8-25-2019

Research on the planning of ships' routeing system in the Eastern Bohai Waters

Wenyu Lyu

WORLD MARITIME UNIVERSITY

Dalian, China

RESEARCH ON THE PLANNING OF SHIPS' ROUTEING SYSTEM IN THE EASTERN BOHAI WATERS

By

WENYU LYU

The People's Republic of China

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

MASTER OF SCIENCE

Maritime Safety Environmental Management

2019

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: Wenyu Lyu

Date: June 28, 2019

Supervised by: DR. BAO JUNZHONG
Professor
Dalian Maritime University

ACKNOWLEDGEMENT

As one of the fruits of my study in MSEM during the year 2018-2019, this work's inspiration and knowledge come from the lectures and assignments from all Professors and the help form my classmates. I hereby extend my grateful thanks to them for their kind help without which the paper would not have been what it is. I am also grateful to my supervisor, Professor Bao Junzhong, whose useful suggestions, incisive comments and constructive criticism have contributed greatly to the completion of this thesis.

Moreover, my sincere gratitude goes to World Maritime University and Dalian Maritime University for offering me this precious opportunity to study. I also deeply appreciated all my colleagues and superiors at School of Foreign Languages, Dalian Maritime University, who have kindly shared my heavy teaching tasks. Any progress that I have made is the result of their profound concern and selfless devotion.

Last but not the least, I would like to thank my family: my father Tangyao Lyu, my mother Lina Han and my husband Lianbo Li. Each time when I meet difficulties, I will think about my father's words. It is he who taught me to be a kind, responsible and honest person. My mother is the one who pushes me to go forward, who comforts me when I feel frustrated and depressed, and who is always there to support me. In those years, it is she who walked me through all the laughs and tears. My husband not only supports me spiritually and financially, but also encourages me to pursue my dreams. He understands and trusts me as a soulmate, cherishes and honors me as a friend, comforts and protects me as a guardian angel, just as he said in our wedding oath. I dedicate all my success to my beloved family.

ABSTRACT

Title of Dissertation: Research on the Planning of Ships' Routeing System in the Eastern Bohai Waters

There are many ports located in the eastern Bohai waters, such as Tianjin Port, Huanghua Port, Caofeidian Port, Dalian Port, Jinzhou Port, etc. In recent years, with the development of the Circum-Bohai Sea Economic Zone, the number, flow, length and tonnage of ships entering and leaving the ports around the eastern Bohai waters are increasing rapidly. The sharp rise of navigation density and ship encounter rates have made traffic environment more complex. In addition, the construction of super-large deepwater terminals and the development of offshore oil platforms have led to high traffic flow in the eastern Bohai waters. All these problems have increased the potential risk of traffic accidents and have posed great challenges to the navigation safety and environmental protection of the waters.

Ships' routeing systems aim to improve the navigation safety in converging areas and areas with high traffic density through measures such as traffic separation scheme, roundabout, recommended route, deep-water route, precautionary area and etc. This thesis explores the natural environment and traffic information of the eastern waters of Bohai Sea. Based on the systematic understanding of the natural environment, navigation environment and traffic accidents statistics of the eastern Bohai waters, this thesis collects and analyzes three traffic flow characteristics, including traffic volume, ship type, ship length provided by AIS data in the fourth quarter of 2018. Then based on *General Provisions on Ships' Routeing*, the planning of ships' routeing system in the eastern Bohai waters is made. Considering the feasibility and necessity, it is recommended that setting traffic separation scheme and precautionary area are appropriate navigational measures to solve the traffic problems in this area.

KEY WORDS: Ship's Roueting System; Navigation Safety; Eastern Bohai Waters; Traffic Separation Scheme; Precautionary area

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
COLREG	Convention on International Regulations for Preventing Collisions at Sea
ECDIS	Electronic Chart Display and Information System
GPS	Global Positioning System
IMO	International Maritime Organization
kn	knot(s)
l	length overall
m	meter(s)
MMSI	Maritime Mobile Service Identity
nm	nautical mile(s)
SOLAS	International Convention for Safety of Life at Sea
UNCLOS	United Nations Convention on the Law of the Sea
VTS	Vessel Traffic Service

Chapter 1: Introduction

1.1 Research Background and Significance

Ships' routeing systems are significantly important to the navigation safety and work as one of the effective solutions for congested traffic of waterways. As mentioned in Chapter V in the *International Convention for the Safety of Life at Sea (SOLAS)*, "ships' routeing systems contribute to safety of life at sea, safety and efficiency of navigation, and/or protection of the marine environment."(IMO, 2014) In order to better establish and give full play to the role of ships' routeing systems, the International Maritime Organization (IMO) has formulated the *General Provisions on Ships' Routeing*, which are contained in the IMO Publication *Ships' Routeing* (IMO, 2015). It provides guidance for the establishment and implementation of ships' routeing systems in countries around the world. There are also international provisions concerning the ships' routeing systems, such as the 1982 United Nations Convention on the Law of the Sea (UNCLOS), the 1974 International Convention for the Safety of Life at Sea (SOLAS) and the 1972 Convention on International Regulations for Preventing Collisions at Sea (COLREG). SOLAS has also made mandatory provisions on issues related to ships' routeing systems in Chapter V. Therefore, much attention is put in to the planning of ships' routeing systems in many courtiers in the world.

With the continuous upgrading of domestic and foreign trade length, the rapidly increasing port handling capacity and frequent ship exchanges in the ports around the Bohai Sea such as Tianjin Port, Huanghua Port, Binzhou Port, Dongying Port, etc. have made the eastern Bohai waters become one of the busiest waters in the world. The sharp rise of navigation density and ship encounter rates have made traffic environment more complex. In addition, the construction of super-large deepwater terminals and the development of offshore oil fields have led to high traffic flow of in the area. All these problems have increased the potential risk of traffic accidents to varying degrees, and have posed great challenges to the navigation safety and environmental protection of the waters. Therefore, it is necessary to take effective measures to solve the navigation problems in the eastern Bohai waters.

1.2 Research Purpose

This thesis aims to research on the planning of ships' routeing system in the eastern waters of Bohai Sea and propose some scientific basis for the relevant maritime departments so as to change the status quo of navigation in the waters. This thesis can also provide reference and research ideas for the planning of ships' routeing systems in other waters.

Specifically, the focus of the research mainy lie in the following four aspects. Firstly, by collecting the information of natural environment, traffic environment (including port, oil field operation area, route planning and etc.) and water traffic accidents statistics in recent years, this thesis aims to fully grasp the navigation environment of the eastern waters of Bohai Sea. Secondly, based on AIS real-state data of traffic flow in the eastern Bohai waters, the characteristics of traffic flow are analyzed, including the traffic volume, the ship type and ship length. Thirdly, the hazardous areas and major risks in the area are studied so as to determine the key planning areas of ships' routeing system. Fourthly, specific implementation of the ships' routeing system in the eastern Bohai waters is planned.

1.3 Outline of the Thesis

In pursuit of the research purpose, this thesis is organized as follows. Chapter 1 introduces the research background, purpose and significance of the research and outlines the thesis in terms of how the idea is developed. General regulations on routeing systems made by IMO and previous studies on planning of ships' routeing systems are introduced in Chapter 2. By consulting and collecting relevant books and literature, Chapter 3 explores the natural environment and traffic information of the eastern waters of Bohai Sea. Water traffic accidents are also analyzed so as to lay the foundation for the establishment of the subsequent routeing system. Chapter 4 analyzes the AIS data based on real-state observation so as to summarize the traffic flow characteristics of the waters from three angles: traffic volume, ship type and ship length, and to provide a scientific reference for the planning of the ships' routeing system in Chapter 5. Chapter 5 develops the convergence idea of the above data and studies the planning area of the eastern waters of Bohai Sea. By referring to the planning scheme of similar waters, the planning of ships' routeing system in the eastern Bohai waters is specifically proposed. Chapter 6 summarizes the findings in this study, and points out limitations and implications.

Chapter 2: Theoretical Basis of Ships' Routeing System

2.1 The Purpose of Setting Routeing Systems

As mentioned in *Ships' Routeing* (IMO, 2015), the purpose of ships' routeing is to improve the safety of navigation in converging areas and in areas where the density of traffic is great or where freedom of movement of shipping is inhibited by restricted sea room, the existence of obstruction to navigation, limited depths or unfavorable meteorological conditions. It is also used to avoid or reduce the risk of damage to the marine environment due to water traffic accidents or anchoring in certain areas. As the actual situation of different waters varies, elements used in traffic routeing systems include: traffic separation scheme, traffic lane, separation zone or line, roundabout, inshore traffic zone, recommended route, deep-water route, precautionary area and area to be avoided.

