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Research on optimization of the ship routeing system in Qiongzhou Strait

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RESEARCH ON OPTIMIZATION OF THE SHIP ROUTEING SYSTEM IN QIONGZHOU STRAIT

By

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The People's Republic of China

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

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In

Maritime Safety Environmental Management

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DECLARATION

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

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

Signature:________

Date: June 28, 2019

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Professor
Captain
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ABSTRACT

Title of Dissertation: **Research on Optimization of the Ship Routeing System in Qiongzhou Strait**

Degree: **Master of Science**

Qiongzhou Strait is an important channel for maritime traffic between Guangdong sea area and Beibu Gulf, and a maritime corridor connecting Beibu Gulf with the middle and east of South China Sea. The ship routeing system can greatly improve the safety of maritime traffic. Due to the change of vessel traffic flow in Qiongzhou Strait, the existing ship routeing system cannot guarantee the safe navigation of ships in this area, so it should be modified.

The optimization of ship routing system should consider several factors. The first is the characteristics of the water area of the ship routeing system, including the geographical environment, weather and other natural conditions of the water area. The second is the traffic flow of the ship, and the third is the rules of the ship routeing system. On the basis of analyzing the current ship routing system and combining the above factors, this paper puts forward an optimization scheme of ship routeing system in Qiongzhou Strait.

The proposed optimization scheme is divided into the overall modification scheme and the modification scheme of key water areas. There are three schemes for the revision of key water areas, each focusing on solving different key problems. Through the questionnaire survey of relevant ship captains and ship traffic management officers, their opinions and choices on different schemes are obtained. Through the feedback of the survey results, the optimization scheme is modified to make it more suitable for safe navigation of ships in Qiongzhou Strait.

KEY WORDS: ship routeing, optijization scheme, traffic flow, questionnaire survey

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
DCPA	Distance to the Closest Point of Approach
EEZ	Exclusive Economic Zone
GPS	Global Positioning System
IMO	International Maritime Organization
MSA	Maritime Safety Administration
MSOD	Minimum Safe Overtaking Distance
nm	nautical mile(s)
P.R.C	People's Republic of China
SOLAS	International Convention for Safety of Life at Sea
UNCLOS	United Nations Convention on the Law of the Sea
VTS	Vessel Traffic Service

Charpter 1: Introduciton

1.1 Background information about Qiongzhou Strait

Qiongzhou Strait is located between Hainan island and Leizhou peninsula, with east-west length about 60 nm, north-south about 12 ~ 20 nm wide, the average depth of about 44 meters, the deepest depth of 119 meters, is the communication of eastern and western coastal waters in southern China a main channel, is also China's opening to the outside world an important sea lanes (Chen, 2018). According to the UNCLOS 1982 and Law of the P.R.C on the Territoral Sea and the Contiguous Zone, Qiongzhou Strait is designated as China's internal water.

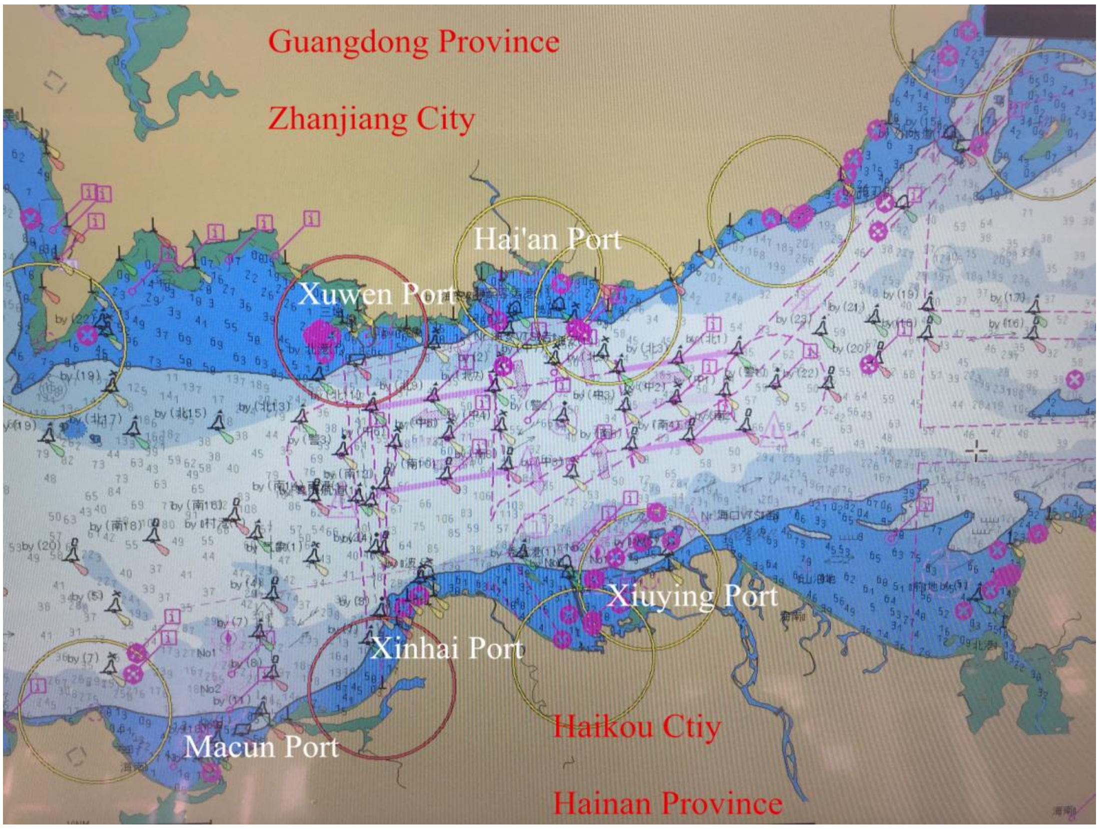

Figure 1-1: Diagram of maritime traffic in Qiongzhou Strait

In order to effectively strengthen the traffic safety management of the waters and ensure the safety of navigation of ships, the VTS has been established in the Qiongzhou Strait. The implementation of the Qiongzhou Strait ship routeing system effectively standardizes the navigation order of ships passing through the Qiongzhou Strait and effectively ensures the navigation safety of ships (Ministry of Transport of the P.R.C, 2011). However, with the adjustments of port function and the change of ship traffic flow in recent years, the existing ship routeing system in Qiongzhou Strait cannot meet the need of safe navigation in the strait.

1.1.1 Adjustment of ports functions

At present, Xiuying port in Haikou, Hainan province is the main port, providing berthing services for passenger ships, container ships and bulk cargo ships. Haikou city will build Xinhai port as a passenger ship and ro-ro ship terminal, and plan to move the container, bulk cargo, ro-ro ship transport function to the west to Makun port and the Xinhai port. The existing Xiuying port will be transformed into a cruise and yacht terminal, the Makun port will be built as a bulk cargo and container transfer center, and the Xinhai port will be built as a large passenger terminal (Wang, Xu & Chen, 2018).

In order to adapt to the adjustment of the function layout of Haikou port, Zhanjiang city of Guangdong province plans to transfer the passenger ship business from Hai'an port to Xuwen port to form docking with the new Haikou port. According to the plan, after the relocation of passenger ships in Hai'an port, Hai'an port will be built into a tourism terminal and docked with Haikou Xiuying port to open up a luxury ro-ro ship, hydrofoil ship, seaplane and other tourism transport express passenger terminal (Chen, 2016).

1.1.2 Traffic flow changes

By March 2019, there were more than 50 passenger ships sailing between Xiuying port in Haikou city and Hai'an port in Zhanjiang city, with an average traffic flow of 120 times per day. According to the new planning of port functions of Xiuying port and Hai'an port, the current busy passenger ship traffic flow between Xiuying port and

Hai'an port will move to the west between the Xinhai port and Xuwen port. At the same time, the traffic flow in and out of Macun port in Haikou will increase greatly. According to the current construction progress forecast of ports on both sides of the Qiongzhou strait, the traffic flow of passenger ships on both sides of the Qiongzhou strait will have the following two new situations:

(a) When the port function adjustment of Haikou port is completed and the corresponding adjustment of Zhanjiang port area is not completed, passenger ships form the traffic flow from the Xinhai port to Hai'an port, as shown in the figure 1-2. According to the current Qiongzhou Strait ship routeing system, the traffic flow of ships in the east and west direction will be greatly increased.

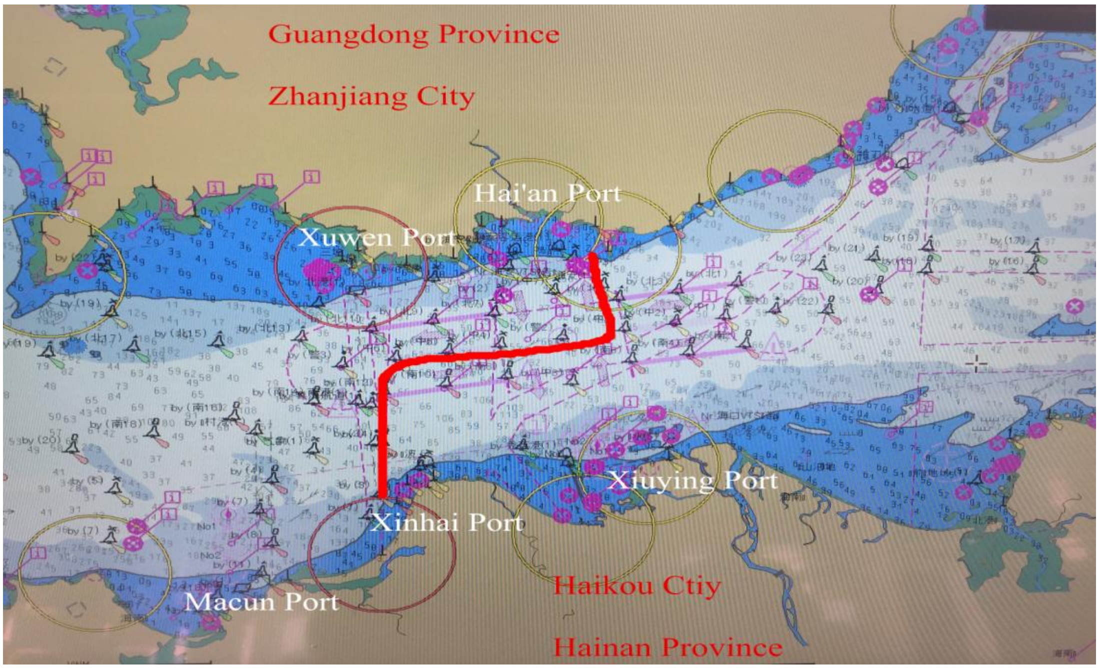

Figure 1-2: Diagram of Qiongzhou Strait passenger ship route

(b) When the port functions of Haikou and Zhanjiang are adjusted, the passenger ships will form the traffic flow from the Xinhai port to Xuwen port. At the same time, the railway ferry route from Guangdong to Hainan will be merged into this route. The Guangdong-Hainan cross-straits railway ferry project plans to build 9-13 new ships which will increase the traffic flow of this route.

The Qiongzhou Strait ship routeing system, therefore, difficult to adapt to in order to ensure the security of Qiongzhou Strait shipping navigation, in order to satisfy the function of Haikou city and Zhanjiang port adjusted ship flow needs, great changes have taken place to ensure the safety of navigation of ships and navigation order, Qiongzhou Strait ship routeing system for the corresponding adjustment is imminent.

1.2 Significance of setting up and adjusting ship routeing system

The implementation of ship routeing system is the main means of effective management in the area with heavy traffic, and an important method of rational planning and effective utilization of navigation routes. It represents the development direction of navigation management of ship traffic (Fan, 2013). The traffic of ships in Qiongzhou Strait is dense and the situation of ships is complicated.

The ship routeing system reduces the risk of collision and improves the safety of maritime navigation by standardizing the traffic behavior of ships within specific waters. With the rapid development of economy, the traffic flow of ships in the Qiongzhou Strait is increasing, and ships are developing in large scale. The navigation environment in the Qiongzhou Strait is becoming more and more complex. Meanwhile, Qiongzhou Strait is one of the important fishing grounds along the southern coast of China. The number of fishing boats in the strait has been increasing rapidly. These urgent requests the competent authority strengthens the traffic management, the standard vessel traffic behavior, in order to avoid because of the traffic chaos to cause the maritime traffic accident the occurrence.

In accordance with SOLAS Convention (IMO, 2016) and SHIPS' ROUTEING, the governments of each contracting state shall be responsible for the initial planning and establishment of SHIPS' ROUTEING. According to the provisions of China's maritime traffic safety law, it is a statutory duty of China's maritime administrative authorities to make scientific and reasonable plans for navigation routes in coastal navigable waters. The establishment of reasonable and efficient ship routeing system is conducive to displaying a good image of China's maritime management agency.

1.3 Rresearch status of the ship routeing system

Ship traffic separation system originated in western countries, and many scholars have made great contributions to the development and maturity of traffic separation system. Spanish Rear Admiral Garcia-frias, captain Maury of the United States, Robichon and Oudet of France, Poll of Belgium and captain Wepster of the Netherlands all made great contributions to the establishment, development and implementation of the seperation system. The earliest guiding document of Ship traffic separation system, general provisions of ship routeing system, was produced in 1977. This document put forward many guiding suggestions for the establishment and implementation of ship routeing system, making the role of ship routeing system in ensuring navigation safety and standardizing traffic more prominent. At the same time, the design practice of various countries tends to be unified. The document has been revised many times since its release in 1979, the last time being IMO resolution A.572 (14) in 1988.

China's Chengshanjiao ship traffic separation system is the first ship routeing system which registered in the IMO (Fan, Hong & Zhang, 2012). The ship routeing system consists of traffic separation scheme, inshore traffic zone and precautionary area, and was revised in 2014 to add the external traffic separation scheme and precautionary area. On June 1, 2004, the ship routeing system of the Pearl River estuary began trial operation. It was officially implemented on July 1, 2015 and registered in IMO in May 2018. It is the second ship routeing system registered in IMO in China. <National coastal ships routeing system overall planning> and <The national overall plan of the coastal rout> which promulgated by the China have important significance for China's coastal route, it clearly describes China routeing system design and implementation of the direction and goals, which will optimize the distribution of ships routeing system in China's coastal and Settings, make the ships routeing system play a more important role on navigation safety.

