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Risk assessment in narrow chanel

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RISK ASSESSMENT IN NARROW CHANNEL

By

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DECLARATION

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

The contents of this dissertation reflect my own views, and are not necessary endorsed by the university.

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ABSTRACT

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With the international trade and economic globalization speeding up, the maritime transportation industry played a huge role which took vessel as the dominant factor. Especially the development of navigation science and technology and shipbuilding technology, which make ships move towards modernization and large-scale. It also increased the traffic volume in the sea, especially on important areas, customary route and channel which are in aeriform. Maritime traffic safety system is an interconnected systems made by person, machine, environment and management interaction. With the increase of vessel traffic volume, navigation environment worsening, as well as machinery and improper equipment repair will bring negative effects to the traffic safety system, which leads to frequent occurrence of traffic accidents in the process of navigation of the ship.

In order to make the maritime transport become safer, analyzing and studying the main factors in maritime transport safety and making the risk assessment, thus taking the pointed measures to improve, are of vital significance to improve navigation safety in narrow channel.

This paper uses fuzzy comprehensive safety assessment method, in view of the needs of the ships' safety in Laotieshan channel, through analyzing the characteristics of the channel, navigation and management environment, to find out the main factors influencing the safety of navigation and established the safety evaluation index system. With the related domestic and foreign research results, the computer simulation results and expert consultation as the basis, set up an evaluation criteria for each evaluation index, through calculating the membership degree of calculating conforms to the evaluation index, using the analytic hierarchy process (AHP) to get the weight of each evaluation index, then building the safety evaluation model of the channel and using the model to evaluate the channel's security. According to the evaluation results, the protective measures of ship navigation safety are put forward, then the route improvements are made and giving the safety management advice to the relevant authorities.

KEYWORDS: Risk assessment; Narrow channel; Navigation environment; Fuzzy comprehensive safety assessment.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
CBA	Cost-benefit Assessment
DMU	Dalian Maritime University
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
IAEA	International Atomic Energy Agency
IMO	International Maritime Organization
MTBF	Mean Time Between Failures
MTSRA	Marine Traffic System Risk Assessment
MSA	Maritime Safety Administration
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PSC	Port State Control
RCO	Risk Control Option
UKC	Under Keel Clearance
VHF	Very High Frequency
VTS	Vessel Traffic Service

CHAPTER 1

INTRODUCTION

1.1 Background

With the speeding up of international trade and economic globalization, the ship is developing in the direction of modernization and large-scale. Maritime traffic safety system is an integral whole made by people, machine, environment and management's interrelation. Sailing ship traffic increase, environment deterioration, personnel training and rest system lacking, and improper maintenance of machinery and equipment, etc., will have a negative impact to the traffic safety system, resulting traffic accidents. In order to deal with shipping environment change, we should strengthen the study of maritime traffic safety system.

Laotieshan channel starts from the Laotieshan's west corner in the north, then it continues to Beihuangcheng island in the south. Its width is about 20kn and 50~60m in depth, which is the main channel from the Yellow sea to the Bohai sea. The tide becomes quick because of the narrow landform and its max speed can be 2.6m/s. Water in channel is divided into two branches: one goes to northwest, and the other one goes to west then to south. Xiaoqin channel, beginning from Beihuangcheng island to Xiaoqin island, has a width of 3.2kn and 45m in depth. Daqin channel, beginning from Xiaoqin island to Daqin island, about 1.5kn in width and 30m in depth. Beituoji channel, from Daqin island to Tuoji island, 5.6kn in width, about 40m in depth in north and about 30m in depth in south. Nantuoji channel, from Tuoji island to Changshan island, is 10kn in width and 20m in depth. Changshan channel, from Changshan island to Dengzhou cape, is 4kn in width and 20m in depth. Some channels in the south of strait are the main gallery in which water in Bohai sea goes back to Yellow sea. So, Laotieshan channel has the name as the throat of Bohai gulf (Xie, Y. H. 2008, pp. 7-14).

Laotieshan channel is obviously influenced by monsoon, especially when the cold wave is active in winter. Because it is in the north wind gap, the north wind can be level 6~8 with the huge wave. There is also much fog in the whole year, about 44 days per year, which usually happens from March to August, especially in June and July, there are many fog days and the time of duration is the longest, sometimes, it can remain 3~4 days. In addition, the biggest flow speed can reach 6.5kt with much undercurrent. There are also lots of maritime accidents happening in this area every year. It brings so much trouble to ship navigation safety which is also called Bermuda in the east (Wan, H. 2014, pp. 32-41).

1.2 The Meanings of This Research

Man, machine, environment and management are the four elements composing of the maritime traffic safety system. We can study the risk of the system from the above four elements by analyzing the crucial reasons of problems and finding out the solution to the problem. This is also the direction a lot of experts and scholars have been trying to get. But because the existence of the above four elements is uncertain it brings a lot of difficulty to the system for judging. How to evaluate the risk assessment scientifically and reasonably has been the development direction which people make efforts in this field and it can also become a legal basis to help ship action decision-making and the maritime administrative department’s law enforcement.

China has always attached great importance to the Laotieshan channel’s safety and risk aversion by establishing the report on line system, hanging signal flag, watching over the VHF and sending navigation information timely to improve the Laotieshan channel’s navigation environment, but due to the special geography, hydrology and narrow channel, which are paid attention to by a lot of captains and pilots seriously. This also shows the importance of the maritime traffic safety system research of the Laotieshan channel from another side.

1.3 The Research and Process of Risk Assessment

As we all know, the shipping industry is a risky industry. People have spent so many years to explore the marine engineering and shipping management by using risk analysis viewpoint and method to study at home and abroad. With the development of safety science and perfection, in the aspect of marine traffic risk, it also made great progress and achievement.

List, George F. (1991) discussed the research result of risk assessment in analyzing the carriage of dangerous goods, which mainly means the work from 1980 and studies the methodology rather than experience (List, G, F. 1991, pp. 100-114)). Gramling, Robert. (1998) used the data which is from the maritime experts to study the relative risk from ship traffic data and geographic position data in database (Robert, G, & George, W. 1998, 557-562).

Before 2000 in China, in fact, because the accident data were scarce and case files had use restrictions, maritime traffic safety management were basically used for analysis. After 2003, as the maritime survey data became semi-public, the marine accident statistics started to implement, absolute data and relative data of a maritime traffic accident could be used and probabilistic safety assessment was applied widely. In 1998, due to FSA method suggested by IMO is imported in China and maritime traffic safety research went into a comprehensive development period. In more than ten years so far, as an important part of security analysis, risk assessment has been one of the core content of safety management technology, at the same time, we can see the application of FSA promote the development of the risk assessment greatly. In this time, the study based on the FSA risk assessment was roughly divided into three stages. The first stage was before 1997, in which the papers of security risk assessment were less published during this period and the method of the research was still in its infancy. The second stage was in 1998 ~ 2003, the educational circles and industry accepted the risk assessment method generally during this period. The third stage was from 2004 to now. This period belonged to the application of FSA method and rethinking, the FSA method is applied to the practical problems in literature, people pay attention to the introduction of safety science, management science, systems engineering science achievement and had a systematic thinking of the risk assessment method.

C. Guedes Soares, et al. (2001). discussed on maritime transportation in different stages with different risk assessment method, who pointed out that in the early stage of the shipping people controlled risk of ship mainly by technical means, during this period, reliability theory prevailed. With the big accident emerging constantly and the nuclear safety concept, PSA dominated the current. At present, in the era which was reigned by management, FSA method occupied the main body of evaluation methods. J. Wang predicted and commented the research emphasis and direction in future for FSA method, which pointed out the lack of reliable safety data and convincing safety assessment technology were mainly two problems of engineering safety analysis (Carlos, G, S. 2001, pp. 299-309). Thomas, Degre made an in-depth research on risk assessment and established a risk assessment model which is applied to the second step in the FSA method of risk assessment (Degre, T. 2003). Cindy G. Jardine. defined risk framework as risk assessment and risk management two parts, where risk assessment including risk analysis and program evaluation, then risk management including decision making, implementation, supervision, evaluation and review, etc. Literature did the research on risk assessment of risk management and risk communication method, and summarized the similarities and differences of various methods (Cindy, J. 2003, pp. 569-641).

At present the application research areas of maritime traffic risk focus on the particular ship type, operation way, ships navigation protection, operation conditions, safety accidents, engineering and technical aspects. Besides, a quantitative analysis to security risks, involving the thorough analysis, includes pre-event evaluation and post-event evaluation was made. These properties and risk measure researches all achieved gratifying results.

1.4 The Method and Thinking of This Research

Throughout the domestic and foreign research results, it is not difficult to find there are two kinds of research ideas and methods. One is to use the navigation operation simulator to simulate the object of study and analyze data for evaluation. This evaluation method is simple whose results have a strong reliability. But when there are too many factors changing the object of study and research, it will be hard to achieve. The other one is using mathematical tools for evaluation through expert analysis and on-the-spot investigation to find out factors of evaluation index and calculate the weights of each factor. This paper mainly studies about narrow channel safety system, which influenced by many factors. For research purpose, this article chooses the second method for evaluation (Xie, B. F. 2011, pp. 14-19).

There are many narrow channel safety influencing factors which are difficult to make sure the index weight and can produce intersection with each other, add difficulty to the accuracy and feasibility of system research. In order to solve this problem, this article selects fuzzy comprehensive evaluation method to evaluate. The first step is establishing evaluation index system according to the needs of the research object. The second step is using the analytic hierarchy process (AHP) to determine evaluation index weights. The third step is building the membership function and calculated the fuzzy relationship matrix. The fourth step is establishing safety fuzzy comprehensive evaluation model and using the model to evaluate the Laotieshan channel to determine its dangerous degree, analyze influential index to find out the root cause and provide the basis for the ship’s safety navigation and the scientific management to improve the navigation environment and reduce hidden accident in narrow channel.

CHAPTER 2

Methods of Risk Assessment

2.1 Risk Assessment Methods of Marine Traffic

There are dozens of system safety analysis methods which analyze the security of the system from different angles. Each kind of risk assessment method has its historical background and the applicable conditions, so some can't be used everywhere. It needs a comprehensive use of various analysis methods to complete an accurate analysis by complementing each other, sometimes compare with others and look at the method in actual situation to judge which is more consistent. Sometimes people need to use the manner of working which was made by safety analysis method to finish a risk assessment preferably. At the same time, it must be combined with the actual situation, sum up the same type system accidents and get the final risk assessment conclusion through analysis and comparison (Hu, S. P. 2014, pp. 18-20).

2.1.1 Probabilistic Safety Assessment

Probabilistic safety assessment (PSA), often referred to as probabilistic risk assessment (PRA), is based on probability theory of quantitative risk assessment technology. The first PSA-based large-scale application was seen in the research on the safety of nuclear power safety study in 1975 (for WASH - 1400). After 30 years of development and perfection, PSA has been recognized as an effective tool for the analysis of security. The International Atomic Energy Agency (IAEA) pointed out that the PSA technology has become a nuclear power plant for safety evaluation of a standardized tool that allows people to have an insight of the nuclear power plant design, performance and environmental impact including the dominant in the identification of risk factors and the various solutions to reduce the risk. PSA method has been widely used in nuclear power plant design, operation, maintenance and other fields, which has played a very important role in promoting the development of nuclear power industry. At present, Chinese new nuclear safety regulation was clearly required using PSA method and applying it in design and operation of the nuclear power plant safety analysis. It can also promote the development of PSA technology in China (Hu, S. P. 2010, pp. 12-25).

2.1.2 Formal Safety Assessment

The FSA method is a kind of structural system method. Appling this method in formulating the specification is to comprehensively thinking about the factors influencing the safety aspects. It aims to put forward reasonable code requirement which can control the risk effectively by the risk assessment, cost and benefit assessment, so as to improve and raise the level of specification continuously.

FSA can be used as a tool to help in the evaluation of new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieving a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs (Bao, J. Z. 2011, pp. 11-37)

Based on the definition of the FSA above, it is a standardized, structured and systematic comprehensive safety assessment method, as a tool, and also has the characteristics of ex post and prospect. FSA should comprise the following steps: 1) Identification of hazards; 2) risk analysis; 3) risk control options; 4) cost-benefit assessment; and 5) recommendations for decision-making.

