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Application of Formal Safety Assessment (FSA) on navigation safety evaluation of the Liaoning waters

Chao Ding

WORLD MARITIME UNIVERSITY

Dalian, China

APPLICATION OF FORMAL SAFETY ASSESSMENT (FSA) ON NAVIGATION SAFETY EVALUATION OF THE LIAONING WATERS

By

DING CHAO

The People's Republic of China

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2014

DECLARATION

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

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

(Signature): Ding Chao

(Date): July 9, 2014

Supervised by:

Fan Zhongzhou

Professor

Dalian Maritime University

Assessor:

Co-assessor:

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ABSTRACT

Title of Research Paper: **Application of Formal Safety Assessment (FSA) on Navigation Safety Evaluation of the Liaoning Waters**

Degree: **Msc**

Dalian port, Yingkou port and Huludao port in Liaoning are all located in the Bohai economic circle, to transport bulk coal, ore and crude oil and run the container and other bulk cargo. They are part of the planning and construction of China important port of coal transportation system, ore and crude oil transportation system, and play an important role in Chinese economic development. The number of ship is increasing rapidly, especially the proportion of large tonnage ships in the waters of the sea. Due to the influence of hydraulic construction in the current construction ships and fishing, traffic accidents frequently occur in recent years, resulting in economic losses and casualties.

This paper, using the method of fuzzy comprehensive evaluation, considers Dalian, Yingkou and Huludao as the evaluation object, makes a comprehensive assessment of navigation safety condition of Liaoning waters. The evaluation indices and their weights were determined through the analysis of expert investigation and AHP method and two level evaluation of water safety condition by using mathematical model of fuzzy comprehensive evaluation, so that the assessments are closer to the actual results. The conclusion of this research could not only provide certain reference of implementation of management and services for waterway safety departments but also provides the reference for this kind of research.

Keywords: FSA, navigation safety, Liaoning waters, fuzzy evaluation

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
FSA	Formal Safety Assessment
IMO	International Maritime Organization
ISM	International Safety Management
MMEM	Man, machine, environment and management
PSC	Port State Control
VTS	Vessel Traffic Service

Chapter 1 Introduction

1.1 Research Background

Ships are the most important means of transportation today, which can carry a huge amount of international freight. It is the link of national economic exchange, main carrier of economic exchanges and economic globalization. Ship transportation safety and environmental protection has always been the focus of attention. Ports are the main nodes in maritime transportation, and the flow of goods between countries in the world mainly relies on shipping; port safety has a remarkable role for trade protection (Ma, 2002). The increasing of ship traffic volume (namely traffic density), the expanding of shipping tonnage and increasing types of goods especially dangerous chemical goods make the navigation environment in port waters more complex and dangerous. In recent years, a series of terrible accidents such as collisions, stranding, grounding, etc. happened in port waters, which has posed great damage and destruction to personal safety, property safety and marine environmental safety. Therefore, we must make a scientific, accurate and comprehensive assessment of navigation safety in the complex condition of traffic environment, to explore the countermeasures and methods for improving the shipping traffic safety (John, 2001).

As a part of the maritime transportation system, environment of port navigable waters became more complex. Thus, we must carry on a corresponding safety research. By exploring the risk of system, we can evaluate the damage caused by these risks and the value of risks we can accept, so as to find a way to decrease the risk degree of the system (Handley, 2004). In order to make a qualitative and quantitative description of the risk of system, people have developed a lot of safety assessment methods, including grey theory, neural networks etc. These methods play a very effective role, but they are not universal. In port navigation safety, there has been no safety assessment tool of either scientific or applicable (Akgiin & Koqkar, 2004). Especially in recent years, these problems have caused a lot of ship safety accidents. According to statistics, the ship safety accidents have caused more than tens of billions of dollars of losses. These problems require us to adopt a scientific decision support tool for port traffic safety evaluation, to avoid missing potential accidents.

Formal Safety Assessment (FSA) is a standardized, structured, systematic analysis method. This method has standard steps, so we could comprehensively evaluate all aspects related to safety of the ship. It provides the safety level of ship operation, guarantees the safety of life and property at sea, and protects the marine environment form being destroyed (CCS, 1999). In this paper, navigation safety assessment applied a FSA method, combining the specific conditions of waters and every step of the FSA method, to find the best solution of shipping traffic safety.

1.2 Research Purpose and Significance

Dalian port, Yingkou port and Huludao port in Liaoning area are the commercial ports first developed from fishing ports. Since the reform of port system, these ports have been rapidly developed, and the navigation environment and infrastructure of Liaoning port areas have also changed obviously. The navigation environment in port waters has become more complex. The ship traffic density is increasing, and the development trend of ship maximization is significant. The increasing of construction projects and more dangerous cargo shipping and other cargo growth factors make the management of ship navigation order more difficult (Zhao, 2009). Therefore, the research to the management of environment and navigation order in Liaoning waters is conducive to the healthy development of port.

Maritime traffic safety is a systematic project, involving the transport system of water and other social factors. The basic elements of maritime traffic safety system consist of human, ship and environment. They are interdependent, mutually influenced and restricted by each other. In maritime traffic safety system, there is a very important subsystem -- the navigation environment subsystem, which is composed of natural environment and traffic environment. In the navigation environment system, safety and sustainable development is directly related to the regional shipping safety and sustainable development. As the authority of traffic safety at sea area of Liaoning, Liaoning MSA undertakes the important responsibility under the jurisdiction of Liaoning shipping safety management (Geng, 2011). Safety-safety management is one of the most important links to ensure the safety of personnel, ports, ships and facilities, and it is the main part of the maritime traffic safety system. This thesis systematically analyzes the present condition of navigation environment of Liaoning area, in a comprehensive understanding of the maritime traffic safety situation in the area, and makes a comprehensive and objective risk assessment on the navigation environmental risk sources, to find out the potential safety risks. Based on the above, this thesis puts forward safety management measures to eliminate potential safety problems and thus reduce the navigation environment risk.

Chapter 2 Literature Review

2.1 Safety Evaluation

2.1.1 Safety System Engineering

Safety system engineering is divided into general system safety engineering and narrow system safety engineering. Narrow system safety engineering uses the concept and method of system theory, and combines with the engineering safety management. It is the application of system engineering in the field of safety, and is a branch of system engineering (Vikas & Shyam, 2005). General system safety engineering applies principles and methods of system engineering, through the relevant event control system, to reduce the possibility of accidents, so that the accident rate is reduced to the minimum, to ensure the protection of personal and property safety and marine environment (Themes, 2001).

The basic procedure of safety system engineering method mainly includes six parts (Zhao, 2010); and the relationship is shown in Figure 2.1:

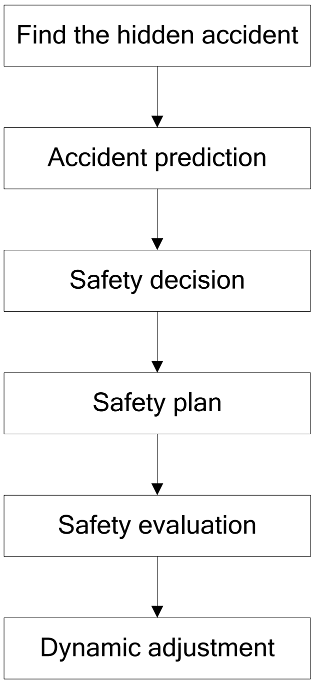

Figure 2-1 Safety engineering evaluation flow diagram
Source: Zhao Xuejun, (2010). Application of FSA in port traffic safety evaluation

These 6 parts are as follows:

a. To find the potential danger of accident in system;

b. Predict events of injury or loss caused by accident and human error;

c. Design and select safety measures and schemes to control the accident for safety decision-making;

d. Implementation of safety countermeasures;

e. To evaluate the system and safety measures;

f. To make dynamic and timely adjustment and improvement, in order to achieve the best effect of safety system.

The advantage of safety system engineering is to make a comprehensive analysis of the safety of the system. Through analysis, all weak links of the entire system and those that may produce accident can be found to predict the consequences of the accident. It is also helpful to find out the way to avoid accident, and reduce the rate of accidents (Jin, 2000). The use of the method of system safety engineering costs less in terms of safety investment and gets the maximum effect. It requires standards and data process in the evaluation and it is also helpful to data collection and various safety standards setting (Datubo, 1994). Besides, using the method of system engineering and safety systems can also promote the level of business and management ability of related staff.

2.1.2 Principle of Safety Evaluation

Safety assessment is to evaluate the system risk and identify risk degree. Assessment method could be qualitative or quantitative analysis. Through the analysis, weak links in the system can be found out, and the danger link and be determine (Barrass, 1981). Safety assessment is part of the safety system engineering. The conclusion through evaluation can determine the risk in advance, to reduce risk and the loss of the accident (Stephen, 1998). Although qualitative analysis can only roughly identify the dangerous source, it is very necessary. If you want to more accurately define the size and severity of the consequences of the accident probability, quantitative identification would be better. With the help of some mathematical methods, qualitative identification can be transformed into quantitative identification, so as to improve the accuracy of qualitative identification (Chen, 2012). Repeated proofreading risk quantitative results and the critical limits can determine the degree of risk. Safety evaluation content and the safety assessment process (Dong, 2010) are shown respectively in Figure 2-2 and Figure 2-3.

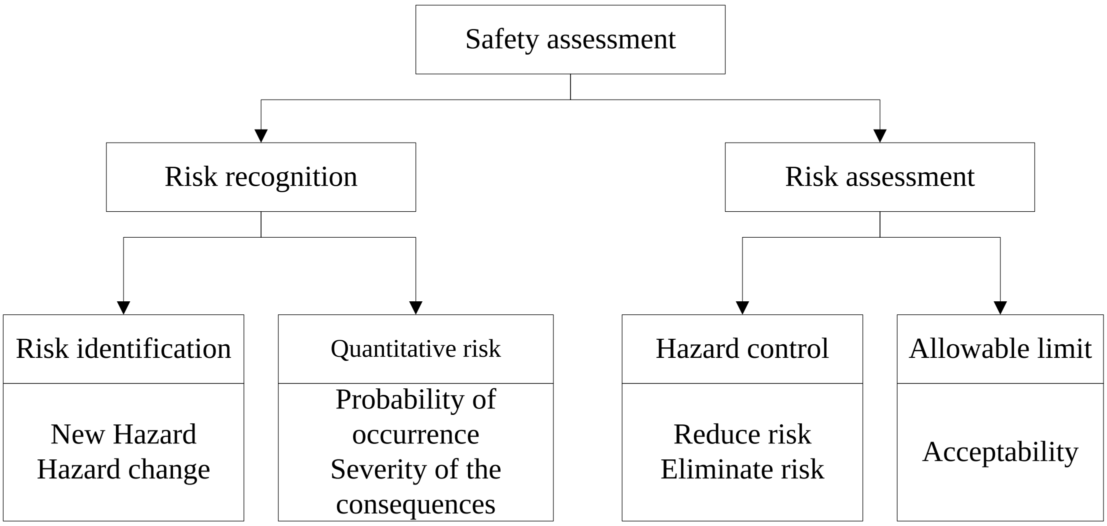

Figure 2-2 Safety evaluation content
Source: Dong Haihui, (2010). Study on the safety assessment method of port berth reconstruction engineering navigable waters

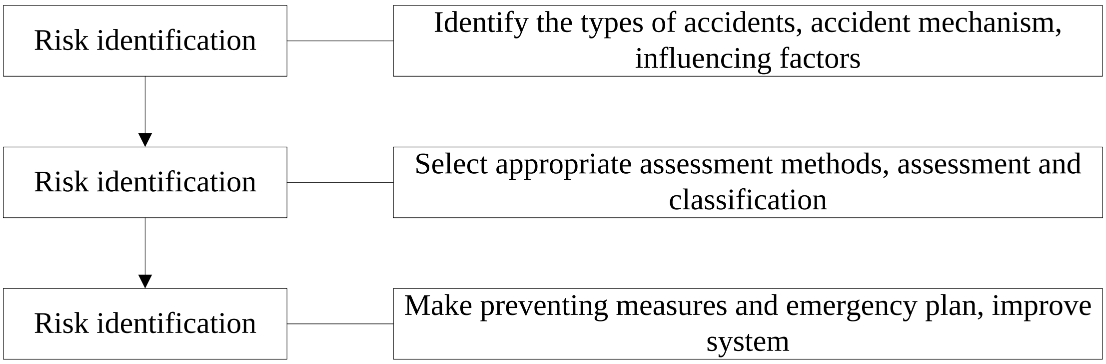

Figure 2-3 Safety assessment grogram flow
Source: Compiled by the author after reading profiles

It can be seen from the content and process of the safety assessment, the structure of safety system engineering is composed of basic elements of man, machine, environment and management (MMEM system), which are in accordance with mariner, ship, navigation environment, shipping company, administration (Goodwin, 1977 & Wang, 2012), such as is shown in Figure 2-4.

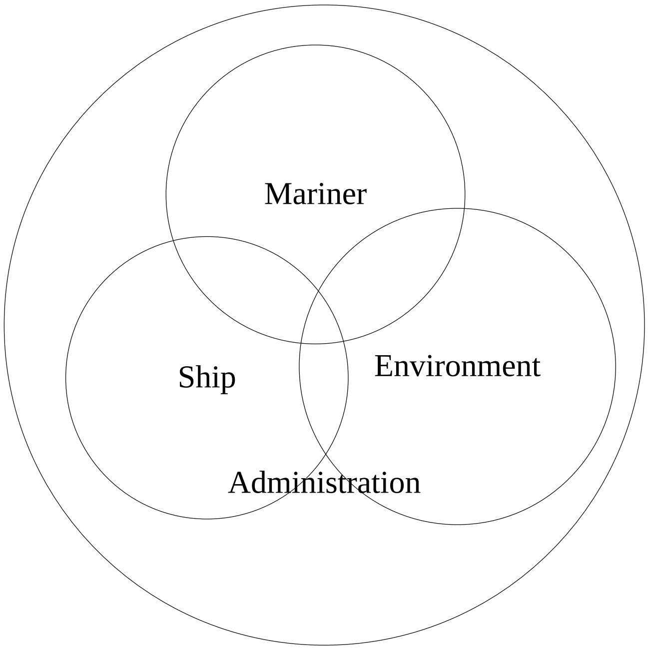

Figure 2-4 The safe navigation systems engineering basic elements of relationship
Source: Goodwin, 1977. Determination of Ship Domain Size, Proceedings of International Conference on Mathematical Aspects of Marine Traffic

The ship navigation safety accidents are devastating events caused by unexpected and disharmonious relationship between mariner, ship, environment and administration. In order to avoid or to reduce accidents, people have to control these four elements, thereby predicting, assessing and limiting accidents.

