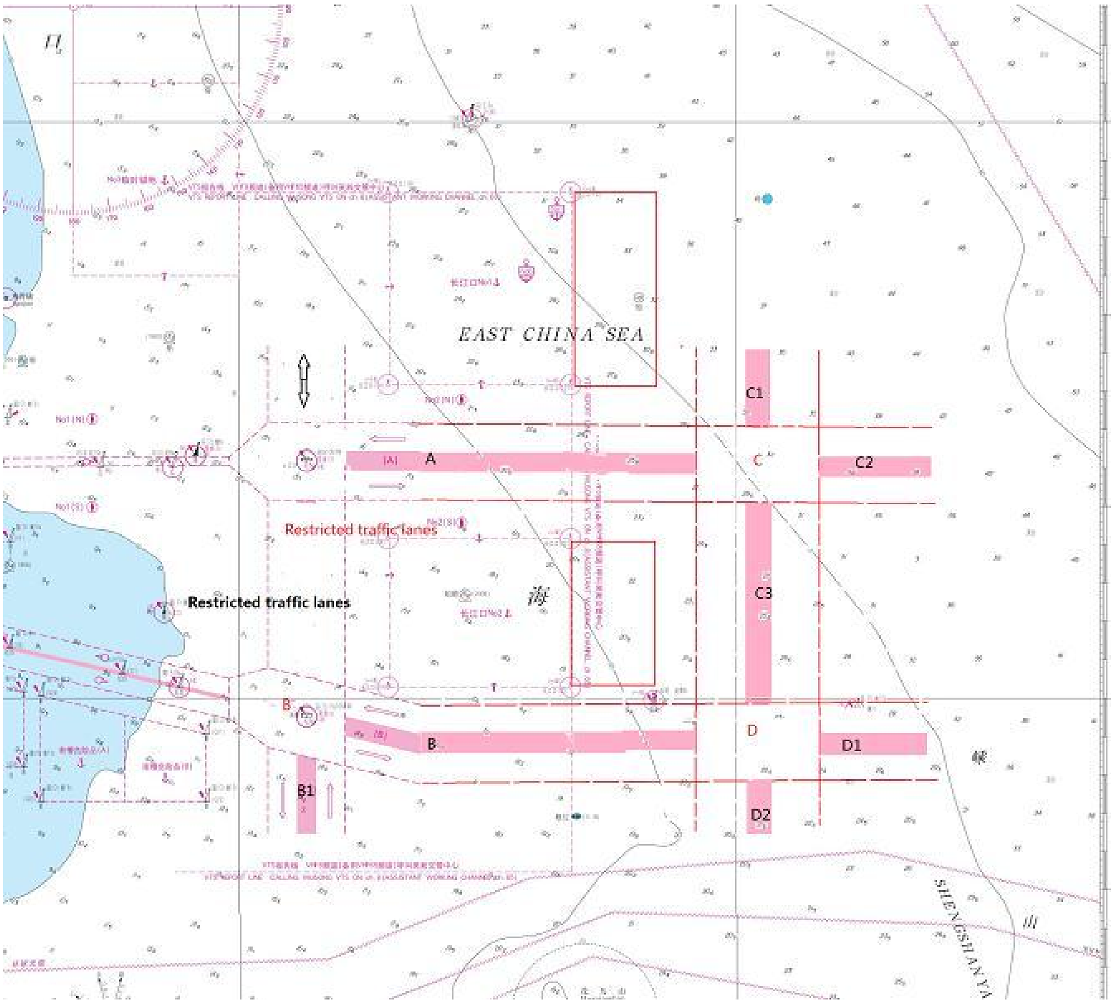

Figure 14. Schematic diagram of optimization scheme
Source: Author

4.2.2 Optimized scheme of traffic lane and separation zone

Although ships sailing in the same traffic lane have the same heading, their sizes and types are different, and their speeds are also different. The difference in speed makes it possible to form a situation of overtaking in the traffic separation lanes, so the width of the traffic separation system depends on the safety distance between the overtaking ships. In addition, in the congestion of coastal ships and restricted waters, traffic flow density and positioning accuracy also determine the width of traffic lanes (Cheng, 2016).

In response to the safety problem between the two ships in an overtaking situation, Japanese scholar Fujii Yahei proposed a basic concept in the domain of ships, as shown in Figure 15. The model points out that under normal circumstances, the field value of the ship being chased is 8L and 3.2L (L is the length of ship). According to the research conclusions of this model, the current maximum length of ships navigating in the Yangtze Estuary is 400m, and the width of the ship domain is 0.69 nautical mile.