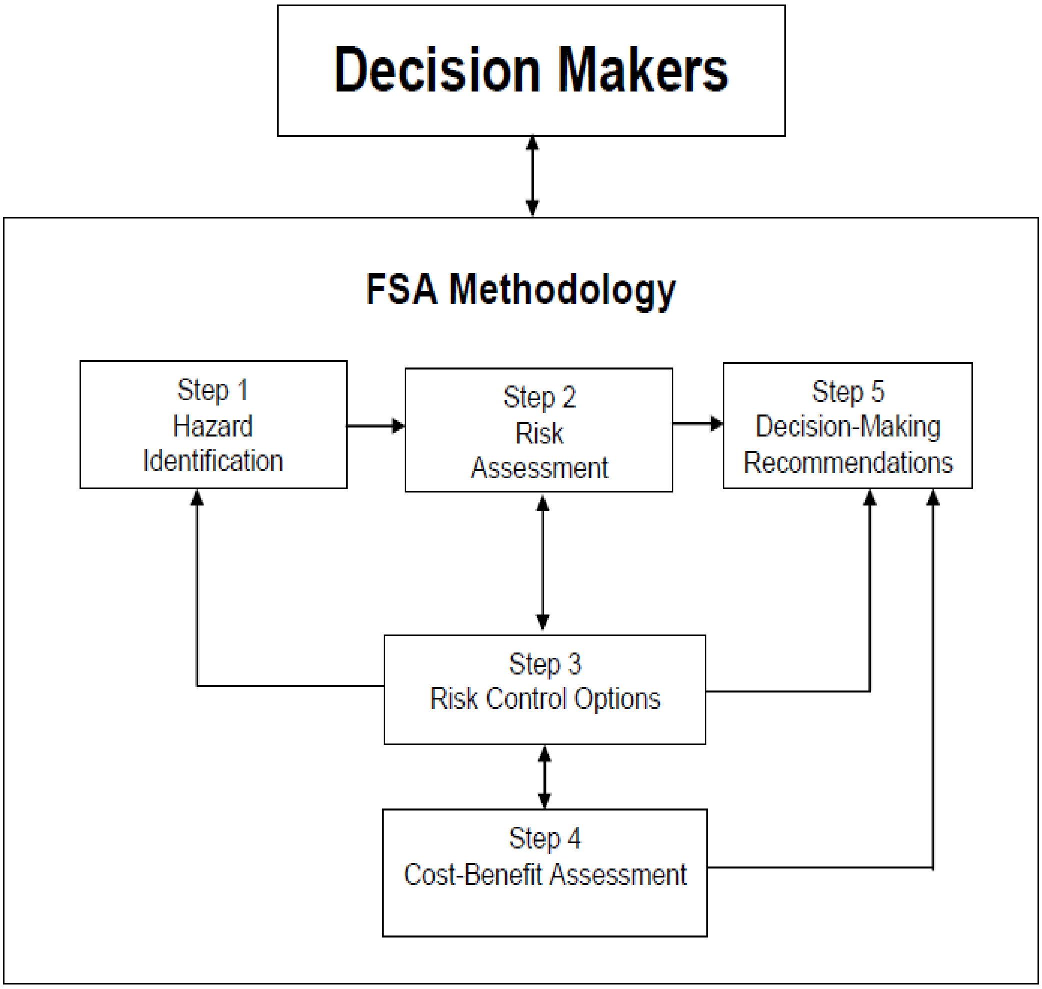

Figure 2.1: Flow chart of FSA methodology

Source: International Maritime Organization. (2013, July 8). *Revised guidelines for formal safety assessment (FSA) for use in the IMO rule-making process(MSC-MEPC.2/Circ.12)*. London: Author.

Identification of Hazards

The purpose of step 1 is to identify a list of hazards and associated scenarios prioritized by risk level specific to the problem under review. This purpose is achieved by the use of standard techniques to identify hazards which can attribute to accidents, and by screening these hazards using a combination of available data and judgment.

Risk Analysis

The purpose of the risk analysis in step 2 is a detailed investigation of the causes and initiating events and consequences of the more important accident scenarios identified in step 1. This can be achieved by the use of suitable techniques that model the risk. This allows attention to be focused upon high-risk areas and to identify and evaluate the factors influencing the level of risk.

Risk Control Options

Step 3 aims at creating risk control options that address both existing risks and risks introduced by new technology or new methods of operation and management. Both historical risks and newly identified risks (from steps 1 and 2) should be considered, producing a wide range of risk control measures. Techniques designed to address both specific risks and underlying causes should be used.

Cost-benefit Assessment

The purpose of step 4 is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3. Costs should be expressed in terms of life cycle costs and may include initial, operating, training, inspection, certification, decommission, etc. Benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, indemnity of third party liabilities, etc., and an increase in the average life of ships.

Recommendations for Decision-making

The purpose of step 5 is to define recommendations which should be presented to the relevant decision makers in an auditable and traceable manner. The recommendations should be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable (IMO, 2013).

The FSA method was proposed and used in maritime field improved the previous nachtraglichkeit of accident treatment in maritime community to a certain extent. Although putting forward the FSA method is based on the concept of safety management, risk management and methods, yet, it experienced transplantation and a certain degree of innovation after all, which is also the first time maritime community puts forward a set of relative system suitable for shipping safety risk decision-making process (Jian, L. 2008, pp. 17-31).

2.1.3 Marine Traffic System Risk Assessment

It can be seen that the method has certain deficiencies in theory and practical application through the in-depth analysis of the FSA method, which was reflected in the following aspects mainly:

i) The FSA method stresses framework structure so much, thus ignoring the scientific methodology of system engineering. It is the lack of support in method, tools and technology that is difficult to guarantee effective operation.

ii) Introducing the reasonability of cost-benefit assessment (CBA) safety evaluation control plan in safety economics is an efficient path to balance the safety and benefit. However, because maritime traffic field not only involves the ship subsystem which can proceed CBA, but also human reliability which is difficult in implementing the CBA. So, this step is not much needed in the maritime traffic safety of human system.

iii) To risk control and prevention, it needs both historical data support and the future trend analysis. It will affect the accuracy if any link is missing. Therefore to establish risk prediction based on time series data is a link in the process of risk assessment. On the other hand, how to detect the subjective data is ignored in research of the FSA for a long time.

iv) Risk assessment objects are various, different object characteristics also have different properties, but the FSA methods provide only a broad framework.

In order to consider the timeliness and spatiality fully, in risk assessment, risk problems should be emphatically considered in the different stages of event. So, Marine traffic system risk assessment (MTSRA) is put forward to combine the actual conditions of marine traffic risk analysis. Its main features are: i) Expansion of case sample size and increase the basis of risk assessment information. ii) Increased risk assessment conclusion analysis of future trend under the time dimension. MTSRA is on the basis of the analysis system and pays attention to the risk assessment and risk prediction. It enables the marine traffic risk assessment to have a better development situation in the future (Hu, S. P. 2014, pp. 44-60).

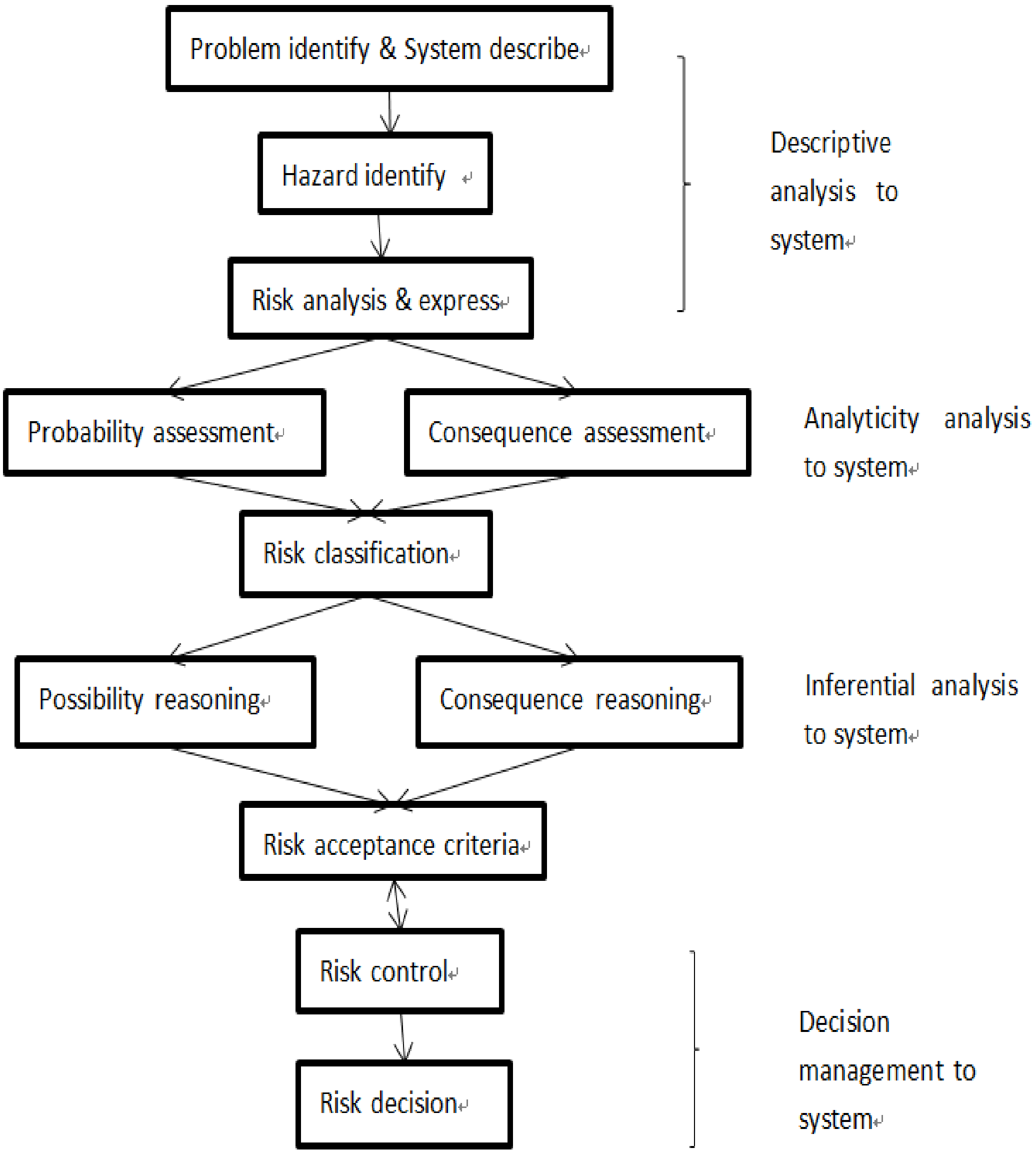

Figure 2.2: Marine traffic system risk assessment

Source: Hu, S. P. (2014). *Risk Assessment on Maritime Transportation: Approach and Technology*, 1st edition. Shanghai: China Communications Press.

2.1.4 Fault Tree Analysis

Fault tree analysis (FTA) starts with analyzing the specific accident or failure, analyzing the reasons layer by layer until finding out the main causes of the accident. These bottom events are called elementary events whose data has been known or the experience has result.

Fault tree analysis method can be used in analyzing nuclear power plants' complex systems, some kinds of system reliability, safety analysis and various production reliability analysis of safety management. Meanwhile, it can be transformed to success tree.

Fault tree analysis can identify and evaluate every systematic risk, not only analyzing the direct reason of accident but also revealing the latent reason hide in the accident. It can describe the causation of the accident intuitively, with a clear and strong logic. It can not only be used for qualitative analysis, but also for quantitative analysis, which is one of the important analysis method of safety system engineering (Cheng, L, & Chen, Z. O. 2013, pp. 2-5).

2.1.5 Fuzzy Comprehensive Assessment

Maritime traffic safety system is made by people, machine, environment and management, which is also affected by many factors and a large number of these indicators have the vague definitions of the concept. It is difficult to evaluate a complex system but fuzzy comprehensive risk assessment can meet the requirements of the maritime traffic safety system evaluation.

Fuzzy comprehensive assessment is an overall evaluation method that can synthesize some factors with so many properties influenced by some good or bad factors. The fuzzy comprehensive evaluation has the following characteristics. Firstly, the result of fuzzy assessment is a collection, rather than a point value which depicts the fuzzy state of the thing itself more accurately. So, the fuzzy comprehensive assessment's result has advantages over the quality of the information. Secondly, quantitative evaluation index is used to measure different aspects of the evaluation objects; therefore it has a different characteristic, value system and evaluation scale. Quantifiable indicators could get evaluation value through simulation or calculation, and the investigative index could be given grade by establishing evaluation standard level and using relative evaluation. Then, collect and analyze the result whose average value could be the grade of membership of index. However, experiential assessment index belongs to macroscopic indicator which is lacking in the specific measuring tool. Therefore, it can be quantificated by expertise grade or relative administrator in fuzzy math subjection principle. Thirdly, the core issue of the Hierarchy evaluation is multi-index comprehensive treatment. There are many evaluation indexes where hierarchy between each other. It must conduct a multi-index classification by setting up index classification system to ensure the scientific nature and feasibility of the evaluation model (Xie, J. J. 2005). According to the characteristics of the fuzzy comprehensive assessment, there are several steps of this assessment; first of all, setting up the weight assembly of evaluation factor, evaluation sets and weight assembly, then making the single factor fuzzy evaluation and fuzzy comprehensive evaluation, and at last, making multi-level fuzzy comprehensive evaluation for systematic factors. According to the fuzzy comprehensive evaluation method, comprehensive evaluation model is to set up the procedure for the design of the assessment factors system and ascertain the weight of each evaluation factor to determine the membership degree and application of comprehensive evaluation model (Shen, J, H, & Fu, X. Y. 2011, pp. 24-32).