2.2 Formal Safety Assessment (FSA)

2.2.1 Origin of FSA

FSA is a structured and systematic analysis method. The purpose of FSA considered various factors of effecting safety. Evaluation of the risk exists in the system, and some possible costs and benefits by using this method can effectively and comprehensively control the risk and reduce the loss (Fang, 2004).

Ship is currently the most important cargo carrier in world trade process, undertaking huge international freight. Ship navigation safety directly affects the international trade system, and is related to people's life and property safety, social progress, economic development, the protection of the marine environment and the earth environment. So, in a long time, people have attached great importance to navigation safety of ship (Zhao, 2010). In recent years, the international trade has made great strides in development, and the international freight volume is increasing significantly. Ships have become much bigger and specialized, causing more navigation accidents, each of which in turn causes bigger losses and destruction to the marine environment (Wu, 1993). Therefore, it makes people pay more attention to the safety of the ship and the pollution of the marine environment. Every maritime accident arouses people's concern, and also prompts IMO to take corresponding measures, promulgate regulations and rules, new convention, to make up for the previous problems. It has urged people to think that we should gradually change this practice, and should consider risk management, and make safety evaluation before the accident occurs, and control these risks so as to reduce the occurrence of accidents. In this regard, some industries like nuclear, chemical and offshore oil development have ready-made experience for reference (Ridolfi, 1995).

In 1993, the British MSA first submitted proposal of FSA method to improve maritime safety and protect the marine environment at IMO MSC62. They recommended FSA as a strategic idea and use FSA in the development of maritime safety and marine environmental protection conventions and rules. FSA's application was expected to be expanded to ship design, construction and operation and management of all shipping companies (Themes, 2001).

2.2.2 Process of FSA

FSA is a comprehensive, systematic and standardized evaluation method. There are five standard steps, including hazard identification, risk assessment, risk control, cost benefit assessment and decision (Zhao, 2010). The five steps of FSA are shown in Figure 2-5. Using this comprehensive safety assessment, we can improve the standards and regulations on the basis of comprehensive review and analysis of current safety management standards and regulations, and combine with the actual work to ensure the navigation safety (Anand, 2003).

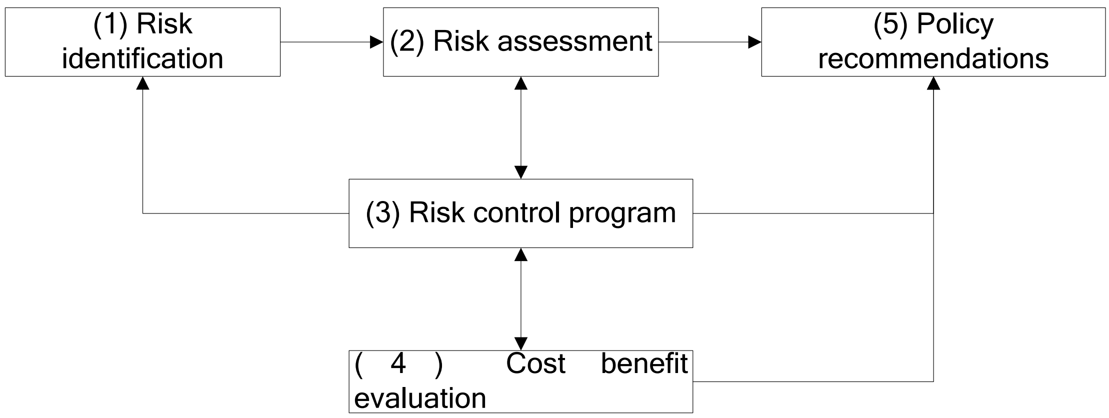

Figure 2-5 FSA Comprehensive safety assessment methods flowchart
Source: Anand Pilly, Jin Wang. (2003). Technology and safety of marine Systems

2.3 Previous Studies on Navigation Safety Evaluation

2.3.1 Maritime Safety Management

Due to the development of shipping industry, people have recognized the danger of this industry. How to guarantee the safety is one of the most difficult problems that need to be solved in the industry (Wu, 1993). For a long time, the main work of coastal countries and the IMO is aiming to create a safety maritime environment (Vikas & Shyam, 2005). So, the international communities, including the industry organization, insurance industry and relevant international organizations, have paid a lot of attention to it and found various means and measures to avoid accidents to ensure navigation safety.

In November, 1993, ISM rule was adopted at the eighteenth session of IMO, and it needs to be enforced. IMO used principle of ISO9000 and formulated ISM maritime safety rules combined with the actual situation of marine safety. It includes modern management science and safety science achievements, such as system theory, control theory, closed management, PDCA cycle principle etc. (Britkov & Sergeev, 1998). At present, the general pattern of the International Maritime Safety Management is: IMO controlled domestic shipping companies and authorized inspection of the classification society by convention and rules of the flag state, to achieve the purpose of management of ships and sailors (Wang & Kieran, 2000); indirectly supervised the flag state, the society and the shipping company comply with the requirements of port country to directly supervise the ship's condition and operation (Cao, 2003). In short, the rules of ISM and PSC examination is the main mode of IMO control of maritime safety.

2.3.2 Application of FSA on Navigation Safety Evaluation

The application of FSA in field of marine safety has lasted for more than ten years. UK has made pioneer study and obtained some achievements (Hoyle, 1990). Scholars and experts have made deep researches on the application of FSA in offshore drilling platform, fishing boat, container ships, tankers, maritime accidents, and some other offshore engineering operation control. In view of the above research project, they presented the decision-making suggestion, and proved that the method, to a certain extent, could decrease and avoid risk and improve the safety level of action (Shapiro, 1985). Japan and USA have developed research rapidly on FSA shipping application. In order to develop the application of FSA research, IACA has also set up a special FSA working group, specially to follow IMO's work, and actively expand the application of FSA unified or consideration of IACS and guide the classification society rules enacted by various research works (Stevens, 2004). The FSA working group collected basic terms based on the research of IMO members of the FSA compilation, and gave them definitions, explanations and examples to help researchers to understand and master the FSA method.

One of the executive directors of IMO is from China, but the research progress in the application of FSA is relatively slow. The main research work is carried out by a few researchers in maritime colleges, the maritime safety administration and relevant research units without support and competent of authority (Wu, 1993). In recent years, Chinese shipping scholars paid more and more attention to FSA. The article "The carriage of noxious liquid substances and comprehensive safety evaluation" applies FSA to noxious liquid substance transport, and it evaluates the ship leakage, puts forward the corresponding countermeasures and measures for accident prevention to deal with possible leakage diffusion and fire, and presents decision-making suggestions on developing contingency plans for emergencies and major accidents (Wang, 2009).

Chapter 3 Construction of Navigation Safety Evaluation Index System of the Liaoning Waters

3.1 Influencing Factors of Navigation Safety in Liaoning Waters

There are many factors that affect the safety of navigation waters, such as the natural environment, traffic environment, traffic conditions, traffic safety management etc. The content of this paper is to analyze safety evaluation of navigation on the waters of Dalian, Yingkou and Huludao in Liaoning, considering the relatively independent and interrelated evaluation objects. Traffic accidents, traffic condition factors and the navigation conditions are selected in the research.

3.1.1 Analysis of Traffic Accident in Liaoning waters

The traditional method of maritime traffic safety evaluation is tracking traffic accident rate and accident probability (such as collision accidents, the collision probability, grounding probability, accident rate etc) as the evaluation index. In maritime traffic conditions, traffic safety situation is also used in traffic accident scale (the number of accidents, indicators such as number of sunken ships, amount of loss, the number of casualties and so on) for description. In this chapter, the relevant statistical data of Liaoning waters in the area from 2009 to 2013 will be used as the case of water traffic accident. The water accident data collected in this paper include stranding, collision, allusion and so on. But the fire accident, disastrous accident and lost anchor accident are not included in the statistical scope.

(1) Traffic Accidents in Dalian Waters

Traffic accidents in Dalian waters refers to the maritime traffic accident occurred in Dalian waters and investigated by Dalian MSA and Liaoning MSA, not including water traffic accidents occurred in these waters but investigated by other MSA. Port area water refers to the water near the berth, fairway and anchorage; outside the harbor waters refers to the area out of the port waters.

Dalian is located in the south of Liaodong Peninsula, with a land area of 12,573.85 square kilometers. Dalian has vast sea area, long coastline, numerous islands and harbors. The sea area amounts to more than 30 thousand square kilometers, the total length of the coastline of 1906 km, and the total length of the coastline accounts for 73% of that in Liaoning province. From 2009 to 2013, there were 79 water traffic accidents in Dalian area, causing 25 deaths and missing, 5 sunken ships, with the direct economic loss being 126,000,000 Yuan. In all the 79 water traffic accidents, there are 55 minor incidents, 5 general accidents, 9 major accidents and 10 significant accidents. Minor accidents account for 69.6% of the total number of accidents; the general accidents account for 6.3%; major accidents account for 11.4%, and significant accidents account for 12.7%, as is shown in Figure 3-1 and Figure 3-2.

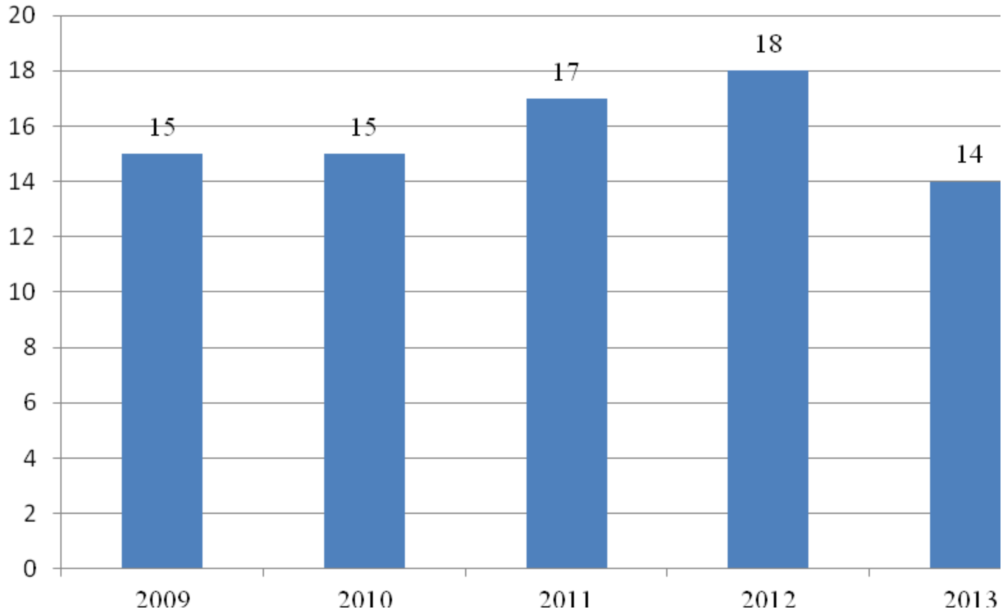

Figure 3-1 The Number of Accidents in Dalian Jurisdiction Waters during 2009-2013
Source: Compiled by the author using Statistics of Dalian MSA.

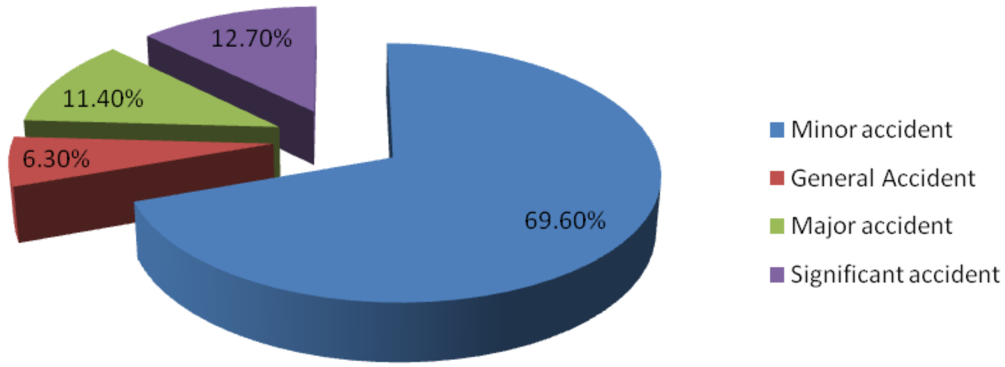

Figure 3-2 The Accident Probability in Dalian Jurisdiction Waters during 2009-2013
Source: Compiled by the author using Statistics of Dalian MSA.

As is shown in Figure 3-1, the accident probability of minor accidents is the largest, i.e. 69.6%, while major accidents and significant accidents are relatively flat. The general accidents are relatively less frequent but cannot be ignored, the probability of which is 6.3%. Therefore, the minor accidents are worthy to be noted; major accidents should be strictly controlled and significant accidents had better be avoided.