1.4 Main research contents

Intends to through a lot of traffic investigation and analysis, this paper applied the theory and methods of Marine traffic engineering, the Qiongzhou Strait waters navigation environment of the combination of qualitative and quantitative analysis reveals the Qiongzhou Strait waters main traffic flow patterns and traffic environment. According to the international maritime organization, international law and the Qiongzhou Strait ship traffic status quo, this paper will put forward the best scheme of ship routeing system in Qiongzhou Strait

1.4.1 Investigation and research on ship traffic in Qiongzhou Strait

The investigation contents mainly include hydrometeorology, traffic conditions, ship traffic conditions, customary route, fishing grounds and ship traffic accidents in Qiongzhou Strait. On the basis of investigation and data analysis and processing, the application of the theory and methods of Marine traffic engineering, the research of traffic flow model and obtain the Qiongzhou Strait waters and the way of transportation, ship rules and influence factors of traffic accidents, as well as the status quo and characteristics of the navigation environment, etc., for the waters of the Qiongzhou Strait shipping routeing system adjustment to lay a solid foundation.

The method of traffic survey is to obtain traffic volume, traffic density, traffic form and other data by using the data provided by Hainan MSA, AIS center and other units. The survey method of navigation condition is to obtain the original data and data of navigation environment of Qiongzhou Strait by means of research group survey, field navigation observation and issuing questionnaire if possible.

1.4.2 Research on ship routeing system adjustment in Qiongzhou Strait

Based on the IMO’s General provisions on ships’ routeing (IMO, 1985) and the current navigation situation of Qiongzhou Strait, this paper studies the basic principles and design standards of route planning for Qiongzhou Strait waters, analyzes and studies the technical factors of Qiongzhou Strait waters, and studies and recommends the best scheme of ship routeing system adjustment for Qiongzhou Strait.

Chapter 2: Theoretical basis of ship routeing system

2.1 Introdution of ship routeing system

In order to improve the safety of ship traffic, standardize the order of ship traffic, reduce the risk of collision, the adoption and development of ship routeing system, which is mainly in the form of traffic separation system, has played an important role in the safety of ship navigation. General Provisions on Ship's Routeing (IMO,1985), which was put forward by IMO in 1977 and adopted in 1985 and subsequently amended several times, provide specific Provisions on the establishment and use of Ship's Routeing. The Ship routeing system in IMO waters around the world (mainly traffic separation scheme and its combination with other routeing measures) is published in the IMO publication <Ship's Routeing>.

Ship routeing system is any system or routeing measure of one or more routes designed to reduce the risk of maritime accidents. Ships' routeing systems contribute to safety of life at sea, safety and efficiency of navigation and/or protection of the marine environment (IMO, 2017). It includes traffic separation scheme, roundabout, inshore traffic zone, two-way route, recommended route, recommended track, deep water route, area to be avoided, no anchoring area, controlled and/or prohibited area and other routeing measures, which can be used alone or in combination according to actual needs (IMO, 1985). In general, an actually adopted ship routeing system is usually composed of separation zone or line, traffic lane, established direction of traffic flow and recommended direction of traffic flow.

Ships routeing system aims to enhance the dense regions of ship convergence zone and traffic, and due to the limited waters, there is obstruction and restricted water depth or poor weather conditions so that the ship's freedom of movement restricted waters of navigation safety, and prevent or decrease due to the ship in environmentally sensitive areas or near the collision, stranding or anchor, or other damage to the Marine environment pollution caused by the risk.

2.2 Implementation of ship routeing system worldwide

In view of the huge economic benefits and safety benefits brought by the ship routeing system, the ship routeing system has been developed rapidly in the world. By December 2017, there were 163 ship routeing systems which adopted by IMO. All 163 are located in areas where ships meet or where conditions are complex. In these waters, the ship routeing system can well dredge the traffic flow, help the ship avoid obstruction, improve the safety factor and traffic efficiency of the ship.

2.2.1 Location of the waters in which the ship routeing system adopted

According to the statistics of the ship routeing system adopted by IMO before December 2017, there is a significant difference in the number of ships in different waters (Cao, 2015). Europe has the longest shipping history and a very developed shipping industry. Therefore, the number of ship routeing systems adopted by IMO in European waters is the largest, while the number of ship routeing systems adopted by IMO in Asian waters is the smallest. See figure 2-1 for details.

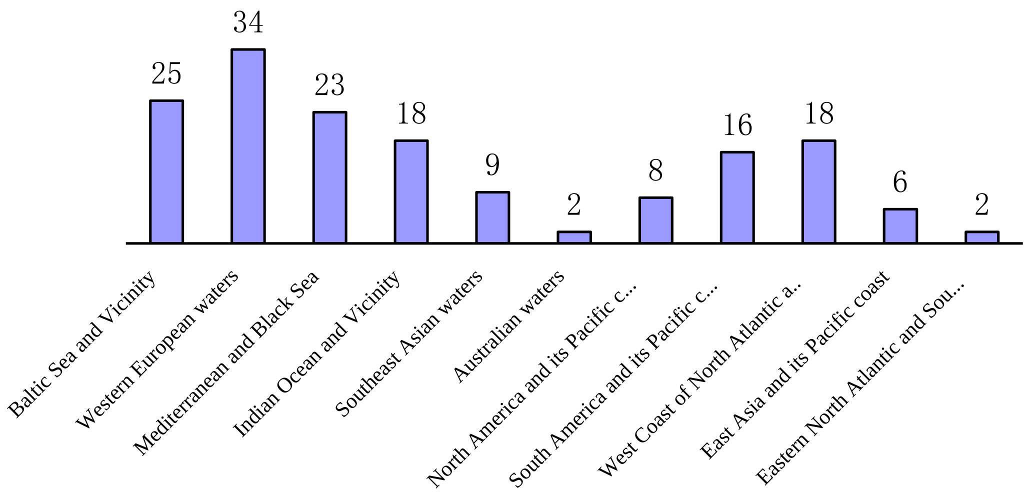

Figure 2-1: Statistics of water areas implemented ship routeing system

2.2.2 Nature of the waters in which the ship routeing system adopted

The establishment of the ship routeing system is influenced by many factors, among which the distance between the ship routeing system and the countries under its jurisdiction and the nature of the water area are particularly important. According to the definition of internal water, territorial sea, contiguous zone, EEZ and high seas of the UNCLOS 1982 (UN, 1982) and the provisions on the rights and limitations of coastal states, this paper adopts internal water, territorial sea, contiguous zone, EEZ and high seas as the measurement standards to indicate the distance between ship routeing system and the country to which it belongs. Figures 2-2 show the distribution of ships in the waters, some entirely within a jurisdiction, and others between two different waters. Relevant data ends in December 2017.

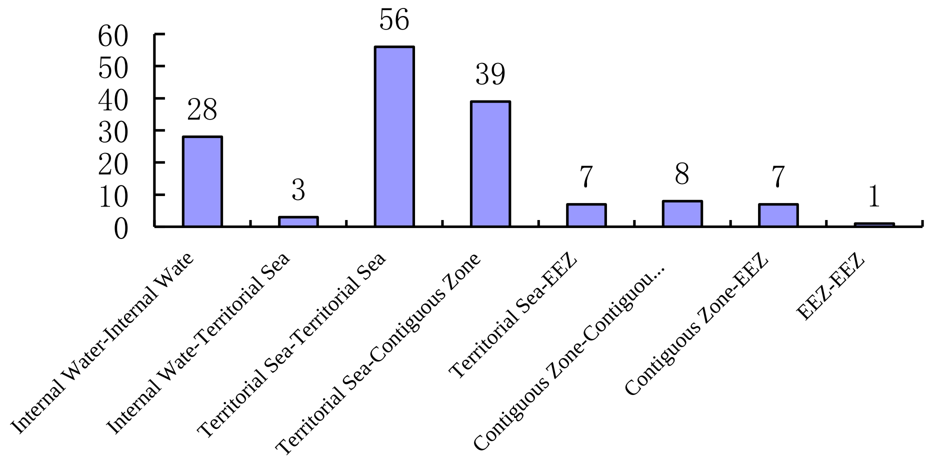

Figure 2-2: Statistics of ship routeing location (jurisdiction)

In addition to the distance from islands or land, the nature of the water area in which the ship routeing system is located also greatly affects the components of the ship routeing system. In this paper, the waters in which ships are located are divided into five categories, namely, reef areas, capes, narrow channels, coastal waters and open seas. A reef area is a body of water with multiple reefs or islets near the ship routeing. A cape is an angular coastal area. A narrow channel is one in which the navigation of a ship is very narrow and the movement and handling of a ship is greatly restricted. Coastal waters refer to the waters that are close to the land and less obstructing to navigation. In this paper, the nearest offshore waters not more than 10 nm are taken as coastal waters, but excluding reef areas, cape waters and narrow channels. Open seas means a body of water without visible obstructions surrounding it and excluding reef areas, capes, narrow channels and coastal waters. Figure 2-3 shows the current distribution of the waters where the ship routeing systems are located. (Yuan, Liu & Xin, 2018)

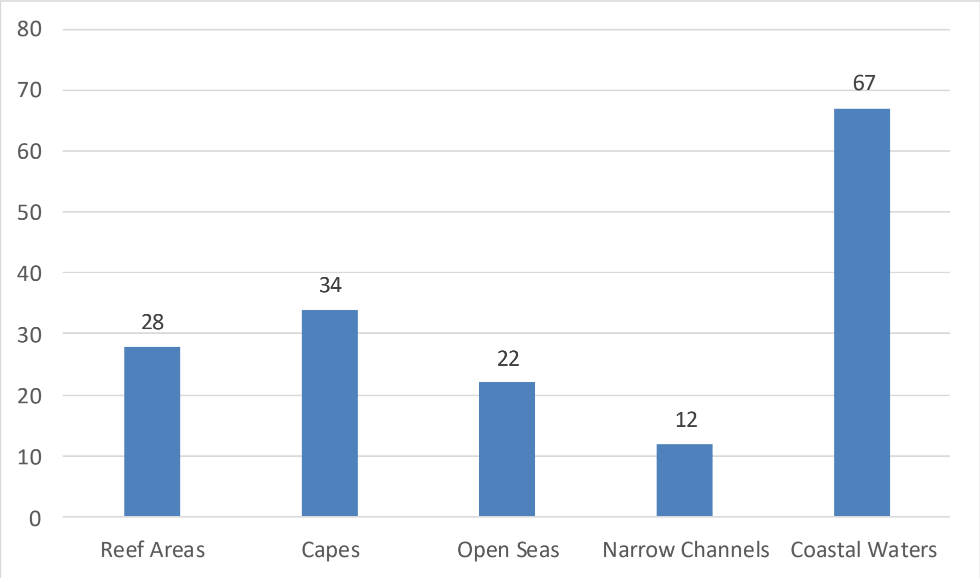

Figure 2-3: Statistics of ship routeing location (water nature)

2.3 Traffic separation scheme design dimensions

Traffic separation scheme is a form of ship routeing system, but it is the most important form. The main content of ship routeing system in Qiongzhou Strait is traffic separation scheme.

2.3.1 Length of traffic separation scheme

IMO experts pointed out that the length of segregations should be considered for navigation safety and long continuous separation should be avoided (Xiao & Zhang, 2010). It is appropriate and effective to design the traffic separation scheme in Qiongzhou Strait by using the intermittent separation system to maintain the whole-course traffic separation, which not only avoids the excessive length of separating system, but also maintains the long-distance traffic separation. The length of traffic separation scheme shall be designed in accordance with the basic principle that it should be short rather than long, and the following factors shall be considered comprehensively:

a. The traffic separation scheme is basically located in areas with dense fishing boats, and the appropriate length is conducive to effectively organizing ships to pass through areas with dense fishing boats;

b. An appropriate length is conducive to maintaining the stability of the course of a ship traveling in a traffic lane for a certain period of time and meeting the requirements of collision avoidance;

c. The appropriate length is conducive to the convenience of positioning and judgment for the ships entering and leaving the end of the traffic lane from the design point of view. In particular, from the perspective of ship control, the object mark is used as the opportunity for the ships entering and leaving the end of the traffic lane as far as possible.

According to the statistics of traffic separation scheme of 30 similar waters (such as strait and cape) adopted by IMO, the average length of the traffic separation scheme is 13.3 nm, which is less than 12 nm, accounting for 43%. The longest Suez is 100 nm, and the shortest is 6 nm. Therefore, the length of each section of the traffic separation scheme is determined to be: 10 to 12 nm for the direct section and the steering section is 21 nm.

2.3.2 Traffic lane width

The width of traffic lanes involves traffic density, traffic volume, positioning accuracy and geographical conditions. According to IMO requirements (IMO, 2017), traffic density and total utilization of the area and available sea areas should be taken into account. The width should correspond to the positioning accuracy of the available positioning method and be sufficient to enable the ship to catch up with the minimum safe overtake distance.

Japanese scholar Mihei Fujii proposed that in the less crowded coastal waters (L^2 conversion ship density of 0.01 ~ 0.1/km^2), ship density and positioning accuracy are the main factors to determine the width of navigable lanes, and suggested that the width of traffic lanes and separation zones is generally 3'--2'--3' to 1'--0.5'--1' (Szlapczynski & Rafal, 2013).

British scholar Robert G. Curtis put forward the idea of minimum safe overtaking distance (MSOD) on the basis of mathematical research and experimental research of radar simulator (Curtis & Robert, 1986). The establishment and use of traffic separation scheme has greatly reduced the collision risk in Head-on Situation and Crossing Situation, but increased the Overtakeing Situation in the traffic lane. Curtis proposed the MSOD in poor visibility based on the research on chasing problem in traffic lane, which is in direct proportion to the reaction time of overtaking ship and the speed of overtaken ship, but has nothing to do with the speed of overtaking ship. Figure 2-4 shows the MSOD curves of the overtaken ship with a length of 325 meters, a turning radius of 0.4 nm, and a reaction time of 3, 5 and 7 minutes respectively. Typical reaction time data proposed by Curtis are: response time of super-large ships is 7 minutes in poor visibility; General cargo ship for 5 minutes; 3 minutes for a ship with good maneuverability. It is suggested that the width of the traffic lane should reach the MSOD.