The objectives of any routeing system will depend upon the particular hazardous circumstances which it is intended to alleviate, but may include some or all of the following :

(1) The separation of opposing streams of traffic so as to reduce the incidence of head-on encounters;

(2) The reduction of dangers of collision between crossing traffic and shipping in established traffic lanes;

(3) The simplification of the patterns of traffic flows in converging areas;

(4) The organization of safe traffic flow in areas of concentrated offshore exploration or exploitation;

(5) The organization of traffic flow in or around areas where navigation by all ships or by certain classes of ships is dangerous or undesirable;
(6) The reduction of risk of grounding to providing special guidance to vessels in areas where water depths are uncertain or critical;
(7) The guidance of traffic clear of fishing grounds or the organization of traffic through fishing grounds.

— from *Ships' Routeing* (IMO, 2015)

In 1961, the first ships' routeing system was approved by the International Maritime Organization (IMO) - the Dover Strait Ships' Routeing System came into being. At present, the world famous waterways, such as the Dover Strait, the Bosporus Strait, the Lawrence Strait, the Malacca Strait and so on, have established traffic separation schemes. At present, major shipping countries in the world have implemented ships' routeing and other management measures in important waters of their respective jurisdictions. By 2011, 261 ships' routeing systems have been adopted by IMO, which effectively dredge the traffic flow, and improve the navigation safety and traffic efficiency of the ships. including 159 traffic separation schemes, 18 deep-water routes, 56 area to be avoided and 28 other routeing measures (Zhao, 2013).

2.2 Previous Studies on the Planning of Ships' Routeing Systems

Many studies have been conducted on the planning of ships' routeing systems. Mou et al. (2010) made use of AIS to investigate the real-state situation of ship collisions in order to solve the problem of collision risk in dense traffic flow waters. They also took the separation scheme of Rotterdam Port in Europe as an example to test and verify the statistical analysis. Kim et al. (2011) discussed the routeing system along the southern coast of South Korea, summarized and analyzed the data of casualties at sea, and made some contributions to the prevention of maritime accidents and the improvement of traffic flow. Szlapczynski (2013) planned the safety routeing of ships in the event of encounter, and compared different routes based on IMO's provisions on the traffic separation scheme. Jensen et al. (2013) solved the problem of bridges connecting Denmark and Germany by traffic separation scheme based on the characteristics that ships will be restricted when sailing in areas with high traffic density and areas with limited waters or obstacles. Jensen (2014) used AIS data to assess the spatial and temporal changes in freight volume in the traffic separation scheme in San Francisco Bay. Olindersson et al. (2015) analyzed the 24-hour AIS data of the Bornholmsgat traffic separation scheme, and summed up the average navigation distance of ships.Sunaryo et al. (2015) studied the heavy traffic phenomenon in the Merak and Sunda Straits of Indonesia. The separation scheme was implemented in order to prevent traffic accidents and ensure the safety of navigation. Pietrzykowski and Magaj (2017) analyzed the traffic separation scheme in south Baltic Sea. AIS data were used to to determine the standard identification of parameters.

In China, many scholars have worked on the optimization of current routeing systems. Through the study and analysis of the navigation environment in the eastern part of Chengshanjiao, Hu (2012) summarized the navigation characteristics of the waters and proposed four kinds of ships routeing options, which were optimized by using the comprehensive evaluation method so as to provide reference for the planning of ships' routeing system of the waters. Fan (2013) expounded the necessity of ships' routeing, then took the Chengshanjiao ships' routeing as an example for the attempt of chossing the best plan from several alternatives. Liu et al. (2013) analyzed the navigation characteristics of ships' routeing system in Ningbo and Zhoushan Port, determined its potential safety hazards, and gave some guidance so as to relieve the rapid growth of traffic in this area. In view of the characteristics of large traffic flow density and complexity in the precautionary areas, Li et al. (2013) made use of traffic conflict technique to solve the traffic flow conflict which provided the decision basis for the research on planning of ships' routeing systems. By analyzing the AIS and VTS data in Ningbo Port and Zhoushan Port area, Liu et al. (2013) summarized the track and traffic characteristics of the waters. Moreover, based on this summary, the ships' routeing system in this area is scientifically designed. Zhao et al. (2013) made a statistical analysis of the traffic flow pattern and water traffic accidents in Bohai waters, and put forward the overall plan, aiming at the problem of rapid increase of traffic volume in Bohai Sea. Through the statistical analysis of the traffic flow of the Dahao Waterway and the Dangan Waterway, combined with the actual traffic environment, Feng (2015) established a comprehensive evaluation system on ships' routeing systems. Through the analysis of the ships' routeing system in Qiongzhou Strait, Zhuo and Tao (2015) found the shortcomings in its operation and gave corresponding solutions. In order to improve the navigation safety of Yangtze Estuary, Bai et al. (2016) analyzed the current situation of the ships' routeing system in the Yangtze Estuary, put forward the optimization scheme, and by using the traffic conflict technique, they took precautionary area as an example to evaluate the optimization scheme. Zhang et al. (2016) analyzed the influence of the current ships' routeing system in Caofeidian waters, aiming to put forward the optimal adjustment scheme for the second harbor basin with reference to the relevant regulations and international practical experience.

Chapter 3: Analysis of Navigation Environment in the Eastern Bohai Waters

3.1 Natural Environment

3.1.1 Meteorology

The Bohai Sea is located in the middle latitude of Monsoon Climate Zone, which belongs to the sub-humid area; therefore its coastal climate has both continental and oceanic characteristics. Its winter is cold, windy and dry, with less snow. In summer, the high temperature time is short with abundant rainfall. In spring, it is dry and windy with comparatively faster temperature recovery. In autumn, cold air activities begin to strengthen, resulting in fast cooling, reduced rainfall and more sunny weather. During the year, the rainfall is mainly concentrated in summer, accounting for about 60%-70% of the annual precipitation, especially in the summer of July and August when strong tropical cyclones visit the Bohai Sea, resulting in frequent high winds and torrential rains. There are many cold currents in winter; therefore the strong cold air can cause the sudden drop in temperature and blizzard weather.

3.1.2 Hydrology

Firstly, the tide. The tides in the Bohai Sea are formed as a left-handed tidal system due to the influence of the Pacific tidal wave, and the time for one rotating is about 12 hours. From the southern end of the Liaodong Peninsula to the Tuanshanjiao of the western bank of Liaodong Bay and from Daqing Estuary of Bohai Bay to Tanggu and other coasts, the tides are irregular semidiurnal tides. Near the Niangniang Temple, and from the Daqing Estuary to the coasts near artificial estuary, the tides are irregular diurnal tides. The tides along the Xinlitun to Qinhuangdao Port are regular diurnal tides. From the south of Tanggu to Dakou Estuary and from Longkou to Penglai, the tides are semidiurnal.

Secondly, the tidal current. The role of tidal currents is very important in the Bohai Sea because of shallow water and weak ocean current. Due to the terrain restrictions near shores, straits, waterways, harbours and other narrow waters, the tidal currents are mostly reversing currents; while in the offshore areas, the currents are mostly rotary. The flow rate of the tidal current is about 1-2kn, while the maximum speed near the Laotieshan Waterway is up to 6.25kn.

Thirdly, the ocean current. In addition to the wind-driven current formed under the influence of the wind on the surface of the Bohai Sea, there is an ocean circulation composed of two systems: coastal flow and warm current. The average speed of wind-driven flow is 2.5kn, strong in summer and weak in winter. Its direction is 15°-20° to the right of the wind blowing. The depth under the influence of wind is generally 10m, with the maximum reaching 20-30m. The Bohai Strait has the circulation coming from north all year round, and the flow rate is strong in summer and weak in winter. After entering the Bohai Sea, due to the influence of topography, the circulation is divided into two tributaries: one goes right into the Liaodong Bay, constituting the Liaodong Bay Circulation; the other goes left into the Bohai Bay, constituting the Bohai Sea Circulation.

Fourthly, the wave. The waves in the Bohai Sea are mainly controlled by the monsoon, large in winter and small in summer. Most waves are wind waves and swells with short wave length and wave period. In January, most (almost 30%) of the waves are northwest waves; the big wave frequency also reaches the maximum value (about 25% of the waves) in this month, In April, the number of southern waves increases with the frequency of big waves below 25%. The southeast wave dominates from July with the frequency of big waves less than 5% (of all te waves). In October, most (almost 30-40%) of the waves are northwest waves; the big wave frequency also increases to more than 20%.

Fifthly, the sea ice. Each winter, there is a different degree of icing phenomenon in China’s Bohai Sea and the northern Yellow Sea. The ice period is about 2-4 months and the so-called severe ice period is from January to the beginning of February. The ice situation in Jingtang Port is better than Yingkou, Jinzhou and Tianjin Port, but slightly worse than Qinhuangdao Port.

3.2 Traffic Environment

3.2.1 Port

Since ports generally locate in the areas with large navigation density, the understanding of the port distribution of planned waters is instructive to the macro-planning of ships’ routeing systems. By consulting the nautical publications such as *Admiralty Sailing Directions*, *Guide to China Ports* and other navigation books, the distribution of the main ports in Bohai Sea are shown in Table 1.