(2) Traffic Accident in Yingkou Jurisdiction Waters

Yingkou is located in the south of Liaoning Province, the left bank of Liaohe River Estuary, and the east of Bohai Bay. Yingkou is one of the most important transportation hubs in Northeast China. Yingkou port has a natural channel, with a total length of 21 miles. According to the channel depth and navigational aids, it can be divided into the levees along the waterway, inner waterway, west waterway and Liaohe waterway. The major ports in Yingkou area include Yingkou port and old Yingkou port. Statistics of traffic accidents in Yingkou jurisdiction waters during 2009-2013 are shown in Figure 3-3:

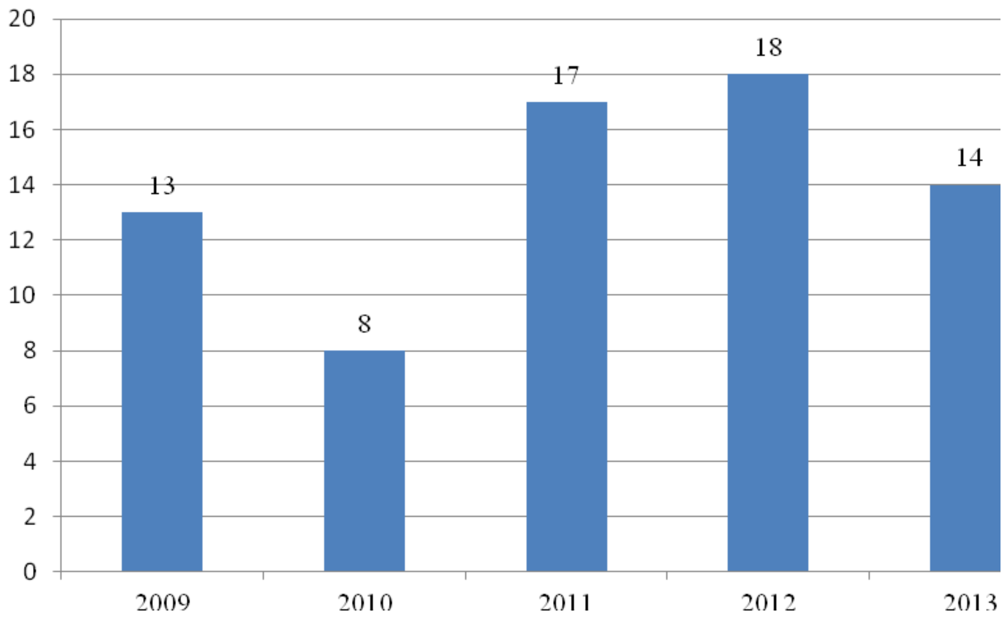

Figure 3-3 The Number of Accidents in Yingkou Jurisdiction Waters during 2009-2013
Source: Compiled by the author using Statistics of Yingkou MSA.

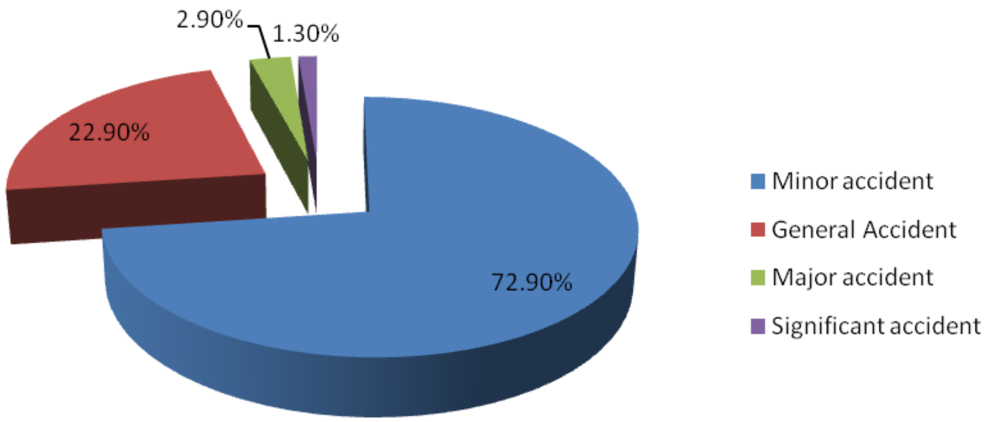

Figure 3-4 The Accident Probability in Yingkou Jurisdiction Waters during 2009-2013
Source: Compiled by the author using statistics of Yingkou MSA.

According to the statistics, minor incidents are the most, with a total of 51, accounting for 72.9% of the total number of accidents. General accidents rank No. 2(16) and account for 22.9%. There are only 2 major accidents, accounting for 2.9%, while significant accident happens only once, as is shown in Figure 3.4. So, it is quite necessary to be fully aware of the danger of minor accidents.

(3) Traffic Accidents in Huludao Jurisdiction Waters

Huludao port is located in the northwest coast of Liaodong Bay, and it is an important geographical location. The vast economic hinterland is rich in resources, and the adequate supply, road, rail traffic developed, and the transportation condition is good. It has always been the regional entrepot, and is a modern port with a comprehensive multi-function. The natural coastline is about 3 km. Statistics of traffic accidents in Huludao jurisdiction waters during 2009-2013 are shown in Figure 3-5:

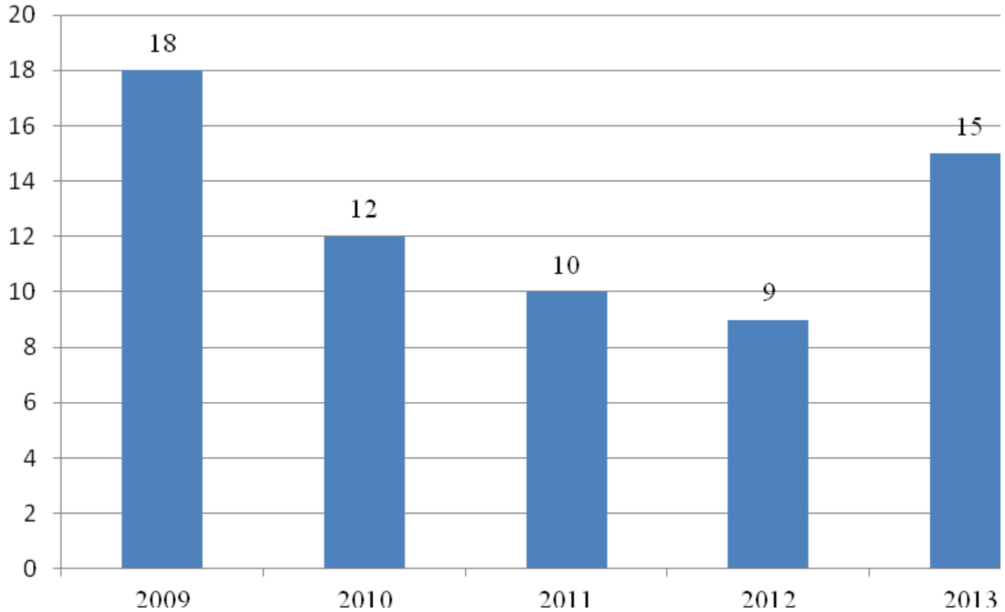

Figure 3-5 The Number of Accidents in Huludao Jurisdiction Waters during 2009-2013
Source: Compiled by the author using Statistics of Huludao MSA.

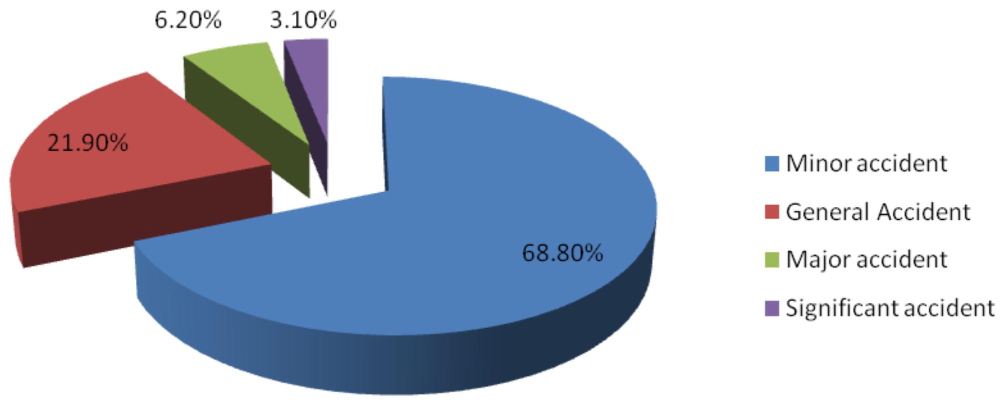

Figure 3-6 The Accident Probability in Huludao Jurisdiction Waters during 2009-2013
Source: Compiled by the author using Statistics of Huludao MSA.

The number of traffic accidents in Huludao waters was 64 from 2009 to 2013. Seen from Figure 3-5, under the jurisdiction of Huludao waters, the number of accidents shows a shape of upward parabola. The number of accidents has increased in 2013, compared with that in 2012. From 2009 to 2013, the level of traffic accident ratio in Huludao waters is shown in Figure 3-6.

3.1.2 Analysis of Traffic Condition in Liaoning waters

Traffic conditions mainly include the density distribution of the ship, ship track distribution, traffic volume, traffic complex condition and port throughput. Introduction and analysis on the traffic condition in Liaoning area is the main content of safety assessment of navigation waters. The total entering and leaving ships in Liaoning waters and ships tonnage increase year by year. The average annual growth of port throughput is more than 10%, and the main cargos of this area include coal, petroleum, natural gas, metal ore etc. The author makes a brief introduction and analysis of traffic conditions in Dalian, Yingkou and Huludao waters according to the relevant statistics.

(1) Traffic Condition in Dalian Area

Dalian waters has a coastline of more than 1592 km, with sea area of 34,000 square kilometers, more than 30 harbors, and a total of more than 320 modernizations berths, 106 dock berths, and 170 berths which can accommodate ships over DW 10,000 ton. In 2012, the port cargo throughput was more than 3,000 million tons. From 2009 to 2013, the traffic volume in Dalian waters was 285,429 ships, including domestic shipping, international shipping, import port ships, inland ships, vessels of foreign nationality and other types, as is shown in Figure 3-7.

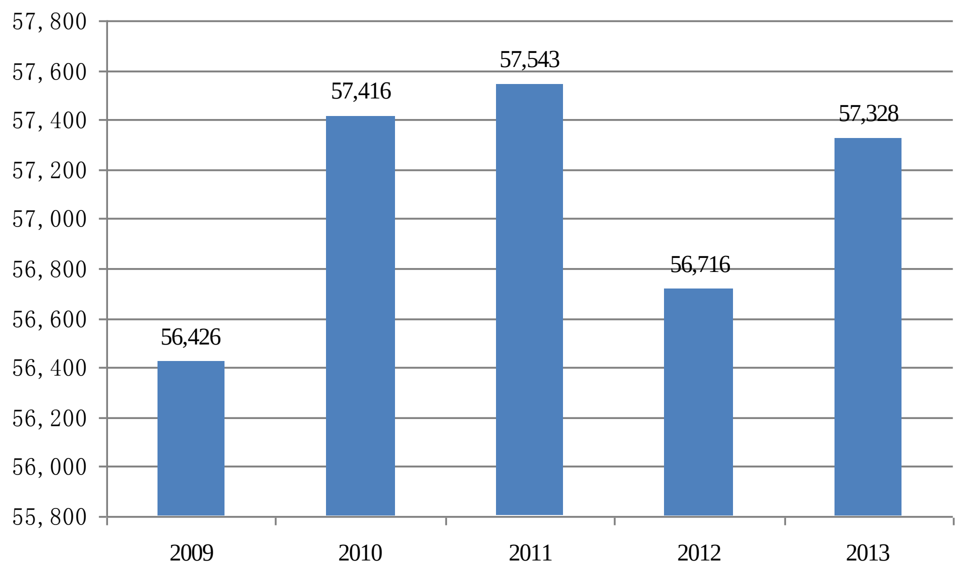

Figure 3-7 The statistics of the traffic volume in Dalian area
Source: Compiled by the author using Statistics of Dalian MSA.

In 2009, it is the stage of recovery after the financial crisis. After 2009, there is an increasing trend for the traffic volume in Dalian waters. Dalian port throughput of 2009 to 2013 is shown in Figure 3-8.

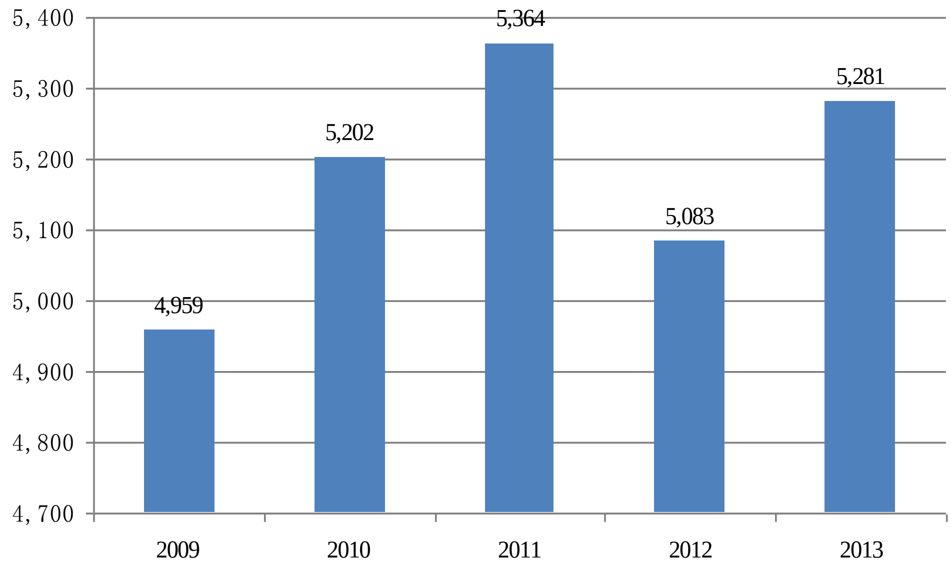

Figure 3-8 The statistics of the harbor throughput in Dalian area (Million ton)
Source: Compiled by the author using Statistics of Dalian MSA.

There are many productive berths, fairway and anchorage, famous tourism scenic area, and lots of ships in Dalian area. In the Gulf of Bohai, there are numerous traffic channels. Main routes include Laotieshan channel, port channel, Ganjingzi channel, Heshangdao channel, big mountain waterway, Dami Bay and so on, and the main channel runs across North South Sea area traffic flow. Navigation in these waters is complex.

(2) Traffic Condition in Yingkou Area

Situated in the central part of Liaodong Peninsula, facing Bohai, Yingkou port is one of the major coastal ports of China and the second largest port in Northeast China. Yingkou port is composed of Yingkou old port area, Bayuquan port and the Xianrendao port. The old port area is located in the Liaohe River delta, which has developed for many years. Bayuquan port is the main sub-port of Yingkou port. Xianrendao port is located about 14 km south of Bayuquan. It has large deep-water berths.