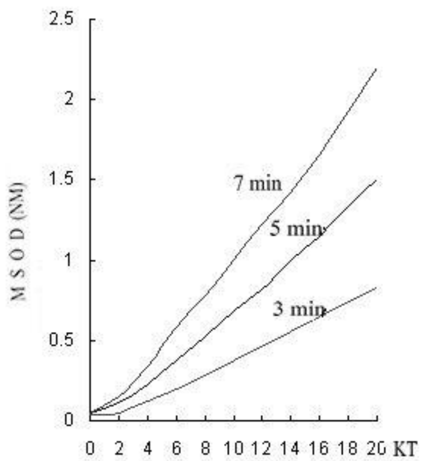

Figure 2-4: MSOD curve

According to the provisions 6.10 of the IMO’s General Provisions on Ships' Routeing (IMO, 1985), the width of the traffic lanes should take into account the traffic density, the overall utilization of the area and the available sea area. According to figure 2-4, in the case of poor visibility, if the reaction time of an overtaking ship is 7 minutes, the overtaken ship is a large ship and its speed is 12 knots, the MSOD is 1.3 nm. If the overtaking ship is a large ship and its reaction time is 7 minutes, the speed of the overtaken ship is 14 knots, then the MSOD is 1.46 nm. Therefore, the width of the traffic lanes should be more than 2 nm.

2.3.3 Separation zone width

According to the statistics of the traffic separation schemes adopted by the IMO for 30 similar waters (such as strait and cape), the average width of the separation zone is 2.1 nm, of which 43% is 2 nm and the narrowest is 0.5 nm.

2.3.4 Traffic capacity of traffic lane

Passing capacity is expressed as the maximum number of ships that can pass in a unit of time, also known as traffic capacity. When the passing capacity cannot meet the actual passing needs of ships, it will cause traffic congestion and affect the passing efficiency of ships. IMO general regulations on ship routeing advocate that as long as feasible, the traffic lane width should be as wide as possible to ensure safe navigation of ships

Japanese scholar Fujii has made theoretical research on the basic traffic capacity of ships corresponding to different scales and speeds in a one-way channel with a width of 1 nm, and the conclusions are shown in table 2-1 (Szlapczynski, 2013). As can be seen from the table, for the 3,000-20,000 GT ships with an average length of 127m and an average speed of 13.4kn, the basic traffic capacity of a 1-nm wide channel is 150 ships per hour and 3600 ships per 24h per day. Obviously, if the one-way traffic width reaches 1 nm, it is more than enough for the traffic capacity.

Table 2-1: Basic traffic capacity of ships of different tonnage (channel width 1 nm)

ship tonnage (GT)	average length (meter)	average speed (knot)	measured average speed (knots)	traffic capacity per hour (ship)
100000～20000	235	16.2	14	53
20000～3000	127	13.4	14	150
3000～500	67	11.1	12	440
500～100	33	9.1	9	1500
100～20	18	7.7	8	4500

2.3.5 Calculation of ship encounter rate

A ship passes through a traffic flow area randomly distributed by ship, as shown in figure 2-5.

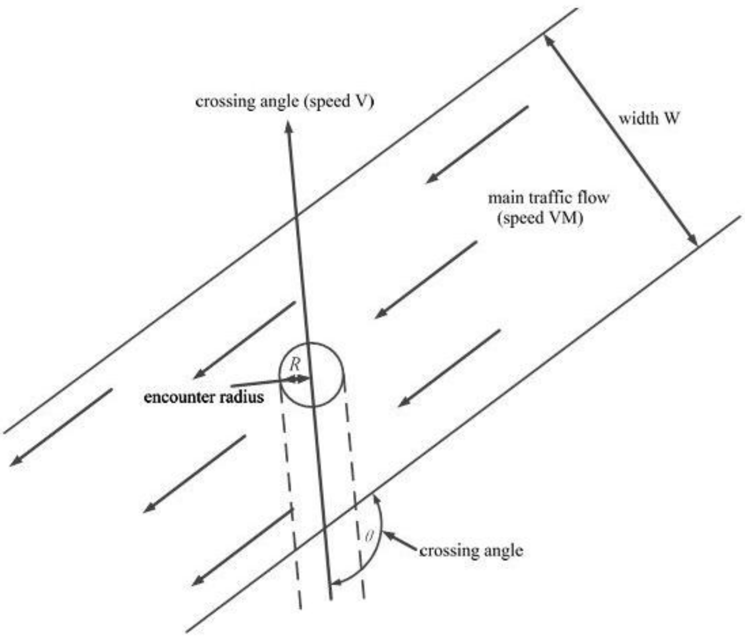

Figure 2-5: Ship crossing traffic flow (theoretical model)

The calculation formula of ship encounter rate is:

$$C = 2R\rho(V_R)$$

Where, R is the encounter radius; ρ refers to the density of traffic flow (number of ships per unit area); V_R is the average speed of the main traffic flow relative to the ship.

Assuming all ships in the traffic flow travel at the same speed, the relative speed is:

$$V_R = \left(V^2 + V_M^2 - 2VV_M \cos\theta\right)^{\frac{1}{2}}$$

Where, V is the speed of a single ship; VM main traffic speed; Theta is the Angle between the boat and the main direction.

The total number of one ship encounters is:：

$$2R_\rho L\left\{1 + \left(V_M / V\right)^2 - 2\left(V_M / V\right)\cos\theta\right\}^{\frac{1}{2}}$$

Where, L is the length of a ship.

When a ship has to pass through a traffic flow, it is not necessary to have uniform density across its width, but a constant density distribution along its length.

$$\text{Encounter number} = 2R\left\{1 + \left(V_M / V\right)^2 - 2\left(V_M / V\right)\cdot\cos\theta\right\}^{\frac{1}{2}}\int_0^L \rho dl$$

$$= 2R\left\{1 + \left(V_M / V\right)^2 - 2\left(V_M / V\right)\cdot\cos\theta\right\}^{\frac{1}{2}}\cos ec\theta\int_0^N \rho dw$$

$$= 2Rn\left\{1 + \left(V_M / V\right)^2 - 2\left(V_M / V\right)\cdot\cos\theta\right\}^{\frac{1}{2}}\cos ec\theta$$

Where, w is the width of traffic flow; N is the number of ships per unit length (linear density).

Encounter number = linear density * encounter width

$$= \left\{1 + \left(V_M / V\right)^2 - 2\left(V_M / V\right)\cdot\cos\theta\right\}^{\frac{1}{2}}\cdot\cos ec\theta$$

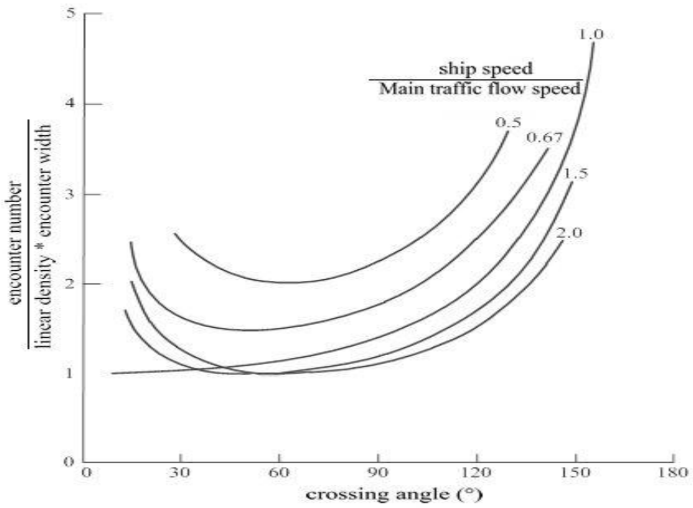

Figure 2-6: A meeting of ships crossing traffic

The function is given in figure 2-6, and the selection of crossing Angle is shown in figure 2-6, which shows how to minimize the DCPA under the condition of given velocity ratio. However, the handling of this encounter situation is still based on the assumption that all ships in the main traffic flow travel at the same speed, but the calculation of the assumed velocity distribution shows that the intersection Angle should be accurate within 10%. When passing through the main traffic flow, the crossing Angle should be as close as possible to 60 °-90 °. (Li, Ma & Wang, 2015).

Table 2-2 gives the results of the numbers of encounters between ships and traffic flow according to the calculation process provided.

Table 2-2: Number of ship encounters

V \ (V_M)	8	9	10	11	12	13	14
8	0.28	0.3	0.33	0.36	0.39	0.43	0.47
9	0.27	0.28	0.3	0.33	0.36	0.38	0.41
10	0.26	0.27	0.28	0.3	0.33	0.36	0.38
11	0.26	0.26	0.27	0.28	0.3	0.33	0.36
12	0.26	0.26	0.26	0.27	0.28	0.3	0.33
13	0.26	0.26	0.26	0.26	0.27	0.28	0.3
14	0.26	0.26	0.26	0.26	0.26	0.27	0.28

Chapter 3: Natural conditions and navigation conditions of Qiongzhou Strait

This chapter mainly studies the Qiongzhou Strait water area, the ship flow distribution and traffic accidents in the Qiongzhou Strait.

3.1 Status of ship routeing system in Qiongzhou Strait

On January 1, 2007, the ministry of transport of P.R.C implemented ship routeing system in Qiongzhou Strait. Qiongzhou strait ship routeing system consists of traffic separation system, precautionary area, area to be avoided and inshore traffic zone. As shown in the figure 3-1.

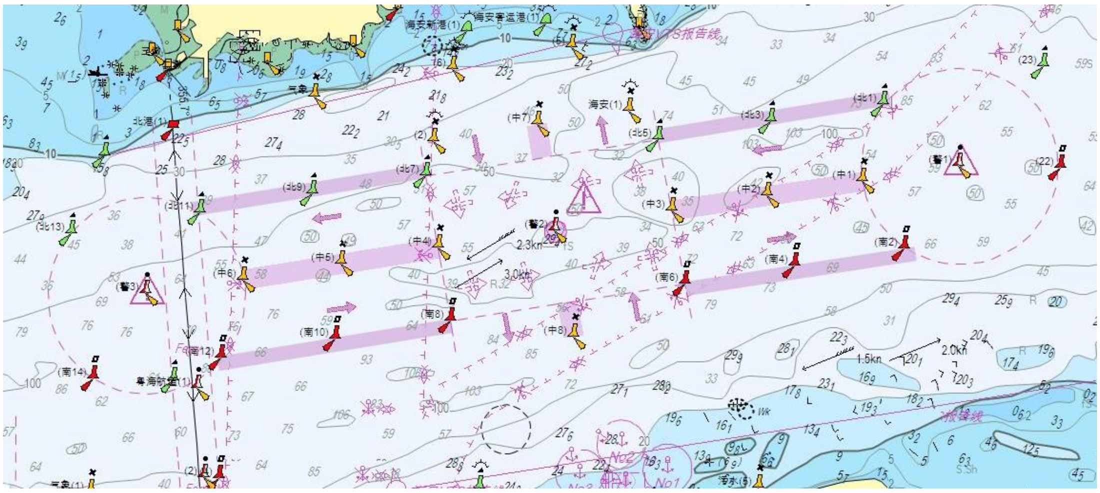

Figure 3-1: Diagram of ship routeing system in Qiongzhou Strait

3.1.1 Separation zones

As shown in the figure 3-1, the compartments of this ship routeing system's separation zones are composed of 8 zones from no. 1 to no. 8. Four separation zones (NO.1, NO.2, NO.4 and NO.7) with a width of 0.4nm are set in the middle of east-west separation zones and north-south separation zones. Four boundary separation zones (NO.3, NO.5, NO.6 and NO.8) with a width of 0.2 nm are set between the boundary of east-west traffic lanes and the inshore traffic zones in the north and south.

3.1.2 Traffic lanes

In the ship routeing system of Qiongzhou Strait, the east-west traffic lanes and north-south traffic lanes are set up respectively.

The east-west traffic lanes are divided into eastbound traffic lanes and westbound traffic lanes. The eastbound traffic lane is 13.8nm long and 1.3nm wide, and the main traffic flow direction is 081°. The westbound traffic lane is 13.8nm long and 1.3nm wide, and the main traffic flow direction is 261°. Eastbound and westbound traffic lanes are separated by a 0.4nm width separation zone (NO.1 and NO.2).

The north-south traffic lanes are divided into southbound traffic lanes and northbound traffic lanes. The southbound traffic lane is 4.4nm long and 2.2nm wide, and the main traffic flow direction is 170°. The northbound traffic lane is 4.4nm long and 2.2nm wide, and the main traffic flow direction is 350°. Southbound and northbound traffic lanes are separated by a 0.4-nm width separation zone (NO.4 and NO.7).

3.1.3 Precautinary area

Qiongzhou Strait ship routeing system has set up three precautionary areas, which are the NO.2 precautionary area in the middle and NO.1 and NO.3 precautionary areas at both ends. The precautionary area is set up to remind all kinds of ships, including those engaged in fishing boats, to pay special attention, and to warn ships to steer carefully and properly handle evasive relations when passing through these waters. The NO.1 and NO.3 precautionary areas are to regulate the navigation of ships entering and leaving the traffic lane, and the NO.2 precautionary area is to regulate the navigation between Guangdong and Hainan and the navigation of ships on and off the two sides.

3.1.4 Area to be avoided

In order to normalize the navigation of ships in the NO.2 precautionary area, avoid the direct passage of ships through the center of the precautionary area, make the navigation intersection of ships in the precautionary area as right as possible, and ensure the safety of ships, avoid navigation area is set in the center of the NO.2 precautionary area. Its geographical position is: water area with 20°10 '34 "N, 110°15' 04" E as the center of the circle and 0.2 nm as the radius.

3.1.5 Inshore traffic zone

In order to facilitate the navigation of small ships, the north inshore traffic zone and the south inshore traffic zone are respectively set up on the north and south sides of the routeing waters. The water area between the northern boundary of traffic separation scheme and Leizhou Peninsula coastline is the northern inshore traffic zone. The water between the southern boundary of traffic separation scheme and Hainan Island coastline is the southern inshore traffic zone.