Table 1 List of major ports in the Bohai Sea

Port Name	Geographical Coordinates
Qinhuang Port	39°54′.6N 119°36′.7E
Tangshan Port	39°12′.8N 119°00′.8E
Tianjin Port	38°59′.1N 117°42′.1E
Huangye Port	38°19′.5N 117°52′.5E
Binzhou Port	38°18′.0N 118°08′.0E
Dongying Port	38°06′.0N 118°59′.0E

3.2.2 Oil Platform

There are a large number of oil platforms in the eastern Bohai waters. The frequent ship encounters are not good for the safety of navigation in the area; so the planning of the ships' routeing systems needs to consider the position of these platforms to ensure the safety of navigation. The position of oil platforms in the eastern waters of Bohai Sea are shown in Table 2.

Table 2 List of oil platforms in the eastern Bohai Waters

No.	Platform Name	Geographical Coordinates
1	WHP-A	38 °41′.999N 118°41′.103E
2	WGP-A	38°46′.221N 118°40′.566E
3	SPM	38°46′.341N 118°42′.296E
4	WHP-C	38°44′.902N 118°43′.481E
5	WHP-D	38°43′.574N 118°50′.505E

6	WHP-E	38°44′.612N 118°53′.516E
7	WHP-F	38°42′.441N 118°53′.697E
8	CFD18-1WHP	38°37′.575N 118°53′.935E
9	CFD18-2WHPC	38°34′.788N 118°57′.321E
10	BZ13-1WHPB	38°33′.041N 119°03′.918E
11	BZ26-2WHPA	38°17′.549N 119°15′.776E
12	BZ26-3WHPA	38°15′.276N 119°13′.922E
13	BZ26-3WHPB	38°14′.122N 119°16′.065E
14	BZ19-4WHPA	38°19′.178N 119°05′.628E
15	BZ19-4WHPB	38°22′.487N 119°05′.649E
16	BZ25-1WHPA	38°15′.866N 119°07′.255E
17	BZ25-1WHPB	38°14′.806N 119°07′.469E
18	BZ25-1WHPC	38°13′.920N 119°05′.979E
19	BZ25-1WHPD	38°12′.668N 119°05′.701E
20	BZ25-1WHPE	38°12′.132N 119°03′.620E
21	BZ25-1WHPF	38°12′.091N 119°01′.148E

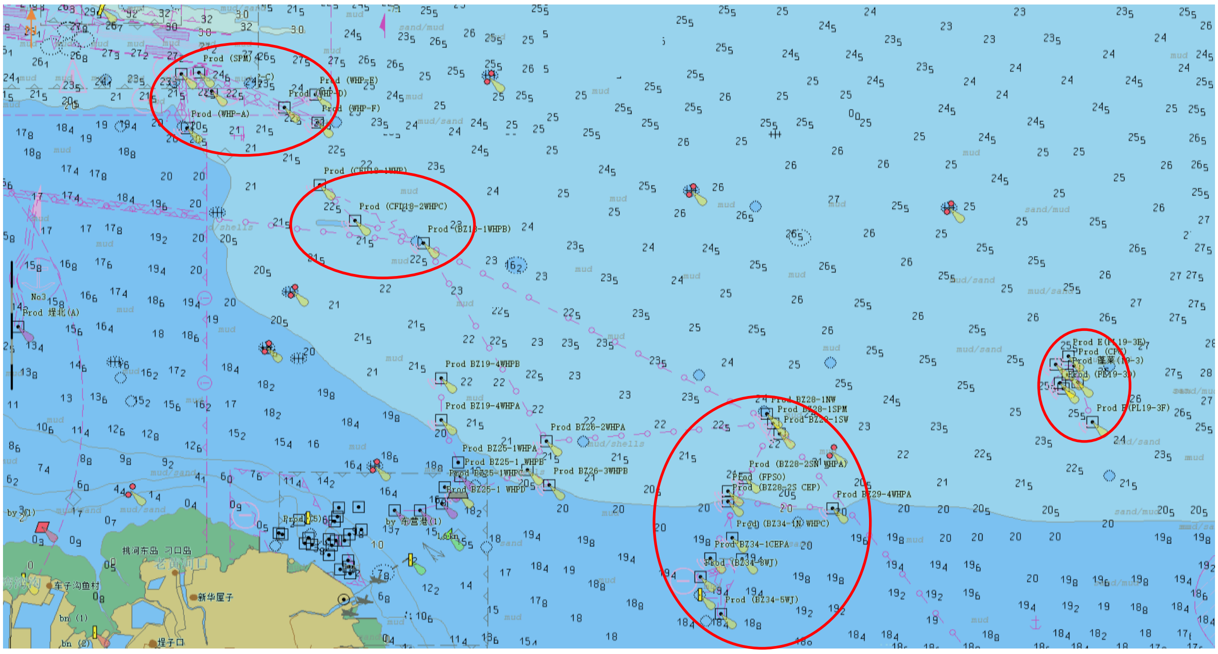

Figure 1 Diagram of oil platform areas in the eastern Bohai Waters

3.2.3 Planning Route

In order to form a systematic navigation system and improve navigational safety and transportation efficiency, China has planned two deep-water routes and five recommended routes in the Bohai Sea as shown in Table 3.

Table 3 Planning route in the Bohai Sea

Type	Name	Width
Deep-water Routes	Laotieshan to Caofeidian	3nm
	Liaotieshan to Yingkou	3nm
Two-way Recommended Routes	Liaotieshan to Tianjin	6nm
	Liaotieshan to Qinhuangdao	6nm
	Liaotieshan to Northern Bohai Bay	6nm

	Changshan to Tianjin (West)	2nm
	Changshan to Tianjin (North)	2nm

3.3 Statistical Analysis of Marine Traffic Accidents

Marine traffic accidents are different from so-called marine casualties. The former is only one part of the latter. In China, the marine traffic accidents can be classified into 7 types, including collision, stranding (grounding & striking), contact, heavy weather, fire & explosion, foundering, missing, engine failure and other. The standard of seriousness can be divide into 5 scales, i.e. small accident, general accident, big accident, serious accident, and extra-large accident.

Through investigation and research on related accident reports from VTS, 24 traffic accidents were detected in the rectangular area from (38°10'00"N,118°10'00"E) to (38°50'00"N, 120°10'00"E) during the period from 2013 to 2017 in the eastern Bohai waters as shown in Figure 2, among which there are 17 collision, 1 contact, 1 fire & explosion, 3 heavy weather and 2 foundering. The statistical results also show that 16 accidents are small accidents, 6 are general accidents, and 2 are big accidents.

Generally speaking, collision and contact accidents are usually closely related to the big density of ships, complex traffic flow and etc. It can be seen from Figure 2 that 8 out of the 18 collision and contact accidents locate in the eastern Bohai open waters, which can actually be avoided by the establishment of ships' routeing systems;

therefore it is necessary to carry out the research and planning of ships' routeing system for the eastern Bohai waters.

Figure 2 Distribution of traffic accidents in the designed water in 2013-2017

Chapter 4: Analysis of the Traffic Reality in the Eastern Bohai Waters

4.1 Customary Route

Automatic Identification System (AIS) is a kind of navigational equipment for ships. The use of AIS can enhance the measures to avoid collision between ships, strengthen the functions of ARPA radar, ship traffic management system and ship report, display visual information of course, route and naming of all ships on electronic chart, and achieve the purpose of improving maritime communication. It also provides a method of direct voice and text communication, which enhances the ship's overall awareness. AIS uses MMSI code, the only global coding system for ships, as a means of identification and provides the following information: ship static data (including ship name, call sign, MMSI, ship type, ship length, ship width, etc.), ship dynamic data (including longitude, latitude, ship heading, track direction, speed, etc.) and ship voyage data (including ship status, draft, destination, ETA, etc.). With the general equipments of AIS on ships, it is possible to use the AIS data as a new means of marine traffic investigation. Compared with the traditional observation methods, the marine traffic survey based on AIS data has the advantages that traditional observation methods do not have. In obtaining the information of ship traffic flow in specific waters, it can be combined with the Electronic Chart Display and Information System (ECDIS), and can directly reflect the macro and micro ship traffic flow in observed waters.

The customary route diagram on the eastern Bohai waters is made based on the AIS track results as shown in Figure 3. This will help to decide the position of gate lines in the following section.