By the end of 2013, there were 61 different kinds of berths in Yingkou port, of which more than 42 are deep-water berths. Cargo capacity is 106,800,000 tons, and the container throughput capacity is 4,815,000 TEU. Yingkou waters traffic volume from 2009 to 2013 was a total of 73,401 port calls, as is shown in Figure 3-9:

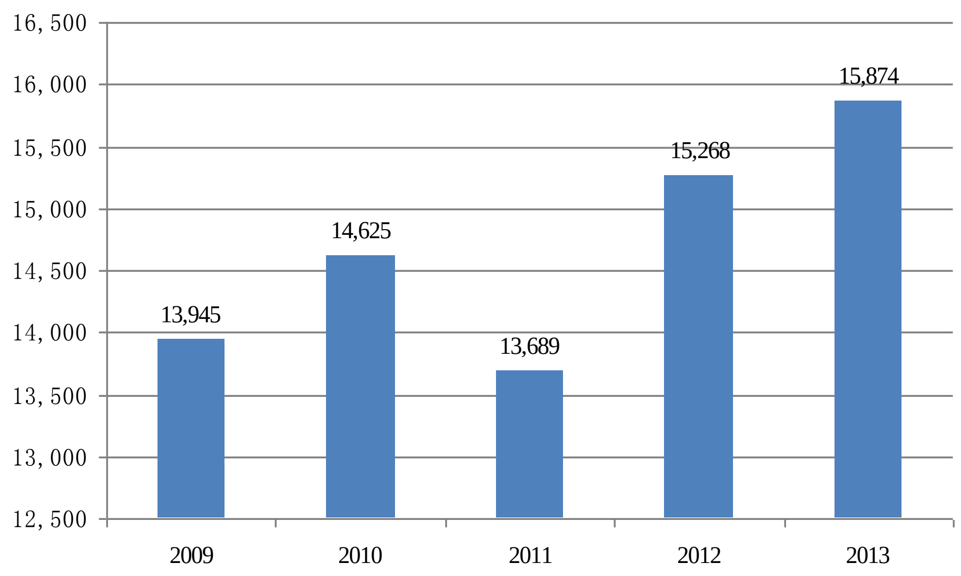

Figure 3-9 The statistics of the traffic volume in Yingkou area
Source: Compiled by the author using Statistics of Yingkou MSA.

In recent years, with the implementation of the development of national economy and revitalization of old industrial base, port throughput has rapidly grown. In

2009-2013, the throughput of Yingkou port is shown in Figure 3-10:

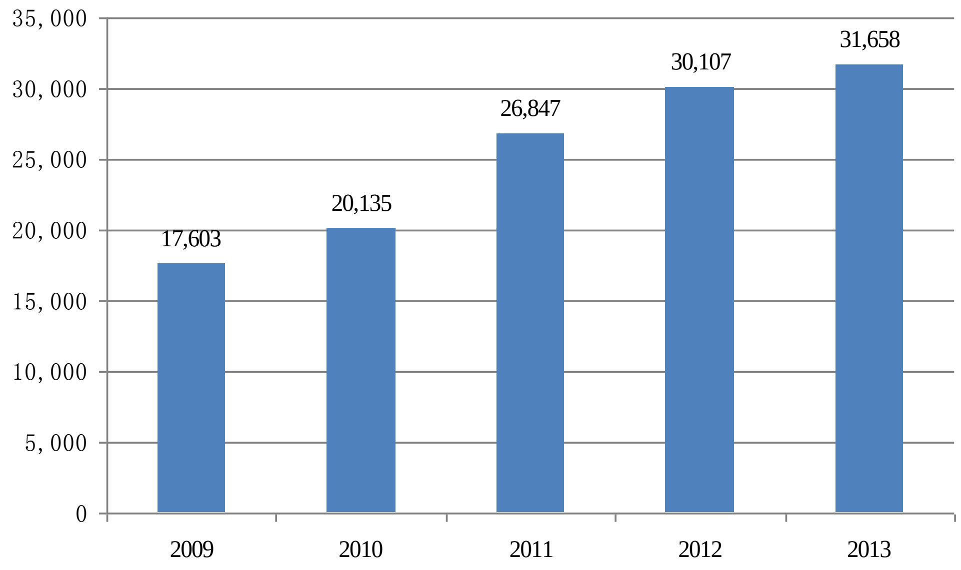

Figure 3-10 The statistics of the harbor throughput in Yingkou area (Million ton)
Source: Compiled by the author using Statistics of Yingkou MSA.

(3) Traffic Condition in Huludao Area

Huludao port is located in the southwest of Liaodong Bay of Bohai Bay, richly endowed by nature and has geographical advantage of the land, with long coastline of 204.6 km, island coastline of 31.9 kilometers. Huludao port lies in a good geographical location, with excellent coastline conditions and developed traffic network and deep depth of water. Huludao harbor is deep and wide, and now is used for the purpose of army and commercial business. Traffic volume of Huludao waters in 2009-2013 was a total of 111,933, as is shown in Figure 3-11:

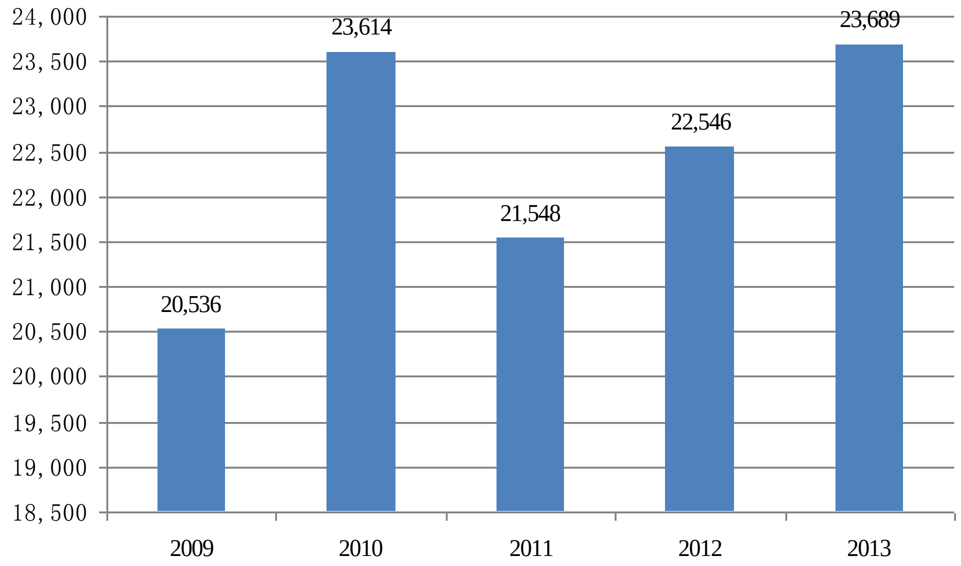

Figure 3-11 The statistics of the traffic volume in Huludao area
Source: Compiled by the author using Statistics of Huludao MSA.

With the rapid development of economy, port throughput is rising. Port throughput of Huludao port in recent years is shown in Figure 3.12. It can be seen from the statistics, in 2009-2013 years, the throughput of Huludao port has an average annual increase of 8.30%. According to the forecast, the throughput of Huludao port will reach 14,030,000 tons in 2020.

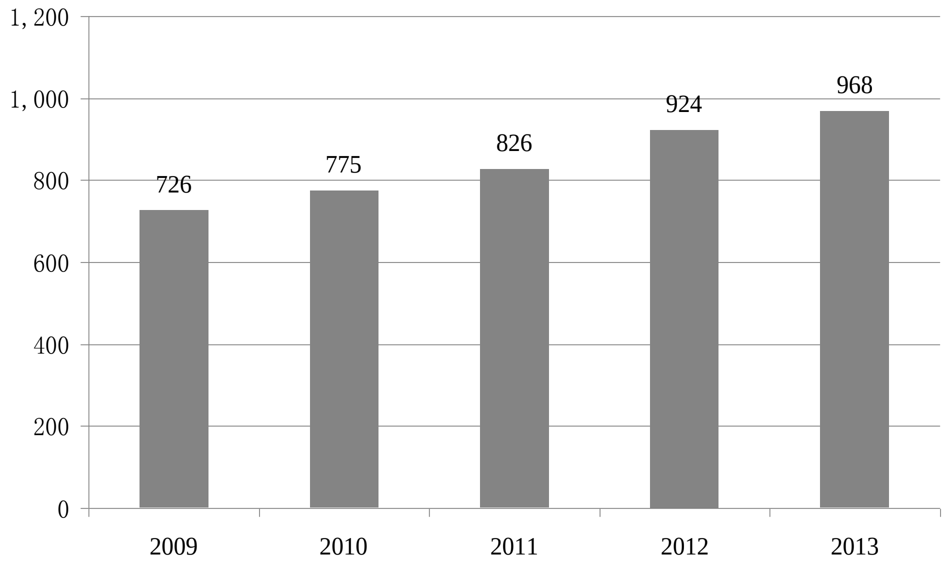

Figure 3-12 The statistics of the harbor throughput in Huludaou area
Source: Compiled by the author using Statistics of Huludao MSA.

3.1.3 Analysis of Navigation Condition in Liaoning waters

The so-called navigation condition refers to water conditions, berths arranged, turning waters, tracing, vessel traffic service and water obstacle navigation related conditions affecting air discharge etc. In order to analyze the navigation condition in Liaoning waters, this thesis divides traffic conditions of Dalian, Yingkou and Huludao area into three aspects. They are fairway condition, obstruction areas and traffic management.

(1) Navigation Condition in Dalian Area

a. Fairway condition

- Laotieshan channel: located in the northern Bohai Strait, it is the most dangerous and urgent channel in China and the main channel from the

Yellow Sea water into the Bohai. The channel is about 45 km in length, 83 meters in depth. Due to military restricted navigation zone, the navigable width is only 5.5 nautical miles and water depth is 50-60 meters.

- Dagang channel: in the East of Dagang District, with a depth of water about 10 meters.
- Ganjingzi channel: located in the North of Dagang Channel, the channel is 90 degrees (270 degrees), with a depth of water of 9 meters.
- Heshangdao channel: from the second ship quarantine anchorage 11 floating lights to 15 floating lights, 9.1 meters in water depth, channel length of 13,500 meters.
- Dasanshan channel: between Sanshandao and Huangbaizui, in the mouth of the south shore, direction 90°, width of about 5 nautical miles, water depth of 20 meters, mostly mud bottom, the channel is the main channel by which ships navigate in and out of Dalian Port. Ships from Dalian Bay must go through this channel.
- Damiwan waterway: The north part of the channel has design depth of 15 meters, width of 285 meters. The south part has depth of 13.5 meters, width of 210 meters.

b. Obstruction areas

In Dalian waters, there are Lvshun fishing port, longwangtang fishing port, bailanzi fishing port, Dongtuozi fishing port and so on. The number of fishing ships is up to 1000 during flood season.

c. Traffic organization and management

Dalian MSA VTS is mainly responsible for maintaining the safety of order and safety of navigation of ships in the harbor area waters. The VTS center provides service to large vessels entering and leaving port ten thousand times every year, and provides important information for more than 1,000 annually. They play a more and more important role in avoiding the emergency. The VTS service is now in a good condition.

(2) Navigation Condition in Yingkou Area

a. Fairway condition

Yingkou port is a natural channel, with a total length of 39,300 meters (21 miles). The harbor entrance channel can be divided into the levees along waterway, Internal waterway, West waterway and Liaohe waterway. Effects of Liaohe River navigable depth and winter ice are more serious. From December to the next March is the embargo period.

Old port channel is of length of 39 km, constant of internal and external waterway. The outer channel has a mouth bar, which is more than 3,000 meters long, and the shallow end is of the depth of -1.7 meters. The 3,000 ton ship can take the tide departure. Internal waterway is depth of -4 meters.

Bayuquan port channel is 8.5 km long, single channel, and the design of the bottom width is about 110 meters.

b. Obstruction areas

In recent years, Yingkou harbor has seen constant emergence of new shipyards, expansion of the scale of shipbuilding, including ship dimensions and tonnage. However, on the navigation capacity of Liaohe, it is always a limit. According to article 9 in the "Regulations of Yingkou harbor water VTS rules", the ship with length of 130 meters and above shall not go in and out of Yingkou harbor waters. In addition, some areas belong to the jurisdiction of military.

c. Traffic organization and management

Yingkou MSA has been performing in the prevention of pollution from ships in the full responsibility. Now it has established the work mechanism for the purpose of accident prevention and emergency response. Until now, oil spill accidents in moderate scale and above have never occurred in Yingkou waters (moderate scale: oil spill up to 10-50 tons). In order to control the pollution accident, they are tracking and monitoring on navigation safeguard, patrolling VTS regional waters and giving navigation order, offering the safety information to help traffic, navigation and berthing, reminding ship to take navigation safety measures, promptly correcting the violations, monitoring vessel traffic emergencies at sea, thereby minimizing the accidents.

(3) Navigation Condition in Huludao Area

a. Fairway condition

The entrance channel of Huludao port is about 8 kilometers long, and it is a one-way channel; the channel width is 148m; the channel depth is 12.82m and the channel bottom elevation is -10.9m.

b. Obstruction areas

CNOOC Suizhong 36-1 oilfield is located in the Huludao Suizhong area; JZ20-2 condensate gas field is located in the north of Bohai, 50 kilometers northwest from Huludao port; SZ36-1 oilfield is located in the Liaodong Bay. Petroleum exploration and production operations are frequent.

Juhua Island in Huludao area is a big tourist resort, situated at the sea 9 km from the beach. There are rare bodhi trees and octagonal wells on the island. People fishing on the island have lived for generations.

c. Traffic organization and management

Huludao port marine VTS is mainly responsible for the maintenance of navigation order and safety of ship in area waters. Huludao port VTS system consists of Huludao radar station and VTS center, applying the VTS9760 system. This system is more advanced, and has high resolution detection and accurate positioning capacity, so it can provide clear and accurate monitoring image; the realization of network is very high, which provides convenient information data for transferring and exchanging; integration of function module is high, implementing the integration of multiple sub function module. Therefore, the system has strong information processing ability, and can handle information of 500 ships at the same time. In addition, this set of equipment is also equipped with the environmental monitoring system, which is able to monitor radar equipment and the surrounding environment in remote, to realize the unattended radar station.

3.2 Principles of Index System Construction

Traffic safety evaluation for the whole Liaoning area is a comprehensive and complex job, influenced by many factors. Furthermore, these factors may have mutual influence and interaction, and final evaluation conclusion hinges on the selection of evaluation index. Therefore, it is essential that we screen from all the factors in the safety navigation to find the most accurate index which is easy to analyze.

3.3 Construction of Navigation Safety Evaluation Index System

Referring to the related research in the field of navigation safety evaluation, the author constructs the index system of the navigation waters safety evaluation in Liaoning area, which is shown in Figure 3-13.