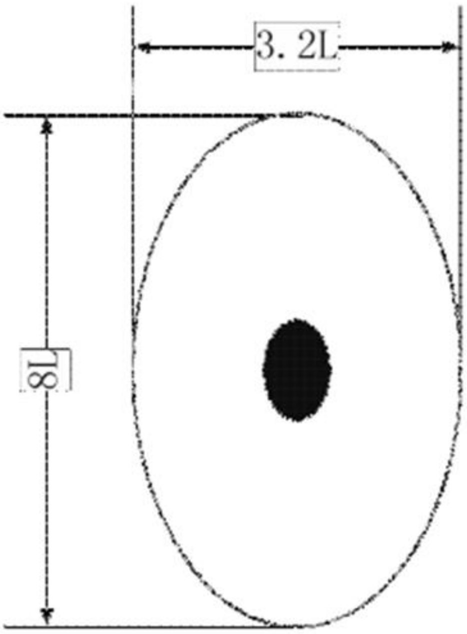

Figure15. Sketch of the ship domain model
Source: Author

The British scholar Abdel-Galil put forward a basic concept of standard separation between ships based on the theory of the ship domain when he studied the safe waters required for the navigation of ships in the traffic separation scheme. According to this theory, the lateral dimension of standard separation for ships larger than 3000GT sailing on the same heading is about 0.79 nautical mile. According to the survey and statistics of ship collision avoidance at sea, the safety distance required by a ship in a overtaking situation at sea is generally at least 1 nautical mile. Based on the above analysis, taking into account the ship traffic flow density in the Yangtze Estuary and the need for ship avoidance maneuvering, the width of the traffic lanes in this waters is designed to be 1 nautical mile.

According to IMO's design requirements for traffic separation systems, the width of the separation zone should be designed to take into account the accuracy of the positioning methods available in the water area. If conditions permit, the minimum width of the partition should be at least three times the horizontal component of the standard error of the corresponding positioning accuracy. At the same time, according to the research of relevant experts of the IMO, the ratio of traffic lanes to separation zones has a "3-2-3" model, or a "2-1-2" model used in some waters. When optimizing, we should consider using the "2-1-2" mode, and keep the width of each separation zone in the water area of the alignment system unchanged at 0.5 nautical miles.

4.3 Analysis and evaluation of the optimization plan

4.3.1 Safety analysis

Traffic conflict technology originated from the study of road traffic intersections. It refers to the method of quantitatively determining the process and degree of traffic conflicts using specific criteria and measurement methods. The data of traffic conflict technical analysis is not based on accident data, but based on the identification data of traffic flow characteristics. It is a non-accident, large sample and fast quantitative statistical method (Qiao, 2009). Scholars such as Li Song proposed that when two or more ships are close to each other to a certain extent in a certain time and space, if they do not change their motion state, there is a danger of collision. This phenomenon is called water traffic conflict. They also introduced "traffic conflict technology" to quantitatively measure and distinguish the occurrence and severity of water traffic conflicts, and apply them to safety evaluation and prediction (Li&Song, 2010). The four indicators to evaluate the severity of traffic conflicts in the precautionary area are the number of conflict points, the complexity of the conflict area, the frequency of conflicts, and the level of conflict. Taking the waters of the North Channel and the South Channel as the comparison unit, a brief evaluation of the conflict between the two waters before and after the optimization of the ships' routeing system is made according to the above 4 indicators, as shown in Table 19.

Table 19. Comparison of traffic conflicts in precautionary areas before and after optimization

Evaluation index	North Channel		South Channel	
	Existing precautionary area	Oprimized scheme	Existing precautionary area	Optimized
Number of conflict points	32	32	32	32+32
Conflict zone complexity	16	9	15	15
Frequency of conflict	After optimization, the east-west ship flow will be the main focus, and the conflict frequency will decrease significantly		After optimization, the warning zone has a large room for avoidance, and most ships have been diverted in the upstream waters, so the frequency of conflicts will dramatically reduced	
Conflict level	After optimization, far away from the reporting line and pilotage area, problems such as side-by-side navigation of ships and poor communication will be improved, and the level of conflict will be reduced.		After optimization, the ship traffic flow will be separated, the density of ships in precautionary area will decrease, and the level of conflict will decrease.	

Source: Author.

It can be seen from Table 19 that after the optimization of the ships' routeing system, the precautionary area of the North channel waters has moved out, and the room for avoidance is greater, which has an obvious effect on alleviating the water traffic conflicts between the ships anchored at the anchorage and entering the pilotage area and the ships on the north-south channel. Although there is "more" precautionary area in the South Channel waters, the number of conflict points has increased, the optimization plan will divide a part of the ship flow, reduce the density of ships in the local waters, and reduce the intensity and level of ship conflicts.

4.3.2 Economic analysis

Economic benefit factors. The "relocation" of the North-South Great Corridor as a whole to the east will greatly improve the safety of the water area, thereby reducing the economic losses caused by the safety of navigation of ships passing through this area. But at the same time, this scheme will cause some ships to deviate to a certain extent and increase the economic burden of deviating ships, especially the detours of ships from Shanghai Port to ports near Jiangsu and Zhejiang. On the basis of improving the navigation safety of ships, the optimization plan fully considers the economic benefits of ships navigating the waters and reduces unnecessary detours. Keeping the B2 traffic lane will not affect ships going south from the South Channel exit and ships going northward from the South Channel along the coast of Zhejiang. At the same time, the restricted navigation between the northern waters of precautionary area A and the precautionary area A and the precautionary area B will be retained to reduce the detour of ships between the North Channel and nearby ports in Zhejiang.