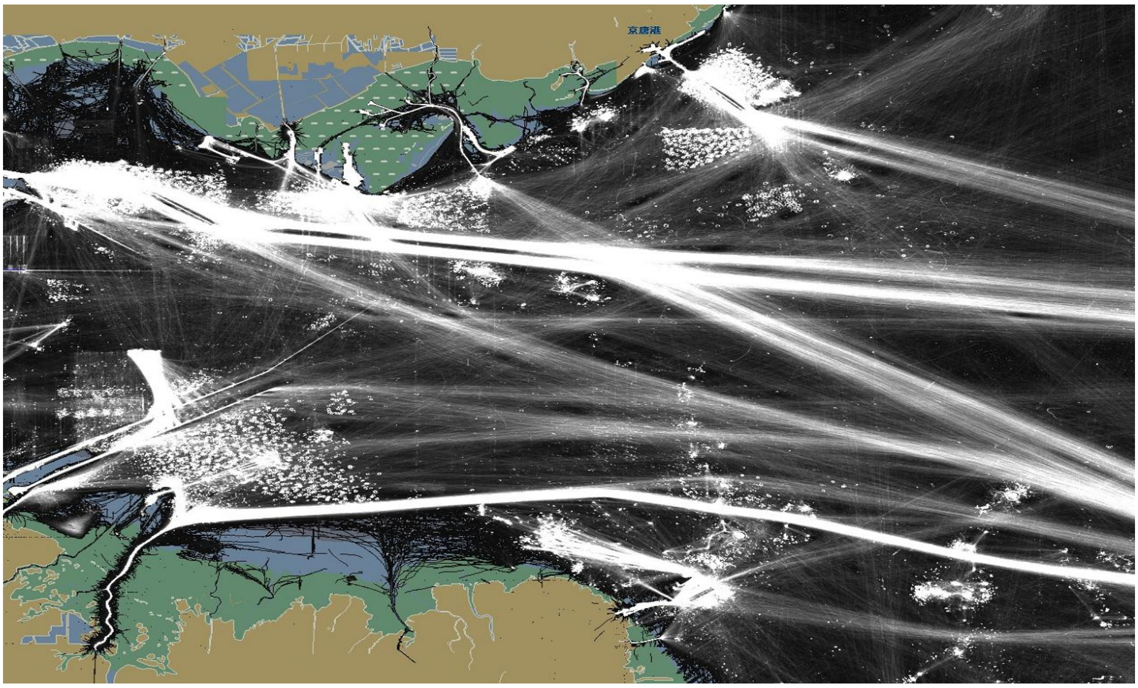

Figure 3 Customary route diagram on the eastern waters of Bohai bay

4.2 The Setting of Gate Lines

In order to understand and grasp the actual traffic flow characteristics of the eastern Bohai waters, 8 AIS gate lines are set according to the customary routes in the eastern part of Bohai Sea as shown in Figure 4.

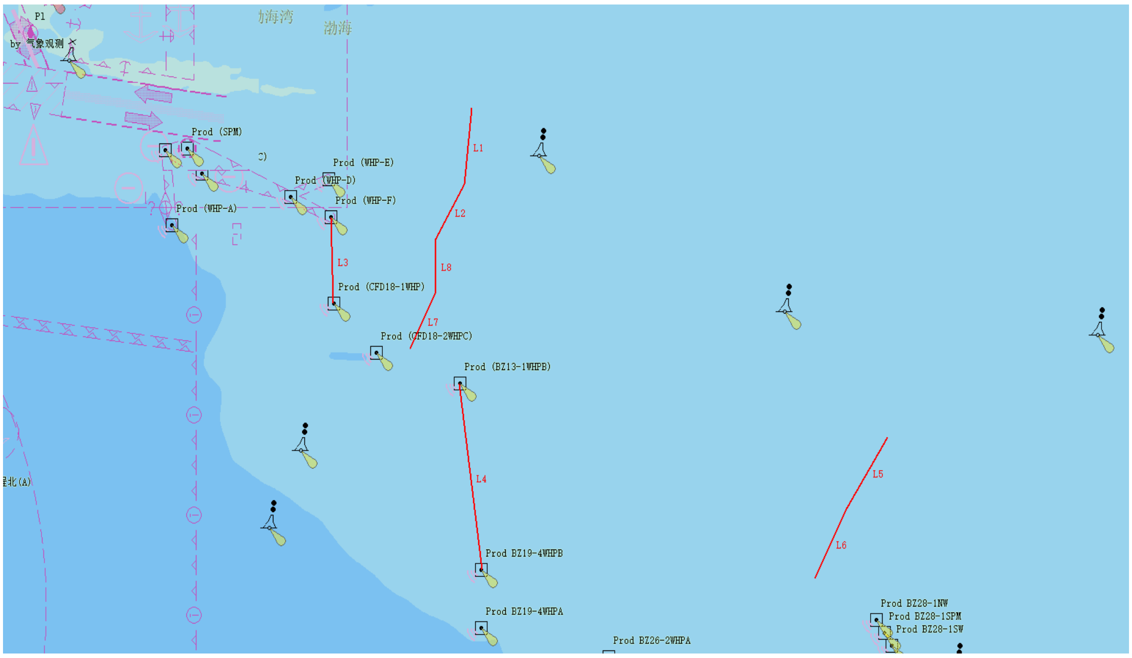

Figure 4 Setting of gate lines in the eastern Bohai waters

Then the traffic flow of each gate line in the fourth quarter of 2018 (October, November, December) was obtained so as to extract and analyze the traffic flow in the eastern Bohai waters from different angles and provide the basis for the planning of the ships' routeing system. The detailed positions of the 8 gate lines are shown in Table 4.

Table 4 Position of gate lines in the eastern Bohai Waters

Gate Line No.	Position
L1	from（38°48′36″，119°04′54″）to（38°44′18″，119°04′18″）
L2	from（38°44′18″，119°04′18″）to（38°41′12″，119°02′00″）
L3	from（38°42′24″，118°53′42″）to（38°37′36″，118°53′54″）
L4	from（38°33′00″，119°03′54″）to（38°22′30″，119°05′42″）
L5	from（38°30′30″，119°37′54″）to（38°26′00″，119°34′42″）

L6	from（38°26′00″，119°34′42″）to（38°22′00″，119°32′06″）
L7	from（38°38′12″，119°02′00″）to（38°35′00″，119°00′00″）
L8	from（38°41′12″，119°02′00″）to（38°38′12″，119°02′00″）

4.3 Traffic Volume

In the fourth quarter of 2018, statistics on traffic volume of each gate line in the eastern Bohai waters are shown in Table 5. The traffic volume of different gate lines varies from 745 to 15418 vessels, among which the gate line L5 has the least traffic (745) and the gate line L7 has the biggest traffic volume (15418).

Table 5 Statistics on traffic volume of each gate line in the eastern Bohai waters

Gate Line	Total Traffic Volume	Inward Traffic Volume	Outward Traffic Volume	Daily Average
L1	7235	3581	3654	78.64
L2	11608	5807	5801	126.17
L3	1700	911	789	18.48
L4	3810	1866	1944	41.41
L5	745	355	390	8.10
L6	6067	3077	2990	65.95
L7	15418	7586	7832	167.59
L8	5057	2620	2437	54.97

4.4 Ship Type

In the fourth quarter of 2018, the amount of each type of ship entering and exiting Bohai Bay are shown in Table 6. It can be seen that most of the ships crossing gate lines L1, L2, L6, L7, L8 are cargo ships, accounting for more than 50% of ships, followed by non-transport vessels, the proportion of which is 10%-40%; while oil tankers, dangerous goods ships, passenger ships are in smaller proportion. The ships crossing L3 are mainly non-transport vessels, accounting for nearly 90% of all ship types. For L4 and L5, most of the ship types are cargo ships and non-transport vessels, with the proportion around 40%-50%. Overall, the results show that the ranking of ships entering and exiting the ports in the eastern waters of Bohai Bay is broadly like this: cargo ships (close to or more than 50%) , non-transport vessels , oil tankers , passenger ships and dangerous goods ships.

Table 6 List of ship types entering and exiting the ports of Bohai Bay

Gate Line	**Percentage of different ship types into and out of ports of Bohai Bay**				
	Passenger Ship	Cargo Ship	Non-transport Vessel	Oil Tanker	Dangerous Goods Ship
L1	0.64%	66.04%	21.00%	6.12%	6.20%
L2	0.96%	74.74%	11.24%	6.62%	6.44%
L3	0	10.12%	87.24%	2.35%	0.29%
L4	0.21%	48.24%	38.14%	12.52%	0.89%
L5	1.07%	45.23%	42.42%	10.6%	0.67%
L6	0	56.87%	36.72%	6.16%	0.25%

L7	0.40%	65.70%	29.27%	3.68%	0.95%
L8	0.99%	70.59%	22.81%	3.42%	2.19%

4.5 Ship Length

In the fourth quarter of 2018, the distribution of ship length of the ships in the eastern waters of Bohai Sea is shown in Table 7 and Figure 5 respectively. As can be seen, the ship length at gate line L1 and L2 distributes relatively balanced. L3 is dominated by ships less than 90m, accounting for more than 90% of all ships, while the number of ships within other ranges of ship length is relatively small. The proportion of ship length of ships crossing gate line L4 and L5 is quite similar. The ship length less than 90m accounts for nearly 50% of the total, while the ship length within the range of 90-150m accounts for about 30% of the total. The ranking of the remaining ship length is150-200m, 200-300m and more than 300m.