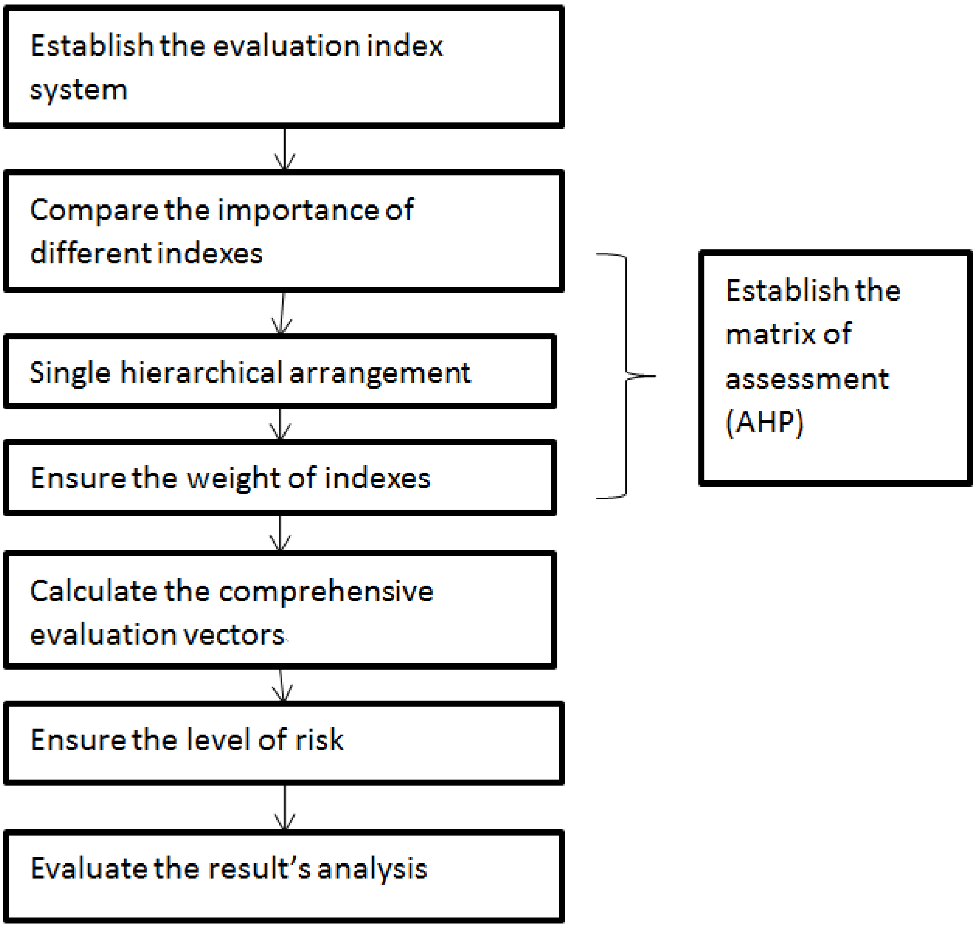

Figure 2.3: Fuzzy comprehensive assessment process

Source: Wang, F, W. (2012). *Research on the Methods of Safety Assessment of Ships' Setting Sail in Heavy Weather*. Dalian, China: Dalian Maritime University Press.

2.2 The Method Employed in This Paper

Narrow channel security system consists of human, machine, environment and management with other factors' interaction. Narrow waterway navigation safety is affected by many factors, but most of these indicators have vague definitions and the quantitative analysis system is difficult. Specific features are shown below

i) There are many factors influencing the evaluation index

Narrow channel security system is influenced by many factors widely. In order to meet the research's need, this article mainly starts in four aspects with ship safety condition, navigation environment safety, environmental safety and navigation channel safety management. The four aspects above include many specific factors. In order to avoid the limitations and one-sidedness brought about by judgment and reflect the narrow channel security situation better, this paper establishes both single factor evaluation and comprehensive evaluation for more than one factor to consider.

ii) The concept of index is fuzzy

"Low risk", "Slight low risk", "General risk" and "Slight high risk" and "High risk" fuzzy concepts are often used in the vessel traffic risk assessment. The expert assignment and expert scoring also have certain fuzziness. This paper chooses fuzzy comprehensive assessment methods, which can solve the issues by analyzing and quantifiably handling fuzzy concepts objectively and subjectively. Then, evaluate the safety situation by calculating the membership degree evaluation system. Lastly, the system improvement suggestions were put forward according to the results to ensure the security of the system better. Safety index method assumes that the scale of the vessel traffic volume is an important factor in causing marine traffic accidents. In this research it uses the unit time unit water ship traffic volume as the basis of study. Grey correlation evaluation method is based on the basic idea of sequence curve geometric shape similarity degree to judge whether the contact is close. Fuzzy comprehensive assessment method can quantitatively calculate various influencing factors of it and consider the middle process, putting forward a beneficial support for system evaluation research. According to the needs of the research object, this paper considers the characteristics of various research methods and chooses the fuzzy comprehensive assessment method as the evaluation method (Qiu, Y. M. 2005, pp. 9-20).

CHAPTER 3

Risk Assessment in Narrow Chanel

3.1 Ensure the Evaluation Index

There are many factors influencing the safety of narrow channel. It will get different evaluation results in different angle. It is also important to select the evaluation index scientifically and reasonably in a comprehensive assessment. The principles are as follows:

3.1.1 Independence and Incompatibility

It is important to make sure that the system is safe and all the indexes should not only reflect the whole, but also have no intersection with each other.

3.1.2 Feasibility and Timeliness

Feasibility mainly means that index could be used conveniently and reliably. Timeliness means that index can fit the changes of time and space to ensure the safety of system.

3.1.3 A Combination of Quantitative and Qualitative Research

Qualitative research can hold the change rule of problems and start with the features of issues by written documents mainly. Quantitative research sometimes starts with the formulation of data and formula, through which we can find the inherent law according to the examples and data provided by qualitative index. So, when the index is selected, this paper considers the principles of index and finishes it in the following steps.

3.1.3.1 According to the Features of Narrow Channel

The features of narrow channel are: curve channel, narrow width, different depth, many shallows, changeable tide, many barriers and complex navigation environment which bring so many problems in ship safety operation.

3.1.3.2 According to the Factors Affecting Navigation

According to some experts opinions about risk analysis, shipping safety are affected by some factors such as human beings, machine, environment and management which is same as narrow channel safety. This paper starts with the four factors above and dissects the proportion of each one in narrow channel. It will consider more about the influencing factors by establishing second and third index which may not have intersection with each other (Guixue, C. 2012).

3.1.3.3 According to the Suggestions from Experts

Qualitative analysis cannot leave the support from experts and employees. What's more, it's the same situation with evaluation indexes which are selected by experts, seafarers and port officers which includes so much acknowledge and experience.

They have authority in their choices which can ensure the weight of indexes. Expert inquiry is a shortcut that is difficult to get in system assessment's process. It will have a big enlightenment through questionnaire survey and interview to solve the problems in qualitative angle. We can make sure the basis of system and main points of operation with experts' help to ensure the systematic indexes.

On the basis of the three points mentioned above, this article gets the factors influencing narrow channel safety. Then, filter the indexes with the special requirements of Laotieshan channel. In the demand of no intersection and systematic decision, this paper makes the assessment in a quantitative and qualitative way including the aspects of the tonnage of ship safety situation, ship age, ship structure strength, ship equipment, emergency reaction level, relative depth, relative width, max steering angle, distance from barriers, channel cross angle, visibility, wind, flow, traffic volume, channel service quality, supportive navigation information and emergency safety level (Wang, F, W. 2012, pp. 21-38).

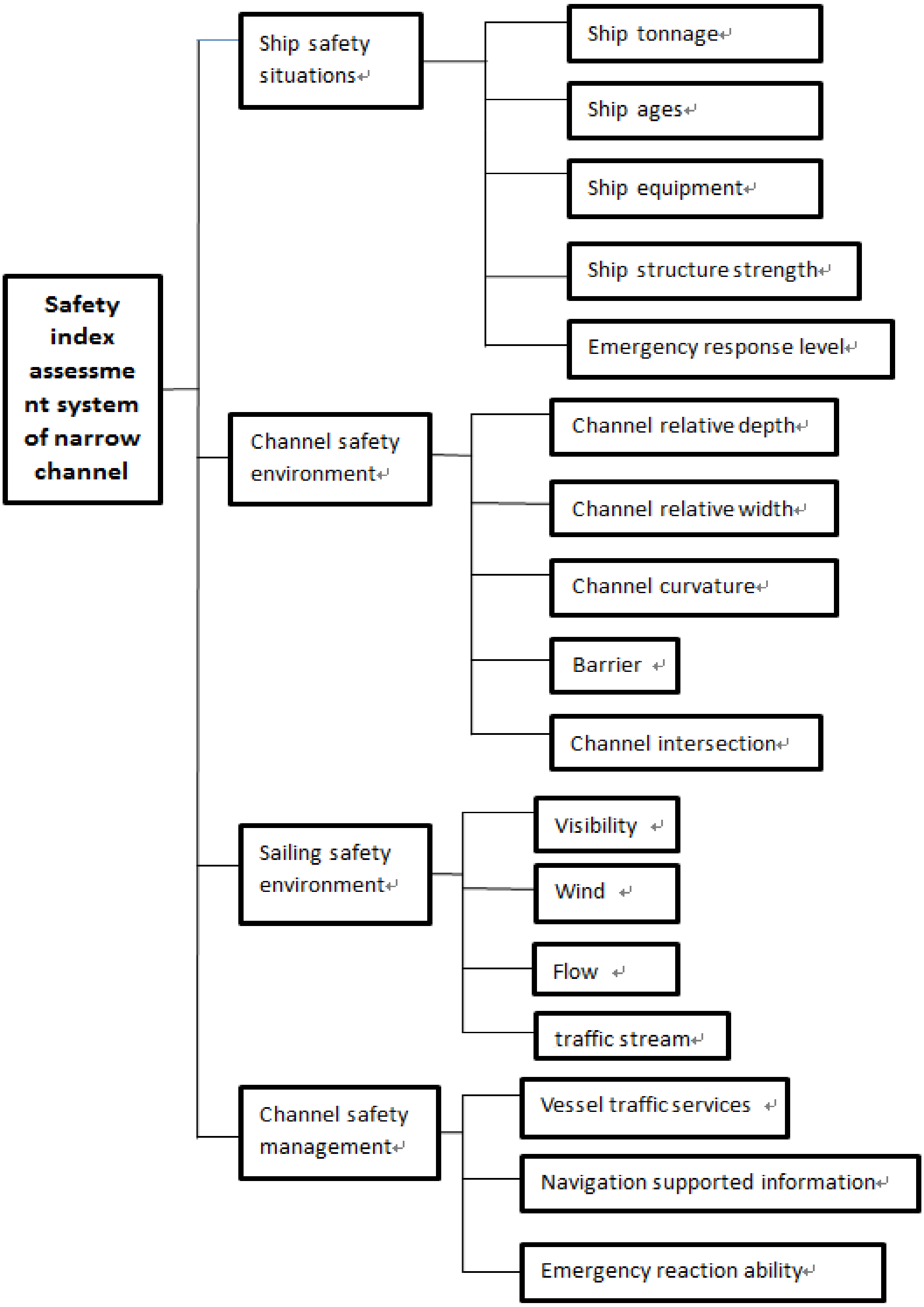

Figure 3.1: Safety index assessment system of narrow channel

Source: Compiled by the author.

3.2 The Analysis of Evaluation Index and Evaluation Standard

3.2.1 Ship Safety Assessment and Evaluation Standard

Man, machine, environment and management are the four factors determining safety. If the ship structure and equipment have hidden dangers, it will directly affect the safety of the whole system. In order to reduce the influence of ship factors, eliminating hidden safety trouble in narrow channel security research is an important link. This section will mainly analyze ship factors with other associated factors from the ship's own inherent physical conditions. It mainly analyzes the ship structure, equipment, ship electronic system and automatic control system. In order to consider the needs of the problems, the technical factors affecting the safety of ship is only for reference. All in all, this section mainly analyzes ship's tonnage, ship age, the strength of ship and the level of emergency response equipment to research the ship system safety (Chen, X. 2006, pp. 29-55).

3.2.1.1. Ship Tonnage

Ship size is directly correlated with the probability of maritime accidents, and the size of a ship is measured by its tonnage and length. When studying maritime accidents, tonnage is usually used to describe the size of a ship. Generally speaking, the bigger the tonnage, the safer the ship, because many statistics by authorities on ship collision probability show that the tonnage of a ship is the leading factor in the occurrence of ship collisions. In this study, the ship tonnage is divided into five levels as is shown in the following chart.