4.3.3 Analysis of Sailing Habits

The world's first definition of human factors wasgiven by Professor Edwards. He believed that human factors involved the optimization of people and their behaviors through the application of human science. In recent years, human factors have received more and more attention. In order to reduce the negative impact of human factors on maritime safety, the IMO has formulated a series of rules and standards (Schröder-Hinrichs et al., 2013). In terms of human factors, the sailing habits of seafarers are greatly affected. In route design, seafarers generally prefer to sail along frequently sailed routes. Familiar with the geographical environment and navigation environment on the route, it can reduce the hazards of ships during the navigation process. Therefore, the optimization plan for the ships' routeing system in the Yangtze Estuary is to move the entire north-south corridor to the due east by 10 nautical miles on the existing basis, thereby reducing the impact of changes on seafarers.

4.3.4 The problem

According to the planning of Shanghai Marine Functional Zone, the waters east of CJK No. 1 and No. 2 anchorages are agricultural and fishery areas. The layout of the rerouted north-south channel will occupy part of the agricultural and fishery area, and will have some impact on the operation of the agricultural and fishery. In addition, anchored ships entering and exiting CJK No. 1 and No. 2 anchorages from the east side may cross the rerouted South-North traffic channel, which will affect the traffic order and safety of ships to a certain extent.

VTS provides services for traffic safety and efficiency and environmental protection (Jia,2011), mainly including information services, navigation assistance services, traffic organization services and joint services, etc., to supervise ship traffic conditions to ensure navigation safety. Good VTS supervision mainly includes two aspects: First, it needs to rely on advanced equipment such as radar, AIS, communication equipments, CCTV, meteorological equipments, and related softwares to effectively supervise the waters under its jurisdiction; second, a professional VTS management team, including professional sailors and professional VTS equipment operation, maintenance and maintenance personnel. The current ships' routeing system is in the Wusong VTS coverage area. VTS can provide corresponding services for ships within the ships' routeing system, but after the ships' routeing system is changed, it exceeds the current VTS coverage area. If the VTS coverage area is adjusted, the corresponding radar and other equipments have to be rearranged, and the workload of the VTSO will increase.

CHAPTER 5 EVALUATION OF OPTIMIZATION SCHEMES FOR SHIPS' ROUTEING SYSTEM IN THE YANGTZE ESTUARY

The comparison and selection of routeing system schemes is one of the common problems in the design of routeing system. Many scholars have introduced system engineering theories such as analytic hierarchy process(AHP), fuzzy comprehensive evaluation method and extension theory in order to select the optimal routeing system plan, and used the Delphi method to solicit opinions from experts in the industry to determine the weights by determining comparison and selection evaluation indicators, calculate and compare each evaluation index to determine the plan that best meets the evaluation criteria.

In the research on the optimization method of the routeing system, Professor Fan Zhongzhou took the four revised options for the ships' routeing system in Chengshanjiao waters as the research object, and analyzed the effect of AHP, the fuzzy neural network method and the extension theory method in the optimization and evaluation of the routeing system plan (Fan,2013).

The research results show that compared with the fuzzy neural network method, the two methods of AHP and extension theory method are more in line with the general rules of routeing system design and the customary practices of seafarers. Therefore, the use of AHP and extension theory method to compare and select the routeing system plans, the effect is better and the conclusion is more credible.

Therefore, this paper mainly refers to the research results of Professor Fan Zhongzhou in the selection of the optimal evaluation of the routeing system, and chooses the AHP as the optimal method of the plan.

5.1 Introduction to Analytic Hierarchy Process

The AHP is a systematic analysis method in which decision-making goals are processed hierarchically according to certain rules, and various levels of factors are analyzed by a combination of qualitative and quantitative methods. This method expresses a complex decision-making problem as an orderly hierarchical structure, and calculates the relative importance of various decision-making schemes under different criteria and general criteria through people's comparison and judgment, so as to sort the pros and cons of the decision-making programs.

Basic steps of hierarchical analysis
Using the analytic hierarchy process, roughly the following four steps can be carried out:

a. Establish a hierarchical structure model;
b. Construct a judgment matrix;
c. Calculate the weight vector;
d. Consistency inspection.