The distribution of ship length crossing gate line L6 is similar to L4 and L5. But the difference is that the number of 150-200m ships is greater than 90-150m ships. For gate line L7 and L8, the dominating ship length is 90-150m, slightly higher than 150-200m and <90m ranges. Overall, the results of the ordering of ships entering and exiting Eastern Bohai Waters by ship length is as follows, ships with 150-200m, 90-150m and <90m ranges have relatively high proportion and relatively few vessels are in the ranges of 200-300m and ≥300m.

Table 7 Distribution list of length of ships in the eastern Bohai waters

Gate Line	**Percentage of different ship length in and out of port of Bohai Bay**				
	≥300	200-300	150-200	90-150	＜90
L1	5.75%	16.60%	27.82%	26.44%	23.39%
L2	6.24%	18.91%	32.12%	29.87%	12.86%
L3	0.47%	0.35%	1.29%	4.65%	93.24%
L4	0.94%	4.51%	10.26%	36.12%	48.17%
L5	2.15%	9.26%	13.02%	26.85%	48.72%
L6	1.07%	9.87%	27.74%	21.10%	40.22%
L7	0.30%	4.79%	21.85%	41.45%	31.61%
L8	1.54%	9.97%	29.29%	35.89%	23.31%

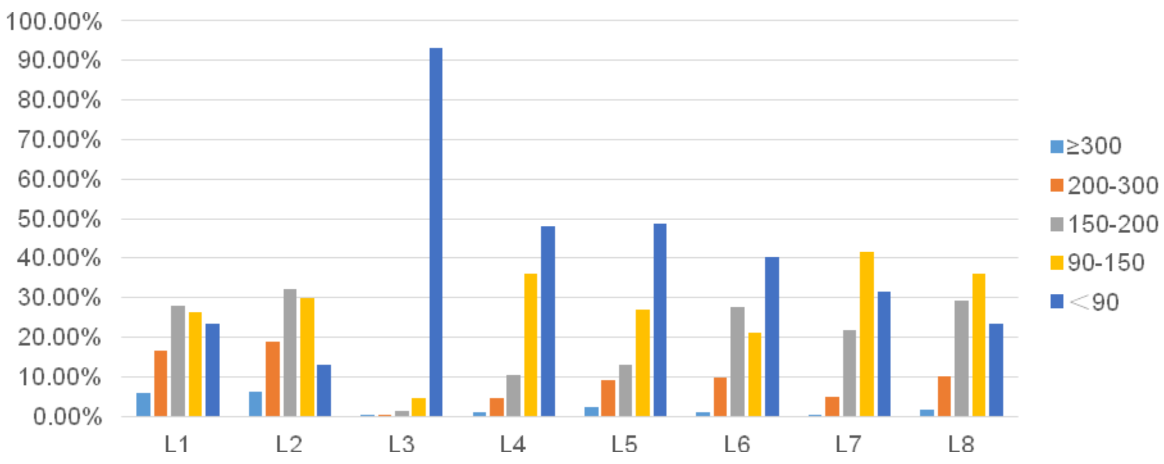

Figure 5 Distribution chart of length of ships in the eastern Bohai waters

Chapter 5: Planning of Ships’ Routeing System in the Eastern Bohai Waters

5.1 Existing Traffic Problems

Various traffic problems existing in the eastern Bohai waters. For example, there are many ports located in this area and they are in scattered distribution in the waters; many traffic flows cross and converge each other; a lot of oil platforms have caused frequent encounters between ships; and many small ships navigate in this area, which aggravates the complexity of the navigation environment. The main safety issues and deficiencies in the waters are as follows.

Firstly, complex navigation environment. There is a crossing situation between the extension line of ship’s routeing system in Caofeidian Waters and Caofeidian Port to Changshan Waters customary route, which influences the flow of ships using these two routes. In addition, there is a convergence situation between Huanghua Port, Binzhou Port to Laotieshan Waterway and Changshan Waterway, increasing the risk of collision or contact.

Secondly, frequent maritime traffic accidents. The customary route of ship’s routeing system from Laotieshan Waterway to Caofeidian waters is an area where maritime traffic accidents happened frequently. As mentioned in Section 3.3, statistics has shown that in the rectangular area from (38°10'00"N, 118°10'00"E) to (38°50'00"N, 120°10'00"E), there were 24 incidents from 2013 to 2017, 18 of which were collisions or contacts, accounting for 75% of the total accidents.

Thirdly, the crossing situation in the oilfield operating area. The traffic flow from Huanghua, Binzhou Port to Laotieshan Waterway and the traffic flow of Changshan Waterway cross each other in the vicinity of the 13-1 oilfield operation area in the Bohai Sea, increasing the risk of collision or contact. There are a large number of platforms in the north and northeast waters of Dongying Port which complicates the traffic flow there. Moreover, there is a ships' convergence area in the vicinity of Caofeidian 18-2 oilfield operation area, increasing the risk of collision or contact.

Fourthly, a lot of small ships. According to the actual traffic flow observation, 4 out of the 8 gate lines have the phenomenon that more than 40% of the total flow of each gate line are ships with less than 90 meters' ship length. The activities of small ships are relatively irregular, making the traffic flow more complicated.

5. 2 Necessity of the Ships' Routeing System

The traffic flow is dense and the navigation environment is complicated in the eastern Bohai waters, increasing the risk of marine traffic accidents. According to the actual traffic observation data, oil tankers and dangerous goods ships account for a certain proportion of navigable ships in the area. Once an accident occurs, it will cause great loss to all aspects concerned. In addition, the collision and contact accidents are the major types of traffic accidents in the eastern Bohai waters. Moreover, many platforms locate in this waters and are established in the vicinity of customary routes, which increases the risk of contact. Frequent traffic of small-scale vessels increases the complexity of traffic flow and the potential risk of marine traffic accidents. The details are as follows.

Firstly, high density of traffic flow. According to the statistics of AIS traffic flow observation data in the fourth quarter of 2018, daily vessel throughput is more than 40 in five of the eight gate lines (L1, L2, L4, L6, L7, L8). With the further development of the ports in the Bohai Sea, the number of vessels navigating in the waters will increase significantly.

Secondly, complicated traffic flow. Intersection situation between the traffic flow from Laotieshan Waterway to Tianjin Port and Caofeidian Port and the traffic flow from Changshan Waterway to Tianjin Port and Caofeidian Port is at the entrance of the ships' routeing system in the Caofeidian waters. The crossing situation between the traffic flow from Laotieshan Waterway to Huanghua Port and Binzhou Port and the traffic flow from Changshan Waterway to Huanghua Port and Binzhou Port is at the southern part of the ships' routeing system in the Caofeidian waters. Therefore, the overall traffic flow in the eastern Bohai waters is complex, and the potential risk of marine traffic accidents is high.

Thirdly, a large proportion of ship collision and contact accidents. According to the data from 2013 to 2017, there were 24 marine traffic accidents in the studied area, of which 18 were collision and contact accidents, which seriously affected the navigation safety in the eastern Bohai waters.

Fourthly, many platforms distributed in the waters. There are many platforms in the eastern Bohai waters, especially in the northern waters of Dongying Port. The vessels navigating through the platforms in the eastern Bohai waters have increased the risk of collision and contact.

Fifthly, quantities of small-scale vessels. Based on the statistical analysis of AIS real-state observation data in the eastern Bohai waters in the fourth quarter of 2018, the small-scale vessels traffic flow at gate lines L3, L4, L5 and L6 account for more than 40% of the total traffic flow at respective gate line. The activities of small ships are relatively irregular, making the traffic flow more complicated

Sixthly, a mass of oil tankers and dangerous goods vessels. Statistical analysis of AIS real-state observation data shows that dangerous goods vessels and oil tankers account for more than 10% of the total traffic flow in the gate lines L1, L2, L4 and L5. If collisions or other marine traffic accidents occur, great losses and hazards will be caused.

Therefore it is quite necessary to set up a reasonable ships' routeing system in the eastern Bohai waters.

5.3 Feasibility of the Ships' Routeing System

In order to ensure that ships using ships' routeing system can keep ships navigating in the corresponding traffic lanes, IMO specifically requires in the *General Provisions on Ships' Routeing* from *Ships' Routeing* (IMO, 2015) that "It should be possible for ships to fix their position anywhere within the limits and in the immediate approaches to a traffic separation scheme by one or more of the following means, both by day and night. (1) Visual bearings of readily identifiable objects, (2) Radar bearing and ranges of readily identifiable objects, (3) D/F bearings." There are many lights in the eastern waters of Bohai Sea, which are beneficial to the positioning of ships, and the advanced VTS system can provide good information services for ships in the region. Rapid and effective solutions can be provided in the event of water emergency. All these provide very favorable conditions for the planning and study of ships' routeing system in the eastern Bohai waters.