Table 3.1: Evaluation standard of ship tonnage

Standard	Low risk	Slight risk	General risk	Slight high risk risk	High risk
Ship tonnage (t)	Less than 5000	5000~50000	50000~100000	100000~200000	More than 200000

Source: Compiled by the author.

3.2.1.2 Ship Age

Ship age is closely related to the safety of a ship. Statistics have shown that between 1991 and 1995, there were 26 sunken bulk freighters worldwide causing the loss of human lives, and most of those ships exceeded their safe service life, with the youngest being 15 to 16 years of age and the oldest being 23 to 26 years of age. Though for some ships the machinery and equipment can remain good working condition with proper maintenance, generally speaking, the probability of shipwrecks increases along with the aging of a ship. The act of using ships of senior age in active shipping duties for the sake of company's profits undoubtedly raises the danger level of narrow channel shipping. To manage the risks of using old ships on a legal level, there has been an increase in the strength and scope of PSC (Port State Control) inspections for ships exceeding their safe service life. Therefore, it is suitable to use ship age as one of the important indexes for evaluating ship safety. Reference values of ship age evaluation can be seen in the chart.

Table 2.2: Evaluation standard of ship age

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Ship age (year)	Less than 5	5~10	10~15	15~20	More than 20

Source: Compiled by the author.

3.2.1.3 Strength of Ship Structure

The strength of a ship's structure is crucial to its safety. To ensure ship structure strength, the building materials for ships are to meet certain standards first and foremost, and then ships are required to secure quality certification from ship inspection authorities before use. It takes combined efforts of the ship owner and the crew members to maintain a ship's structure strength. The owner of a ship is supposed to provide supplies for ship's daily maintenance, and the ship crews are supposed to take good care of the ship body, reducing external forces upon the ship to the minimum. In reality, often times the ship crew lack the necessary attention to ship structure strength due to their lack of relevant knowledge and awareness for the potential danger that comes with poor ship structure strength. For the purposes of this study, the degree of attrition is considered as the index for measuring ship structure strength.

Table 3.3: Evaluation standard of ship structure strength

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Ship attrition rate	Less than 5%	5%~10%	10%~15%	15%~20%	More than 20%

Source: Compiled by the author.

3.2.1.4 Ship Equipment

Ship equipment includes main engine equipment, rudder equipment, electrical system, navigation and communication system, etc. Failure of any of these equipment or systems will negatively affect a ship's seaworthiness, thus leading to maritime accidents. Though there are measures that can be taken to fix the faulty equipment, it is difficult to completely avoid the accidents stemming from poor equipment. Therefore, the best way to ensure that ship equipment work smoothly and safely is by choosing quality equipment in the first place. However, most shipping companies have both new ships and old ships with fluttering equipment conditions. Some companies even overly extend their ships' service time without proper maintenance, thus contributing to potential equipment-related danger. To ensure safety in the maritime traffic system, it is important to study and ensure ship equipment safety. The average fault-free time is used as the evaluation index for studying ship equipment safety.

Table 3.4: Evaluation standard of ship equipment

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
MTBF(hour)	More than 2500	1500~2500	750~1500	400~750	Less than 400

Source: Compiled by the author.

3.2.1.5 Ship Emergency Reaction Level

With the development of nautical technology and the ever-improving maritime safety regulations and sea crew's qualifications, ship today are much better at preventing danger. However, with a myriad of potential causes for accidents, it is difficult for ships to avoid maritime accidents altogether. People have gradually realized the importance of reacting quickly and actively, by taking measures to reduce damage when accidents happen, thus giving rise to many maritime emergency plans and guides. A ship's emergency reaction level is reflected in the condition of its emergency reaction equipment, its crew's qualifications, its emergency plans and its management quality. A ship's emergency reaction equipment include: survival equipment, fire-fighting devices, pollution abatement equipment, leak proof equipment, telecommunication equipment, etc. The qualifications of a ship's crew include ship managers' management skills and sea crew's experience and adaptability; a ship's emergency plans and management entail its emergency deployment plan, oil pollution emergency plan, emergency drills and emergency training. A ship's emergency reaction safety is a crucial safety factor in traveling in narrow channels. This study uses the ship's emergency reaction readiness as the index for evaluating ship emergency reaction level.

Table 3.5: Evaluation standard of Emergency reaction level

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Level of emergency safety	More than 90%	80%~90%	70%~80%	60%~70%	Less than 60%

Source: Compiled by the author.

3.2.2 Analysis and Evaluation Standards of the Safe Environment of Channels

Narrow channels refer to channels with shallow relative depth or small relative width, thus causing difficulty in maneuvering ships courses. Examples of such channels include: port areas, rivers and lakes, canals, anchorage ground, island and reef areas, mine fields, narrow straits, etc. The particularity of shallow channels causes much trouble for shipping, giving rise to phenomena such as shallow water effect and bank effect. Drawing upon related studies and authoritative opinions, this study holds that the main factors affecting the safety of shipping through narrow channels are relative depth, width and curvature degree of the channels, as well as barriers and channel intersections.

3.2.2.1 Relative Depth of Channels

Relative depth of channels is the ratio of water depth to a ship's sea gauge. As the ratio decreases, a ship will experience various effects such as the shallow water effect. Under keel clearance (UKC) equates depth of navigable waters minus a ship's sea gauge. When UKC is small, a ship will experience an increase in sailing resistance with less speed, more following wake and slight ship sinkage. In extreme cases, a ship may even get stranded. A ship's safety will be compromised due to any of the reasons above.

Table 3.6: Evaluation standard of relative depth

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Relative depth (H/d)	≥10	4~10	2.5~4	1.5~2.5	≤1.5

Source: Compiled by the author.

3.2.2.2 Relative width of Channels

The relative width of a channel is the ratio of the width navigable waters to the length of a ship. The lower the ratio, the more limited the space available for a ship's maneuver, and consequently the ship's ability to change course or stay on course will be affected to various degrees. Experiments with both real ships and model ships suggest that the closer a ship comes towards shore, the narrower the navigable width of the channel becomes, and that the bigger the ship, the more speed it has and the more apparent the bank effect grows. The width of a channel refers to the width of the bottom of the waters a ship sails through. The experiments with model ships passing through canals at 5kn under windless condition suggest that ships with good maneuverability require channel width of 1.6B, and that ships with average maneuverability require channel width of 1.8B, and that ships with poor maneuverability require 2.2B of channel width. When the ratio of off-shore distance to ship width is below 1.5, it is difficult for a ship to stay on course, and the bigger and faster the ship, more apparent the bank attraction and repulsion effects become. Foreign studies on the lengths of large ships show that when the channel width is between 4L and 5L, the nerves of the captain is most relaxed, and that the mental need for channel width also changes with the shipping environment. Drawing upon related studies and keeping in mind the findings above, this study uses the ratio of the narrowest width of navigable channel to ship length as an evaluation index.

Table 3.7: Evaluation of relative width

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Relative width (B/L)	≥15	15~10	10~5	5~2	≤2

Source: Compiled by the author.

3.2.2.3 Channel Curvature Degree

Narrow channels are mostly naturally created by the combined forces of winds, currents as well as environmental and geological changes. Thus, straight channels are pretty rare, thus causing much challenge for shipping. The curvature of channels and the drastically different speed and direction of currents also have huge effects on ships. If a ship sails at a low speed passing through a channel, the currents may push it ashore and make it stranded, but if a ship's speed is too fast, it will experience violent strokes. If the curvature degree of a channel is too great, it will be nearly impossible for ships to pass through, because narrow channels usually have an input lane and an output lane, and the fast change in helm angle will put pressure on ships on the other lane. Also, a slow change in helm angle is also not good for safe shipping. Therefore, it is important to study the curvature degrees of each section of the narrow channel that a ship is passing through beforehand. The curving of channels brings big changes to currents, which limits the degree of a ship's course changing, thus making ship maneuvering much more difficult. It is natural that the curving spot of a channel is likely to be a black spot for maritime accidents. The influence that channel curvature has on ships' safe sailing can be described by steering angles, therefore this study uses the max steering angle in course changing as the danger evaluation index.

Table 3.8: Evaluation standard of channel curve

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk

Max steering angle	Less than 15°	15~30°	30~45°	45~60°	More than 60°

Source: Compiled by the author.

3.2.2.4 Barriers

The main barriers affecting ships' safe sailing in narrow channels or channels in general are shoals, sunken ships, reefs, etc. The existences of barriers create much challenge for ships sailing near forked channels. The number of barriers, the distance between forked channels and the concealedness of barriers are all the factors determining the danger level of barriers. Barriers are divided into natural and man-made ones. With the passing of time, the size and shape of barriers may change or even move along the channels sometimes. Barriers are often latent, ships should be able to locate and keep enough distance from them in time while sailing. Many studies from home and abroad have been done on the influence of barriers on shipping environment using different evaluation indexes. Drawing upon related studies, this study holds that the distance from barriers is the most important factor in safe shipping, while the number of barriers only affects the frequency of shipping activities and has little effect on shipping safety. Considering the subjects of this study, the distance from the nearest barriers is used as the evaluation index.

Table 3.9: Evaluation standard of barriers

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Distance from	≥200	100~200	75~100	25~75	≤25

barriers(m)					

Source: Compiled by the author.

3.2.2.5 Channel Intersection

The intersection and convergence of narrow channels can cause high shipping density in particular areas and difficulty in maneuver. According to relevant studies, when the steering angle is given, the danger level of converging channels is 1/3 to 1/4 that of intersecting channels. So clearly channel intersection is much more dangerous than channel convergence. When studying channel intersection, the intersecting angle and frequency are two factors that are considered. However, in real life cases, channels that intersect frequently are pretty rare, therefore the intersecting angle is the main factor in choosing an evaluation index for channel intersection, and this study uses the largest intersecting angle as an evaluation index. Different intersecting angles come with different collision danger levels. When the intersecting angle is 10 degrees, the danger level is the highest.

Table 3.10: Evaluation standard of channel intersect

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Cross angle	Less than 20°	20°~45°	45°~60°	60°~70°	More than 70°

Source: Compiled by the author.

3.2.3 Safe Shipping Environment Analysis and Evaluation Indexes

A ship's safe sailing is always subject to the influence of weather and sea condition. The size of traffic volume can also affect the danger level of shipping. Shipping environment is described by all external factors that may affect a ship's safe sailing, and these factors mainly include visibility, winds, currents and traffic volume, etc.

3.2.3.1 Visibility

Visibility, the longest horizontal distance within the ability of eyesight in sea, is one of the most important factors in a ship's safe sailing. There are two basic levels of visibility: good and poor. Poor visibility refers to circumstances when visibility is compromised by fog, haze, snow, storm, dust storm, etc. Visibility is crucial to safe sailing. According to relevant statistics, more than 40% of all collision accidents are due to poor visibility. Gradation of visibility can be seen in the following chart.

Table 3.11: Evaluation standard of visibility

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Poor visibility days(day)	Less than 15	15~25	25~40	40~50	More than 50

Source: Compiled by the author.

3.2.3.2 Wind Influence

The larger the tonnage and length of a ship, the more possible it is subject to external forces. According to related studies, when the wind passes level 6, the stronger the wind, the more influence it has on ships' safe sailing by possibly causing maritime accidents such as water penetration, cargo loss and even ship capsizing. Therefore, when studying the shipping environment's influence on safe sailing, wind is considered one of the most important factors. Drawing upon studies done on wind affecting sailing, this study uses the number of days with winds of level 6 or stronger as the evaluation index.

Table 3.12: Evaluation standard of wind

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Standard wind days(day)	Less than 30	30~50	50~100	100~150	More than 150

Source: Compiled by the author.

3.2.3.3 Current Influence

As a natural phenomenon, currents have a huge impact on sailing, which has a lot to do with the area below a ship's waterline. When shipping through Laotieshan channel, because of the rapid difference in current speed and the ever-changing and narrow channel itself, it is usually wise to wait for advection or relatively slow current speed to happen before sailing through the channel. It is obvious that currents have a much bigger influence on narrow channel sailing than wind does, because currents are affected by various factors such as channel terrain, tides and forks and are responsible for the bank effect and splashes. If the current and the bow of a ship have an included angle, as the current speed and flowing pressure angle increase, the ship will tend to move downstream, which is difficult to maneuver. When sailing through a narrow channel, the rudder needs to be handled properly to counterbalance the effects of currents, which may affect other ships' judgment or even cause collision. When calculating and analyzing the effects of currents, current direction and current speed are the two important factors that should be considered. It is a complex task to analyze or discuss current direction, and it has far less influence on ships' safe sailing than current speed. Therefore, this study uses the max current speed as an evaluation index.

Table 3.13: Evaluation standard of current

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Current speed(kt)	Less than 2	2~3	3~4	4~5	More than 5

Source: Compiled by the author.