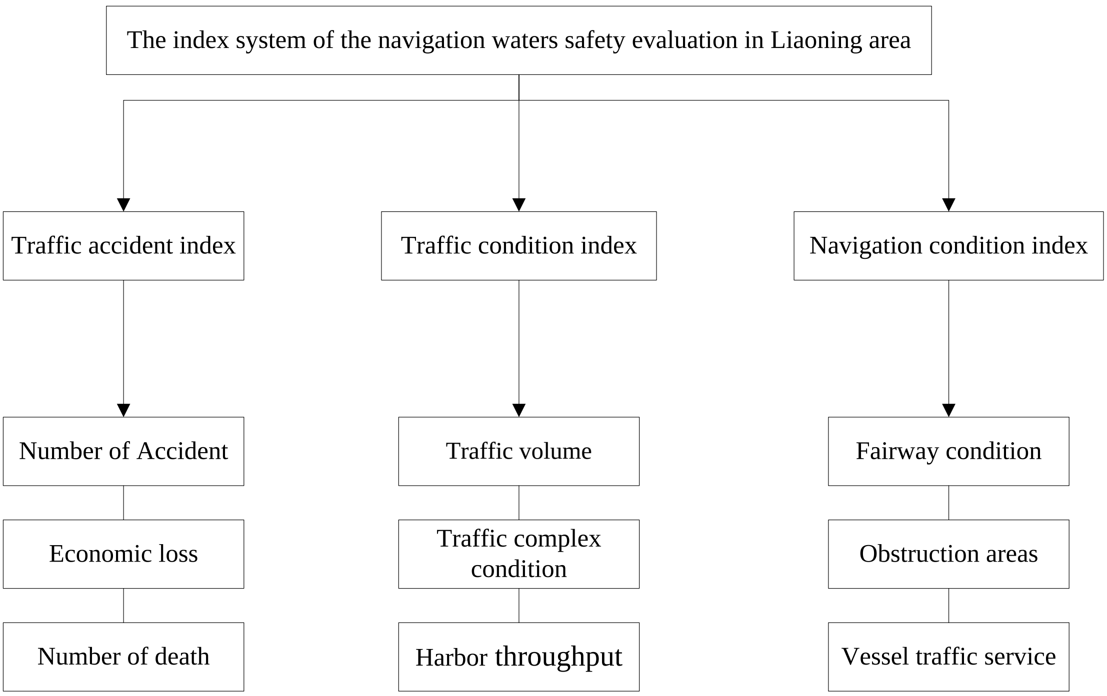

Figure 3-13 The index system of the navigation waters safety evaluation in Liaoning area
Source: Compiled by the author.

3.3.1 Traffic Accident Subsystem

(1) Number of Accidents

During 2009-2013, there are 194 water accidents in Liaoning area, and 138 of them were related to navigation accidents. Accidents in Dalian and Yingkou occur more frequently, accounting for 43.6% and 34.2% respectively.

The number of traffic accidents in each area during 2009 - 2013 as is shown below:

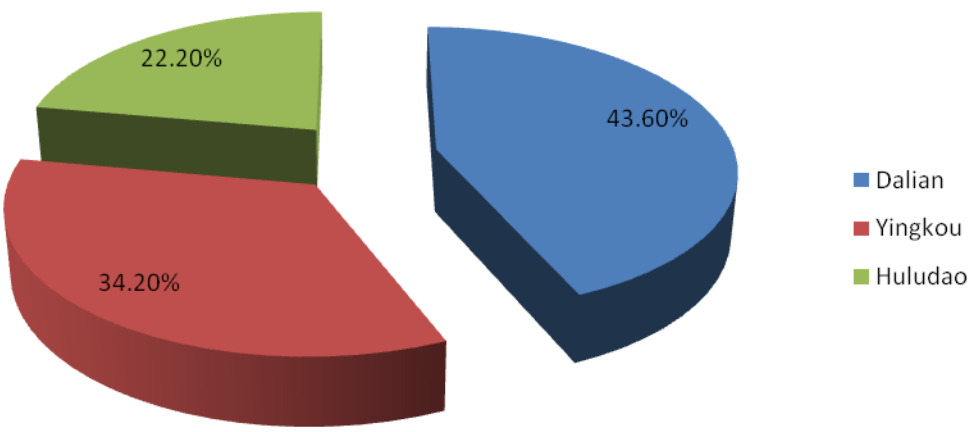

Figure 3-14 The statistics of the marine traffic accidents in Liaoning area
Source: Compiled by the author.

The number of various levels of accidents in Dalian, Yingkou and Huludao during 2009 - 2013 is shown in Table 3-1:

Table 3-1 The number of various levels of accidents in Liaoning waters

Level / Area	Significant accident	Major accident	General Accident	Minor accident	Total
Dalian	10	9	5	55	79
Yingkou	1	2	16	51	70

Huludao	2	4	14	44	64

Source: Liaoning MSA.

Based on the data above, we can obtain the percentage of accidents as described in the following table:

Table 3-2 The percentage of traffic accidents between 2009 and 2013

Level / Area	Significant accident	Major accident	General Accident	Minor accident
Dalian	12.7%	11.4%	6.3%	69.6%
Yingkou	1.3%	2.9%	22.9%	72.9%
Huludao	3.1%	6.2%	21.9%	68.8%

Source: Compiled by the author.

From the data we can see that the water traffic accidents are mainly small accidents. The major accidents in Dalian are significantly more frequent than those in other regions due to more vessel traffic volume and larger capacity of vessel. In addition, the number of general accidents in Yingkou is big, which probably is stem from ship sank, according to the relevant statistical data.

(2) Economic loss

The economic loss in each area during 2009 - 2013 is shown below:

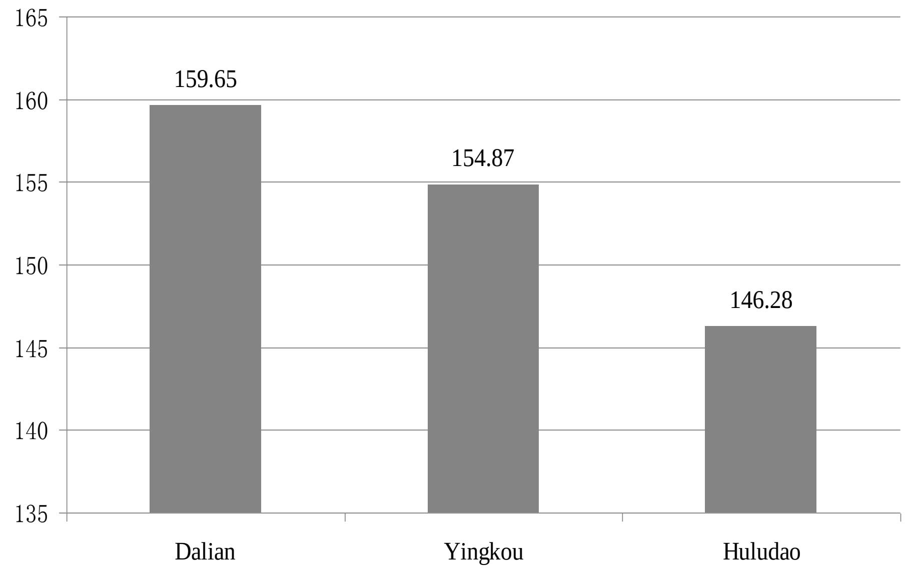

Figure 3-15 The traffic accidents cost in Liaoning area between 2009 and 2013 (Million Yuan)
Source: Compiled by the author.

Considering the different number and grade of accidents in each area, this paper calculates the weighted number of accidents firstly, and then the average losses caused by the accident can be obtained. The weight of accident is shown in the following table.

Table 3-3 The conversed weight of the marine traffic accidents

Level	Significant accident	Major accident	General Accident	Minor accident
Weight	1.3	1.1	0.9	0.7

Source: Compiled by the author.

Through the weighted calculation, traffic accidents in Dalian area are 46, Yingkou 40, and Huludao 16. The average loss of accident is shown in Table 3.4. As can be seen, the loss in Huludao is the largest, which is more than other two areas. This is associated with more shipwreck in accidents of Huludao.

Table 3-4 The average loss amount of accidents

Result / Area	Weighted accidents	Loss of each accident (Million)
Dalian	46	33.03
Yingkou	40	38.95
Huludao	16	85.30

Source: Compiled by the author.

(3) Number of Deaths

Through the processing of the accident data analysis, the author found that there are only a small number of traffic accidents causing deaths in Liaoning area. Between 2009 and 2013, 8 people died (exclude the missing and injured; only associated with traffic accidents). Most deaths are caused by accidents in shipwreck.

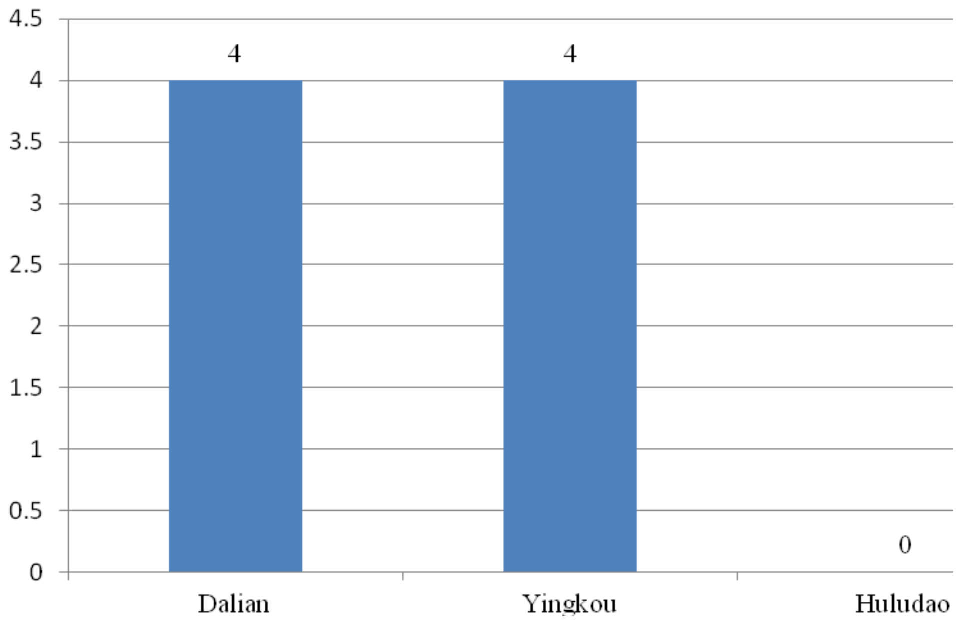

Figure 3-16 The death statistics of the marine traffic accidents in Liaoning area
Source: Compiled by the author.

3.3.2 Traffic Condition Subsystem

(1) Traffic Volume

Traffic volume change in Liaoning area from 2009 to 2013 was introduced and analyzed in the last section. This chapter focuses on comparative analysis between each district. Limited to the statistical data and heavy workload, this thesis will take the average treatment on the traffic volume.

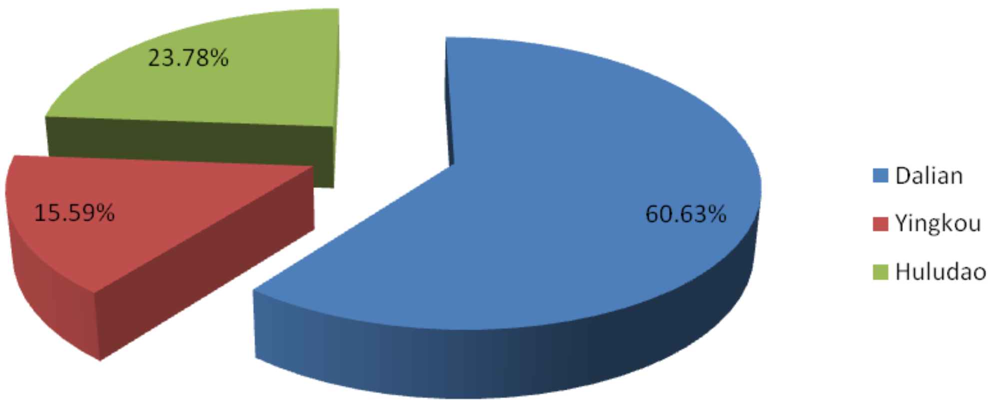

Figure 3-17 The average traffic volume statistics of Liaoning area
Source: Compiled by the author.

As can be seen from the Figure 3-17, Dalian traffic volume is the biggest and accounts for 60.63% of Liaoning area. The port of Yingkou and Bayuquan have been developing rapidly in recent years. In Yingkou area, there are a large number of vessels of foreign nationality, which is mainly due to the increasing of foreign vessels transporting ore from Jingtang District. Besides, 300,000 ton crude oil terminal was ready in 2010; the traffic density became greater and greater. The traffic volume of Huludao area is mainly concentrated at Liutiaogou port.

(2) Harbor Throughput

The average cargo throughput in Liaoning area during 2009-2013 is shown below:

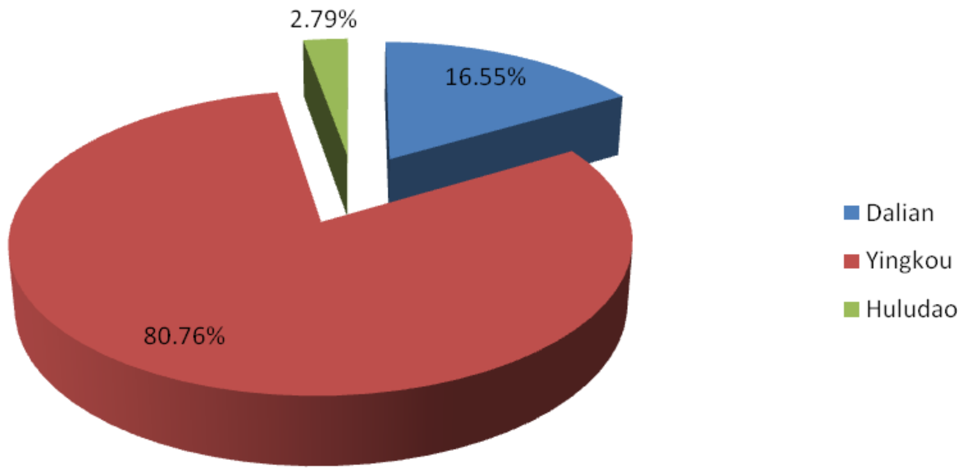

Figure 3-18 The statistics of average cargo throughput in Liaoning area
Source: Compiled by the author.