Moreover, the planning of ships' routeing system in the Bohai Sea can draw lessons from similar international waters. For example, like the Bohai Sea, the Baltic Sea is a relatively closed water area. It is also a waters with numerous ports, complex navigation environment and dense traffic flow. The planning and implementation of ships' routeing system in the Baltic Sea can provide a good reference for the planning of ships' routeing system in the Bohai Sea. Therefore, it can be concluded that the planning and implementation of ships' routeing system in the eastern Bohai waters is feasible.

5.4 Planning of Ships' Routeing System in the Eastern Bohai Waters

5.4.1 Purpose of the Planning

Based on the actual situation, the general purposes of this research is to study on the planning the ships' routeing system of the eastern Bohai waters from the following five aspects. Firstly, separate traffic flows in the opposite direction to reduce the occurrence of ship encounter situations. Secondly, reduce the risk of collision of ships sailing within traffic separation scheme. Thirdly, simplify the flow of traffic in the area where traffic flows converge. Fourthly, organize safe traffic flows in waters where coastal exploration or development activities are concentrated. Fifthly, organize traffic flows in or around areas that are dangerous or detrimental to all ships or to certain kinds of ships.

5.4.2 General Planning

In order to realize the purpose of the planning the ships' routeing system in eastern Bohai waters, setting traffic separation scheme and precautionary area are considered as the appropriate navigational measures to solve the traffic problems in this area. Six factors should be considered for the planning.

5.4.2.1 Planning Area

The planning area should locate on the main routes. In order to regulate the navigation of ships, the main routes in the eastern Bohai waters should be chosen on the routes between the main passage in and out of the Bohai Sea and the important ports in the Bohai Sea, where the volume of traffic is extremely big. In addition, the planning area should locate in accident-prone areas. The purpose of ships' routeing system is to standardize ship navigation and reduce accidents. Therefore, navigation system should generally be set in areas where traffic accidents occur frequently. At last, consider the development trend of coastal ports. In addition to Dalian Port, Yingkou Port, Qinhuangdao Port, Tianjin Port and Yantai Port, Bohai Sea also has Tangshan Port, Huanghua Port, Jinzhou Port and Panjin Port, which have formulated long-term development plans and developed rapidly in recent years. The selection of the location of ships' routeing system in the eastern Bohai Waters should consider not only the current situation of each port, but also the requirements of its future development.

According to the purpose of establishing ships' routeing systems, the summary of areas with traffic flow convergence, dense traffic volume and areas with obstacles is as follows.

Firstly, the intersection situation between the traffic flow from Laotieshan Waterway to Tianjin Port and Caofeidian Port and the traffic flow from Changshan Waterway to Tianjin Port and Caofeidian Port is at the entrance of the ships' routeing system in the Caofeidian waters. Secondly, the traffic flow from Huanghua, Binzhou Port to Laotieshan Waterway and the traffic flow of Changshan Waterway cross each other in the vicinity of the 13-1 oilfield operation area in the Bohai Sea. Thirdly, the customary routes from Changshan Waterway to Tianjin and Caofeidian Port are in the vicinity of the central Bohai sea 25-1 oilfield operation area. Fourthly, the traffic flow from Tianjin, Caofeidian, Huanghua, Binzhou Port to Laotieshan Waterway and Changshan Waterway converge in the vicinity of the 18-2 oilfield operation area near Caofeidian Waterway.

The planning and implementation of ships' routeing system in the above-mentioned waters can effectively improve the navigation environment of vessels in the eastern

Bohai waters, help to reduce marine traffic accidents and ensure the maritime traffic safety in the waters.

5.4.2.2 Types of Routeing

Considering the current traffic environment in the eastern Bohai waters, combined with the ships’ routeing systems recommended by IMO *General Provisions on Ships' Routeing* and the ship routeing system already used in similar waters, it is advisable to adopt the routeing system consisting of traffic separation schemes and precautionary areas in the eastern Bohai waters. Separation zones will be used to separate the traffic flow from opposite directions. Precautionary areas will be established at routes convergence and intersection points.

5.4.2.3 Traffic Lane Width

The width of traffic lanes should meet the corresponding requirements of IMO, i.e. traffic density, the full use of the area and available sea areas should be taken into account. The minimum widths of traffic lanes and of traffic separation zones should be related to the accuracy of the available position fixing methods, accepting the appropriate performance standards for shipborne equipment as set out in IMO resolutions and recommendations. In addition, considering the traffic density, traffic volume, positioning accuracy and geographical conditions, 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. Therefore in open coastal waters, if conditions permit, the width of traffic lanes for vessels under 100,000 tons should be no less than 0.4 n mile, and that for vessels above 100,000 tons should be no less than 0.5 n mile.

Moreover, according to the Japan Ministry of Land, Infrastructure, Transport and Tourism (Fan, 2013), if the navigation lane is long, then the recommended width is 2.0L for frequent encounters and 1.5L for non-frequent encounters. If the navigation lane is not long, then the recommended width is 1.5L for frequent encounters and 1.0L for non-frequent encounters.

5.4.2.4 Traffic Lane Length

Many factors should be considered in the selection of traffic lane length. In order to enhance the safety of navigation, the design of traffic lane length should not be too short to ensure the continuity of navigation, thus reducing the risk of collision caused by frequent changing of routes. Of course, the long continuous length of traffic lanes limits the application of resources. Therefore, under the condition that the safety of ship navigation can be guaranteed the design of the length of the traffic lanes should limit the legitimate rights and interests and customs of ships in the area as little as possible. Considering the above factors, the length of traffic lanes in the eastern Bohai waters should be maintained at 1-2 n mile.

5.4.2.5 Traffic Separation Method

Since the eastern waters of the Bohai Sea are open waters and there are enough available waters, separation zones are preferred to separate the opposite traffic flow and adjacent traffic lanes. It is easy to locate landmarks in the eastern waters of the Bohai Sea. Therefore, it is recommended to use a separation zone with a width of 0.1-0.2 n mile to segment the opposite traffic flow.

5.4.2.6 Establishment of Precautionary Area

The purpose of the precautionary areas is to remind ships sailing in this area to be cautious. Therefore, the area is usually set in the convergence or intersection area of the routes, or at the end of any route. In the eastern waters of the Bohai Sea, there are four convergence and intersection areas or terminal points of navigation routes. Therefore, four precautionary area should be set up.

5.4.3 Specific Scheme of the Ships' Routeing System

Combined with the above information, it is decided that eight traffic separation schemes (using separate zones to separate opposite traffic flows) and four precautionary areas will be planned in the eastern waters of Bohai Bay. The specific scheme is as follows.

(1) The traffic separation scheme of Laotieshan Waterway to Tianjin Port and Caofeidian Port (TTS-1)

From the point (38°46′.330N，119°03′.200E) on and a 2.0 nm line segment in the direction of 096.5° as the central axis, a 0.52-0.62 nm wide separation zone is established. On both sides of the separation zone, a 1.3 nm wide * 2.0 nm long traffic lane is established respectively.

(2) The traffic separation scheme of Changshan Waterway to Tianjin Port and Caofeidian Port N-1 (TTS-2)

From the point (38°43′.300N，119°01′.950E) on and a 2.0 nm line segment in the direction of 120° as the central axis, a 1.0 nm wide separation zone is established. On both sides of the separation zone, a 1.0 nm wide * 2.0 nm long traffic lane is established respectively. The waters between the traffic lanes on the north side of TSS-2 and the traffic lanes on the south side of TSS-1 shall be separated by a quadrangular separation zone.

(3) The traffic separation scheme of Caofeidian 18-2 Oilfield Operation Area (TTS-3)

From the point (38°39′.653N，118°51′.447E) on and a 2.0 nm line segment in the direction of 090° as the central axis, a 0.5 nm wide separation zone is established. On the north side of the separation zone, a 1.0-1.5 nm wide * 2.0 nm long traffic lane is established. On the south side of the separation zone, a 1.5-1.0 nm wide * 2.0 nm long traffic lane is established.

(4) The traffic separation scheme of Center Bohai Sea 13-1 Oilfield Operation Area (TTS-4)

From the point (38°30′.248N，119°03′.900E) on and a 2.0 nm line segment in the direction of 090° as the central axis, a 0.5 nm wide separation zone is established. On the north side of the separation zone, a 0.5 nm wide * 2.0 nm long traffic lane is established. On the south side of the separation zone, a 1.0 nm wide * 2.0 nm long traffic lane is established.

(5) The traffic separation scheme of Changshan Waterway to Tianjin Port and Caofeidian Port N-2 (TTS-5)

From the point (38°28′.430N，119°32′.117E) on and a 2.0 nm line segment in the direction of 120° as the central axis, a 1.0 nm wide separation zone is established. On both sides of the separation zone, a 1.0 nm wide * 2.0 nm long traffic lane is established respectively.