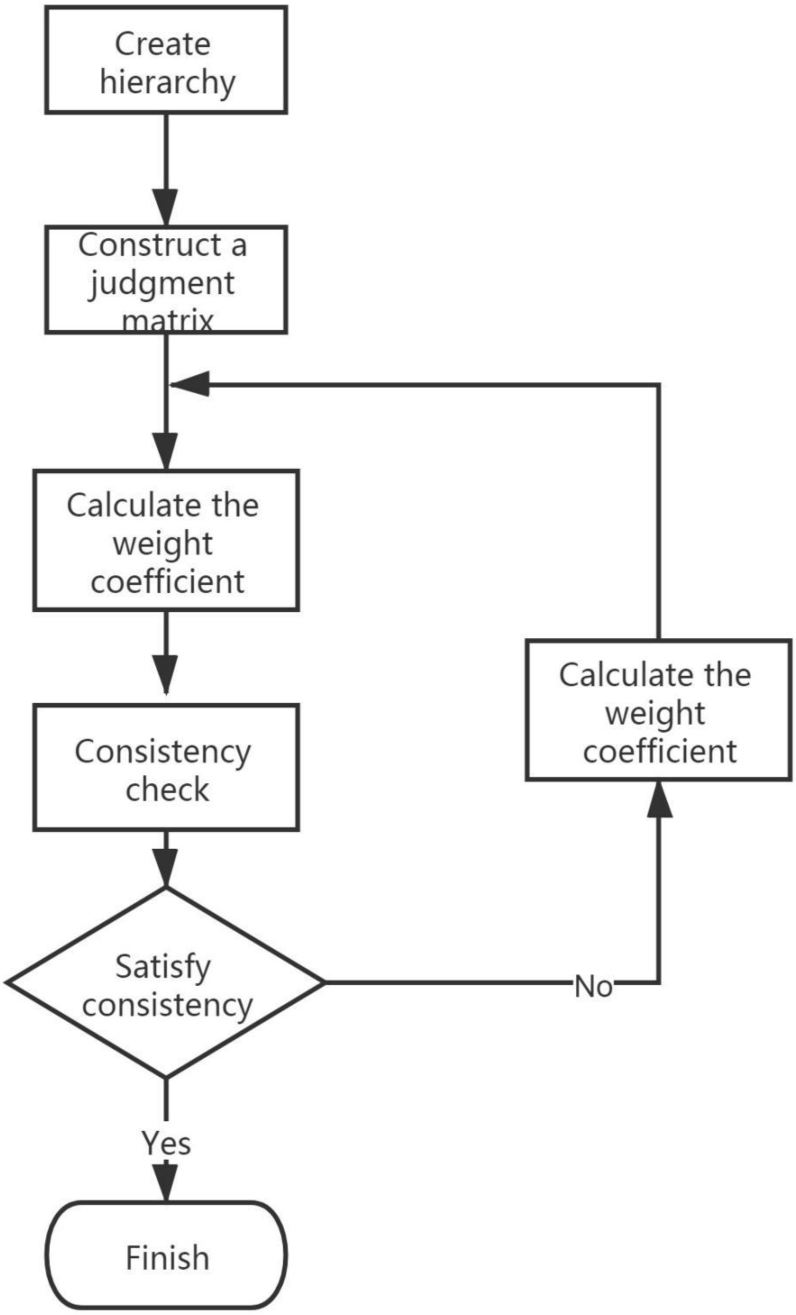

Figure 16. Basic steps of AHP

Source: Author

Establish a hierarchical structure model: In order to conduct multi-level and multi-factor evaluation of the routeing system design plan, it is necessary to construct an appropriate evaluation index system and establish a hierarchical structure model. In the model establishment, each factor is divided into several layers from top to bottom according to its attributes, and the order from top to bottom is: target layer, indicator (or criterion) layer, and object (or plan) layer. Generally, the same-level factors will affect the upper-level factors and at the same time dominate the next-level factors.

Construction of the judgment matrix: starting from the second layer of the hierarchical structure model, the judgment matrix is constructed using pairwise comparisons and 1-9 comparison scales for the upper-level factors. And use A_{ij} to represent the importance of the i-th element and the j-th element relative to an element in the upper layer. The specific importance of A_{ij} can refer to related materials, and the experts and decision-making will jointly study and decide.

Table 20. Judgment matrix scale and its meaning

A_{ij}	definition	A_{ij}	definition
1	A_i and A_j are equally important	2,4,6,8	The importance is between two adjacent rank
3	A_i is slightly more important than A_j		
5	A_i is more important than A_j		
7	A_i is much more important than A_j		
9	A_i significantly more important than A_j		

Sourcce: Author.

Calculate the weight vector and check the consistency:

The largest characteristic root and corresponding characteristic vector are calculated for the paired comparison matrix, and the consistency is checked. If the test passes, the feature vector (after normalization) is the weight vector; if it fails, the judgment matrix needs to be reconstructed.

The steps of the consistency check are as follows:

Calculate paired matrix A (n>1 order square matrix) inconsistency measure CI

CI=(λ_{max}- n) /(n-1), λ_{max} is the maximum eigenvalue of matrix A

RI for determining the consistency of matrix A: RI is the average random consistency index, which is determined by the order of the matrix

Table 21. Consistency check RI value table

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

Source: Internet

Calculate the random consistency ratio CR of matrix A: CR=CI/RI

When CR<0.1, the judgment matrix A has satisfactory consistency or its inconsistency level is within an acceptable range: otherwise, matrix A needs to be adjusted until it has a suitable consistency.

5.2 Evaluation of optimization scheme based on AHP

According to the analysis process of the analytic hierarchy process, the existing ships, routeing system and the optimized plan are respectively analyzed and calculated by the analytic hierarchy process and through the Matlab program. The specific process is as follows:

(a) Build a hierarchical model

Refering to Professor Fan Zhongzhou's index system in the process of evaluating the routeing system plan, and combining the characteristics of the navigation environment and traffic situation in the Yangtze River estuary waters, we will construct the evaluation of the ships' routeing system in Yangtze estuary optimization program from the two aspects of safety and standardization. Hierarchical model and its specific structure model are shown in Table 22.