3.2 Comprehensive natural conditions

3.2.1 Natural conditions of Qiongzhou Strait

Climate. Qiongzhou Strait year-round warm climate, abundant rainfall, frequent typhoons. The average annual temperature of the strait is about 24℃, the highest extreme temperature is 38℃ ~ 40℃, the lowest temperature is 28℃. The average annual precipitation is more than 1500 mm. May to October for the rainy season, many thunderstorms showers; November to April is the dry season, with no snow all year round. The prevailing wind is southwest in summer and the prevailing northeast wind in winter. From November to March of the next year, it is a strong wind season with a long and frequent northeast wind. The annual northeast wind is the largest, accounting for about 18% of the frequency. The strait is mainly affected by typhoons from May to October, with the largest number from August to October, and the average number of typhoons affected is 3-4 times per year. Typhoons are one of the major natural disasters in the region.

Wind and Waves. From November to March every year, the wind direction is mostly from north to northeast, with an average wind force of 3~4 and light to medium waves. When the strong cold air influences, it is cloudy and rainy, with wind force of 5~6, big waves and big waves. From June to September, the wind direction is mostly southeast; with an average wind force of 3, small to light waves. When tropical storms strike, gusts of 8 and above reach a maximum of 12, and there are large waves and wild waves, with the wave height reaching more than 8 meters. January to April, morning and evening or night foggy, the average foggy days 5 to 7 days, the highest up to 17 days, the continuous foggy days generally 2-3 days, the longest 8 days.

Hydrology. Qiongzhou Strait tidal is irregular diurnal mixed tidal type; tidal range is small, usually about 1 meter. Under the influence of typhoon, the tidal range increases, and the difference of the maximum spring tide along the coast can reach 3~4 meters. Current in Qiongzhou Strait belongs to regular daily current and is reciprocating current. The middle current velocity is generally 4~5 knots, theend of channel at east and west is 3~4 knots. The middle surface velocity is more than 6 knots, and the bottom velocity is more than 4 knots.

3.2.2 Fishery situation

Qiongzhou Strait is one of the most important fishing grounds in southern China, more than ten thousand of fishing boats in the strait waters every year. After the end of May to August in Hainan fishing moratorium, there will be a large number of fishing boats lined up to occupy the Qiongzhou Strait ship routeing of the westbound route from the west to the east across the strait into the sea fishing.At the same time, there are a large number of fixed nets in the strait. In foggy days, poor visibility or at night, collisions between large ships and fishing boats or damage of fishing nets by large ships are very likely to occur (Dong & Ye, 2013).

3.2.3 Navigational AIDS in Qiongzhou Strait

At present, the navigational aids in Qiongzhou Strait is quite complete, has the Zhuzhailing, Baohushan and so on the natural navigational aid mark, and has various lighthouse, the light beacon. The MSA on both sides of the strait also set many buoy light in the harbor water area and the ship routeing system water area. There are 9 lighthouses in Qiongzhou Strait and 8 special marks for traffic separation, 11 side marks for starboard side and 11 marks for port side, and 4 special marks for safe waters.

3.3 Traffic flow in Qiongzhou Strait

Routes should follow as closely as possible the existing patterns of traffic flow in areas as determined by traffic surveys. In order to grasp the traffic flow status of Qiongzhou strait, this paper sets up 9 position lines to collect the traffic flow status of ships in different waters, as shown in figure 3-2 and table 3-1. Line 1 collects the traffic flow of ships northbound through the NO.2 precautionary area, Line 2 collects the traffic flow of ships southbound through the NO.2 precautionary area, Line 3 collects the traffic flow of ships in north (westbound) traffic lane, Line 4 collects south (eastbound) traffic lane of traffic flow situation, Line 5 collects traffic flow status in north inshore traffic zone, Line 6 collects traffic flow status in south inshore traffic zone. The AIS data is from the Hainan MSA, which covers the period from April 1th (second quarter) in 2018 to March 31st (first quarter) in 2019.

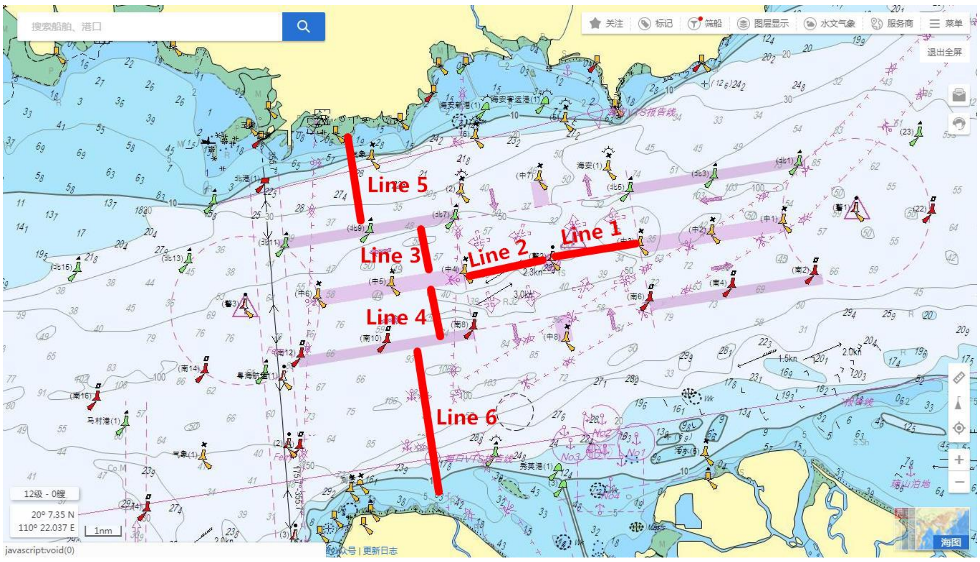

Figure 3-2: Location of 6 lines in Qiongzhou Strait

Table 3-1: Position of 6 lines

Line NO.	Location	GPS position Point 1	Point 2
Line 1	Northbound in NO.2 precautionary eara	110°15'5.4" 20°10'32"	110°17'37" 20°10'58"
Line 2	Southbound in NO.2 precautionary eara	110°12'34" 20°10'11"	110°15'5.4" 20°10'32"
Line 3	Westbound traffic lane	110°10'26" 20°9'52"	110°10'12" 20°11'34"
Line 4	Eastbound traffic lane	110°10'26" 20°9'52"	110°10'50" 20°8'13"
Line 5	North inshore traffic zone	110°8'0" 20°11-13	110°7'51" 20°13-8
Line 6	South inshort traffic zone	110°9-39 20°8-6	110°9-54 20°4-36

3.3.1 Ship traffic flow statistics through Line 1

The statistical of ship AIS flow through Line 1 is shown in the following tables:

Table 3-2: Statistical of ship traffic flow through Line 1 northbound

Time / Ship types	Second quarter	Third quarter	Fourth quarter	First quarter	Total
Passage ship	3806	5071	6237	6014	21128
Cargo carrier	195	194	104	134	627
Non-transport Ship	140	138	270	221	769
Oil tanker	7	3	13	7	30
Dangerous goods ship	84	24	7	42	157
Total	4232	5430	6631	6418	22711

Table 3-3: Statistical of ship traffic flow through Line 1 southbound

Time / Ship types	Second quarter	Third quarter	Fourth quarter	First quarter	Total
Passage ship	6	7	45	102	160
Cargo carrier	37	55	40	34	166
Non-transport Ship	188	121	130	99	538
Oil tanker	5	0	4	1	10
Dangerous goods ship	2	1	1	00	4
Total	238	184	220	236	878

AIS statistics show that the number of northbound ships which passing the Line 1 increased gradually from the second quarter of 2018 to the first quarter of 2019, and the number of backward southbound ships remained basically stable. Due to the end of the year and the beginning of the year is Hainan tourism season. For the northbound ships, 93% are passenger ships, passing through 1,761 ships every month on average, while the other ships only account for 6.97%. Through the four quarters of AIS ship traffic flow statistics analysis, and recommend the direction of traffic flow in the opposite direction of ships, the non-transport ship account for most (61.28%), while in the NO.2 precautionary area the northbound direction is recommend, but there are still a small amount of southbound ships in order to cut corners, or to avoid the urgent situation between ships.

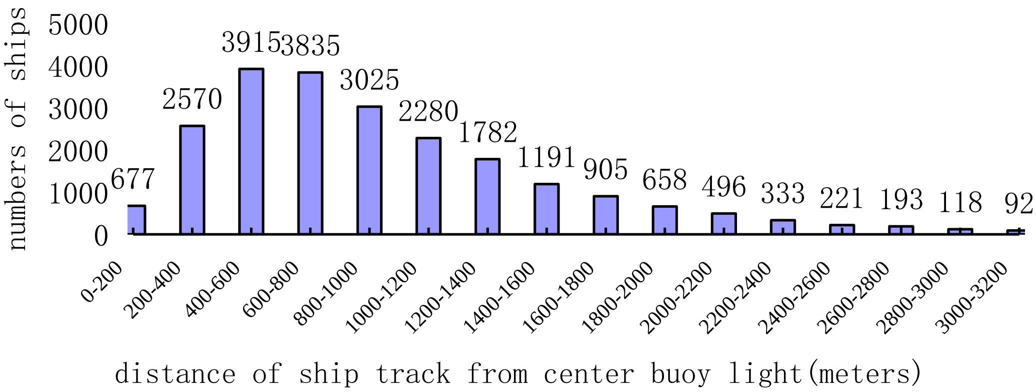

Figure 3-3: number and track distribution of ships passing through Line 1

According to the latest year for which statistics, after the passenger ships, which account for 93% of all ships in this route, removed from this route, a day on average only 6 north-south ships through this area, for such a small traffic flow, this precautionary area on the east side of the NO.2 precautionary area can be canceled. However, in view of the safe navigation of large cruise ships in the future, and in the season of heavy traffic flow in winter, passenger ships are expected to restart this route from Xiuying port to Hai'an port, and it is suggested to keep the precautionary area on the east side of the central light buoy.

By Haikou MSA that Qiongzhou Strait NO.2 precautionary area is designed to be wide at that time, because around 2006, passenger ships sailing in the Qiongzhou strait were smaller in size, if there are any east or norteast wind, ship will appear severe rolling, therefore, the ship needs to go forward by zigzag route, and the required water area is relatively large. However, at present, the size of passenger ship has been larger than before, and it is not required to follow the old zigzag route, so the width of the NO.2 precautionay area can be narrowed appropriately. According to the figure 3-3, about 98.2% of the northbound ships passed within 0-3200 meters from the central light buoy, while only 1.8 percent (basically non-transport ships) passed beyond 3200 meters from the central light buoy. Therefore, it is feasible to shift the eastern boundary of the NO.2 precautionay area 0.7 nm to the west.

3.3.2 Ship traffic flow statistics through Line 2

The statistical of ship AIS flow through Line 2 is shown in the following tables.

Table 3-4: Statistical of ship traffic flow through Line 2 southbound

Time Ship types	Second quarter	Third quarter	Fourth quarter	First quarter	Total
Passage ship	1440	1441	2235	1608	6724
Cargo carrier	506	548	410	391	1855
Non-transport Ship	217	214	346	192	969
Oil tanker	18	20	28	27	93
Dangerous goods ship	21	6	5	23	55
Total	2202	2229	3024	2241	9696

Table 3-5: Statistical of ship traffic flow through Line 2 northbound

Time Ship types	Second quarter	Third quarter	Fourth quarter	First quarter	Total
Passage ship	276	301	388	108	1073
Cargo carrier	55	58	42	24	179
Non-transport Ship	91	121	192	88	492
Oil tanker	1	1	1	3	6
Dangerous goods ship	9	4	0	0	13
Total	432	485	623	223	1763

As shown in table 3-4, the number of southbound ships through the NO.2 precautionay area is basically kept at 2200 ships per quarter, and about 69% of the southbound ships passing through Line 2 are passenger ships, with an average of 560 ships per month. According to the AIS statistical analysis, 61% of the ships sailing in the opposite direction of the recommended traffic flow are non-transport ships.

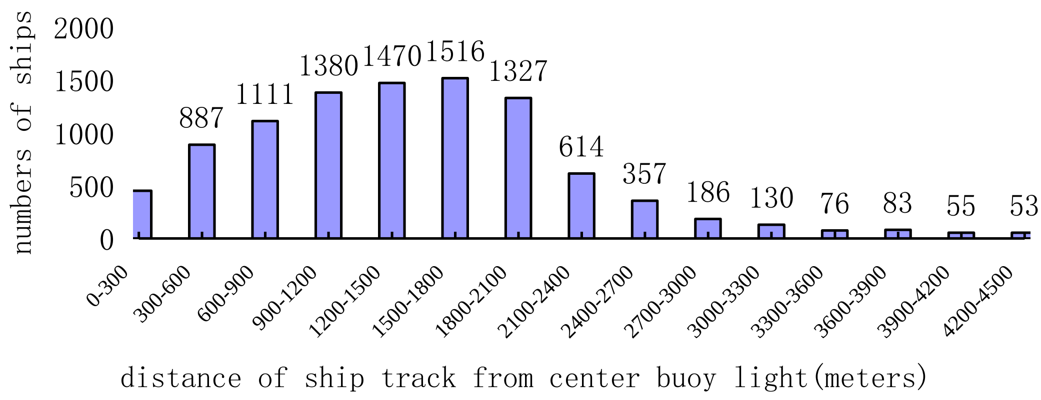

Figure 3-4: Number and track distribution of southbound ships passing through Line 2

Similar with the west side of NO.2 precautionay area, after the passenger ships, which account for 69% of all ships in this route, removed from this route, only 10 ships of all types pass through this area on average every day. However, considering the safety of navigation and the future major cruise traffic flow is busy, it is suggested to reserve this area. According to figure 3-4, more than 96% of the southbound ships passed within 0-3300 meters from the central light buoy, and only about 4% (mostly non-transport ships) passed over 3300 meters from the central light buoy. Therefore, the eastern boundary of the NO.2 precautionay area can be shifted 0.7 nm to the west.

3.3.3 Ship traffic flow statistics through Line 3 and Line 4

The statistical of westbound ships which passing the Line 3 is shown in the figure 3-5. From April 2018 to March 2019, the number of westbound ships through the Qiongzhou Strait is 33693, with an average of 90 ships per day. Adding the 3517 retrograde means approximately 102 times per day. Retrograde ships are mainly non-transport ships, accounting for 87% of the total retrograde ships. In addition, according to the statistical AIS data, passenger ships account for about 42% of the ships passing through Line 3, cargo ships, oil ships and dangerous goods ships account for about 37%, and non-transport ships account for 21%.