3.2.3.4 Traffic Volume

Traffic Volume refers to the number of ships passing through a particular area of waters in a particular period of time, which is also the characterizing quantity of ship's density. When the traffic volume increases, the space available for ship maneuvering shrinks. With the already limited space for sailing, when traffic volume reaches a certain point, there will be so much pressure on the ship driver's shoulders that the probability of dangerous accidents rises. The effects of environmental changes on drivers' mental state are undeniable. Therefore, traffic volume is another important factor that influences shipping environment danger level. Ship maneuver space and ship drivers' mental pressure are the two aspects when it comes to analyzing traffic volume's influence on sailing environment. Drawing upon related studies and taking into consideration the subjects, this study uses traffic volume made of ships that exceed 5,000 tons as the evaluation index for sailing environment danger level.

Table 3.14: Evaluation standard of traffic stream volume

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Traffic stream volume(ship/day)	Less than 50	50~100	100~200	200~300	More than 300

Source: Compiled by the author.

3.2.4 Channel Safety Management Analysis and Evaluation Indexes

3.2.4.1 Sea Traffic Management Service

The quality of traffic management service is reflected in its ability to effectively manage ship traffic and increase sailing efficiency. Sea traffic management entails a channel monitor department and traffic management rules. A channel monitor department is specifically set up for all narrow channels. Depending on the needs of the channel, traffic volume, weather condition, etc., the department will manage the channel's traffic by standardizing traffic flow and reducing the probability of ship accidents. The department will also provide ships within its jurisdiction with information on traffic and weather, thus further securing the safe sailing of ship. Also the department has control over ships' sailing and anchoring, keeping a safe sea traffic environment by making ships sail in form. And the traffic management rules are written to standardize ship handlers' operation in accordance with the characteristics of the narrow channel, thus reducing complex and various ship maneuvers, creating order in sea and ensuring that all ships can pass smoothly. Though it is hard to quantitatively describe traffic management service, in light of related studies and expert advice, this study uses the completeness of traffic management service as the evaluation index.

Table 3.15: Evaluation standard of Channel service level

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Channel service quality	More than 90%	80%~90%	70%~80%	60%~70%	Less than 60%

Source: Compiled by the author.

3.2.4.2 Navigation Support Information

For ships sailing through narrow channels, navigation support information refers to service information such as sea chart information and safety facility information. Sea chart information are rectified information and reference materials necessary for safe sailing, including sea chart, navigation warning, harbor guidance, sea route guidance, etc. Safety facility information is information on secure harbor, safety beacons, light towers, etc. The main factors for ships are the navigation support signs and traffic service facility. For narrow channels, it is important to make sure that the number of navigation signs are proper, the lights and shapes are easily recognizable at critical turns. The accuracy of navigation support information and the speed of its reception by the ship handlers are crucial for ship maneuvers and its safety. This study uses the completeness of navigation support information as the evaluation index.

Table 3.16: Evaluation standard of navigation information

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Information integrity level	More than 90%	80%~90%	65%~80%	50%~65%	Less than 50%

Source: Compiled by the author.

3.2.4.3 Emergency Reaction Ability

Due to narrow channels' unique traffic and geological condition, they are critical for local economy and shipping industry. To standardize traffic flow and reduce the risk of accidents, ports and authorities should publish sailing information, accident report, and coordination communications in a timely manner, and when ships are in danger, they should be able to deploy search planes and boats to the rescue. The ability to react, formulate plans, deploy resources in the face of emergencies are really important. With all factors considered, this study uses ports' emergency safety level as the evaluation index for measuring port emergency reaction ability.

Table 3.17: Evaluation standard of port emergency level

Standard	Low risk	Slight risk	General risk	Slight high risk	High risk
Emergency safety level	More than 90%	80%~90%	70%~80%	60%~70%	Less than 60%

Source: Compiled by the author.

3.3 Fuzzy Comprehensive Assessment Model Establishment

When conducting safety assessment, the establishment of a fuzzy comprehensive assessment model is really important. This study uses fuzzy mathematics principles to establish an assessment model suitable for this study.

3.3.1 The Establishment of Comprehensive Assessment Model and Factor Sets

This study uses the gradation discussion method, which is suitable for the establishment of the model.

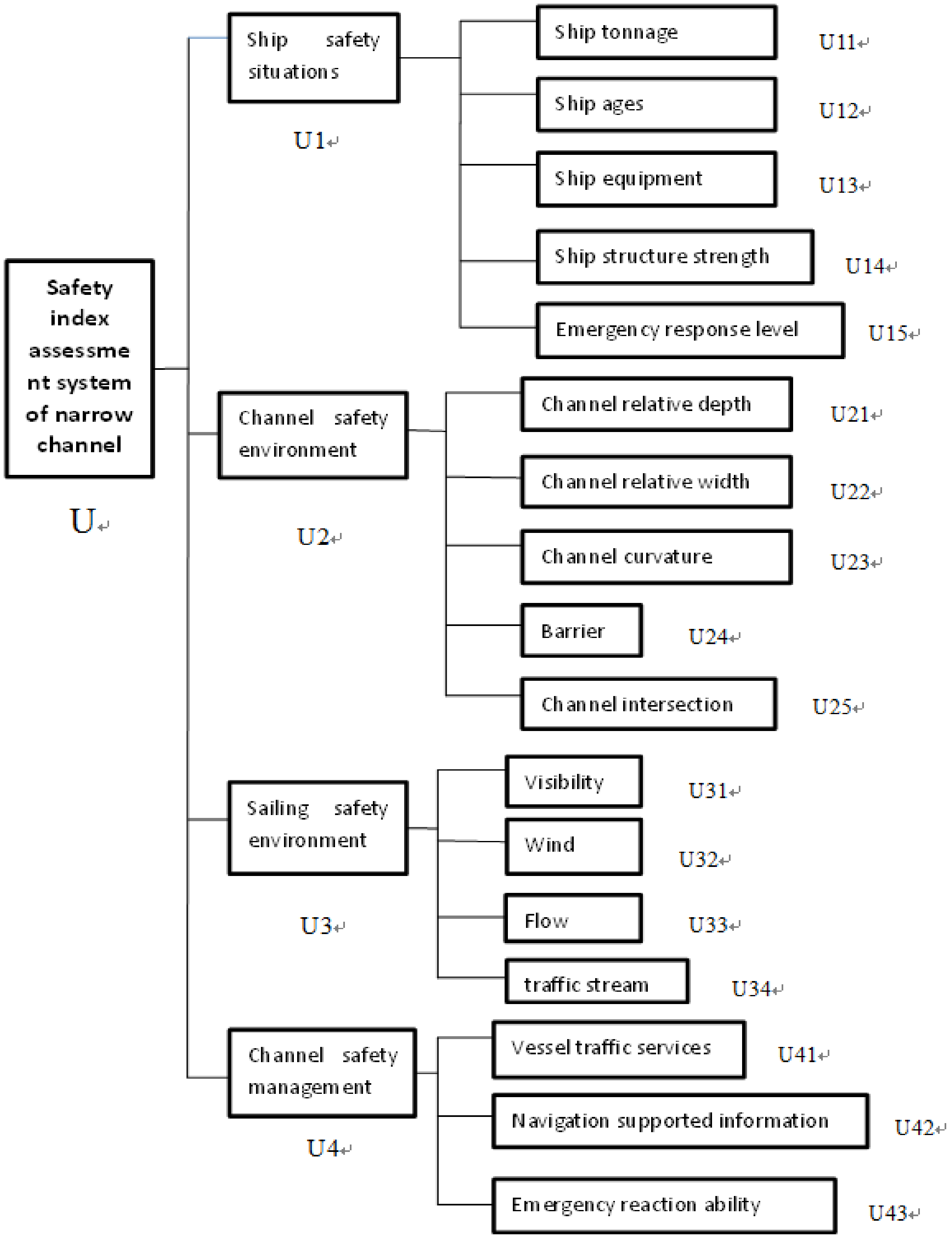

Figure 3.2: The model of safety index assessment system of narrow channel

Source: Compiled by the author.

We can find the comprehensive evaluation setting according to the system as follows:

Safety index of narrow channel：(ship safety, channel safety, shipping safety, channel safety management), expression of math model： $U= (U_1\ U_2\ U_3\ U_4)$.

Ship safety：(ship tonnage, ship age, ship structure strength, ship equipment, ship emergency reaction level), expression of math model： $U_1= (U_{11}\ U_{12}\ U_{13}\ U_{14}\ U_{15})$.

Channel safety：(relative depth，relative width, curvature degree, barriers, channel intersection), expression of math model： $U_2= (U_{21}\ U_{22}\ U_{23}\ U_{24}\ U_{25})$.

Shipping safety：(visibility, wind, current, traffic volume), expression of math model： $U_3= (U_{31}\ U_{32}\ U_{33}\ U_{34})$.

Channel safety management：(traffic management service, navigation support information, emergency reaction ability), expression of math model： $U_4= (U_{41}\ U_{42}\ U_{43})$.

3.3.2 Evaluation Index Weighing

In the mid-70s of the 19th century, an American professor T. L. Saaty raised the level analysis method, which incorporates opinions and suggestions from all sides in accordance to the study subject's needs while combining the quantitative and the qualitative to solve complex multi-factor systems. The method establishes multi-layer systems to analyze indexes by the category and compare them with each other. It establishes a description matrix and then calculates the weighing of each index (Saaty, T. L. 1980). The fundamental steps needed for the level analysis method are as follows:

Establish Structure Model

Divide indexes into objective level, standard level, and to-be-sequenced level, and then establish a level structure for channel safety indices according to the needs of the description system and use second-stage fuzzy comprehensive evaluation model.

Construct Judgment Matrix

After the establishment of the model, the factor values need to be determined. Usually the upper level factors are used as judgment standards, and the lower level factors are compared in pairs to determine the matrix.

B_K	C_1	C_2	⋯	C_n
C_1	C_{11}	C_{12}	⋯	C_{1n}
C_2	C_{21}	C_{22}	⋯	C_{2n}
⋯	⋯	⋯	⋯	⋯
C_n	C_{n1}	C_{n2}	⋯	C_{nn}

The ones on the upper left are the objective factors from the upper level, and those in the vertical and horizontal columns are lower level objective factors. The importance level of C_1 to C_1, B_k is represented by C_{ij} .

To treat judgment needs quantitatively, this study uses Saaty's calibration method.

Meaning	Evaluation

C_i is the same important with C_j	C_{ij} gets the value of 1
C_i is slightly important than C_j	C_{ij} gets the value of 3, oppositely, 1/3
C_i is important than C_j	C_{ij} gets the value of 5,oppositely, 1/5
C_i is more important than C_j	C_{ij} gets the value of 7,oppositely, 1/7
C_i is the most important than C_j	C_{ij} gets the value of 9,oppositely, 1/9
Value 2,4,6,8 and their reciprocal mean the middle values between values above	

Level Sequencing and Consistency Test

Level sequencing refers to sequencing the ratio of the values of this level's factors to the ones on the upper level. The max latent root and eigen vector can be obtained from judgment matrix calculation. The importance of sequencing can be described by eigen vectors and normalized in the end. Due to the complexity of the study subject and different angles, the matrix constructed are not the same. For study's purpose, it is necessary to run consistency test and calculate consistency index CI：

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

Exponent of the judgment matrix is n and the max latent root is λ. To reach a satisfying consistency, new consistency index RI, RI, and their values can be seen in the chart.

Table 3.18: Value of average random consistency index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0. 58	0. 89	1. 12	1. 26	1. 36	1. 41	1. 46

Source: Compiled by the author.

When n＞2, the ratio of consistency index to average random consistency index RI is CR (random consistent ratio): CR=CI/RI

When CR＜0.10, the results have satisfying consistency; Otherwise, it should be calibrated till perfect.

Level Sequencing and Consistency Test

Level sequencing refers to sequencing of values of all factors relative to top level. For the level immediately following the top level, single sequencing of the level is total sequencing. Set up upper level C’s factors as $C_1, C_2, \ldots C_n$, the total sequencing of the level is confirmed, the weighing on each factor is $c_1, c_2, \ldots, c_n$. Corresponding to factor with weighing the lower level D’s factors $D_1, D_2, \ldots, D_m$ single sequencing is $[d_1^k, d_2^k, \ldots, d_m^k]^Q$. Level total sequencing is as follows

C \ D	D_1, D_2, …, D_n d_1, d_2, …, d_n	Hierarchy general ranking of C
C_1	$d_1^1, d_1^2, \cdots, d_1^m$	$\sum_{k=1}^{m} d_k c_1^k$
C2	$d_2^1, d_2^2, \cdots, d_2^m$	$\sum_{k=1}^{m} d_k c_2^k$
…	…	…
Cn	$d_n^1, d_n^2, \cdots, d_n^m$	$\sum_{k=1}^{m} d_k c_n^k$

If C_k and D_1 are not related, then c_k^j is zero, therefore C_k’s total sequencing weighing is $d_k c_n^k$

And apparently, $d_k c_n^k = 1$.