In recent years, cargo throughput grows significantly in Liaoning area. One of the main reasons is rapid development of Dalian port and the surrounding ports. Coal, ore and other forms of strategic energy play an important role in development of national economy. They are transported through Liaoning ports, and the majority of goods are coal and steel.

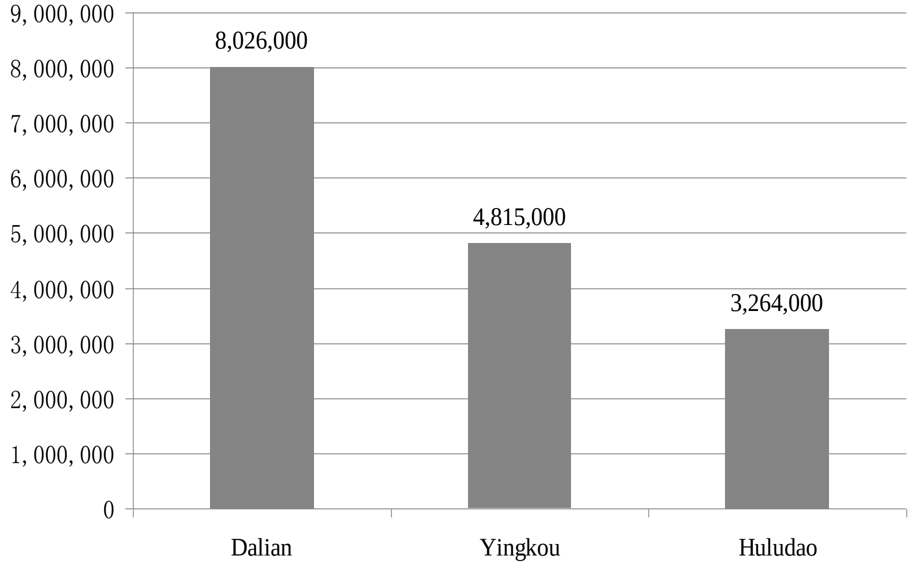

Figure 3-19 The statistics of the container freight in Liaoning area 2013 (TEU)
Source: Compiled by the author.

At present, the harbor throughput of Dalian area still holds an important position in Liaoning area. However, cargo throughput of Yingkou and Huludao will rapidly increase in foreseeable future.

(3) Traffic Complex Condition

Liaoning is located in North China, facing Bohai. The water route leading to Shandong, Tianjin, and North Bay mostly intersect at this area. In general, traffic conditions in Dalian and Yingkou are more complex than those in Huludao.

3.3.3 Navigation Condition Subsystem

(1) Fairway Condition

The navigation safety of ship is affected by channel direction, channel depth, channel width and special points.

Navigation channel direction mainly associates with local wind, streams and other natural factors. Good channel design will ensure the angle among waterway, wind and wave as small as possible. A broad channel can provide the ship plenty of room to adjust course in time. Good condition of channel depth can decide navigable vessel size and whether the ship leaves port by tide. Special channel mainly refers to the channel end or elbow where there is jet flow or changing direction etc. Because the area of Liaoning port is mostly affected by the dredged channel, port fairway sand dyke, breakwater and dumping area, the direction of flow usually changes and flow rate increases.

From the current status of channel in Liaoning jurisdiction, the waterway of Yingkou Bayuquan port area is better than those in other districts, and has realized two-way shipping in 2008. But the channel entrance jet is more serious, which is easy to cause accidents. Remediation was carried out in channel of Huludao to construct breakwater, which has greatly improved the waterway conditions.

(2) Obstruction Areas

The obstruction areas in Dalian, Yingkou and Huludao waters are oil and gas areas, military exercise areas, tourist resort, fishing and water aquaculture area etc.

Dalian navigation area is mainly influenced by the military exercises zone, the yacht activity area and water aquaculture zone. However, they are concentrated near the coastal waters, posing little threat to traffic of merchant ships.

There are many offshore oilfields in Yingkou area. These oilfields can cause certain influence to passing ships, especially to sites near drilling platforms and subsea pipeline. In addition, the military exercises will have a certain influence on normal navigable waters.

Huludao navigation area mainly considers the coastal aquaculture areas, which has little effect on traffic of merchant ships. But we need to pay attention to activities of large number of fishing boats in the flood season.

In general, the condition of Huludao water is better than other sea areas.

(3)Vessel Traffic Service

At present, all three districts are provided with VTS. The evaluation of vessel traffic service system is divided into five levels, which are listed as follows.

- Very low: provide navigation services according to the request; provide vessel traffic service according to law;
- Low: management by the pilot;
- Intermediate: implementation of signal control to the ship, demand for report and approval procedure;
- High: ship reports actively to VTS, and VTS implements traffic monitoring and provides information services;
- Very high: the institutionalization of ship reporting system and approval system.

The higher level standard covers the content of the lower. VTS in Dalian and Yingkou can be considered at a very high level; Huludao is at a high level.

Chapter 4 Construction of Navigation Safety Evaluation Model of the Liaoning waters

4.1 Fuzzy Synthetic Evaluation Model and Method

This paper uses the fuzzy comprehensive evaluation model for evaluation of navigation safety in Liaoning waters. Fuzzy comprehensive evaluation involves four elements: factor set, evaluation set, Single factor evaluation and multi factor fuzzy comprehensive evaluation.

(1) Establish the factor set U , $U=(U_1,U_2,...U_n)$, $U_1,U_2,...U_n$ refers to every influencing factor, namely the first-level of index system. The second-level influencing factor subsystem is $u_1=(u_{11},u_{12}...u_{1n})$; $u_2=(u_{21},u_{22}...u_{2n})$ … $u_n=(u_{n1},u_{n2}...u_{nn})$. Then,

$$U=\begin{bmatrix} u_1 \\ u_2 \\ . \\ u_n \end{bmatrix}=\begin{bmatrix} u_{11},u_{12},...u_{1n} \\ u_{21},u_{22},...u_{2n} \\ ... \\ u_{n1},u_{n2},...u_{nn} \end{bmatrix}$$

(2) The influence of various factors on the final evaluation results are different, thus factors require to be weighed. The weight set is also known as the important degree of fuzzy subsets, which are indicated by $A = \{a_1, a_2, ..., a_m\}$, and the second level index is $A = \{a_{11}, a_{12}, ..., a_{1n}\}$.

If $V = \{v_1, v_2, ..., v_m\}$ is a set of elements based on the M choice level (i.e. the evaluation results), the objective of fuzzy comprehensive evaluation is to consider all factors on evaluation objects, so as to obtain an optimal evaluation results from the evaluation set V. One of the tasks of evaluators is to establish the correspondence between N factors and M reviews. Due to fuzziness of various factors and personal attitudes of evaluators, the correspondence is often a fuzzy matrix, called the evaluation matrix, each row of which is an evaluation vector, indicating the subjection degree between a factor and M grade in V. Evaluation vector is indicated by $r_n = \{r_{1n}, r_{2n}, ..., r_m\}$.

The form of evaluation matrix is:

$$R = \begin{bmatrix} r_1 \\ r_2 \\ . \\ r_n \end{bmatrix} = \begin{bmatrix} r_{11}, r_{12}, ... r_{1n} \\ r_{21}, r_{22}, ... r_{2n} \\ ... \\ r_{n1}, r_{n2}, ... r_{nn} \end{bmatrix}$$

Given the factor weight set A and evaluation matrix R, according to the fuzzy matrix multiplication algorithm, we can obtain the fuzzy comprehensive evaluation of B.

$$B = A \circ R = (a_1, a_2, ..., a_n) \circ \begin{bmatrix} r_{11}, r_{12}, ... r_{1n} \\ r_{21}, r_{22}, ... r_{2n} \\ ... \\ r_{n1}, r_{n2}, ... r_{nn} \end{bmatrix} = (b_1, b_2, ..., b_n)$$

In the formula, b_n is called the fuzzy comprehensive evaluation index, which is the subjection degree between objects of evaluation and the first *n* element in V.

4.2 Factor Set and Evaluation Set

(1) Establishment of Factor Set of Navigation Safety Evaluation

In this thesis, the author sets up comprehensive evaluation model set U :

U = { u_1 (Traffic accident index), u_2 (Traffic condition index), u_3 (Navigation condition index)}

Factor set of each subsystem is listed as follows:

u_1 = { u_{11} (Number of Accident), u_{12} (Economic loss), u_{13} (Number of death)}

u_2 = { u_{21} (Traffic volume), u_{22} (Harbor throughput), u_{23} (Traffic condition)}

u_3 = { u_{31} (Fairway condition), u_{32} (Obstruction areas), u_{33} (Vessel traffic service)}

(2) Establishment of Evaluation Set

The evaluation of navigation safety in Liaoning is divided into five levels:
$V = \{v_1, v_2, v_3, v_4, v_5\} = \{-2, -1, 0, +1, +2\}$

-2 is very bad,-1 is bad,0 is general,+1 is good,+2 is very good.

4.3 Navigation Safety Evaluation Index Weight

4.3.1 Analytic Hierarchy Process (AHP)

The degree of importance of each evaluation index of evaluation objects is different. The distinction for important degree of various factors is helpful for evaluation results (Wang, Li, 2012). In general, the expert investigation method is used to determine the weights of factors. According to the survey results, the influences of factors are sorted using analytic hierarchy process (AHP). Process steps of AHP are listed below.

(1) Building of Judgment Matrix

Table 4-1 The standard and definition of the judgment matrix

Scale	Meaning
1	Same importance
3	The former is slightly important than the latter
5	The former is more important than the latter
7	The former is highly important than the latter
9	The former is extremely important than the latter
2,4,6,8	Median
reciprocal	The latter is more important than the former

Source: Wang Yong, Li Zan, (2012). Research on navigational safety harbor waters based on FSA theory

Using Table 4-1, we can convert the qualitative evaluation into quantitative evaluation. The judgment matrix is shown below:

Table 4-2 The judgment matrix

A_i	B_1	B_2	…	B_n

B_1	b_{11}	b_{12}	$\cdots$	b_{1n}
B_2	b_{21}	b_{22}	$\cdots$	b_{2n}
. .	. .	. .	$\cdots$	. .
B_n	b_{n1}	b_{n2}	$\cdots$	b_{nn}

Source: Wang Yong, Li Zan, (2012). Research on navigational safety harbor waters based on FSA theory

The judgment matrix above should satisfy:

$$\begin{cases} b_{ij} = 1(i = j) \\ b_{ij} = 1/b_{ji}(i \neq j) \end{cases}$$

(2) Hierarchical Ranking

In this step, characteristic root and eigenvector of matrix which satisfies $BW = \lambda_{\max} W$ are calculated. Maximum characteristic root of B is $\lambda_{\max}$, and the normalized feature vectors of $\lambda_{\max}$ is W.

The steps of calculating $\lambda_{\max}$ and W are shown below:

a. Calculate the product of each row element in matrix,

$$M_i = \prod_{j=1}^{n} b_{ij}, i = 1,2,...,n$$

b. Calculate the root $\overline{W}$,

$$\overline{W} = \sqrt[n]{M_i}$$

c. Normalize $\overline{W} = (\overline{W_1}, \overline{W_2}, ..., \overline{W_n})^T$,

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_j}}, i = 1,2,...,n$$

Through the above treatment, vector finally obtained $W = (W_1, W_2, ..., W_n)^T$ is set of weights A and A_i .

d. Calculate maximum characteristic root λ_{max}

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}$$

(3) Check of the Consistency of Judgment Matrix

CI is the index for checking the consistency of matrix:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

The more the value of CI , the worse the consistency of matrix. When $CI = 0$, Matrix is complete consistency. To judge the consistency of matrix, we calculate the ratio between CI and RI , namely $CR = CI / RI$, i.e. the average random consistency index. When $CR < 0.10$, we consider that consistency of matrix satisfies the requirements. The average arbitrary coincidence indicator of 1-9 rank matrixes is shown below:

Table 4-3 The average arbitrary coincidence indicator of 1-9 rank matrix

Order number	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Source: Ma Zhanxin, Ren Huilong(2002). Study on evaluation method of FSA

If the consistency does not meet the requirements, it needs to readjust the matrix assignment.

4.3.2 Navigation Safety Evaluation Index Weight of the Liaoning waters

According to the AHP method and expert questionnaire, the author calculated the index of navigation safety evaluation in Liaoning jurisdiction. An example is taken to demonstrate the weight calculation steps in this section. For the other indices, final results are given in this paper.

The judging matrix of the safety navigation in Liaoning area is shown in Table 4-4:

Table 4-4 The judging matrix of the safety navigation in Liaoning area

	Traffic accident index u_1	Traffic condition index u_2	Navigation condition index u_3
Traffic accident index u_1	1	2	2
Traffic condition index u_2	1/2	1	2
Navigation condition index u_3	1/2	1/2	1

Source: Ma Zhanxin, Ren Huilong(2002). Study on evaluation method of FSA

Steps of weights calculation are as follows:

a. Calculate the product of each row in judgment matrix:

M1=1×2×2=4

M2=1/2×1×2=1

M3=1/2×1/2×1=1/4

b. Calculate $\sqrt[3]{M_n}$:

$$\overline{W_1} = \sqrt[3]{M_1} = \sqrt[3]{4} = 1.587$$

$$\overline{W_2} = \sqrt[3]{M_2} = \sqrt[3]{1} = 1$$

$$\overline{W_3} = \sqrt[3]{M_3} = \sqrt[3]{1/4} = 0.630$$

c. Normalize $\overline{W} = (\overline{W_1}, \overline{W_2}, \overline{W_3})^T = (1.587, 1, 0.630)^T$:

$$\sum_{j=1}^{3} \overline{W_j} = \overline{W_1} + \overline{W_2} + \overline{W_3} = 1.587 + 1 + 0.630 = 3.217$$

$$W_1 = \frac{\overline{W_1}}{\sum_{j=1}^{3} \overline{W_j}} = \frac{1.587}{3.217} = 0.4933$$

$$W_2 = \frac{\overline{W_2}}{\sum_{j=1}^{3} \overline{W_j}} = \frac{1}{3.217} = 0.3108$$

$$W_3 = \frac{\overline{W_3}}{\sum_{j=1}^{3} \overline{W_j}} = \frac{0.630}{3.217} = 0.1959$$

So, the eigenvector is $W = (0.4933, 0.3108, 0.1959)^T$

d. Calculate maximum characteristic root $\lambda_{\max}$

$$AW = \begin{bmatrix} 1 & 2 & 2 \\ 1/2 & 1 & 2 \\ 1/2 & 1/2 & 1 \end{bmatrix} \circ (0.4933, 0.3108, 0.1959)^T$$

$$(AW)_1 = 1 \times 0.4933 + 2 \times 0.3108 + 2 \times 0.1959 = 1.5067$$
$$(AW)_2 = 1/2 \times 0.4933 + 1 \times 0.3108 + 2 \times 0.1959 = 0.9493$$
$$(AW)_3 = 1/2 \times 0.4933 + 1/2 \times 0.3108 + 1 \times 0.1959 = 0.5980$$

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} = \sum_{i=1}^{3} \frac{(AW)i}{nW_i} = \frac{(AW)_1}{3W_1} + \frac{(AW)_2}{3W_2} + \frac{(AW)_3}{3W_3} = 3.0537$$

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{3.0537 - 3}{3-1} = 0.02685$$

$CR = CI / RI = 0.02685 / 0.58 = 0.0463 < 0.10$, So the judgment matrix has a good consistency.