Table 22. Evaluation index system

Target layer	Criterion layer	Measures layer
Evaluation index system of the ships' routeing system in the Yangtze Estuary	safety A_1	Ship traffic flow densityA_{11}
		Cross meeting of ships A_{12}
		Water velocityA_{13}
		Wind A_{14}
		Visibility A_{15}
	Normative A_2	Separate traffic flow in opposite directionsA_{21}1
		Simplify the mode of converging traffic flowA_{22}
		Organize traffic flow in dangerous areas of navigationA_{23}
		Instruct the ship to clear or pass through the fishing areaA_{24}

Source: Author

(b) Expert questionnaire

When calculating the weight of each indicator, a questionnaire survey is used. With the help of the maritime authorities, a total of 10 questionnaires were sent out and received. Among them, 4 copies were sent to experts with navigation experience and engaged in navigation research, 2 copies were issued to the senior captain of the Yangtze Estuary waters, 2 copies were sent to the VTS center, and 2 copies were issued to the pilot.

(c)Determine the evaluation matrix for integrated expert decision-making

On the basis of collecting and sorting out the questionnaire survey, the formed judgment matrix is constructed and analyzed through the Matlab program, and the final matrix evaluation result integrating the decision of each expert is derived. After calculation and analysis, the results of the judgment matrix of the second layer of safety and effectiveness are shown in the Table 23; the results of the judgment matrix between the factors of the next layer of safety and effectiveness are shown in the table 20 respectively.

Table 23. Target layer judgment matrix

Evaluation index	A_1	A_2	W_i
A_1	1	5	0.8333
A_1	1/5	1	0.1667

Source: Author

In the analytic hierarchy process, CR is the random consistency ratio of the judgment matrix. It is generally believed that when CR <0.10, the judgment matrix has satisfactory consistency, and the result obtained is the judgment matrix of the target layer.

According to the established judgment matrix, the characteristic vector is $W=[0.8333, 0.1667]^T$, and the maximum characteristic root is $\lambda_{max}=2$. It has been tested that the judgment matrix has satisfactory consistency. The weight values of the target layer are 0.8333 and 0.1667 respectively. The same method can be used to obtain the weight of the factor layer. The calculation results are shown in Table 24-Table 25.

Table 24. A_1 index judgment matrix

Evaluation factor	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	W_i
A_{11}	1	5	4	4	4	0.5048
A_{12}	1/5	1	1	2	2	0.1528
A_{13}	1/4	1	1	2	1	0.1397
A_{14}	1/4	1/2	1/2	1	2	0.1089
A_{15}	1/4	1/2	1	1/2	1	0.0939

Source: Author

λ_{max}=5.2273, CR=0.0507, with satisfactory consistency.

Table 25. A_2 index judgment matrix

Evaluation factor	A_{21}	A_{22}	A_{23}	A_{24}	W_i
A_{21}	1	3	3	3	0.5000
A_{22}	1/3	1	1	1	0.1667
A_{23}	1/3	1	1	1	0.1667
A_{24}	1/3	1	1	1	0.1667

Source: Author

λ_{max}=4，CR=0.0000, with satisfactory consistency.

The research index system and its weight are obtained from the above judgment matrices, see Table 26.

Table 26. Index system and its weight

Target layer	Comprehensive evaluation layer		Factor evaluation layer		
	Evaluation index	Weights	Evaluation factor	Weights	Rank
A	A_1	0.8333	A_{11}	0.4206	1
			A_{12}	0.1274	2

		A_{13}	0.1164	3
		A_{14}	0.0907	4
		A_{15}	0.0782	6
A_2	0.1667	A_{21}	0.0833	5
		A_{22}	0.0278	7
		A_{23}	0.0278	7
		A_{24}	0.0278	7

Source: Author

After the questionnaire was collected, it was calculated and tested in accordance with the AHP. For the questionnaires that pass the test, the geometric mean method is used to integrate the results of the questionnaires. After standardization, the weight of each criterion can be obtained. After the integration of the weight, the comprehensive weight of each criterion item at each level is obtained. From the weights obtained, it can be seen that for safety in the Yangtze Estuary, the A_{11} ship density is the most important criterion factor, and the rest are the A_{12} ship encountering cross situation, A_{13} water velocity, A_{14} wind, and A_{15} visibility. The weight of safety is as high as 0.8333, while the weight of effectiveness is 0.1667. Among them, safety is more important than normative. It can be seen that the evaluation and selection of the design scheme of the Yangtze Estuary routeing system should give priority to safety.

5.3 Comprehensive evaluation of routeing system optimization

After the project evaluation influencing factors and the weight of each factor are determined, determined, the Likert five-point scale evaluation questionnaire of the plan is redesigned. An objective basis for the ranking of the existing ships' routing system and the optimized routeing system of the four schemes is provided. The content of the questionnaire is based on the theme of each influencing factor. After the interviewees have understood and mastered the basic information of the optimization plan, they will score the status of the existing and optimized plans, so as to obtain the improvement of the relevant influencing factors in each plan. The specific evaluation value is based on the Likert five-point scale as the standard, and the value is used to convert the quality of each indicator. Among them, the evaluation value of excellent reviews represents 5 points, the evaluation value of good reviews represents 4 points, and the other reviews decrease in order. By averaging the results of the five-point scale evaluation questionnaire for the design plan, adding weights and assigning values to calculate the comprehensive evaluation value of the plan, the ranking of the pros and cons of the plan can be obtained.

Based on the investigation and analysis of the basic data of the different routeing schemes in this article, the five-point Likert scale is used to carry out the numerical conversion of the indicators of each scheme. After counting the average of the questionnaire criteria for each program, a summary Table 27 of the Likert five-point scale evaluation scores of 10 experts for different programs can be obtained.