The calculation for consistency test is as follows：

$$CR = \frac{\sum_{k=1}^{m} d_k CI_k}{\sum_{k=1}^{m} d_k RI_k}$$

In the equation, CI_k is the consistency index of d_k's corresponding factors on level C relative to D_k's level's single sequencing. It is the corresponding average random consistency index. When CR＜0.10, the judgment matrix has satisfying consistency, otherwise, it needs to be re-calibrated.

As can be seen from the channel safety index system, different safety indexes have different importance levels; therefore, they are given different weighing. This study uses 1-9 calibration method to compare factors in pairs, creating matrixes of second-tier indexes and first-tier indexes.

（1） Establishing the judgment matrix, there are U-U_i and U_3 –U_{3j}' results (others are shown in appendix B).

Table 3.19: Judgment matrix U-U_i

U				
	U_1	U_2	U_3	U_4
U_1	1	2/3	4/5	4/3
U_2	3/2	1	6/5	2
U_3	5/4	5/6	1	5/3
U_4	3/4	1/2	3/5	1

Source: Compiled by the author.

Table 3.20: Judgment matrix U_3-U_{3j}

U_3				
	U_{31}	U_{32}	U_{33}	U_{34}
U_{31}	1	3/4	3/2	3/5
U_{32}	4/3	1	2	4/5
U_{33}	2/3	1/2	1	2/5
U_{34}	5/3	5/4	5/2	1

Source: Compiled by the author.

（2） Calculations of proper vectors and the U-U_i's vector is

A=[0.2121 0.3323 0.2672 0.1891]

U-U_{3J}'s vector is

A_3=[0.1429 0.2143 0.2857 0.3571]

We can calculate other vectors by this method as follows：

A_1=[0.2323 0.1845 0.1607 0.2750 0.1475]

A_2=[0.1877 0.2133 0.2667 0.1467 0.1856]

A_4=[0.3403 0.4080 0.2517]

3.3.3 Comprehensive Evaluation Model Establishment

Suppose V={V1,V2,⋯,VQ} is the set of Q judgments, making it the judgment set, this study divides second-tier index danger degree into five levels, and the judgment set of the five levels is V={V1,V2，V3，V4，V5}={low danger，relatively low danger，danger，relatively high danger，high danger}, with corresponding value ranging from 0.5~1.5,1.5~2.5,2.5~3.5，3.5~4.5,4.5~5.5, definite value can choose 1,2,3,4,5, which can form fuzzy membership function as follows:

$$f_1(x)=\begin{cases} 1 & 0 \le x < 0.5 \\ (1.5-x)^2 & 0.5 \le x < 1.5 \\ 0 & x \ge 1.5 \end{cases}$$

$$f_2(x)=\begin{cases} 0 & 0 \le x < 0.5 \\ (x-0.5)^2 & 0.5 \le x < 1.5 \\ 1 & 1.5 \le x < 2.5 \\ (3.5-x)^2 & 2.5 \le x < 3.5 \\ 0 & x \ge 3.5 \end{cases}$$

$$f_3(x)=\begin{cases} 0 & x < 1.5 \\ (x-1.5)^2 & 1.5 \le x < 2.5 \\ 1 & 2.5 \le x < 3.5 \\ (4.5-x)^2 & 3.5 \le x < 4.5 \\ 0 & x \ge 4.5 \end{cases}$$

$$f_4(x)=\begin{cases} 0 & x<2.5 \\ (x-2.5)^2 & 2.5 \le x < 3.5 \\ 1 & 3.5 \le x < 4.5 \\ (5.5-x)^2 & 4.5 \le x < 5.5 \\ 0 & x \ge 5.5 \end{cases}$$

$$f_5(x) = \begin{cases} 0 & x<3.5 \\ (x-3.5)^2 & 3.5 \le x < 4.5 \\ 1 & x \ge 4.5 \end{cases}$$

Taking into consideration the experts' opinions on safe sailing and sorting through the second-tier factors that correspond the first-tier indices, we obtain D=（D1，D2，D3，D4）, and then after calculation of the above fuzzy membership function, we obtain membership degrees for each factor. Fuzzy relationship matrix is as follows:

$$R_1=\begin{bmatrix}R_{11} & R_{12} & R_{13} & R_{14} & R_{15}\end{bmatrix}=\begin{bmatrix} r_{111} & r_{121} & r_{131} & r_{141} & r_{151} \\ r_{112} & r_{122} & r_{132} & r_{142} & r_{152} \\ r_{113} & r_{123} & r_{133} & r_{143} & r_{153} \\ r_{114} & r_{124} & r_{134} & r_{144} & r_{154} \\ r_{115} & r_{125} & r_{135} & r_{145} & r_{155} \end{bmatrix}\begin{matrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{matrix}$$

$$R_2=\begin{bmatrix}R_{21} & R_{22} & R_{23} & R_{24} & R_{25}\end{bmatrix}=\begin{bmatrix} r_{211} & r_{221} & r_{231} & r_{241} & r_{251} \\ r_{212} & r_{222} & r_{232} & r_{242} & r_{252} \\ r_{213} & r_{223} & r_{233} & r_{243} & r_{253} \\ r_{214} & r_{224} & r_{234} & r_{244} & r_{254} \\ r_{215} & r_{225} & r_{235} & r_{245} & r_{255} \end{bmatrix}\begin{matrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{matrix}$$

$$R_3=\begin{bmatrix}R_{31} & R_{32} & R_{33} & R_{34}\end{bmatrix}=\begin{bmatrix} r_{311} & r_{321} & r_{331} & r_{341} \\ r_{312} & r_{322} & r_{332} & r_{342} \\ r_{313} & r_{323} & r_{333} & r_{343} \\ r_{314} & r_{324} & r_{334} & r_{344} \\ r_{315} & r_{325} & r_{335} & r_{345} \end{bmatrix}\begin{matrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{matrix}$$

$$R_4=\begin{bmatrix}R_{41} & R_{42} & R_{43}\end{bmatrix}=\begin{bmatrix} r_{411} & r_{421} & r_{431} \\ r_{412} & r_{422} & r_{432} \\ r_{413} & r_{423} & r_{433} \\ r_{414} & r_{424} & r_{434} \\ r_{415} & r_{425} & r_{435} \end{bmatrix}\begin{matrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{matrix}$$

The fuzzy comprehensive evaluation process is as follows:

First step: conduct single factor fuzzy evaluation, confirming $U_1U_2U_3U_4$ relative to level V’s membership function. The specifics are as follows:

If $T_i=A_i\bullet R_i^T$, i=1,2,3,4

Then $T=[T_1\ T_2\ \dots T_4]$

Or $U_1U_2U_3U_4$'s membership function relative to level V

It can be found by calculating：

$$T=\begin{bmatrix} t_{11} & t_{21} & t_{31} & t_{41} \\ t_{12} & t_{22} & t_{32} & t_{42} \\ t_{13} & t_{23} & t_{33} & t_{43} \\ t_{14} & t_{24} & t_{34} & t_{44} \\ t_{15} & t_{25} & t_{35} & t_{45} \end{bmatrix} \begin{matrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{matrix}$$

Second step: confirm U's membership vector relative to evaluation set V through constructing fuzzy matrix, the specifics are as follows:

Make $B=A\bullet T^T$

Then B is the membership vector of U relative to evaluation set V.

Third step: use max membership degree principle to determine a channel's danger level.

CHAPTER 4

Risk Assessment of Laotieshan Channel

4.1 Natural Condition of Laotieshan Channel

Laotieshan channel starts from Laotieshan of Liaotung peninsula to Beihuang island with about 20nm in width and 39m to 68m in depth. However, the narrowest waterway of it is only about 2nm except military no-navigate zones in north and south. It is the only way of passage in Bohai gulf water, known as the throat of Bohai gulf.

Figure 4.1: Map of Laotieshan channel

4.1.1 Temperature Condition

Apart from latitude difference, the temperature of Bohai Sea also varies between land and sea. The temperature changes gently and descends successively from south to north and from east to west. The annual average temperature is 8℃ to 10℃. The average temperature for January is -6℃ to -8℃ and for July is 22℃ to 24℃. The sea temperature of the area is under 28℃ in summer. The offing temperature is not high and only when land wind blows constantly, the temperature of the sea surface along the coast will rise to 30℃ to 35℃. In winter, the temperature drops to -10℃ to -15℃ due to the invasion of strong cold air.

4.1.2 Wind Condition

Bohai Sea shows obvious monsoon characteristics. Winter monsoon lasts for 6 months from October to March in the following year. The monsoon is mainly northerly wind, particularly northwesterly wind, which is strong in power and stable in direction. Summer monsoon is from May to August in which July and August are the heyday. It is mainly southerly wind, especially southeasterly wind, which is not strong and unstable. Due to geographical constraints of Bohai Sea, southeasterly monsoon is not obvious and there is a transition period between winter monsoon and summer monsoon. The transition period from winter to summer is long and from summer to winter is rather short (Zhao, N. 2013, pp. 38-45).

The wind power conditions of Bohai Sea are as follows: the wind of northern water is stronger than that of southern waters and the wind of open seas are stronger than that of coastal areas. This is mainly because of pressure gradient and friction between land and sea. From the perspective of seasonal distribution, winter monsoon is the strongest, especially in January, with an average scale of five. Spring and summer monsoon rank after winter monsoon and when it comes to autumn, the wind begins to build. In terms of geographical distribution, the wind of Bohai Strait is stronger than that of western coastal waters. The average wind power of Liaodong Bay is strongest in spring but the maximum value appears in November. The average wind power of August is at the scale of three. The average wind power of Bohai west bank is strongest in spring, especially in April, with the scale of three to four. Winter ranks the second and August is the weakest, with an average of force three. The average wind power of Changxing Island and Bohai Strait is strongest in the end of autumn and in winter, with a monthly average of force four to five, followed by spring and summer, with an average of force two to three.

Windy weather is the main disastrous weather in Bohai Sea area. Storms mainly appear from October to March in the following year and the main causes are cold high, extra-tropical cyclone and tropical cyclone. According to statistics, the average time with strong wind that are over force eight is around 60 days. In terms of season, storms happen all the year round and are strongest in winter and most frequent in spring. Since the first cold windy day of every winter, ships navigating in Bohai Sea are likely to be troubled in danger and accidents due to the lack of prevention. Therefore, before the first cold windy day of every winter, Maritime Safety Administration of Ministry of Transport will remind passing ship owners and ships to treat the weather with the standard of preventing typhoon. Strong winds are frequent, stable and long lasting in winter. Southerly wind and northerly wind blow alternately in spring and shows clear periodicity. The wind is normally at the scale of six to eight and does not last long. Strong winds are common in summer and are mainly caused by typhoon and cyclone. Inconstant thunderstorms also lead to windy days, but often in a small scale and short duration. According to meteorological data of Bohai Sea in last 30 years, typhoon weather happened once in June, most often in July, sometimes in August and seldom in September. Since autumn, the number of windy days increase and strong northerly wind comes along with the southward of cold air. From the perspective of geographical distribution, under the same weather system, the wind of Bohai Strait is one to two force stronger than other areas. When cold air goes across Northeast Plain from Inner Mongolia, with the influence of Changbai Mountain, it runs southwesterly along the western foot of Changbai Mountains, passes Liaodong Peninsula and goes into the northern part of Bohai Sea and Yellow Sea. The cold air often arouses northeastern wind at the scale of six to seven. When cold air moves from inland to coast and is blocked by mountains, it arouses air turbulence, causing the near sea wind inconstant and unstable in power and direction (Zhao, N. 2013, pp. 15-37).