Thus, navigation safety evaluation index weight of the Liaoning waters is $A = (0.4933, 0.3108, 0.1959)$.

4.3.3 Traffic Accident Subsystem Weight

The judging matrix of the traffic accident subsystem is shown below:

Table 4-5 The judging matrix of the traffic accident subsystem

	Number of Accident u_{11}	Economic loss u_{12}	Number of death u_{13}	Eigenvector W_1
Number of Accident u_{11}	1	3	5	0.6370
Economic loss u_{12}	1/3	1	3	0.2583
Number of	1/5	1/3	1	0.1047

death u_{13}				
$\lambda_{\max} = 3.0385 \quad CR = 0.033 \le 0.10$ (satisfies requirements)				

Source: Calculated by the author.

So, the traffic accident subsystem weight is $A_1 = (0.6370, 0.2583, 0.1047)$.

4.3.4 Traffic Condition Subsystem Weight

The judging matrix of the traffic condition subsystem is shown below:

Table 4-6 The judging matrix of the traffic condition subsystem

	Traffic volume u_{21}	Harbor throughput u_{22}	Traffic complex condition u_{23}	Eigenvector W_2
Traffic volume u_{21}	1	1/3	1/3	0.1396
Harbor throughput u_{22}	3	1	1/2	0.3325
Traffic complex condition u_{23}	3	2	1	0.5279
$\lambda_{\max} = 3.0536 \quad CR = 0.046 \le 0.10$ (satisfies requirements)				

Source: Calculated by the author.

The traffic condition subsystem weight is $A_2 = (0.1396, 0.3325, 0.5279)$.

4.3.5 Navigation Condition Subsystem Weight

The judging matrix of the navigation condition subsystem is shown below:

Table 4-7 The judging matrix of the navigation condition subsystem

	Fairway condition u_{31}	Obstruction areas u_{32}	Vessel traffic service u_{33}	Eigenvector W_3
Fairway condition u_{31}	1	1/4	1/3	0.1172
Obstruction areas u_{32}	4	1	3	0.6144
Vessel traffic service u_{33}	3	1/3	1	0.2684
$\lambda_{max} = 3.0736 \quad CR = 0.063 \le 0.10$ (satisfies requirements)				

Source: Calculated by the author.

The navigation condition subsystem weight is $A_3 = (0.1172, 0.6144, 0.2684)$.

4.3.6 Summary of Navigation Safety Evaluation Index Weight

Based on the above calculations, the weight of each index factor in navigation safety evaluation of Liaoning waters is shown in the following table:

Table 4-8 The weight of indices

Navigation safety evaluation index system		Weight
Traffic accident index u_1 0.4933	Number of accident u_{11}	0.6370
	Economic loss u_{12}	0.2583
	Number of death u_{13}	0.1047

Traffic condition index u_2 0.3108	Traffic volume u_{21}	0.1396
	Harbor throughput u_{22}	0.3325
	Traffic complex condition u_{23}	0.5279
Navigation condition index u_3 0.1959	Fairway condition u_{31}	0.1172
	Obstruction areas u_{32}	0.6144
	Vessel traffic service u_{33}	0.2684

Source: Compiled by the author from 4.3.2 to 4.3.5.

4.4 Subjection degree of Navigation Safety Evaluation Index

For a given fuzzy set, membership function not only embodies the fundamental characteristics of fuzzy concept, but also can achieve the corresponding mathematical operation. For the determination of the membership function, there are several methods proposed, in which the representatives are: intuitionist fuzzy method, binary contrast sorting method, statistical method and the minimum fuzzy degree method etc.

In this paper, to determine the index membership functions as far as possible to ensure the final evaluation results, the author adopt probability distribution method.

4.4.1 Subjection Degree of Traffic Accident Subsystem

(1) Number of Accidents

The traffic accident statistics in Liaoning area water has been introduced above, based on statistics from 2009 to 2013. According to the feedback and experience, the accidents are divided into four grades: good, better, general and bad.

- Good: The case that the number of significant accidents is 1-3, the total number of accidents is in the range of less than 40 within five years, the proportion of significant accidents is within 5%-10%, and minor accidents account for more than 80%.
- Better: The case that the number of significant accidents is 3-5, the total number of accidents is in the range of 40-50 within five years, the proportion of significant accidents is within 10%-15%, and minor accident account more than 70%.
- General: The case that the number of significant accidents is more than 5, the total number of accidents is in the range of 50-60 within five years, the proportion of significant accidents is within 10%-15%, and minor accidents account for more than 60%.
- Bad: The case that there are very significant accidents in jurisdiction, the total number of accidents is more than 60 within five years, the proportion of significant accidents is more than 15%, and minor accidents account for more than 60%.

Subjection degree of annual ship accidents is shown below:

Table 4-9 Subjection degree of annual ship accidents

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.15	0.85
Better	0	0	0.05	0.80	0.15
General	0	0.10	0.80	0.10	0
Bad	0.05	0.90	0.05	0	0

Source: Compiled by the author.

(2) Economic Loss

Economic loss caused by water traffic accidents from 2009 to 2013 is divided into four grades: good, better, general and bad, according to the total loss and the average loss per accident.

- Good: Economic loss ranges from 10 to 13 million Yuan, and the average loss per accident is within 0.2-0.3 million Yuan.
- Better: Economic loss ranges from 13 to 16 million Yuan, and the average loss per accident is within 0.3-0.4 million Yuan.
- General: Economic loss ranges from 16 to 20 million Yuan, and the average loss per accident is within 0.4-0.5 million Yuan.
- Bad: Economic loss is more than 20 million Yuan, and the average loss per accident is more than 0.5 million Yuan.

Subjection degree of economic loss is shown below:

Table 4-10 Subjection degree of economic loss

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.10	0.90
Better	0	0	0.05	0.80	0.15
General	0	0.05	0.85	0.10	0
Bad	0.10	0.80	0.10	0	0

Source: Compiled by the author.

(3) Number of Deaths

The number of deaths is divided into three grades: good (0-2), general (2-5) and bad

(>6).

Subjection degree of the death number is shown below:

Table 4-11 Subjection degree of the death number

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.15	0.85
General	0	0.20	0.70	0.10	0
Bad	0.15	0.80	0.05	0	0

Source: Compiled by the author.

4.4.2 Subjection Degree of Traffic Condition Subsystem

(1) Traffic Volume

According to traffic data during 2009-2013, the traffic volume is divided into four grades: good (average annual traffic volume in 50,000 vessels below), better (average annual traffic volume in 5-10 million vessels), general (average annual traffic volume in 10-15 million vessels) and poor (average annual traffic volume more than 150,000 vessels).

Subjection degree of the traffic volume is shown below:

Table 4-12 Subjection degree of the traffic volume

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.10	0.90
Better	0	0	0	0.80	0.20
General	0	0.10	0.80	0.05	0
Bad	0.10	0.90	0	0	0

Source: Compiled by the author.

(2) Harbor Throughput

According to the statistical data during 2007-2010, the throughput is divided into four grades: well (annual throughput of the port less than 100 million tons), better (annual throughput of the port in 100-200 million tons), general (annual throughput of the port in 200-300 million tons), poor (annual throughput of the port more than 300 million tons).

Subjection degree of the harbor throughput is shown below:

Table 4-13 Subjection degree of the harbor throughput

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.15	0.85
Better	0	0	0.10	0.90	0
General	0	0.05	0.80	0.15	0
Bad	0.20	0.80	0	0	0

Source: Compiled by the author.

(3)Traffic Complex Condition

Traffic complex is divided into three grades: good (the waterway is far from the port, and have no cross), general (the waterway is near from the port, and has partially cross), poor (the waterway is very near from the port, and has frequently cross).

Subjection degree of the traffic complex condition is shown below:

Table 4-14 Subjection degree of the Traffic complex condition

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.10	0.90

General	0	0.10	0.80	0.10	0
Bad	0.15	0.85	0	0	0

Source: Compiled by the author.

4.4.3 Membership of Navigation Condition Subsystem

(1)Fairway Condition

Taking into account the complexity of Dalian, Yingkou and Huludao areas, the author classifies fairway conditions qualitatively from the overall view.

- Good: Abundant channel length, channel depth and width, channel bends and special area is small, normal water flow at the end of the channel.
- Better: Sufficient channel length, channel depth and width, channel bends and special area is small, small change of water flow at the end of the channel.
- General: Channel length, channel depth and width can meet the maximum design ship, more channel bends and special area, rapid water flow at the end of the channel.
- Bad: Channel length, channel depth and width can meet the maximum design ship, a lot of channel bends and special areas, water flow at the end of channel increases greatly, waterway dredging is poor.

Subjection degree of the fairway condition is shown below:

Table 4-15 Subjection degree of the Fairway condition

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.20	0.80
Better	0	0	0.05	0.85	0.10
General	0	0.10	0.80	0.10	0
Bad	0.20	0.80	0	0	0

Source: Compiled by the author.

(2) Obstruction Areas

Obstruction area mainly includes oil and gas, military exercise areas, tourist resort, fishing and water aquaculture areas etc. According to the above analysis, obstruction area is divided into three grades:

Good (less oil and gas fields, less influence by military exercises and other water recreation, fishing activities have little effect on ship navigation);

General (some oil and gas fields, military exercises, other activities and fishing activities have certain influence);

Poor (many oil and gas fields, more influence by military exercises, other activities and fishing activities).

Table 4-16 Subjection degree of obstruction areas

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Good	0	0	0	0.15	0.85
General	0	0	0.70	0.30	0
Bad	0.20	0.80	0	0	0

Source: Compiled by the author.

(3) Vessel Traffic Service

The vessel traffic service is divided into five levels: very low, low, intermediate, high and very high (given in previous chapter).

Subjection degree of the vessel traffic service is shown below:

Table 4-17 Subjection degree of the vessel traffic service

Level / Condition	Very bad-2	Bad -1	General 0	Good +1	Very good +2
Very low	0.90	0.10	0	0	0
Low	0.15	0.8	0.05	0	0
Intermediate	0	0	0.90	0.10	0
High	0	0	0	0.15	0.85
Very high	0	0	0	0.10	0.90

Source: Compiled by the author.

Chapter 5 Navigation Safety Evaluation of the Liaoning waters

According to the evaluation index system and membership function established above, mathematical model of fuzzy comprehensive evaluation is used to evaluate and analyze the navigation safety of Dalian, Yingkou and Huludao waters. The subjection degree involved in navigation safety evaluation of the Liaoning waters is shown in the following table:

Table 5-1 Subjection degree of the safety navigation of Liaoning area

Navigation safety evaluation index system		Dalian	Yingkou	Huludao
Traffic accident index	Number of accidents	General	General	Good
	Economic loss	Better	Better	Bad
	Number of deaths	General	General	Good
Traffic condition index	Traffic volume	Bad	Better	Better
	Harbor throughput	General	Better	Good
	Traffic complex condition	General	General	Good
Navigation condition index	Fairway condition	Better	Good	Better
	Obstruction areas	General	General	Good
	Vessel traffic service	Very high	Very high	High

Source: Compiled by the author from Chapter 4.

5.1 Navigation Safety Evaluation of Dalian Area

5.1.1 Single Factor Evaluation

(1) Single factor evaluation for traffic accident index

Number of accident $R_{11} = (0,0.10,0.80,0.10,0)$

Economic loss $R_{12} = (0,0,0.05,0.80,0.15)$

Number of death $R_{13} = (0,0.20,0.70,0.10,0)$

Thus, evaluation matrix of traffic accident index R1 is

$$R1 = \begin{bmatrix} 0 & 0.10 & 0.80 & 0.10 & 0 \\ 0 & 0 & 0.05 & 0.80 & 0.15 \\ 0 & 0.20 & 0.70 & 0.10 & 0 \end{bmatrix}$$

Then, weight $A1 = (0.6370,0.2583,0.1047)$

Calculate by $B = A \circ R$:

$$B = (b_1, b_2, ..., b_m), bj = \sum_{i=1}^{n} (a_i \cdot r_{ij}),\ j = 1,2,...,m, \sum_{i=1}^{n} a_i = 1$$

Consequently,

$$B1 = A1 \circ R1 = (0.6370 \quad 0.2583 \quad 0.1047) \circ \begin{bmatrix} 0 & 0.10 & 0.80 & 0.10 & 0 \\ 0 & 0 & 0.05 & 0.80 & 0.15 \\ 0 & 0.20 & 0.70 & 0.10 & 0 \end{bmatrix}$$

$$= (0 \quad 0.0846 \quad 0.5958 \quad 0.2808 \quad 0.0387)$$

(2) Single factor evaluation for traffic condition index

Traffic volume $R_{21} = (0.10,0.90,0,0,0)$

Harbor throughput $R_{22} = (0,0.05,0.80,0.15,0)$

Traffic complex condition $R_{23} = (0,0.10,0.80,0.10,0)$

So, evaluation matrix of traffic condition index R2 is

$$R2=\begin{bmatrix}0.10 & 0.90 & 0 & 0 & 0\\ 0 & 0.05 & 0.80 & 0.15 & 0\\ 0 & 0.10 & 0.80 & 0.10 & 0\end{bmatrix}$$