The statistical of eastbound ships which passing the Line 4 is shown in the figure 3-5. From April 2018 to March 2019, there are more than 32,800 ships passing through the

Line 4, and the number of ships passing through the south traffic lane in Qiongzhou strait is increasing every quarter, mainly because of the shift of berth of passenger ship to the west. The number of reverse westbound ships remains at more than 300 per quarter. In addition, according to AIS statistics, passenger ships account for about 47% of the ships traveling eastbound through Line 4. Cargo ships, oil tankers and dangerous goods ships account for about 45% and non-transport ships account for 13%.

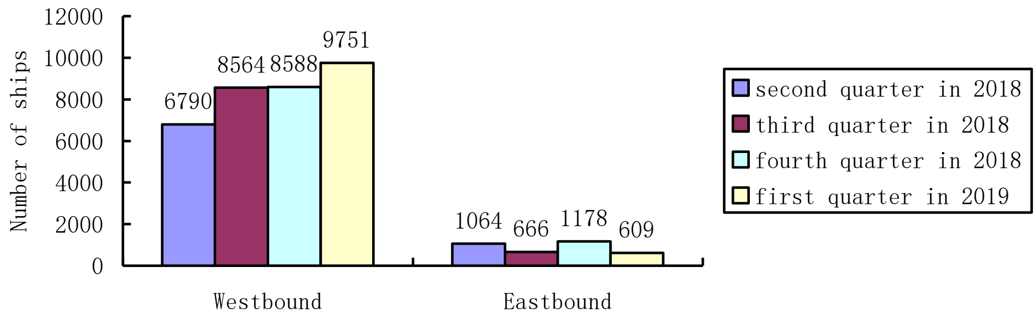

Figure 3-5: Statistics of traffic flow in the westbound traffic lane

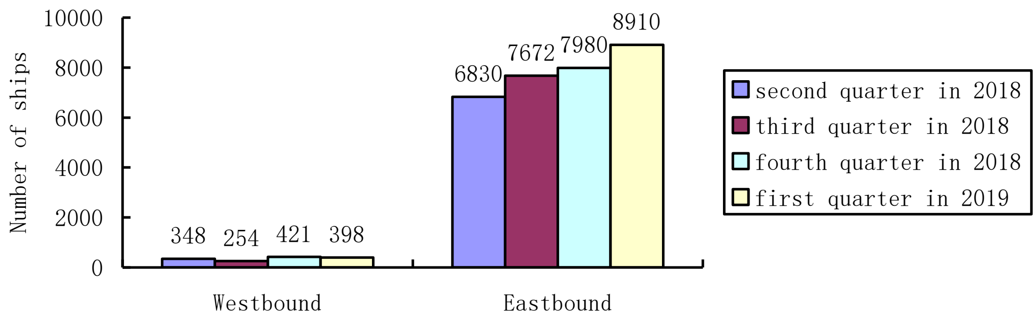

Figure 3-6: Statistics of traffic flow in the eastbound traffic lane

3.3.4 Ship traffic flow statistics through Line 5 and Line 6

AIS data statistics of ships sailing in the northern inshore traffic zone are shown in figure 3-7. From April 2018 to March 2019, the ships passing through the northern inshore traffic zone is 4992 times, with an average of 14 ships per day, 46% for non-carriers, with an average of 6 ships per day, and 8 ships for other types of merchant ships.

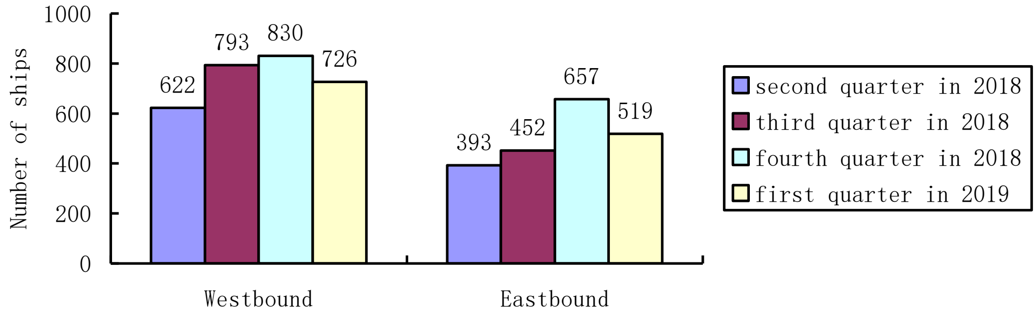

Figure 3-7: Statistics of traffic flow in the northern inshore traffic zone

AIS data statistics of ships sailing in the southern inshore traffic zone are shown in figure 3-8. From April 2018 to March 2019, the number of ships in the southern inshore traffic zone in the Qiongzhou Strait is obviously higher than that in the northern. The average daily ship is 14 times in the east, around 11 times in the west, a total of 25 times a day, 13 times a day for non-transport ships and 12 times a day for other cargo ships.

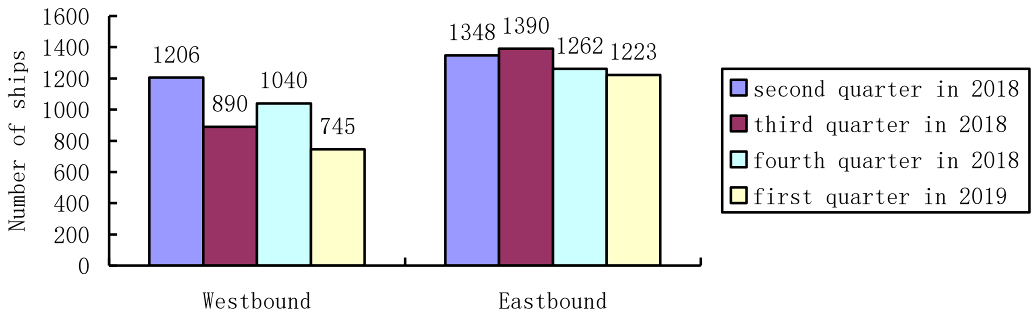

Figure 3-8: Statistics of traffic flow in the southern inshore traffic zone

3.4 Traffic accident in Qiongzhou Strait

The ship traffic accident is directly related to the actual situation of maritime traffic (traffic flow density and ship handle behavior), ship routeing and maritime traffic management. This chapter first reviews the statistics of traffic accidents in Qiongzhou Strait before the implementation of ship routeing system from 2001 to 2006, and then analyzes the traffic accidents in Qiongzhou Strait after the implementation of ship routeing system from 2007 to 2018.

3.4.1 Maritime traffic accidents from 2001 to 2006

From 2001 to 2006, a total of 53 maritime accidents occurred in the jurisdiction of Haikou MSA, and one person was killed, as shown in table 3-6. There were 13 accidents in the waters covered by the current ship routeing system, all of which were collisions, accounting for 25% of the total.

Table 3-6: Maritime traffic accident statistics for 2001-2006

Type of accidents / Times / Year	collision	grounding	touch damages	fire and explosion	others	total
2001-2006	26	10	14	0	3	53
Proportion	49%	19%	26%	0	6%	-

3.4.2 Maritime traffic accidents from 2007 to 2018

From 2007 to 2018, a total of 104 maritime accidents occurred in the jurisdiction of Haikou MSA, and 10 people were killed and missing, as shown in table 3-7. There were 7 accidents in the ship routeing system, all of which were collision accidents, 1 major accident, 1 major accident, 5 minor accidents, and 3 people dead and missing.

Table 3-7: Maritime traffic accident statistics for 2007-2018

Type of accidents / Times / Year	collision	grounding	touch damages	fire and explosion	others	total
2007-2018	58	20	13	5	8	104
Proportion	56%	19%	13%	5%	7%	-

3.4.3 Analysis of accidents in ship routeing system from 2007 to 2018

From 2007 to 2018, there were 7 ship collision accidents in the Qiongzhou Strait ship routeing system, among which 4 were merchant ships and fishing boats, accounting for 57% of all; 2 cases involving merchant and passenger ships, accounting for 29% of the collision accidents within the ship routeing system; 1 accident occurred between merchant ships, accounting for 14%. 3 people were missing and 3 injured in the cases.

From 2007 to 2018, there were two collision accidents in the Qiongzhou Strait in January and February, accounting for 29% of the collision accidents in the ship routeing system, and one in April, May and November, accounting for 42% of the collision accidents.

From 2007 to 2018, according to the time period of the duty officer on watch, two collision accidents occurred during 0-4 hours and 12-16 hours respectively in the ship routeing system in Qiongzhou Strait, accounting for 29% of the collision accidents respectively. 4-8, 8-12, 16-20 each happened 1time of collision accident.

Chapter 4: Optimization scheme of ship routeing system in Qiongzhou Strait

4.1 Adjustment scheme of ship routeing system in Qiongzhou strait

Combined with the questionnaire in the appendix, the adjustment scheme of ship routeing system in Qiongzhou Strait is made as shown in figure 4-1. The adjustment contents are mainly as follows:

a) The definition of the NO.1 precautionary area changed from a circle to an arc；

b) The east-west length of the NO.2 precautionary area decreased from 4.8 nm to 3.4 nm;

c) The shape of the NO.3 precautionary area changed from circle to rectangle;

d) Add the NO.4 arc precautionary area (Luo, 2017);

e) The length of the first (easternmost) traffic separation scheme increased from 4.6 nm to 5.2 nm;

f) The length of the second traffic separation scheme reduced from 4.5 nm to 3.1 nm;

g) Add a third (westernmost) traffic separation scheme of 0.9 nm.

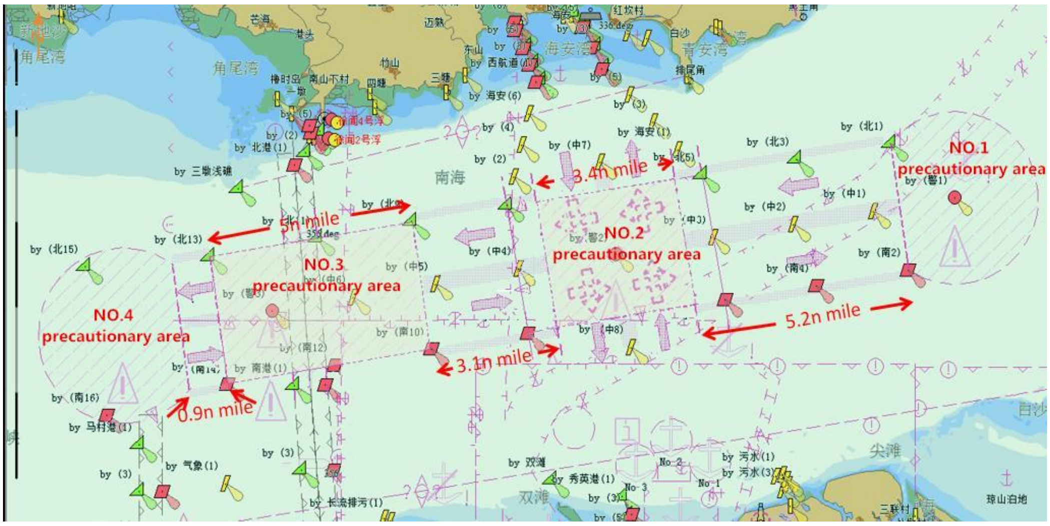

Figure 4-1: New ship routeing adjustment scheme in Qiongzhou Strait

Considering that the design scheme of the NO.3 precautionary area is the key content of the ship routeing system adjustment in Qiongzhou Strait (Fan, Wu & Zhang, 2013), this paper sorts out the traffic flow inside the NO.3 precautionary area and forms the following several detailed schemes.

4.1.1 Scheme A

Diagram of scheme A is shown in figure 4-2, which includes the following points:

a) The Guangdong-Hainan railway ferry has no change in the existing 800-meter channel. Two light buoys are set up in the center of the precautionary area, with an interval of 1500 meters. The light buoys in the west separate the traffic flow between Guangdong-Hainan railway ferry and the passenger ship. The light buoys in the east are the circular area to be avoided center with a diameter of 0.2 nm, to separate the southbound and northbound traffic flow of passenger ships;

b) The passenger ship follows the recommended traffic flow direction (green line in figure 4-2). In the center of the NO.3 precautionary area, the maximum distance of southbound and northbound traffic flow is 1150 meters, and the distance of southbound and northbound traffic flow of the sideline on the north side of the precautionary area is 800 meters (Pietrzykowski, Zbigniew & Magaj, 2017);

c) In the north and south direction of the NO.3 precautionary area, recommended routes are set for the Guangdong-Hainan railway ferry. (Note: the side lines of both sides of the 1500m channel of the Guangdong-Hainan railway ferry are not drawn in the ship routeing system, and they are not erased in the scheme for the reference of the conventional route);

d) In order to avoid both avoiding collision and turning in the south of the NO.3 precautionary area, the north route of the deep green line in the figure 4-2 is preferred, so as to avoid the intersection or setting of the turning point of the passenger ship in and around NO.3 precautionary.

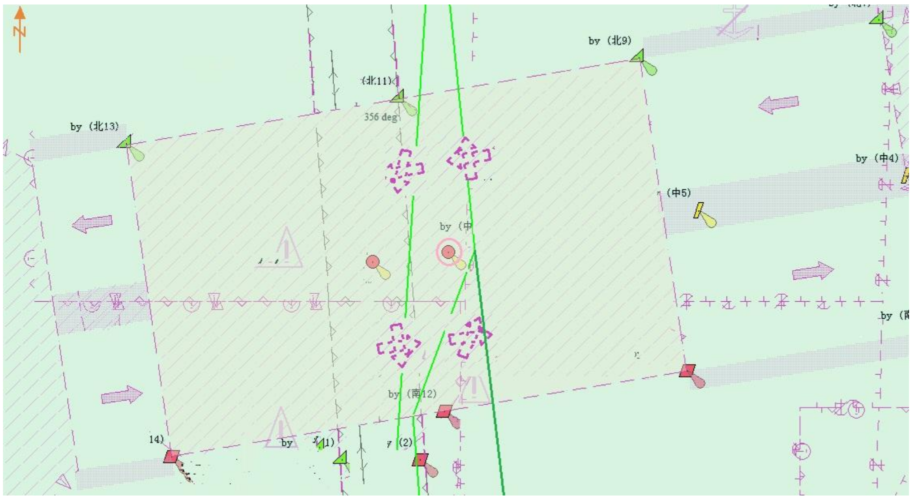

Figure 4-2: Diagram of scheme A

4.1.2 Scheme B

Diagram of scheme B is shown in figure 4-3, which includes the following points:

a) Scheme B makes full use of the existing 1500-meter channel, set up a light buoy in the center, and 0.2 nm diameter area to be avoided is set around the buoy. The east side of the light buoy is the northbound traffic flow, while the west side is the southbound traffic flow (Fan, Wu & Zhang, 2014).

b) In the NO.3 precautionary area near the north and south ends of the traffic flow have crossed, due to the close distance of ports, in order to avoid the Guangdong-Hainan railway ferry and passenger ship of cross, also in order to ensure the railway ferry on time, the Xuwen port need to control the time of departure of the passenger ship, the Xinhai port also need to control the arrivaling time of the passenger ship, to thoroughly solve crossing problem of the Guangdong-Hainan railway ferries and passenger ships.