4.1.3 Fog Condition

Sea fog is the key factor that influences the visibility of sea areas. March to July is the fog season of the year. Sea fog starts in March, sometimes in February and begins to increase until reaching its maximum in June and July. Annual foggy time is 20 to 24 days. Sea fog plays an important role in safety navigation. More than half of the ship collisions happen in foggy days with low visibility. When Laotieshan meets extremely foggy days, the offshore visibility is less than 100 meters and thus has high requirements for ships in manipulating collision avoidance. Ships navigating in this area have to be extremely careful and stay in close contact with VTS Center. By analyzing the meteorological data collected from Dalian VTS Center, the report of the poor invisibility days of Laotieshan Channel is as follows:

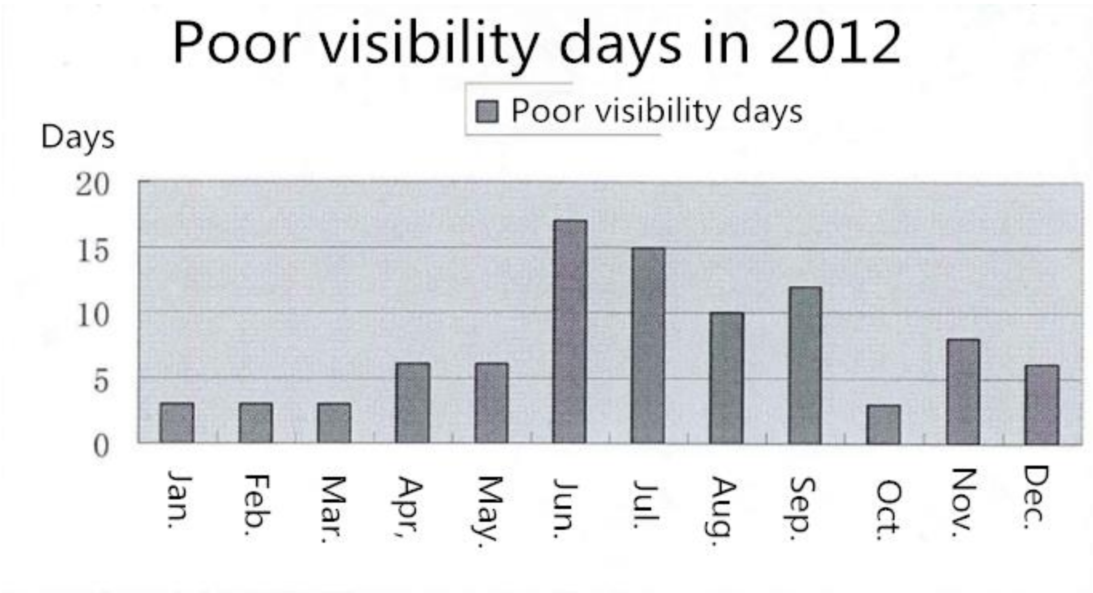

Figure 4.2: Chart of poor visibility days in 2012

Source: Fan, J. (2012). *Routeing Design and Analysis in the Precautionary Area of Laotieshan Channel*. Dalian, China: Dalian Maritime University Press.

4.2 Restricted Navigation Areas of Laotieshan Channel

On the north side of Laotieshan Channel, there is Laotieshan Channel West Point Lighthouse and on the south is the Beihuang Island Lighthouse. The straight-line distance between the two is 22.5 nautical mile. But there are two military restricted navigation areas in southern and northern waters respectively. Specific locations are as follows:

Take Laotieshan Channel West Point Lighthouse as the center and draw an arc with radius of 10 nautical miles. The fold line and the arc enclose an area that prohibits the navigation of domestic and foreign merchant ships.

① 38°47’07”N， 121°08’27”E；

② 38°47’07”N, 121°01’03”E；

③ 38°35’19”N, 121°01’03”E。

Take Beihuang Island Lighthouse as the center and draw a circle. The enclosed area is restricted for the navigation of domestic and foreign merchant ships. Because of military restricted areas, the width of navigable waters is reduced from 22.5 nautical miles to 5.5 nautical miles. Under the traffic separation scheme, there is a median strip, making two channels of 2.25 nautical miles in width, one to the west on the northern side and the other to the east on the southern side. Military restricted navigation areas reduce the usable area for ships, making Laotieshan Channel one of the most crowded channels in China and forming a special navigating mode. Large number of ships from different directions gathered in the center of the channel, causing huge pressure to the navigation, especially in the west waters of the channel. In this area, the tracks are complex and ships cross carefully and thus needs further planning and integration.

4.3 The Routing System and Reporting System of Laotieshan Channel

4.3.1 The Routing System of Laotieshan Channel

The routing system of Laotieshan Channel regulates and organizes the navigation of the ships with traffic separation system and precautionary area. When the routing system is carried out, Laotieshan Channel with 5.5 nautical miles in width are divided into two channels of 2.25 nautical miles in width and 12 nautical miles in length by a median strip which is 9 nautical miles in length and 1 nautical mile in width. Ships from Yellow Sea to Bohai Sea run in northern channel and ships from Bohai Sea to Yellow Sea run in southern channel. The mainstream of the previous channel is 300° and of the latter one is 120°, meeting the common navigation courses of most ships. Because in the west port of Laotieshan Channel, there are ships coming from or going to Tianjin, Qinhuangdao, Bayuquan, Jingtang, Jinzhou, etc, routing system sets a precautionary area with a radius of 5 nautical miles in order to remind the passing ships of careful driving. The following is the map of Laotieshan Channel routing system.

Figure 4.3: Map of Laotieshan ship separation scheme

Source: Fan, J. (2012). *Routeing Design and Analysis in the Precautionary Area of Laotieshan Channel*. Dalian, China: Dalian Maritime University Press.

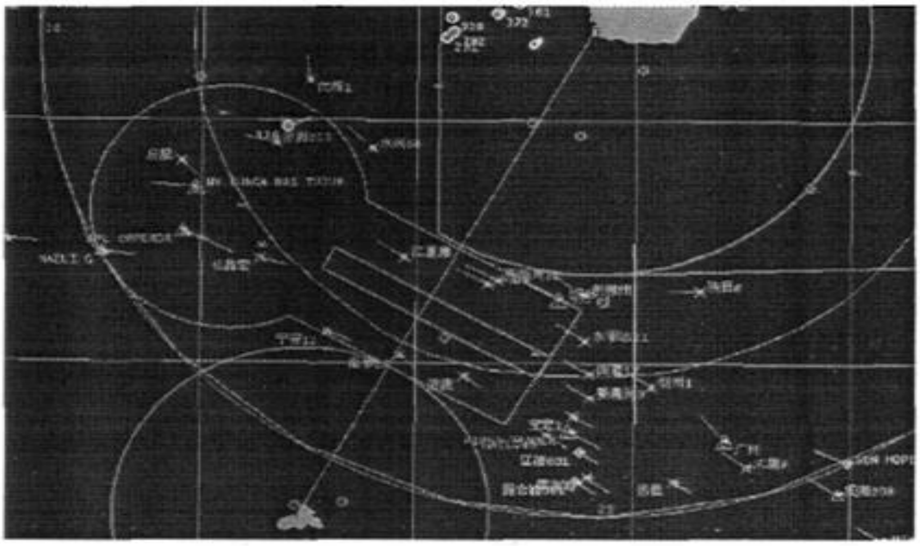

Figure 4.4: Radar observing of Laotieshan channel

Source: Zhao, N. (2013). *The Vessel Traffic Capacity in Laotieshan Channel*. Dalian, China: Dalian Maritime University Press.

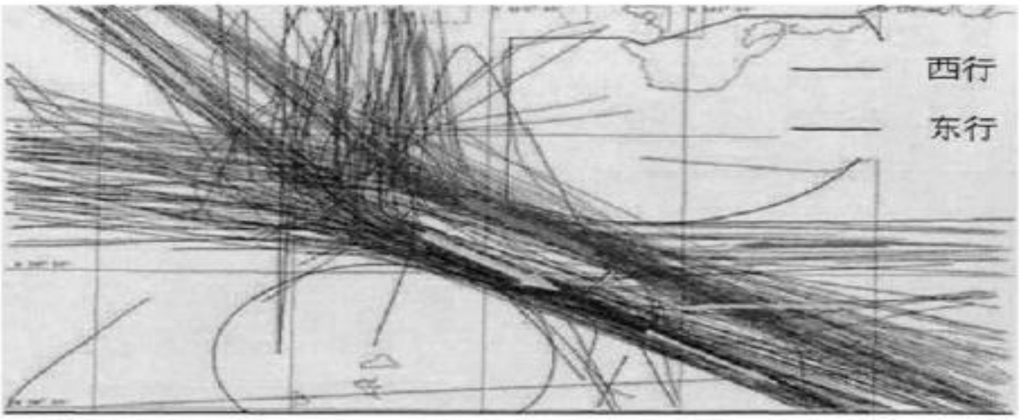

Figure 4.5: Ship track distribution of Laotieshan channel ship routing system.

Source: Miao, H, L. (2010). *Study and Evaluation of the Difficulty in Shipping Operation*. Unpublished master's thesis, Dalian Maritime University, Dalian, China.

4.3.2 Reporting System of Laotieshan Channel

‘Reporting system of ships in Laotieshan Channel

1. Applicable ships

Any ship that meets the requirement of Laotieshan Channel and the following rules:

1.1. Passenger ships

1.2. Any ship that is or above 300 tons

1.3. Ships under 300 tons that are willingly to join the reporting system

2.Applicable geographical areas and numbers and versions of related sea charts

2.1. Applicable area is a circle sea area centered on Laotieshan Lighthouse (38°43′37″N/121°08′02″E), with radius of 20 nautical miles.

2.2. Related sea charts: sea charts of Chinese version 11910、10011、11010、11300、10116、 10112, etc.

3. Report form, contents and requirements

3.1. Report form

The form of the report is the format prescribed in the supplementary of IMO A.851(20) meeting.

3.2. Report contents

A: Ship name, call-sign, maritime mobile service identities (if applicable)

C Or D: location (latitude and longitude or relative position to a landmark)

E: course

F: Speed

G: Departure port

I: Destination

O: Drawbacks and limitations (tugboat should report the name and length of the tow)

U: Overall length and gross tonnage

3.3 Report requirements

3.3.1. When ships entering the reporting system area, apart from reporting all information in 3.2, they should report the nationality and type of the ship to Dalian VTS Center.

3.3.2. Ships should report the ship name when living the area.

3.3.3. Once traffic accidents or pollution incidents happen in the area, ships should report the type, time location, damage and pollution condition of the accidents and whether they need assistance. They should also report other information related to the accident according to the requirements of competent authorities.

4. Competent authority and report-operating authority

4.1. Competent authority is Maritime Safety Administration of the People's Republic of China.

4.2. Report-operating authority is Dalian VTS Center.

5. Providing information for ships

Dalian VTS Center should provide information including vessel traffic, weather conditions and maritime safety for ships that join the reporting system.

6. Calling channels and language used in reporting system

6.1. The channel of Dalian VTS Center is VHF10.

6.2. Reporting language is Mandarin or English and radiotelephone communications should use format prescribed by marine communication.

7. Shore-based facilities supporting the reporting system

7.1. Dalian VTS Center has radar system, VHF telecommunication system, information processing and displaying system, information transferring, recording and reproducing system and meteorological sensors. They can be used for data collection, assessing and processing, information offering, transport organizing, navigation supported information and joint action.

7.2. Dalian VTS Center is on duty for 24 hours every day.

8. Specialized rules

8.1. Ships that use Laotieshan Channel routing system should listen to channel VHF10 and VHF16 and follow the rules by Maritime Safety Administration of the People's Republic of China Dalian Maritime Safety Administration vessel traffic management system safety supervision management and regulations.

8.2. Ships using the routing system should not across channels. If they have to, they should report to Dalian VTS Center to get the permission.

8.3 For those who disobey the rules, competent authority should punish the ship with fine according to related regulations' (MSA, 2016, website).

4.4 The Characteristics of Ship Traffic Flow of Laotieshan Channel

This thesis illustrates the traffic flow form of Laotieshan Channel by using ship traffic flow distribution, track classification, traffic flow graph, etc. The result shows the characteristics of ship traffic flow of Laotieshan Channel:

4.4.1 High Traffic Density

Because of the military restricted navigation areas on both southern and northern sides, the width of navigable waters of Laotieshan Channel is reduced from 22.5 nautical miles to 5.5 nautical miles. In 2007, the daily average traffic flow is 215 ships and the hourly average traffic flow is 9 ships. This leads to high traffic density for the busy Laotieshan Channel which is only 5.5 nautical miles in width. It is expected that the daily average traffic flow is 288 ships and the hourly average traffic flow is 12 ships in 2015. Due to the limitation of information, this thesis divides the gross tonnage of passing ships in Laotieshan Channel in 2010 and 2011 by the total number of ships and gets a standard data. In 2010, the number of ships is 84799, the average length of the ship is 144 meters and the average tonnage is 14100 tons per ship; in 2011, the number of ships is 85579, the average length of the ship is 149 meters and the average tonnage is 14600 tons per ship. Thus, 145 meters and 14500 tons per ship are chosen as the standard.