(6) The traffic separation scheme of Changshan Waterway to Tianjin Port S-2 (TTS-2)

From the point (38°28′.403N，119°32′.117E) on and a 2.0 nm line segment in the direction of 120° as the central axis, a 0.5 nm wide separation zone is established. On both sides of the separation zone, a 1.0 nm wide * 2.0 nm long traffic lane is established respectively. The waters between the traffic lane on the north side of TSS-6 and the traffic lane on the south side of TSS-5 shall be separated by a quadrangular separation zone.

(7) The traffic separation scheme of Changshan Waterway to Tianjin Port and Huanghua Port S-1 (TTS-7)

From the point (38°37′.251N，119°00′.293E) on and a 1.93 nm line segment in the direction of 115.8° as the central axis, a 0.5 nm wide separation zone is established. On both sides of the separation zone, a 1.0 nm wide * 1.93 nm long traffic lane is established respectively.

(8) The traffic separation scheme of Laotieshan Waterway to Huanghua Port (TTS-8)

From the point (38°39′.635N，119°00′.991E) on and a 1.732 nm line segment in the direction of 090° as the central axis, a 0.5 nm wide separation zone is established. On both sides of the separation zone, a 1.0 nm wide * 1.732 nm long traffic lane is established respectively. The waters between the traffic lane on the north side of TSS-8 and the traffic lane on the south side of TSS-2 shall be separated by a quadrangular separation zone. The waters between the traffic lane on the south side of TSS-8 and the traffic lane on the north side of TSS-7 shall be separated by a triangular separation zone.

(9) Precautionary area 1

A circular precautionary area is established in the left waters of TSS-1 and TSS-2.

(10) Precautionary area 2

A polygonal precautionary area is established in the waters formed by connecting the north and south extreme points of TSS-3 with the south extreme point of TSS-7 and the north extreme point of TSS-8.

(11) Precautionary area 3

A circular precautionary area is established in the right waters of TSS-2 and TSS-8.

(12) Precautionary area 4

A circular precautionary area is established in the left waters of TSS-3.

The Specific scheme of ships' routeing system in the eastern waters of Bohai Bay is shown in Figure 6.

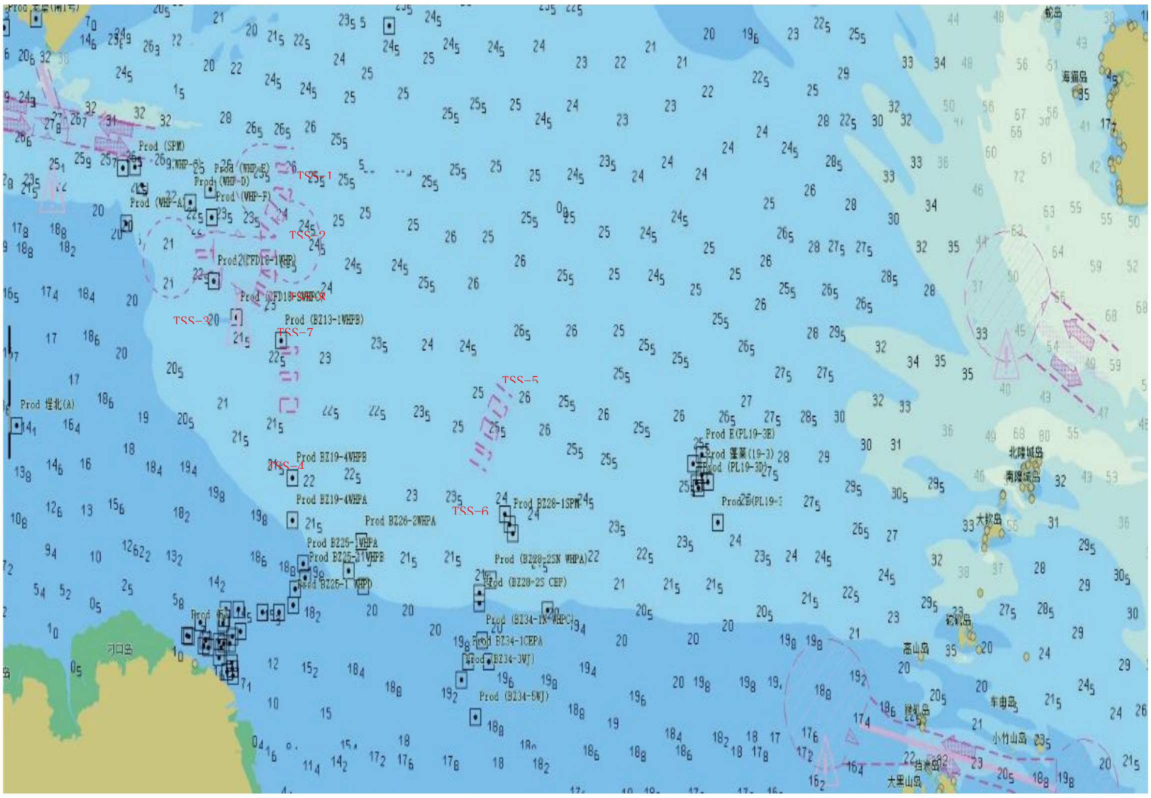

Figure 6 Diagram of the ships' routeing system in the eastern Bohai waters

5.4.4 The Problems Solve by the Ships' Routeing System

The inter-relation of the ships' routeing system is shown in Figure 7.

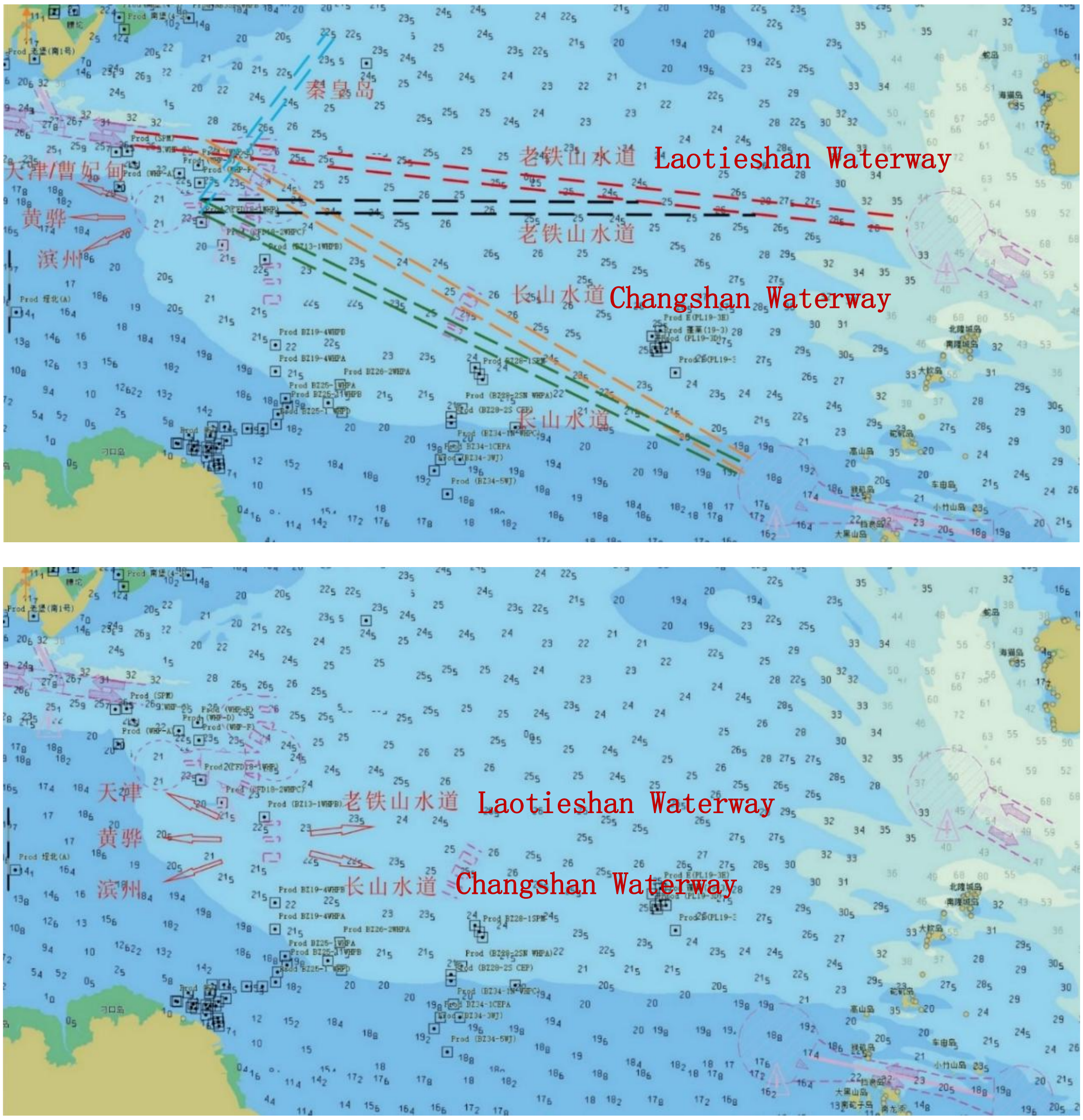

Figure 7 Inter-relation of the ships' routeing system in the eastern Bohai waters

The Ships' Routeing System in the Eastern Bohai mainly solves the following traffic problems.