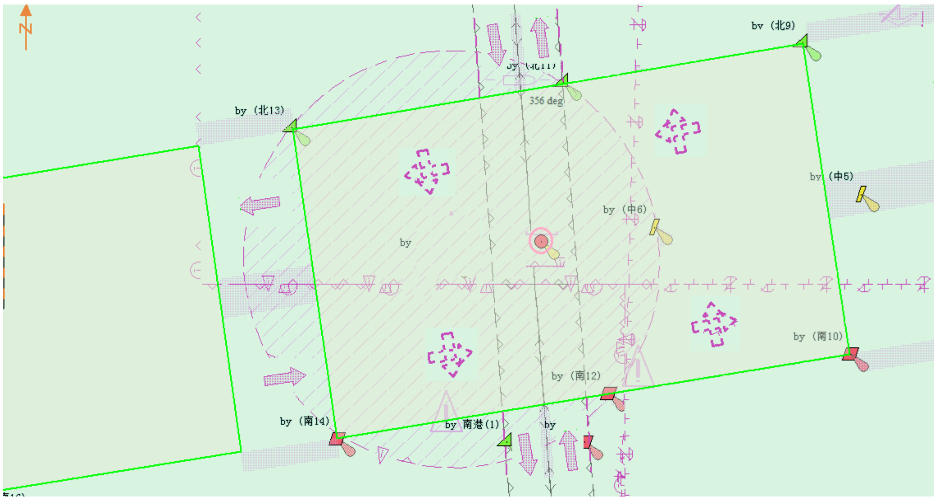

Figure 4-3: Diagram of scheme B

4.1.3 Scheme C

a) The Guangdong-Hainan railway ferry uses the 800 meters on the west side of the existing channel, and has a 200-meter interval with the southbound of the passenger ship. Two light buoys are set in the center of the precautionary area.

The light buoys in the west separate the traffic flow between Guangdong-Hainan railway ferry and the passenger ship. The light buoys in the east are the circular area to be avoided center with a diameter of 0.2 nm.

b) In the north and south direction of the precautionary area, recommended routes are set for the Guangdong-Hainan railway ferry;

c) The deep green line in the figure is the preferred northbound route for passenger ships (as in scheme A).

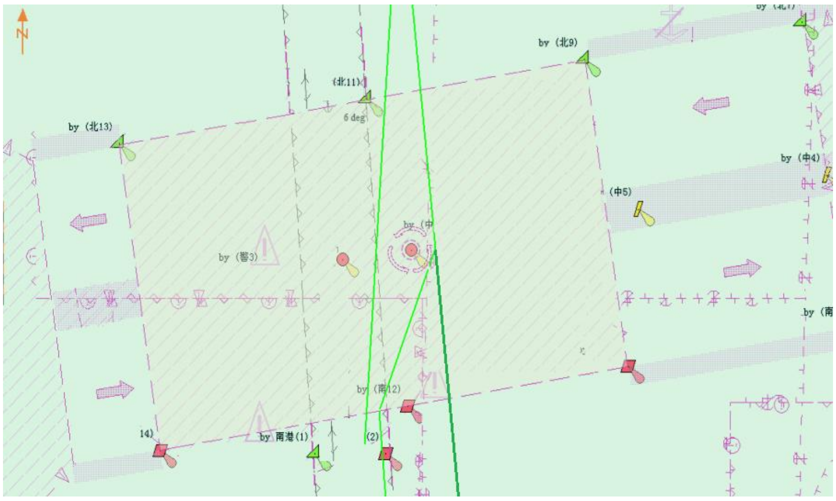

Figure 4-4: Diagram of scheme C

4.2 Questionnaire and results analysis

4.2.1 Survey of factors affecting navigation safety

On April 20, 2019 to 2019 on May 28, this paper conducted a questionnaire survey of relevant personnel through Hainan MSA. The respondents of the questionnaire include passenger ship captains, Haikou VTS officers, shipping company management officers, and merchant ship captains berthing at Yangpu port. A total of 50, 16, 7 and 71 valid questionnaires were collected. Appendix 1 is the contents of the questionnaire. The specific feedback and analysis results of the questionnaires are as follows.

In terms of analyzing the factors affecting ship traffic in Qiongzhou Strait, this paper conducts a questionnaire survey from the influence of ship traffic conditions, geographical conditions of water area and meteorological and hydrological conditions, and the results are shown in figure 4-5. It can be seen that the traffic conditions of ships and geographical conditions of waters have a slight impact on the ship safety in Qiongzhou Strait, while the meteorological and hydrological conditions have a moderate impact on the safety of ship in Qiongzhou Strait.

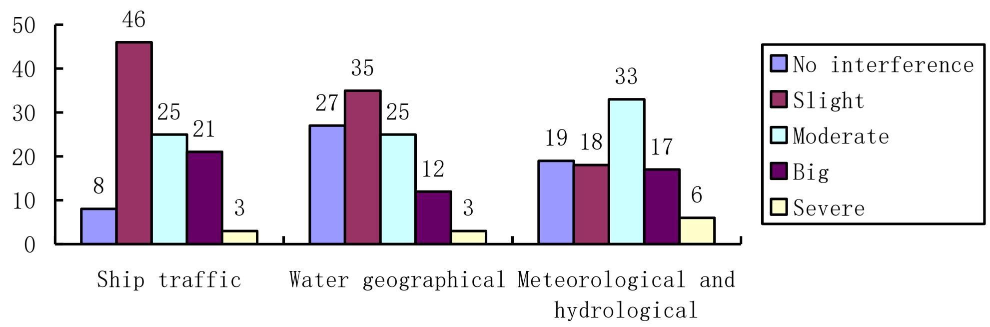

Figure 4-5: Traffic impact of ships in Qiongzhou Strait waters

In terms of analyzing the influence degree of ship traffic conditions in the ship routeing system on the navigation safety of ships, this paper conducts the investigation from the three aspects of traffic density, condition of ship crossing situation and condition of merchant-fishing boat meeting, and the results are shown in figure 4-6. It can be seen that the condition of ship crossing situation and condition of merchant-fishing boat meeting have a slight impact on the ship safety, while the traffic density of merchant and fishing boats have a big impact on the ship safety in Qiongzhou Strait.

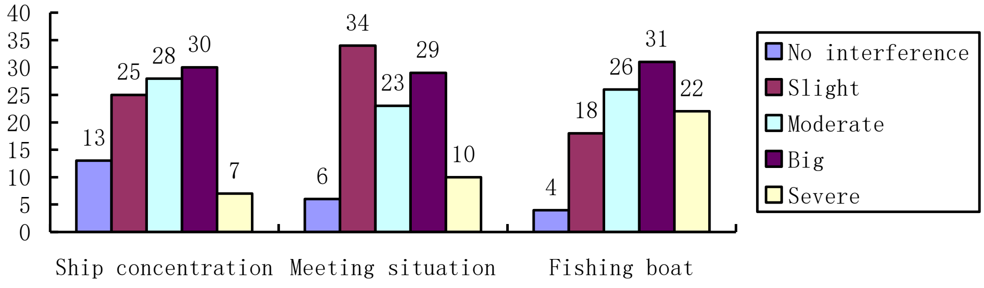

Figure 4-6: The influence of ship traffic condition on navigation safety

In terms of analyzing the influence degree of various factors of geographical conditions on navigation safety, this paper conducts the investigation from four aspects: underwater obstacles (sunken ships, submerged reefs, etc.), water depth, fishingnets and aquaculture, other factors, and the results are shown in figure 4-7. It can be seen that in the geographical conditions of water areas, underwater obstacles and water depth have slight impact on the navigation safety of ships, while fishingnets and aquaculture have a big impact on the navigation safety of ships.

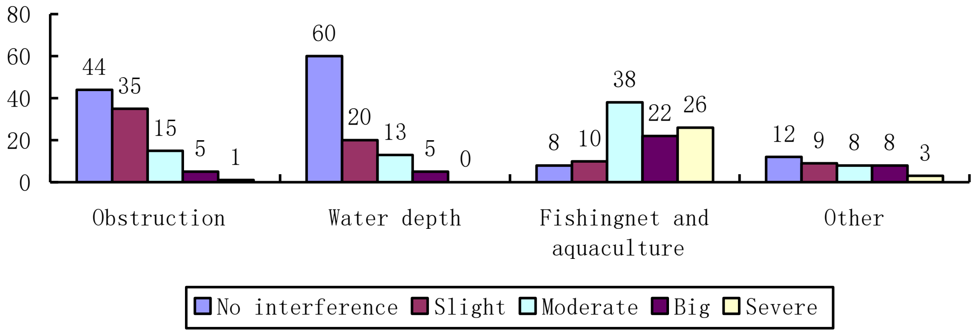

Figure 4-7: The influence of geographical conditions on navigation safety

In terms of analyzing the influence degree of various factors of meteorological and hydrological conditions on navigation safety, this paper conducts the investigation from current, winds, visibility (fog, etc.), tides and others (fishing boats, sailing boats, unknown ships, severe convective weather, wind waves, etc.), and the results are shown in figure 4-8. It can be seen that in the meteorological and hydrological conditions, the current, wind and tide have a slight impact on the safe navigation of ships, visibility has a moderate impact on the safe navigation of ships, and other factors have little impact on the safety of ships.

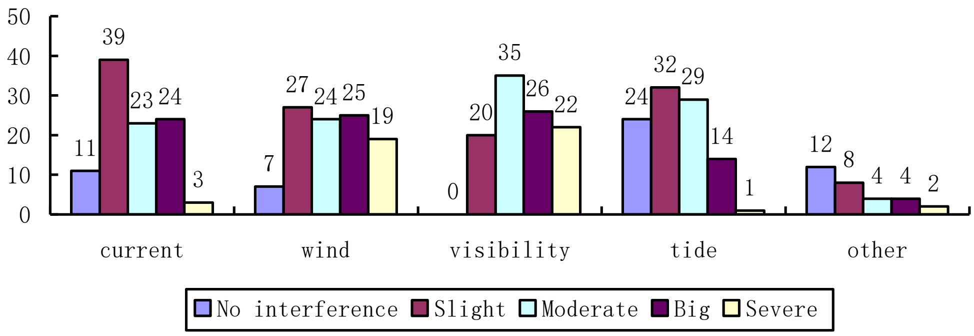

Figure 4-8: The influence of meteorological and hydrological conditions on navigation safety

In the survey of adding the NO.4 precautionary area and designing a circular arc, the survey results is that a total of 127 people agree, accounting for 94.1% of the total number of people. Among them, a total of 66 merchant ship captains agree, accounting for 93% of the merchant ship captains participating in the questionnaire.

According to the survey of reduce the width of NO.2 precautionary area from 4.8 nm to 3.4 nm, a total of 127 people agree, accounting for 94.8% of the total number of people. Among them, a total of 65 merchant ship captains agree, accounting for 92% of all the merchant ship captains participating in the survey.

4.2.2 Survey result of three scehemes of NO.3 precautionary area

As for the survey in the NO.3 precautionary area, the questionnaire results show that 126 people agree, accounting for 95.5% of the total number of people. Among them, 66 merchant ship captains agree with this modification plan, accounting for 93% of all the merchant ship captains participating in the survey.

For the three detailed schemes of the NO.3 precautionary area, the survey results are shown in figure 4-9.

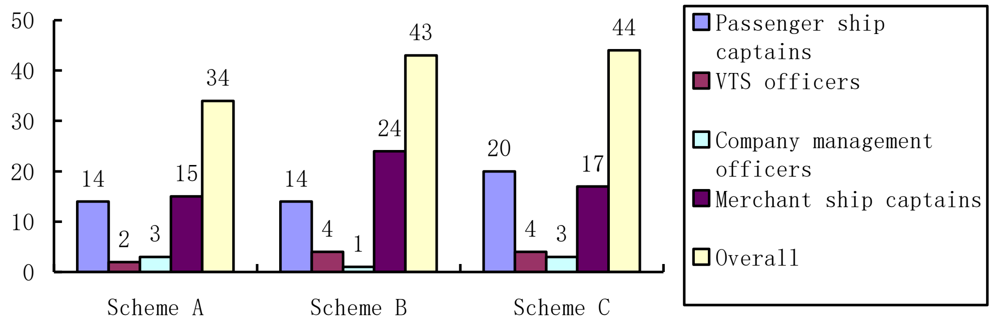

Figure 4-9: survey result of three adjustment schemes in the NO.3 precautionary area

4.3 Optimization of the recommend scheme

Combined with previous research and questionnaire survey results (Zhuo & Tao, 2015), this paper considers that scheme C is the preferred plan. Meanwhile, scheme C is optimized and the schematic diagram of the recommended scheme is shown in figure 4-10.