Table 27. Evaluation score sheet

Evaluation object	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{21}	A_{22}	A_{23}	A_{24}
Existing routeing system	2.1	2	3.6	3.4	3.6	4.4	2.3	3.5	3.7
Optimization	3.4	4.2	2.6	1.8	3.7	4.5	4.3	3.5	1.9

Source: Author

According to the evaluation formula: $F=\sum_{i=1}^{n} w_i x_i$,

Where w_i is the weight of each indicator, x_i is the score of each indicator, and F is the total score.

The scores of the two evaluation objects are calculated as: 2.77762 and 3.36487.

It can be seen from the results that the optimized ships' routeing system is better than the existing ships' routeing system.

CHAPTER 6 SUMMARY, CONCLUSION AND OUTLOOK

6.1 Summary and conclution

This paper starts with the research method of the optimization evaluation of the routing system, and has learned a variety of methods for the optimization evaluation of the routing system at home and abroad. Combining the specific characteristics of the ships' routeing system in Yangtze Estuary, using investigation, data analysis, and fuzzy comprehensive evaluation based on the principle of ship traffic conflict and AHP as the main research methods of this article, the following work has been mainly completed:

(a) In view of the increasingly severe situation of ship traffic in Yangtze Estuary, the increase in the number of ships and the frequent occurrence of collision accidents, the necessity of optimizing the ships' routeing system in Yangtze Estuary is clear, and the research of the thesis purpose and significance is dertemined. At the same time, the specific situation of the routeing system was investigated, and based on the ship traffic conflict theory, the optimization plan of the routing system was proposed to provide a reference for the optimization of the existing routeing system.

(b) Through investigation, we obtained traffic flow data of the ships' routeing system in Yangtze Estuary, and carried out statistics, classification and analysis of the data.

(c) On the basis of reading a large number of relevant documents, in-depth study and research on the optimal method of ships' routeing system. Based on the characteristics of the safety and effective normative evaluation of the ships' routeing system in Yangtze Estuary, this paper decides to use the fuzzy comprehensive evaluation based on the AHP to study the safety and standardization of the routeing system.

(d) In view of the characteristics of the ships' routeing system in Yangtze Estuary and the general situation of the routing system, a questionnaire survey was designed, and the results of the questionnaire survey were analyzed statistically. This paper combines fuzzy mathematics and analytic hierarchy process to evaluate the safety and effectiveness of the ships' routeing system in the Yangtze Estuary, and finally reached the conclusion that the optimized scheme is better than the existing routeing system.

6.2 Outlook

Although this paper has developed a questionnaire based on the characteristics of the alignment system, due to the limited information obtained, coupled with the subjective factors in the questionnaire, it is inevitable that the selection of evaluation indicators is not comprehensive enough. The focus of the next step is to conduct further research on post-evaluation methods and propose a more comprehensive evaluation index system.

Although the optimization plan of the ships' routeing system in Yangtze Estuary proposed in this paper is better than the existing routeing system by the optimization evaluation model, the selection of evaluation indicators is not comprehensive. Although it is superior to the existing solutions in terms of safety and other aspects, there are problems to be solved in terms of economic benefits and traffic management effectiveness, and the optimized solution will occupy part of the farming and fishery operations area. These problems need to be further studied and resolved.

REFERENCE

Ai, X.B. & Hu, Y.N. (2015). *Research on the optimal method of ships’ routing system.* Statistics and Management. (07):141-142. doi:CNKI:SUN:TNGL.0.2015-07-080.

Bai, X.E., Zhou, W., Xiao, Y.J. & Ling, G.Y. (2016). *Optimization and design of ships’ routing system in the Yangtze Estuary.* Shipping Management. 38(09):1-3+8. doi:10.13340/j.jsm.2016.09.001.

Cai, X.J., Wang, Q., Zhu, Z.H., & Shen, Q.Y. *Characteristics study and forecast validation of the gale along the coast of Shanghai*. Marine Forecasts. 37(02):46-53. doi:CNKI:SUN:HYYB.0.2020-02-006.

Chen, H.，Liu, B.S. & Weng, G.L. (2013). *Comprehensive Risk Assessment of Shipping Environment in Luoyuan Bay.* Navigation of China. 36(04):86-91. doi:CNKI:SUN:ZGHH.0.2013-04-021.

Cheng, H.Z. (2016). *Study on the Design and Optimization of Ships' Routeing System in the Miniiang Estuary*. [Master’s thesis, Wuhan University of Technology]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201901&filename=1018806014.nh

Chu. L.H. (2009). *Research on Ships' Routeing System in the Adjacent Waters off Lian YunGang Port.* [Master’s thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2009&filename=2009107146.nh

Cui, J. (2012). *The Safety Evaluation After The Implementation Of Routeing System*. [Master’s thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2012&filename=1012345408.nh

Dong, Y., Frangopol, D.M., & Sabatino, S. (2016). *A decision support system for mission-based ship routing considering multiple performance criteria.* Reliability Engineering and System Safety. 150:190-201. doi:10.1016/j.ress.2016.02.002.