(1) Intersection situation between the traffic flow from Laotieshan Waterway to Tianjin Port and Caofeidian Port and the traffic flow from Changshan Waterway to Tianjin Port and Caofeidian Port;

(2) Intersection situation between the traffic flow from Laotieshan Waterway to

Huanghua Port and Binzhou Port and the traffic flow from Changshan Waterway to Huanghua Port and Binzhou Port;

(3) Intersection situation between the traffic flow from Laotieshan Waterway to Tianjin Port and Caofeidian Port and the traffic flow from Laotieshan Waterway to Huanghua Port and Binzhou Port;

(4) Ship convergence situation of the traffic flow near oilfield operation platforms entering into Huanghhua Port and Binzhou Port and departing from Huanghhua Port and Binzhou Port;

(5) Heading-on situation of the traffic flow from Laotieshan Waterway to Tianjin Port and Caofeidian Port in the southern waters of Caofeidian Port;

(6) Heading-on situation of the traffic flow from Changshan Waterway to Tianjin Port and Caofeidian Port in the southern waters of Caofeidian Port;

(7) Heading-on situation of the traffic flow near oilfield operation platform entering into Huanghhua Port and Binzhou Port and departing from Huanghhua Port and Binzhou Port;

(8) Heading-on situation of the traffic flow entering into Huanghhua Port and Binzhou Port and departing from Huanghhua Port and Binzhou Port in the northeast waters of Dongying Port;

(9) Heading-on situation of the traffic flow near Changshan Waterway from Changshan Waterway to Tianjin Port and Caofeidian Port;

(10) Heading-on situation of the traffic flow near Changshan Waterway from Changshan Waterway to Huanghua Port and Binzhou Port;

(11) Heading-on situation of the traffic flow from Changshan Waterway to Huanghua Port and Binzhou Port in the northeast waters of Dongying Port;

(12) Heading-on situation of the traffic flow from Laotieshan Waterway to Huanghua Port and Binzhou Port.

Chapter 6: Conclusion

Aiming at the phenomena of dense traffic flow and complex traffic environment in the eastern Bohai waters, this thesis analyses the traffic problems existing in the area, studies on the and plans the planning of the ships' routeing system in the eastern Bohai Waters, so as to solve the problems of intersection, convergence and encounter situations in the waters through the panning and improve the safety of navigation in the waters.

Based on the international conventions and relevant domestic laws and regulations, drawing on the successful experience and mature practices of ships' routeing system, this thesis makes use of AIS to observe the real-state status of traffic, and makes a systematic understanding of the natural environment, navigation environment and traffic accidents statistics of the eastern Bohai waters by collecting and analyzing three traffic flow characteristics, including traffic volume, ship type, ship length provided by AIS data in the fourth quarter of 2018(October, November and December). The traffic conditions in the Bohai Sea and its eastern waters and the existing traffic separation schemes in adjacent waters conform to the principles and requirements of the IMO *General Provisions on Ships' Routeing*, and basically coincide with the existing traffic flow situation in the waters. It is recommended that eight traffic separation schemes (using separate zones to separate opposite traffic flows) and four precautionary areas will be planned in the eastern waters of Bohai Bay. The planning and implementation of the ships' routeing system in the eastern Bohai Waters will play an important role in reducing ship collision accidents, ensuring the safety of ship navigation and protecting the marine environment.

It should be pointed out that the planning scale of the ships' routeing system designed in this thesis is smaller than that of ships' routeing system in similar waters. This is mainly due to the existence of a large number of platforms in the eastern waters of the Bohai Bay. Theoretically, the scale should be bigger, but the conditions and resource distribution in different waters are different. According to the design principle of IMO ships' routeing system, the planning of ships' routeing system should avoid restricting the legitimate rights and interests on the premise of ensuring the safety of navigation in the region. Since there are a large number of fishing vessels and oil platforms in the eastern Bohai Waters, if the scale of ships' routeing system is too large, it will affect the comprehensive utilization of water resources. Therefore the planning scale of the ships' routeing system designed in this thesis is smaller than that of ships' routeing system in similar waters.

References

Bai, X., Zhou, W., & Xiao, Y. (2016). The Optimization and Evaluation of Ships' Routeing System in Yangtze Estuary. *Shipping Management, 38*(09), 1-3, 8.

Fan, Z. (2013). *Research on the Optimized Method of Ship Routeing Schemes*. Doctoral Dissertation. Dalian: Dalian Maritime University.

Feng, Z. (2015). *Research on the Post-evaluations of the Ship Routeing Schemes of Pearl River Estuary Waters*. Master Dissertation. Dalian: Dalian Maritime University.

Hu, Z. *Evaluation of Large Ships' Routeing System in the Eastern Waters of Chengshanjiao*. Master Dissertation. Dalian: Dalian Maritime University.

International Maritime Organization (IMO). (1972). *Convention on International Regulations for Preventing Collisions at Sea (COLREG).* London: International Maritime Organization.

International Maritime Organization (IMO). (1982). *United Nations Convention on the Law of the Sea (UNCLOS).* London: International Maritime Organization.

International Maritime Organization (IMO). (2014). *International Convention for the Safety of Life at Sea (SOLAS)*. London: International Maritime Organization.

International Maritime Organization (IMO). (2015). *Ships' Routeing*. London: International Maritime Organization.

Jensen, C. (2014). *Spatial and Temporal Variability in Shipping Traffic around San Francisco Bay*. Master Dissertation. San Francisco: San Francisco State University.

Jensen, T., Hansen, M., Lehn-Schiøler, T., Melchild, K., Rasmussen, F., & Ennemark, F. (2013). Free Flow – Efficiency of a One-way Traffic Lane between two

Pylons. *Journal of Navigation*, *66*(6), 941-951.

Kim, C., Jeong, J., & Lee, H. (2011) A Study on the Effect of Designated Domestic Traffic Separation Scheme(TSS). *Journal of the Korean Society of Marine Environment & Safety, 17*(1), 61-68.

Li, S., Zhou, J., Xu, T, & Bao, X. (2013). Optimal Design of Precautionary Area Routeing Based on Navigational Traffic Conflict Technique. *Navigation of China*, *36*(01), 95-100.

Liu, J., Zheng, G., & Ding, T. (2013). The Discussion on the Navigation Safety in the Ningbo-Zhoushan Roueting Waters. *China Water Transportation*, *13*(10), 11-12.

Liu, Y., Xiao, Y., & Guan, K. (2013). Study on the Design of Ships' Routeing System Based on AIS Marine Traffic Survey. *Journal of Nantong Vocational & Technical Shipping College*, *12*(04), 37-41.

Mou, J., Tak, C., & Ligteringen, H. (2010). Study on Collision Avoidance in Busy Waterways by Using AIS Data. *Ocean Engineering*, *37*(5/6), 483-490.

Olindersson, F., Janson, C., & Dahlmann, J. (2015). Maritime Traffic Situations in Bornholmsgat. *Transnav the International Journal on Marine Navigation & Safety of Sea Transportation, 9*(1), 115-120.

Pietrzykowski Z, & Magaj, J. (2017). Ship Domain as a Safety Criterion in a Precautionary Area of Traffic Separation Scheme. *Transnav International Journal on Marine Navigation & Safety of Sea Transportation*, *11*(1), 93-98.

Sunaryo, S., Arif Priadi, A., Tjahjono, T. (2015). Implementation of Traffic Separation Scheme for Preventing Accidents on the Sunda Strait. *International Journal of Technology*, *6*(6), 990.

Szlapczynski, R. (2003). Evolutionary Ship Track Planning within Traffic Separation Schemes – Evaluation of Individuals. *Transnav International Journal on Marine Navigation & Safety of Sea Transportation*, *7*(2), 301-308.

Zhang, W., Li, G., & Yin, J. (2016). The Optimization of the Ships' Routeing System in the Caofeidian Waters. *Ship & Ocean Engineering*, *45*(03), 173-176.

Zhao, C., Xie, H., & Xiao, Z. (2013). Research on Ships' Routeing System in Bohai Waters. *World Shipping*, *36*(01), 15-20.

Zhuo, Y., & Tao, J. (2015). The Analysis and Evaluation of Ships' Routeing System in the Qiongzhou Channel. *Navigation of China*, *38*(01):80-84.