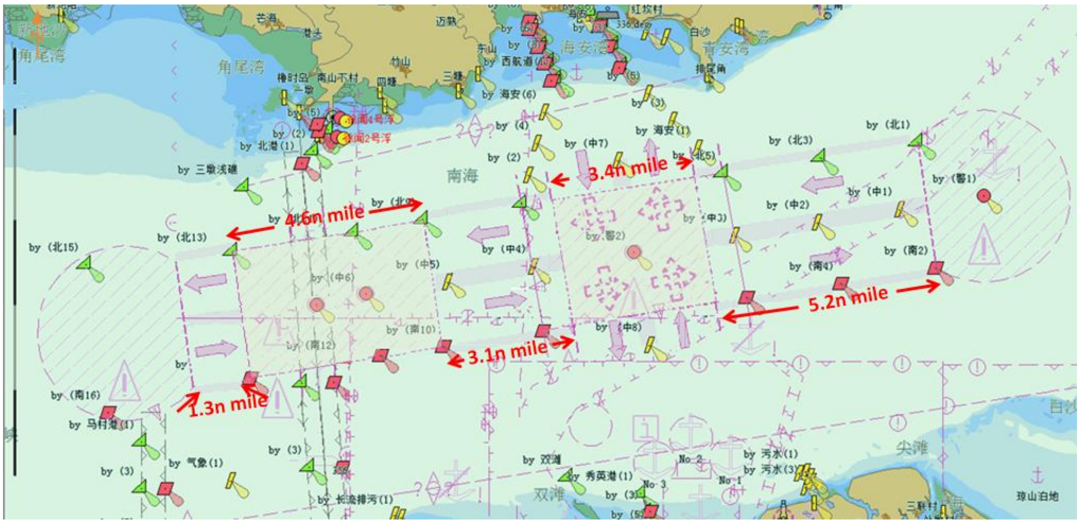

Figure 4-10: Diagram of optimization of Qiongzhou Strart ship routeing system

The optimization contents of scheme C for ship routeing system in Qiongzhou Strait are as follows:

a) Increase the distance between two central light buoys in the NO.3 precautionary area. The center between the two light buoys in the NO.3 precautionary area of scheme C is 1500 meters, which is not wide enough for the southbound passenger ship (Ren, 2018). When the southbound passenger ship and the eastbound ship, the westbound ship and the northbound Guangdong-Hainan railway ferry appear at the same time near the central light boy, the meeting situation of multiple ships will be formed (Yu, 2018). The distance between the two light buoys should be increased to 2100 meters to provide more open water for multiple ships to avoid collision (Sun, 2016).

b) Move the western boundary of the NO.3 precautionary area eastward. The west boundary of scheme C is 2.1 nm away from the west side of the center of the NO.3 precautionary area. The west boundary of the NO.3 precautionary area can be moved 0.4 nm to the east, so that the west boundary is 1.7 nm away from the center of the precautionary area, which is the same as the east boundary of the precautionary area is 1.7 nm away from the east side of the center.

c) Shift south 12 and north 11 light buoys. Move the south 12 and north 11 light buoys to the east to the equal distance of the north and south sides of the central light buoys on the east side (1.7 nm from the boundary line on the east side of the NO.3 precautionary area), and serve as the reference point for passenger ships entering and leaving the NO.2 precautionary area.

d) The recommended route on the north and south sides of the NO.3 precautionary area moves westward. In order to increase the distance between current Guangdong-Hainan railway ferry routeing and the routeing for passenger ships which calling the Xinhai port and Xuwen port, the recommended route on both sides of the NO.3 precautionary area should be shifted to the west by 200 meters, so that the horizontal distance between the recommended route in the NO.3 precautionary area and the light buoy on the west side of the precautionary area should be 1000 meters. Given that the turning circle of ordinary passenger ships is 3-6 times of ship length, the spacing of 1000 meters can ensure that even if the passenger ship is fully loaded, it will not turn to the southbound route of the Xinhai port and Xuwen port. The optimized scheme C and the present and future traffic flow diagram are shown in figure 4-11 and 4-12.

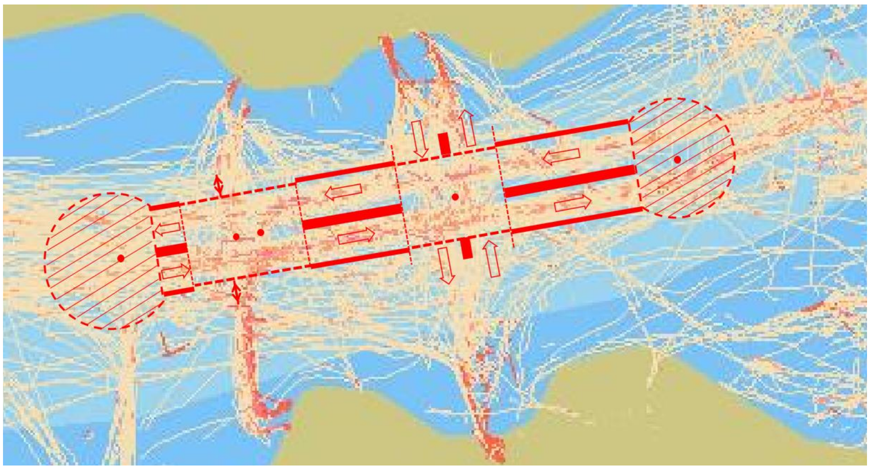

Figure 4-11: Contrast diagram of optimized scheme C with present traffic flow

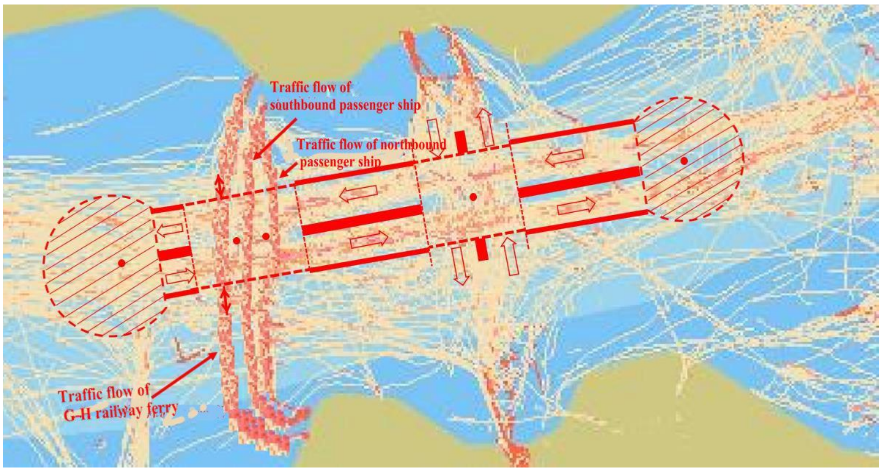

Figure 4-12: Contrast diagram of optimized scheme C with future traffic flow

Chapter 5: Conclusions

Ship routeing or managing the shipping traffic can be easily called the most important aspect of entire maritime industry. Managing shipping traffic, especially in regions of high traffic load or congested areas, ship routeing comes as even more important task.

The optimization scheme of ship routeing system proposed in this paper is based on international conventions and China's domestic laws and regulations, and guided by the relevant international standards. This scheme is based on the relevant influence factors in the comprehensive evaluation and demonstration on the basis of making, conform to the IMO’s General Provisions on Ships Routeing, also give full consideration to the traffic conditions over the waters of the traffic flow and the adjacent waters, and the waters coincided basically with the existing form of traffic flow, and give full consideration to the development trend of the nearby port.

More precisely, based on the research on the related theory of ships routeing system, this paper analyzes the problems existing in the current shipping routeing system, has a detailed understanding of the distribution and characteristics of ship traffic flow in Qiongzhou Strait. After considering the characteristics of ship accidents in Qiongzhou Strait waters, according to the adjustment of ports function on both sides of Qiongzhou Strait, this paper puts forward an optimization scheme of ship routeing system for Qiongzhou Strait. After formulating the optimization scheme of ship routeing system in Qiongzhou Strait, this paper makes the selection of the optimization scheme by the way of questionnaire survey for ship drivers and marine traffic managers, and puts forward the modification suggestions. After screening and modifying the optimization scheme, the final optimization scheme of Qiongzhou Strait ship routeing system is determined.

The relevant measures proposed in this optimization scheme are in line with the safe navigation of ships in Qiongzhou Strait, but some aspects require the relevant competent authorities to take some measures to ensure the safe navigation of ships in this area. In order to separate the reverse passenger ship traffic flow as early as possible, to eliminate the passenger ship may turnning and avoiding collision at the same time in the NO.2 precautionary area, and to reduce the collision of ships in the southern part of the waterway due to the narrow waters, it is suggested that relevant competent authorities clear fishing nets in the southern waters of the NO.3 precautionary area. At the same time, it is suggested that the relevant competent authorities move and add some of the navigation marks and light buoys in Qiongzhou strait to meet the new requirements of ship routeing system.

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Appendix：Questionnaire on optimization scheme of ship routeing system in Qiongzhou Strait

Date: April 15, 2019

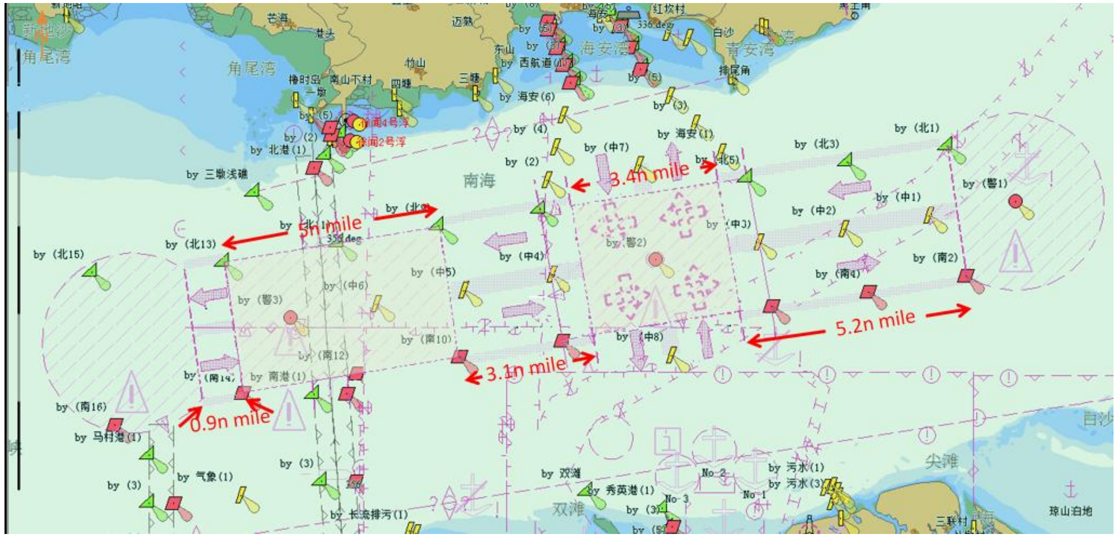
Purpose of survey: With the adjustment of ports function on both sides of Qiongzhou Strait, the traffic condition of ships in Qiongzhou Strait will change. In order to ensure the orderly, smooth and efficient navigation of ships and protect the navigation environment, this paper optimizes the ship routeing system. As a user of Qiongzhou Strait, you are familiar with the ship traffic in this area. This paper would like to hear your opinions and suggestions, so that the ship routeing system optimization scheme formulated in this paper can meet the interests of most crew members, ship companies and relevant departments. Your answer is very important, thank you very much for your cooperation!

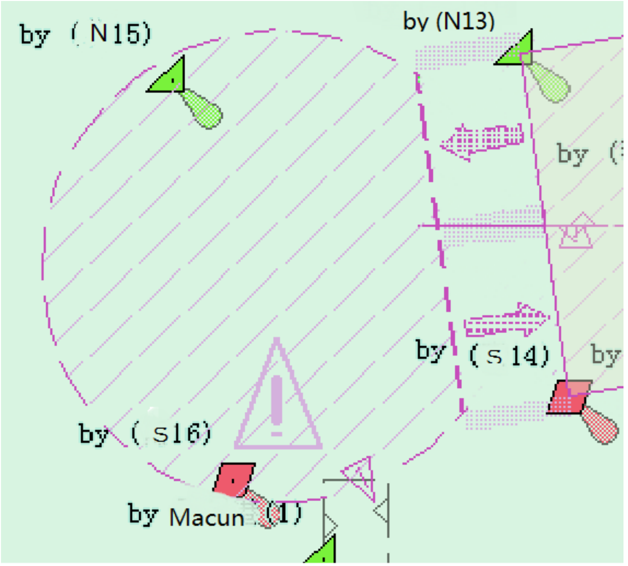
Content of survey: Opinions and Suggestions on optimization scheme of ship routeing system in Qiongzhou Strait

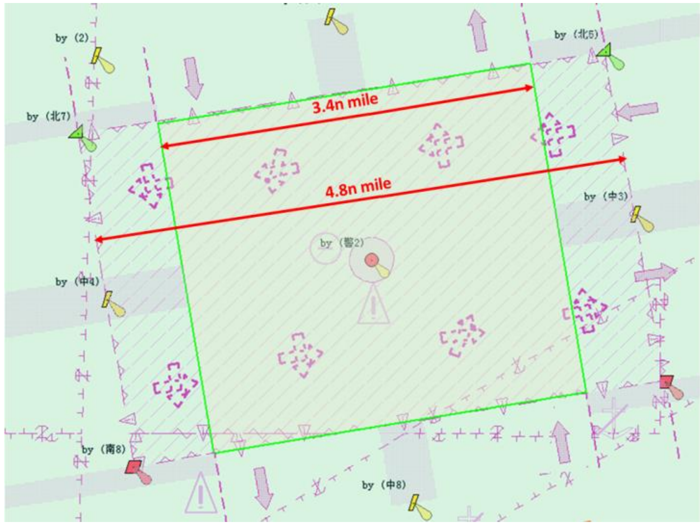
Questionnaire filling method: Tick "√" in the box after the option you agree with. If there is no option you agree with and you want to make necessary supplement, please write in the "other" column

A. Your basic information	
Role	(a)passenger ship captains □ (b)Haikou VTS officers □ (c)shipping company management officers □ (d)merchant ship captains □ (e) others □
Years of current role	(a)less than 1 year □ (b)1year to 5years □ (c)5years to 10years □ (d)10years to 20years □ (e) more than 20years □
B. Information of your ship	
Type of your ship	(a)passenger ship □ (b)container ship □ (c)oil tanker □ (d)LNG or LPG tanker □ (e)dangerous cargo carrier □ (f)bulk carrier □ (g)others □
GT of your ship	(a)500 GT~3,000GT □ (b)3,000 GT ~10,000 GT □ (c)10,000 GT ~50,000 GT □ (d)50,000 GT ~100,000 GT □ (e)More than 100,000 GT