Fan, Z.Z. (2013). *Research on the Optimized method of Ship Routeing Schemes*. [Doctoral dissertation, Dalian Maritime University]. https://kns.cnki.net/

KCMS/detail/detail.aspx?dbname=CDFD1214&filename=1014155810.nh

Fan, Z.Z., Wu, Z.l. & Zhang, C. (2014). *Assessment methods of ship's routeing based on grey theory.* Journal of Dalian Maritime University. 40(01):37-40. doi:10.16411/j.cnki.issn1006-7736.2014.01.012.

Feng, Z.J. (2015). *Research on the post-evaluations of the Ship RouteingSchemes of Rearl River eatuary waters*. [Master’s thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201601&filename=1015657345.nh

Gao, W.J. (2009). *The Optimization Study on Integration Scheme of Ships' Routeing in the Waters of Eastern Bohai Straits*. [Master’s thesis, Wuhan University of Technology]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2011&filename=2010036814.nh

Guo, W.B., & Fan, Z.Z. (2014). *Suggestions on the revision of ships, routing system in Dangan waters.* Marine Technology. (02):26-27. doi:CNKI:SUN:HHJS.0.2014-02-016.

Hoshida, Y. (2006). *Improvement of Analytic Hierarchy Process procedures*. Geographic Information Systems Association. 14(2):135-144. doi:10.5638/thagis.14.135.

Hu, B., & Zhan, H.D. (2015). *Thoughts on the Optimum Setting of the Precautionary areas of the Ships’ routeing System in Yangtze Estuary*. China Ports (02):60-61. doi:CNKI:SUN:GUKO.0.2015-02-024.

Hu, Z.H. (2012). *Evaluation of large ships' routeing system in the eastern waters of Chengshanjiao.* [Master’s thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2012&filename=1012345433.nh

Huang, C.H., Xiao, Y.J.，Gao, D.Y.，Peng, Y.，Zhao, Y.B. & Bai, X.E. (2014). *Design of Ship Routeing Scheme in Minjiang Estuary.* China Safety Science Journal. 24(02):93-99. doi:10.16265/j.cnki.issn1003-3033.2014.02.017.

Hwang, S.J., Kobayashi, E., Wakabayashi, N., & Im, N. (2016). *A New Risk Evaluation Model for Safety Management on an Entire Ship Route*. International Journal on Marine Navigation and Safety of Sea Transportation.

10(1):93-98 doi:10.12716/1001.10.01.10.

International Maritime Orgnization. (1986). *General Provision Ships' Routeing.* https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.572(14).pdf

International Maritime Orgnization. (2021). *Historical background on ships' rou teing.* https://wwwcdn.imo.org/localresources/en/OurWork/Safety/Documents/Ships'%20routeing/Historical%20background%20on%20ships.pdf

Jensen, T.K., Hansen, M.J., Lehn-Schiøler, T., Melchild, K., Rasmussen, M.F., & Ennemark,F., (2013). *Free Flow – Efficiency of a One-way Traffic Lan e between two Pylons.* Journal of Navigation. 66(6):941-951. doi:10.1017/S0373463313000362.

Jia, J.R. (2011). *The Research on VTS Vessel Traffic Management Integrated Information System*. [Master's thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2011&filename=1011110775.nh

Li, H.J. (2015). *Research on Optimization of the Amendment Schemes to Dan' gan Traffic Separation Scheme*. [Master's thesis, Dalian Maritime Univer sity]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201601&filename=1015657341.nh

Li, S., & Shao, J.L. (2010). *Application of traffic conflicts technique in ships' routing precautionary areas.* Port & Waterway Engineering. (07):111-115. doi:10.16233/j.cnki.issn1002-4972.2010.07.013.

Li, S.，Zhong, J.H.，Xu, T.L., & Bao. X.G. (2013). *Optimal Design of Preca utionary Area Routeing Based on Navigational Traffic Conflict Technique.* Navigation of China. 36(01):95-100. doi:CNKI:SUN:ZGHH.0.2013-01-021.

Liang, Q.H. (2008). *Study on Ships' Routeing Systems in Bohai Sea.* [Master's thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2009&filename=2008209839.nh

Liu, D.X., Yang, S.R. (1989). *Research on planning design and comprehensive evaluation of traffic separation*. Journal of Dalian Maritime University. (03):13-19. doi:10.16411/j.cnki.issn1006-7736.1989.03.003.

Liu, J.B.，Zheng, G.L., & Ding, T.M. (2013). *Discussion on the countermeasures for safe navigation in the waters of Ningbo-Zhoushan Port*. China Water Transport. 13(10):11-12. doi:CNKI:SUN:ZSUX.0.2013-10-008.

Liu, Y.H.，Xiao, Y.J. & Guan, K.P. (2014). *Ship's routeing for Ningbo-Zhoushan core harbor area based on marine traffic investigation of AIS*. Journal of Shanghai Maritime University. 35(1):1-5. doi:10.13340/j.jsmu.2014.01.001.

Merrick, J.R.W, Van Dorp, J.R., Blackford, J.P., Shaw, J.L., Harrald, J., Mazzuchi, T.A., &Mazzuchi, T.A. (2003). *A traffic density analysis of proposed ferry service expansion in San Francisco Bay using a maritime simulation model.* Reliability Engineering and System Safety. 81(2):119-132. doi:10.1016/S0951-8320(03)00054-1.