Weight $A2=(0.1396,0.3325,0.5279)$

Consequently,

$$B2=A2\circ R2=(0.1396\quad 0.3325\quad 0.5279)\circ\begin{bmatrix}0.10 & 0.90 & 0 & 0 & 0\\ 0 & 0.05 & 0.80 & 0.15 & 0\\ 0 & 0.10 & 0.80 & 0.10 & 0\end{bmatrix}$$

$$=(0.0140\quad 0.1951\quad 0.6883\quad 0.1027\quad 0)$$

(3) Single factor evaluation for navigation condition index

Fairway condition $R_{31}=(0,0,0.05,0.85,0.10)$

Obstruction areas $R_{32}=(0,0,0.70,0.30,0)$

Vessel traffic service $R_{33}=(0,0,0,0.10,0.90)$

So, evaluation matrix of navigation condition index R3 is

$$R3=\begin{bmatrix}0 & 0 & 0.05 & 0.85 & 0.10\\ 0 & 0 & 0.70 & 0.30 & 0\\ 0 & 0 & 0 & 0.10 & 0.90\end{bmatrix}$$

Weight $A3=(0.1172,0.6144,0.2684)$

Consequently,

$$B3=A3\circ R3=(0.1172\quad 0.6144\quad 0.2684)\circ\begin{bmatrix}0 & 0 & 0.05 & 0.85 & 0.10\\ 0 & 0 & 0.70 & 0.30 & 0\\ 0 & 0 & 0 & 0.10 & 0.90\end{bmatrix}$$

$$=(0\quad 0\quad 0.4359\quad 0.3108\quad 0.2533)$$

5.1.2 Two Level Fuzzy Comprehensive Evaluation

Evaluation matrix of Dalian navigation safety R is

$$R = \begin{bmatrix} 0 & 0.0846 & 0.5958 & 0.2808 & 0.0387 \\ 0.0140 & 0.1951 & 0.6883 & 0.1027 & 0 \\ 0 & 0 & 0.4359 & 0.3108 & 0.2533 \end{bmatrix}$$

Weight $A = (0.4933, 0.3108, 0.1959)$

So, comprehensive evaluation grade of Dalian navigation safety is:

$$B = A \circ R = (0.4933 \quad 0.3108 \quad 0.1959) \circ \begin{bmatrix} 0 & 0.0846 & 0.5958 & 0.2808 & 0.0387 \\ 0.0140 & 0.1951 & 0.6883 & 0.1027 & 0 \\ 0 & 0 & 0.4359 & 0.3108 & 0.2533 \end{bmatrix}$$

$$= (0.0044 \quad 0.1024 \quad 0.5932 \quad 0.2313 \quad 0.0687)$$

According to the weighted average method, we can calculate matrix B and evaluation set V (-2,-1, 0, +1,+2), and then get the result:

$$v = \frac{\sum_{j=1}^{5} b_j v_j}{\sum_{j=1}^{5} b_j} = \frac{0.2575}{1} = 0.2575$$

Referring to related papers and experts' views, this paper provides the range of the final evaluation results as follows: bad (-2-1.5), worse (-1.5-0.5), general (-0.5-0.5), better (0.5-1.5), good (1.5-2). Since 0.2575 drops in (-0.5-0.5), so navigation safety evaluation of Dalian area is: general.

5.2 Navigation Safety Evaluation of Yingkou Area

5.2.1 Single Factor Evaluation

(1) Single factor evaluation for traffic accident index

Number of accident $R_{11} = (0,0.10,0.80,0.10,0)$

Economic loss $R_{12} = (0,0,0.05,0.80,0.15)$

Number of death $R_{13} = (0,0.20,0.70,0.10,0)$

So, evaluation matrix of traffic accident index R1 is

$$R1 = \begin{bmatrix} 0 & 0.10 & 0.80 & 0.10 & 0 \\ 0 & 0 & 0.05 & 0.80 & 0.15 \\ 0 & 0.20 & 0.70 & 0.10 & 0 \end{bmatrix}$$

Weight $A1 = (0.6370,0.2583,0.1047)$, consequently,

$$B1 = A1 \circ R1 = (0.6370 \quad 0.2583 \quad 0.1047) \circ \begin{bmatrix} 0 & 0.10 & 0.80 & 0.10 & 0 \\ 0 & 0 & 0.05 & 0.80 & 0.15 \\ 0 & 0.20 & 0.70 & 0.10 & 0 \end{bmatrix}$$

$$= (0 \quad 0.0846 \quad 0.5958 \quad 0.2808 \quad 0.0387)$$

(2) Single factor evaluation for traffic condition index

Traffic volume $R_{21} = (0,0,0,0.80,0.20)$

Harbor throughput $R_{22} = (0,0,0.10,0.90,0)$

Traffic complex condition $R_{23} = (0,0.10,0.80,0.10,0)$

So, evaluation matrix of traffic condition index R2 is

$$R2 = \begin{bmatrix} 0 & 0 & 0 & 0.80 & 0.20 \\ 0 & 0 & 0.10 & 0.90 & 0 \\ 0 & 0.10 & 0.80 & 0.10 & 0 \end{bmatrix}$$

Weight $A2 = (0.1396,0.3325,0.5279)$, consequently,

$$B2 = A2 \circ R2 = (0.1396 \quad 0.3325 \quad 0.5279) \circ \begin{bmatrix} 0 & 0 & 0 & 0.80 & 0.20 \\ 0 & 0 & 0.10 & 0.90 & 0 \\ 0 & 0.10 & 0.80 & 0.10 & 0 \end{bmatrix}$$

$$= (0 \quad 0.0528 \quad 0.4556 \quad 0.4637 \quad 0.0279)$$

(3) Single factor evaluation for navigation condition index

Fairway condition $R_{31} = (0,0,0,0.20,0.80)$

Obstruction areas $R_{32} = (0,0,0.70,0.30,0)$

Vessel traffic service $R_{33} = (0,0,0,0.10,0.90)$

So, evaluation matrix of navigation condition index R3 is

$$R3 = \begin{bmatrix} 0 & 0 & 0 & 0.20 & 0.80 \\ 0 & 0 & 0.70 & 0.30 & 0 \\ 0 & 0 & 0 & 0.10 & 0.90 \end{bmatrix}$$

Weight $A3 = (0.1172, 0.6144, 0.2684)$, consequently,

$$B3 = A3 \circ R3 = (0.1172 \quad 0.6144 \quad 0.2684) \circ \begin{bmatrix} 0 & 0 & 0 & 0.20 & 0.80 \\ 0 & 0 & 0.70 & 0.30 & 0 \\ 0 & 0 & 0 & 0.10 & 0.90 \end{bmatrix}$$

$$= (0 \quad 0 \quad 0.4301 \quad 0.2346 \quad 0.3353)$$

5.2.2 Two Level Fuzzy Comprehensive Evaluation

Evaluation matrix of Yingkou navigation safety is:

$$R = \begin{bmatrix} 0 & 0.0846 & 0.5958 & 0.2808 & 0.0387 \\ 0 & 0.0528 & 0.4556 & 0.4637 & 0.0279 \\ 0 & 0 & 0.4301 & 0.2346 & 0.3353 \end{bmatrix}$$

Weight $A = (0.4933, 0.3108, 0.1959)$

So, comprehensive evaluation grade of Yingkou navigation safety is:

$$B = A \circ R = (0.4933 \quad 0.3108 \quad 0.1959) \circ \begin{bmatrix} 0 & 0.0846 & 0.5958 & 0.2808 & 0.0387 \\ 0 & 0.0528 & 0.4556 & 0.4637 & 0.0279 \\ 0 & 0 & 0.4301 & 0.2346 & 0.3353 \end{bmatrix}$$
$$= (0 \quad 0.0581 \quad 0.5198 \quad 0.3286 \quad 0.0934)$$

According to the weighted average method:

$$v = \frac{\sum_{j=1}^{5} b_j v_j}{\sum_{j=1}^{5} b_j} = \frac{0.4573}{1} = 0.4573$$

Finally, navigation safety evaluation of Yingkou area is: general and better.

5.3 Navigation Safety Evaluation of Huludao Area

5.3.1 Single Factor Evaluation

(1) Single factor evaluation for traffic accident index

Number of accident $R_{11} = (0,0,0,0.15,0.85)$

Economic loss $R_{12} = (0.10,0.80,0.10,0,0)$

Number of death $R_{13} = (0,0,0,0.15,0.85)$

So, evaluation matrix of traffic accident index R1 is

$$R1 = \begin{bmatrix} 0 & 0 & 0 & 0.15 & 0.85 \\ 0.10 & 0.80 & 0.10 & 0 & 0 \\ 0 & 0 & 0 & 0.15 & 0.85 \end{bmatrix}$$

Weight $A1 = (0.6370, 0.2583, 0.1047)$, then,

$$B1 = A1 \circ R1 = (0.6370 \quad 0.2583 \quad 0.1047) \circ \begin{bmatrix} 0 & 0 & 0 & 0.15 & 0.85 \\ 0.10 & 0.80 & 0.10 & 0 & 0 \\ 0 & 0 & 0 & 0.15 & 0.85 \end{bmatrix}$$

$$= (0.0258 \quad 0.2066 \quad 0.0258 \quad 0.1113 \quad 0.6304)$$

(2) Single factor evaluation for traffic condition index

Traffic volume $R_{21} = (0,0,0,0.80,0.20)$

Harbor throughput $R_{22} = (0,0,0,0.15,0.85)$

Traffic complex condition $R_{23} = (0,0,0,0.10,0.90)$

So, evaluation matrix of traffic condition index R2 is

$$R2 = \begin{bmatrix} 0 & 0 & 0 & 0.80 & 0.20 \\ 0 & 0 & 0 & 0.15 & 0.85 \\ 0 & 0 & 0 & 0.10 & 0.90 \end{bmatrix}$$

Weight $A2 = (0.1396, 0.3325, 0.5279)$, consequently,

$$B2 = A2 \circ R2 = (0.1396 \quad 0.3325 \quad 0.5279) \circ \begin{bmatrix} 0 & 0 & 0 & 0.80 & 0.20 \\ 0 & 0 & 0 & 0.15 & 0.85 \\ 0 & 0 & 0 & 0.10 & 0.90 \end{bmatrix}$$

$$= (0 \quad 0 \quad 0 \quad 0.2143 \quad 0.7857)$$

(3) Single factor evaluation for navigation condition index

Fairway condition $R_{31} = (0,0,0.05,0.85,0.10)$

Obstruction areas $R_{32} = (0,0,0,0.15,0.85)$

Vessel traffic service $R_{33} = (0,0,0,0.15,0.85)$

So, evaluation matrix of navigation condition index R3 is

$$R3 = \begin{bmatrix} 0 & 0 & 0.05 & 0.85 & 0.10 \\ 0 & 0 & 0 & 0.15 & 0.85 \\ 0 & 0 & 0 & 0.15 & 0.85 \end{bmatrix}$$

Weight $A3 = (0.1172,0.6144,0.2684)$, then,

$$B3 = A3 \circ R3 = (0.1172 \quad 0.6144 \quad 0.2684) \circ \begin{bmatrix} 0 & 0 & 0.05 & 0.85 & 0.10 \\ 0 & 0 & 0 & 0.15 & 0.85 \\ 0 & 0 & 0 & 0.15 & 0.85 \end{bmatrix}$$

$$= (0 \quad 0 \quad 0.0059 \quad 0.2320 \quad 0.7621)$$

5.3.2 Two Level Fuzzy Comprehensive Evaluation

Evaluation matrix of Huludao navigation safety R is

$$R = \begin{bmatrix} 0.0258 & 0.2066 & 0.0258 & 0.1113 & 0.6304 \\ 0 & 0 & 0 & 0.2143 & 0.7857 \\ 0 & 0 & 0.0059 & 0.2320 & 0.7621 \end{bmatrix}$$

Weight $A = (0.4933,0.3108,0.1959)$

So, comprehensive evaluation grade of Huludao navigation safety B is:

$$B = A \circ R = (0.4933 \quad 0.3108 \quad 0.1959) \circ \begin{bmatrix} 0.0258 & 0.2066 & 0.0258 & 0.1113 & 0.6304 \\ 0 & 0 & 0 & 0.2143 & 0.7857 \\ 0 & 0 & 0.0059 & 0.2320 & 0.7621 \end{bmatrix}$$

$$= (0.0127 \quad 0.1019 \quad 0.0139 \quad 0.1670 \quad 0.7045)$$

According to the weighted average method:

$$v = \frac{\sum_{j=1}^{5} b_j v_j}{\sum_{j=1}^{5} b_j} = \frac{1.4487}{1} = 1.4487$$

Finally, navigation safety evaluation of Huludao area is: Good and better.

5.4 Results Analysis

In summary, the safety evaluation of Liaoning area is shown below:

Table 5-2 Safety evaluation of Liaoning area

Results / Area	Evaluation grade	Navigation safety condition
Dalian	0.2575	General
Yingkou	0.4573	General and good
Huludao	1.4487	Good and better

Source: Compiled by the author from 5.1 to 5.3.

From the comprehensive evaluation results we can see that the navigation safety of Huludao waters is the best among three area waters in Liaoning. Due to heavy port throughput and much shipping, the navigation safety of Yingkou and Dalian waters is general. Therefore MSA shall pay attention to traffic management and strengthen the supervision in Dalian and Yingkou to balance economic development and navigation safety.

Chapter 6 Conclusions and Suggestions

The conclusions of this paper are summarized as follows:

The overall navigation safety condition of Liaoning waters is good. Dalian area navigation safety is in general, Yingkou area is general and good, and Huludao area is good and better.

The results about comprehensive evaluation in this paper is reasonably in accordance with the actual situation of Liaoning jurisdiction, the system can cover most factors involved in comprehensive evaluation of navigation safety.

The method of two level fuzzy comprehensive evaluation is used in this paper. It is a relatively mature safety evaluation method. The questionnaire and experience of experts are applied in construction of evaluation index and subjection degree to meet the requirements of calculation.

The evaluation results can provide certain reference for MSA. Meanwhile, the research method and calculating steps can also provide ideas for similar navigation safety comprehensive evaluation in other waters.

In the light of time and statistics, some parts of this thesis need to be further improved. Although the two level index system established in this paper can basically meet the requirement of comprehensive evaluation， in order to make the evaluation results more practical, we need more subdivision to cover the indices more widely. In addition, the subjection degree is not constructed by the membership function and some subjective factors are mixed. Therefore, in the future, more membership function should be adopted to determine the subjection degree of each evaluation index which is close to the actual situation.

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