Dimensions and speed of your ship	(a)ship length：______m (b)ship width：______m (c)full draft： _____ m (d)sea speed：________ kts
C. Investigation on traffic hazard level of ships in Qiongzhou Strait (north-south routeing)	
a. How do the ship routeing system and surrounding ships traffic conditions affect the navigation safety?	
traffic density	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
condition of ship crossing situation	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
condition of merchant-fishing boat meeting	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
How do you feel about the overall level of danger of ships sailing in this area?	(a)no dangerous□ (b)slight dangerous□ (c)moderate dangerous□ (d)big dangerous□ (e)serve dangerous□
b. What are the influences of various factors of geographical conditions on navigation safety?	
underwater obstacles	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
water depth	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
fishingnets and aquaculture	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
others：（ ）	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
c. What are the influences of various elements in meteorological and hydrological conditions on navigation safety?	
current	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
wind	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
visibility	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
tide	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
others：（ ）	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
D. Investigation on the weight of ship traffic influencing factors	

How do you think the following factors affect navigation safety in Qiongzhou Strait?	
Traffic separation scheme and surrounding ships	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
Geographical conditions of the waters	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
Meteorological and hydrological conditions	(a)no interference□ (b)slight interference□ (c)moderate interference□ (d)big interference□ (e)serve interference□
E. Investigation on optimization scheme of ship routeing system in Qiongzhou Strait	
a. Diagram of ship routeing system in Qiongzhou strait after adjustment	

b. Add the NO.4 precautionary area. The shape of the newly added NO.4 precautionary area is circular arc (the shape of the NO.1 precautionary area and the NO.4 precautionary area should be the same as far as possible). The precautionary area is connected with the inbound and outbound channel of Makun port.	 NO.4 precautionary area (a). Agree□ (b). Do not agree□ If not, please state your reasons:

<table>
<tr>
<td>c. The width of NO.2 precautionary area has been reduced from 4.8 nm to 3.4 nm (see green line) for the following reasons:
(a).The passenger ship route will change from Xiuying-Hai’an to Xinhai-Xuwen. The traffic flow in the NO.2 precautionary area will be greatly reduced, which does not need such a wide precautionary area.
(b).Xiuying port and Hai'an port also have emergency transport functions for passengers and goods, and some passenger ferry capacity needs to be retained.
(c).Provide corresponding control space for the future entry and exit of large cruise ships in Xiuying port.
(d). Provide the nearest convenient lane for other coastal ships.</td>
<td>

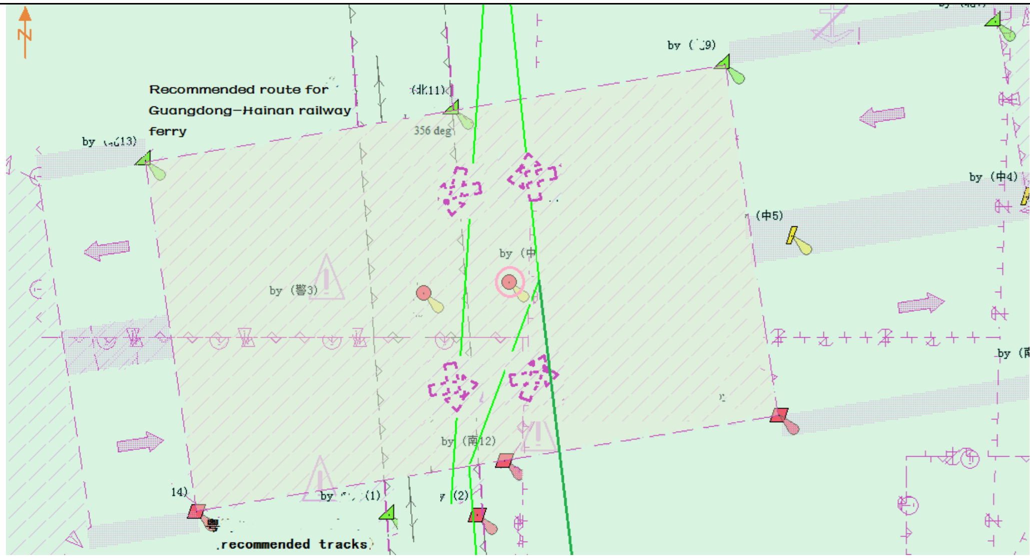
NO.2 precautionary area

(a) Agree□ ② Do not agree□

If not, please state your reasons:</td>
</tr>
<tr>
<td colspan="2">d. The NO.3 precautionary area is changed from a circular precautionary area to a rectangular precautionary area with a length of 5 nm and a width of 3 nm, based on the following reasons:
(a). It is used to set the channel of passenger ships;
(b). It is convenient for east-west international ships to enter the waters to prepare for avoidance in advance;
(c). Give larger areas for passenger ships to avoid collision, and reserve precautionary areas for the future operation of high-speed ships of Guangdong-Hainan railway;
(d). Minimum buoy movement, saving money.
(a). Agree□ (b). Do not agree□
If not, please state your reasons:</td>
</tr>
</table>

e. The following three pictures show three optimization schemes of the NO.3 precautionary area of ship routeing system in Qiongzhou Strait. According to your navigation experience in this water, which ship routeing system should be adopted, please sort it or or choose any of the three diagrams to draw the routeing you recommend.

Scheme A:



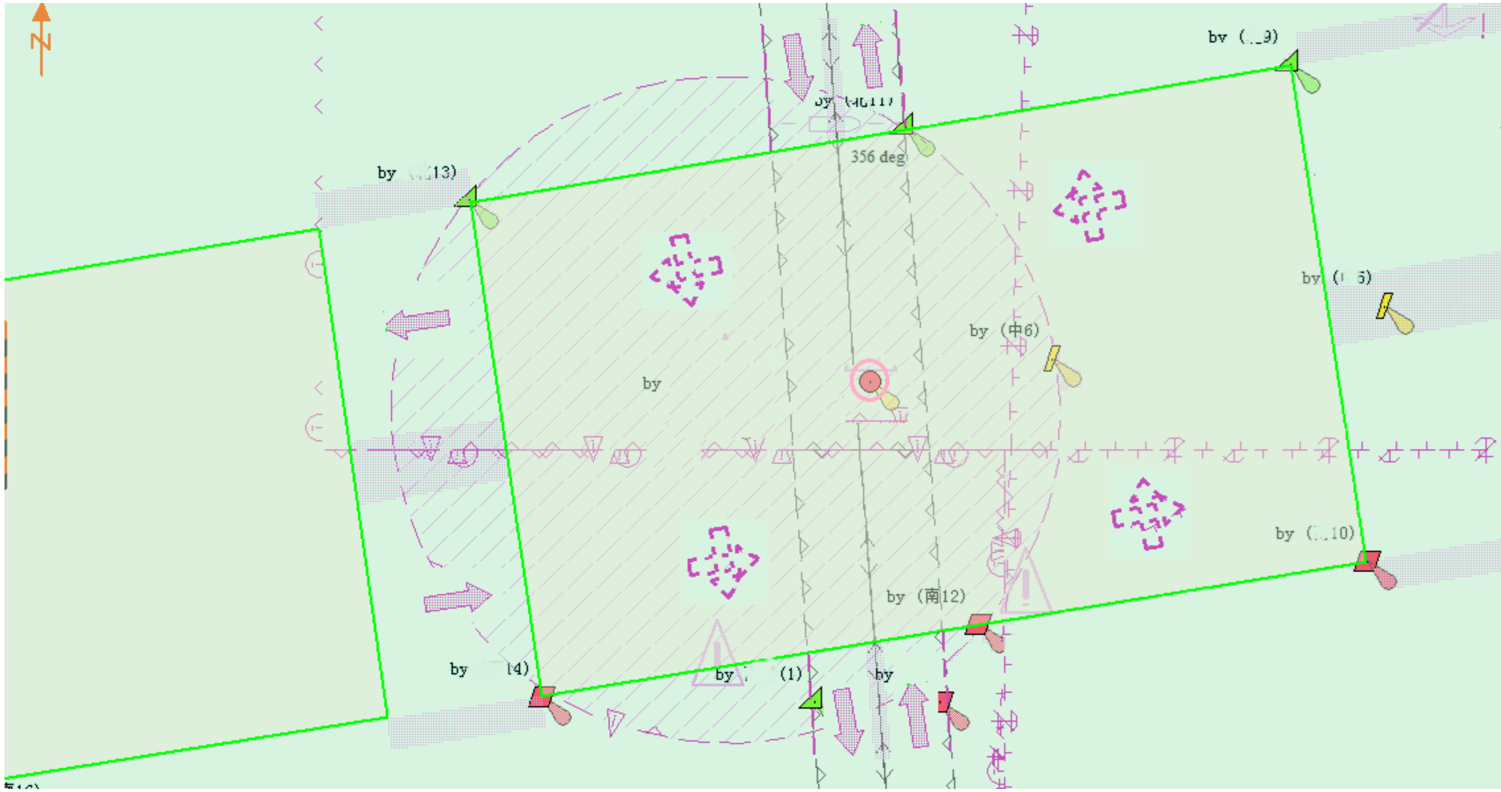
(a). The route of Guangdong-Hainan railway ferry has no change in the existing 800-meter channel. Two light buoys are set up in the center of the precautionary area. The light buoy in the west separate the traffic flow between Guangdong-Hainan railway ferry and passenger ships, and the light buoy in the east set up a circular 0.2 nm area to be avoided to separate the traffic flow of passenger ships in the south and north.

(b). The passenger ships shall sail in the recommended direction of traffic flow (green line). In the center of the NO.3 precautionary area, the maximum distance of southbound and northbound traffic flow is 1150 meters, and the distance of southbound and northbound traffic flow of the sideline on the north side of the precautionary area is 800 meters.

(c). The north-south direction of the NO.3 precautionary area is the recommend routes for Guangdong-Hainan railway ferries.

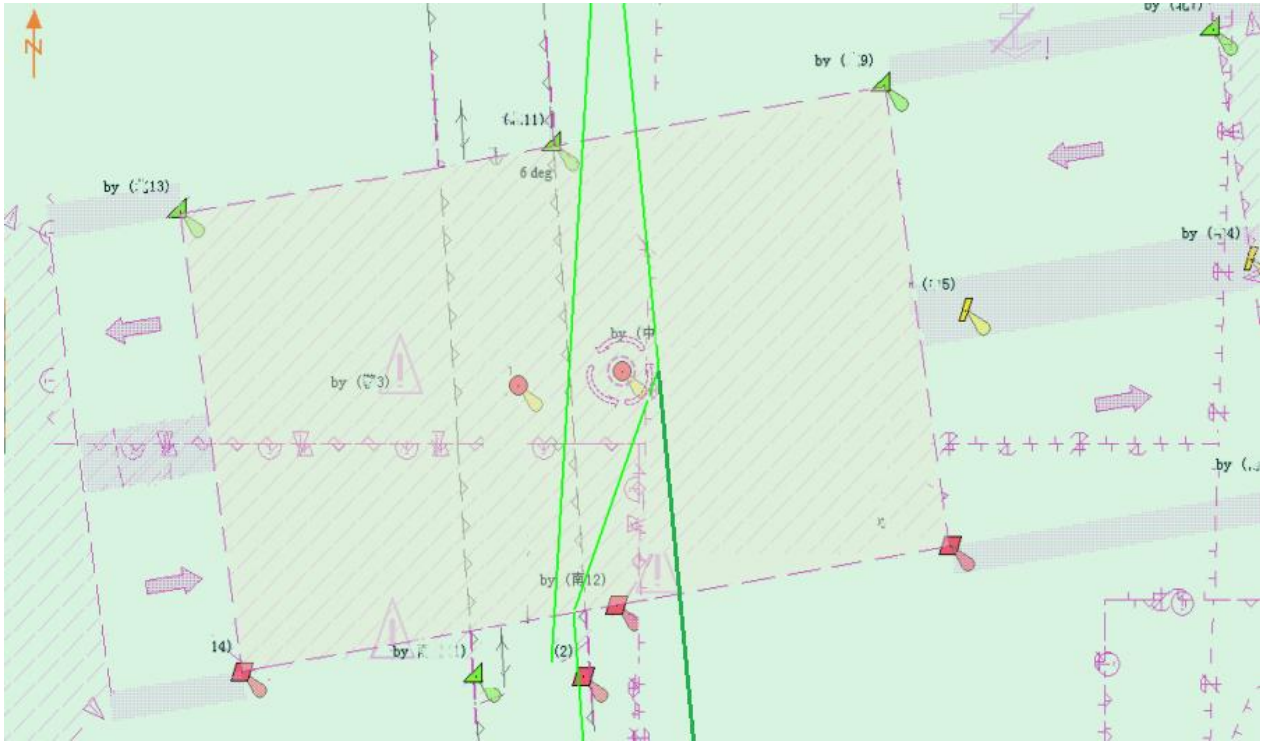
(d). The deep green line in the figure is the preferred northbound route for passenger ships. It is suggested that the passenger ship should not meet or set the turning point in the NO.3 precautionary area.

Scheme B:



(a). Scheme B makes full use of the existing 1500-meter channel, with a light buoy in the center and a 0.2 nm area to be avoided around the light buoy. The east side of the light buoy is the northbound traffic flow, while the west side is the southbound traffic flow.

(b). In the NO.3 precautionary area near the north and south ends of the traffic flow have crossed, due to the close distance of ports, in order to avoid the Guangdong-Hainan railway ferry and passenger ship of cross, also in order to ensure the railway ferry on time, the Xuwen port need to control the time of departure of the passenger ship, the Xinhai port also need to control the arrivaling time of the passenger ship, to thoroughly solve crossing problem of the Guangdong-Hainan railway ferries and passenger ships.

Scheme C: 

(a). The Guangdong-Hainan railway ferry uses the 800 meters on the west side of the existing channel, and has a 200-meter interval with the southbound of the passenger ship. Two light buoys are set in the center of the precautionary area. The light buoys in the west separate the traffic flow between Guangdong-Hainan railway ferry and the passenger ship. The light buoys in the east are the circular area to be avoided center with a diameter of 0.2 nm.

(b). In the north and south direction of the precautionary area, recommended routes are set for the Guangdong-Hainan railway ferry.

(c). The deep green line in the figure is the preferred northbound route for passenger ships (as in scheme A).

According to your comparative analysis of the above three schemes, your first choice is scheme (   ), the second is scheme (   ), and the last is scheme (   ). Why are you sorting this way?

Your answer:

Do you have any comments and Suggestions on the optimization of ship routeing sysytem?

Your answer:

Thank you again for your cooperation !