Maritime Safety Administration of the Peoples Republic of China. (2011). *Master Plan for China's Coastal Ship Route.* shttps://www.msa.gov.cn/page/article.do?type=hsfg&articleId=70D8518B4CA6329FE0533A0820C67141

Mou, J.M., Tak, C., & Ligteringen, H. (2010). *Study on collision avoidance in busy waterways by using AIS data.* Ocean Engineering. 37(5):483-490. doi:10.1016/j.oceaneng.2010.01.012.

Özbaş, B., & Or, I. (2007). *Analysis and control of maritime transit traffic through the İstanbul Channel: a simulation approach.* Central European Journal of Operations Research. 15(3):235-252. doi:10.1007/s10100-007-0028-9.

Qian, W.Z., & Li, Z.Y. (2010). *On the effective implementation of the ship routing system in the Yangtze Estuary.* Marine Technology. (01):13-15. doi:CNKI:SUN:HHJS.0.2010-01-008.

Qiao, G.M. (2009). *Analysis of Navigation Safety in Restricted Waters.* Navigation of China. 32(01):102-105+110. doi:CNKI:SUN:ZGHH.0.2009-01-022.

Schröder-Hinrichs, J.U.，Hollnagel, E.，Baldauf, M., Hofmann, S., & Kataria, A. (2013). *Maritime human factors and IMO policy.* Maritime Policy & Management. 40(3):18. doi:10.1080/03088839.2013.782974.

Sheng, Y.X., (2015). *The feasibility study to broaden the LaoTieShan channel.* [Master's thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201601&filename=1015657503.nh

Sun, H. (2016). *Research on post-evaluation of the Amendment Schemes to Dan'gan Traffic Separation Scheme.* [Master's hesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201701&filename=1017036579.nh

Szłapczyński, R. (2013). *Evolutionary sets of safe ship trajectories with speed reduction manoeuvres within traffic separation schemes*. Polish Maritime Research. 21(1):20-27. doi:10.2478/pomr-2014-0004.

Tan, J., Wang, J.H., Zhou, C.Y. & Teng, K. (2012). *On the Establishment of Ship Routing System for Xijiang trunk waterway*. Navigation of China. 35 (02):72-75. doi:CNKI:SUN:ZGHH.0.2012-02-017.

Vladimir M Trbojevic, & Carr, B.J. (2000). *Risk based methodology for safety improvements in ports.* Journal of Hazardous Materials. 71(1):467-480. doi:10.1016/S0304-3894(99)00094-1.

Wang, L. (2007). *The Study About The Social Evaluation Of The Ships' Routeing Of The Region Of Changiiang In AnHui.* [Master's thesis, Wuhan University of Technology]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2007&filename=2007147801.nh

Xing, C.Y. (2013). *Regularity Study on Constituent Elements of Traffic Separation Schemes.* [Master's thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201302&filename=1013204539.nh

Xing, Y.H. (2008). *Performance Evaluation on Ships' routeing in Laotieshan watercourse*. [Master's thesis, Dalian Maritime University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2009&filename=2008209314.nh

Xu, C.Y., Zheng, Y.Z., Gan, L.X., Zhou, C.H., Zhang, L., & Cheng, H.Z. (2017). *Design of Ship Routeing Scheme in Minjiang Estuary.* Navigation of China. 40(04):45-50. doi:CNKI:SUN:ZGHH.0.2017-04-010.

Y, Z.T., Liu, K.Z., Xin, X.R., Yang, X., & Liu, J.J. (2018). *Design method of* *ships' routeing in bay waters*. Journal of Shanghai Maritime University. 39(04):14-19+43. doi:10.13340/j.jsmu.2018.04.003.

Yin, X.M. (2011). *Study on Ships' Routeing system in Nearby Waters of Rizhao Port.* [Master’s thesis, Wuhan University of Technology]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2011&filename=1011104161.nh

Zhang, H., Yu, B., Xiao, Y.J., Yang, X.J., & Bai, X.E. (2010). *Alternative design evaluation of ship's routeing system.* Journal of Shanghai Maritime University. 31(03):5-9. doi:CNKI:SUN:SHHY.0.2010-03-003.

Zhang, S.S. (2019). *Temporal and spatial variation of tidal range in the Changiiang Estuary and its environmental significance.* [Master’s thesis, East China Normal University]. https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD201902&filename=1019835366.nh

Zhang, W.J., Li, G.S., Yin, J.C., & Song, F.X. (2016). *Optimization of Routing System in Caofeidian Waterway*. ship & ocean engineering. 45(03):173-176. doi:CNKI:SUN:WHZC.0.2016-03-038.

Zhao, C.Y.，Xie, H.B.，Xiao, Z.M., & Jiang, H.B. (2013). *Research on the planning of ships’ routing system in the Bohai Sea.* World Shipping. 36(01):15-20. doi:10.16176/j.cnki.21-1284.2013.01.010.

Zhuo, Y.Q., & Tao, J. (2015). *Effectiveness Analysis and Evaluation of Qiongzhou Strait Ship Routeing Scheme.* Navigation of China. 38(01)，80-84. doi:CNKI:SUN:ZGHH.0.2015-01-020.