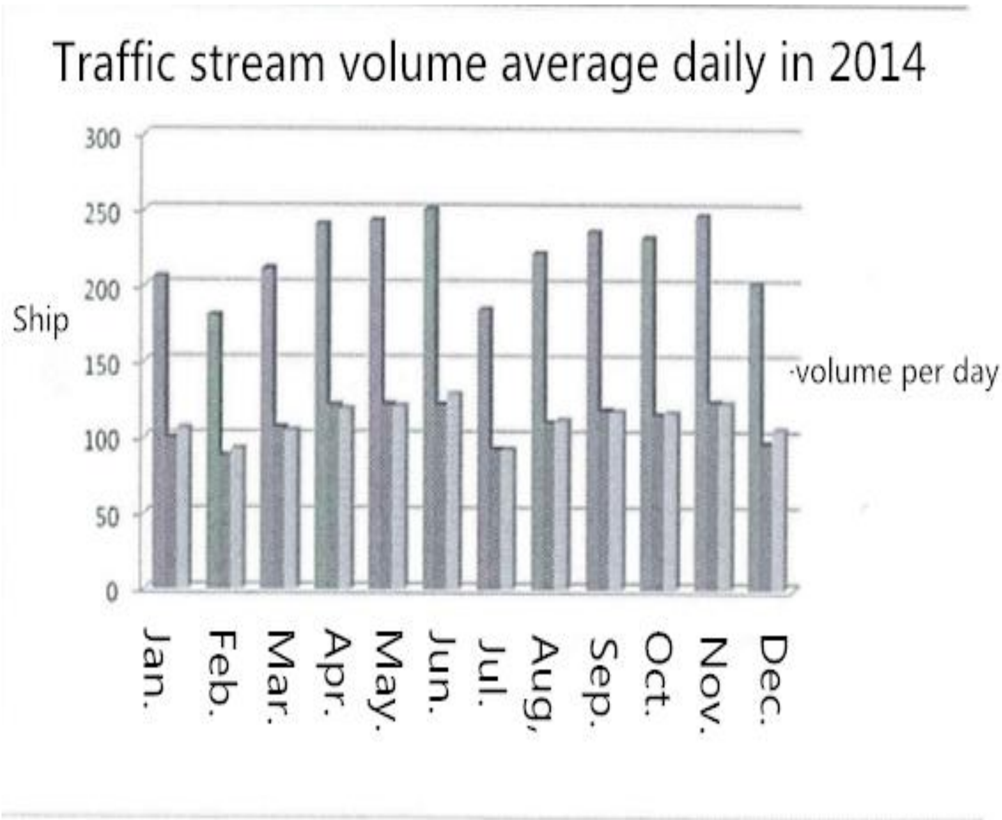

Figure 4.6: Average daily flow diagram of ships passing Laotieshan Channel in 2014

Source: Wan, H. (2014). The Research of traffic Volume in Laotieshan Channel. *Tianjin Navigation*, 2, 14-15.

4.4.2 The Conflict Conditions of Ships Are Obviously

The ship traffic of Laotieshan Channel is mainly composed of ships coming in and going out the Bohai Sea from east to west. The survey shows that the trend of ships to the east and west are basically the same, meaning that it is more likely to have conflicts between ships to the east and west, and gather in small areas (Xie, Y. H. 2008, pp. 16-20).

4.4.3 Tracks of the West Port Are Complex and of the East Port Are Simple.

The main course of ships entering from the east is 300°. Ships have to change direction before entering the channel. The main course of ships going out of the east is 120°. It is far more complex for ships to enter from the west than the east. Some obvious courses are 100°, 135° and 180° and the main courses of ships going out of the west are 280°, 300°, 320° and 360°. The analysis of the Laotieshan Channel watercourse report also shows that the hazard is that passenger ships and train ferries to and from Dalian Lvshun New Port and other ports in Jiaodong are vertical to previous ship courses. Meanwhile, there are numbers of fishing vessels working or parking in Laotieshan Channel, increasing the accidents in this area.

Figure 4.7: Distribution of fishing boats in Laotieshan channel

Source: Xie, Y. H. (2008). *Performance Evaluation of Ship's Routine in Laotieshan Waterway*. Dalian, China: Dalian Maritime University Press.

4.5 The setting of Laotieshan Channel evaluation index

Factors that affect the safety of Laotieshan Channel includes ship safety, channel security environment and channel security management. Chapter three poses analysis and research on narrow channel safety and builds an evaluation mode for narrow channel safety. This chapter quantifies different factors in order to evaluate channel safety. On the basis of investigating, analyzing and arranging large amounts of data, the thesis works out the index value and related data of Laotieshan Channel safety evaluation. Then, experts have to grade the index value according to the evaluation mode, the graph is shown as follows:

Table 4.1: Index value of Laotieshan channel

Evaluated objects	Evaluated target	Index of target	Unit	Quantized value
Ship tonnage	Average tonnage of ships in channel	14500	Tonnage	3.7
Ship age	Average age of ships in channel	15	Year	3.5
Ship structure strength	Ship attrition rate	16%	------	3.7

Ship equipment	Mean time between failures (MTBF)	720	Hour	3.6
Emergency reaction level	Ability of emergency reaction	75%	------	3.0
Relative depth	Depth of channel/ship max draft	2.5	------	3.5
Relative width	Width of channel/ship length	13.5	------	3.0
Max steering angle	The max steering angle in channel	20	Degree	1.8
Distance from barriers	The nearest distance from the barriers	80	Meter	3.3
Channel cross angle	The max angle from two fairways	30	Degree	2.1
Visibility	Poor visibility days	92	Day/year	5.0
Wind	Standard wind days	108	Day/year	3.7

Flow	Max flow speed in channel	6.5	Knot	5.0
Traffic volume	Traffic stream volume in channel per day	288	Ship/day	4.4
Channel service quality	Traffic management integrity level	90	------	1.5
Navigation supported information	Navigation marks integrity level	95	------	1
Emergency safety level	Emergency safety level	90	------	1.5

Source: Compiled by author.

4.6 The Risk Assessment of Laotieshan Channel

On the basis of chapter 3 (comprehensive assessment model), chapter 4 does the risk assessment of Laotieshan channel.

D1={3.7 3.5 3.7 3.0}

D2={3.5 3.0 1.8 3.3 2.1}

D3={5.0 3.7 5.0 4.4}

D4={1.5 1.0 1.5}

Take these values and the matrix proper vectors in chapter 3 into the comprehensive assessment model, we can find 5 grades of membership of each affected factor. The fuzzy relation matrixes are as following.

$$R_1=[0.2323 \quad 0.1845 \quad 0.1607 \quad 0.2750 \quad 0.1475]\begin{bmatrix}0 & 0 & 0.16 & 1 & 0.04\\ 0 & 0 & 1 & 1 & 0\\ 0 & 0 & 0.16 & 1 & 0.04\\ 0 & 0.01 & 0.81 & 1 & 0.01\\ 0 & 0.25 & 1 & 1 & 0\end{bmatrix}$$

$$=[0 \quad 0.40025 \quad 0.8062 \quad 1 \quad 0.02]$$

$$R_2=[0.1877 \quad 0.2133 \quad 0.2667 \quad 0.1467 \quad 0.1856]\begin{bmatrix}0 & 0 & 1 & 1 & 0\\ 0 & 0.25 & 1 & 0.25 & 0\\ 0 & 1 & 0.09 & 0 & 0\\ 0 & 0.04 & 1 & 0.16 & 0\\ 0 & 1 & 0.36 & 0 & 0\end{bmatrix}$$

$$=[0 \quad 0.511493 \quad 0.518891 \quad 0.334913 \quad 0]$$

$$R_3=[0.1429 \quad 0.24143 \quad 0.2857 \quad 0.3571]\begin{bmatrix}0 & 0 & 0 & 0 & 1\\ 0 & 0 & 0.16 & 1 & 0.04\\ 0 & 0 & 0 & 0 & 1\\ 0 & 0 & 0.01 & 1 & 0.81\end{bmatrix}$$

$$=[0 \quad 0 \quad 0.1580862 \quad 0.59853 \quad 0.7275082]$$

$$R_4=[0.3403 \quad 0.4080 \quad 0.2517]\begin{bmatrix}0 & 1 & 0 & 0 & 0\\ 0.25 & 0.25 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0\end{bmatrix}$$

$$=[0.085075 \quad 0.694 \quad 0 \quad 0 \quad 0]$$

So, we can calculate the T according to the results above

$$T=[0.2119 \quad 0.3302 \quad 0.2693 \quad 0.188]\begin{bmatrix} 0 & 0.40 & 0.80 & 1 & 0.02 \\ 0 & 0.511 & 0.52 & 0.33 & 0 \\ 0 & 0 & 0.16 & 0.60 & 0.73 \\ 0.01 & 0.09 & 0 & 0 & 0 \end{bmatrix}$$

$$=[0.0018 \quad 0.3832 \quad 0.3843 \quad \underline{\mathbf{0.4824}} \quad 0.2023]$$

According to the last passage, the max grade membership value in the results is 0.4824 and it seats in the district of [3.5~4.5] which means a slightly high risk. So, it shows that Laotieshan channel is in a slight high risk level.

4.7 Suggestions on Laotieshan Channel Improvement

According to previous evaluation, it is clear to see that Laotieshan Channel is at high-risk. It can be found from the evaluation index that channel security management has little influence on channel security while the speed, visibility, flow and traffic volume pose greater risk on channel security. In order to improve the channel safety, this thesis carries out constructive suggestions from the perspective of navigation measures and channel management.

4.7.1 For Conditions of the Ship

Ships in Laotieshan Channel are various in number, type and course due to the important geographical location of Laotieshan Channel, which has a great impact on the navigation environment of the strait. Most ships passing Laotieshan Channel are more than10 years and often with poor ship structure strength and equipment. In order to guarantee the security of ships and the channel, channel security authorities should focus on the reporting system, grasp the age of the ship and checking information, evaluate the safety of passing ships on time, offer more detailed security information, guide the ship through the strait and pilot forcibly and limit passage if necessary (Zhou, Z. 2005). For underway ships, pilot and captain are asked to check the security equipment before entering the channel in order to reduce the influence caused by machines or equipment. They should clearly know the information of the strait and navigation and send somebody to watch and make emergency plans when necessary. Besides, they should choose the right opportunity of passing the strait and make contact between the bridge and the cabin, strengthening cooperation and reducing collaborating mistakes.

4.7.2 For Navigation Environment

Visibility, wind, flow and traffic volume are subjective factors. The daily shipping volume is more than 300 and such big volume becomes the main factor of maritime accident. The geographical location and channel terrain of Laotieshan Channel lead to great trend change with maximum of 6 kt and thus is difficult to control. However, measures can be carried out to reduce the influence. Channel security authorities should release hydro meteorological information according to the change of visibility, wind and flow. Then they should divert traffic by traffic restrictions based on the size and tonnage of passing ships. Pilots and captains should seek for the right opportunity and measures of passing the strait by knowing the voyage plan and draft status of the ship. By checking *Tide Table, Sailing Directions and Inbound Guide*, pilots and captains know the safety information of the channel and by listening to the prescript channel, they make contact with maritime VTS center on time and accept all kinds of advice and guidance. Before entering Laotieshan Channel, ships should control the sailing speed, grasp the right opportunity and avoid passing in jet stream.

Ships should be well prepared before entering the channel, including preparation of vehicles and rudder, checking the lights, shapes and code flag (Fan, J. 2012, pp. 21-34).

4.7.3 For Channel Management

Dalian Maritime VTS Center is responsible for security and information service of Laotieshan Channel. Navigation beacons and strait tide signal board are set in the channel in order to carry out reporting system among passing ships. These measures highly improve the navigating environment of the strait channel. With the increase of trade volume and fast development of science and technology, authorities should highly improve the channel efficiency based on its actual conditions. The center is able to guide and restrict the traffic if necessary by video surveillance of the ships and making security navigating plan under the requirement of the ship. Besides, it should maximize the emergency safety level of the channel, make plan in advance and remedy after the accident. As ship pilot and captain, they should grasp the navigating environment and put security information into practice, take avoiding actions in advance, and consider the influence caused by car steering effect and navigate the ship carefully (Chen, W. J. 1998).

CHAPTER 5

Conclusion

Laotieshan Channel owns important shipping status. But the various ship types and complex navigating and channel environment pose great threat to navigating security. This thesis focuses on the research of the security evaluation of Laotieshan Channel. From the perspectives of ship security, channel security environment, navigating security environment and channel security management, the thesis establishes a narrow channel security evaluation system by finding and organizing relevant information and asking expert for advice. Besides, it also determines the judging criteria for the evaluation index, weights out every index by using AHP and establishes the narrow channel security evaluation system by fuzzy comprehensive evaluation. The thesis carries out the evaluation system on Laotieshan Channel and the results coincide with actual conditions. According to the evaluation results, the thesis makes security suggestions for ships passing Laotieshan Channel and also makes suggestions on more scientific supervision for Laotieshan Channel security management authorities. Domestic and foreign literatures have various demonstrations on channel security and evaluation methods. Although this thesis has a relatively comprehensive evaluation index on narrow channel security and membership and weights of each index are based on actual situation, the calculation results may be objective and model structure may have shortage due to the limitation of my personal ability. I am looking forward to the guidance and suggestions from experts.

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APPENDIX: A

Dear experts:

In order to make the narrow channel navigation risk assessment, issue the following questionnaires to the experts to get the relevant data from experts who have rich sailing experience and analyze the relevant data to determine ship safety, channel safety, shipping safety and channel safety management. For this, after consulting the opinions from different aspects, we set the following consideration factors and hope experts can put forward your precious opinions according to personal experience in shipping. Please fill in the table below.

Please do the pairwise comparison judgment to the factors which in column or line, and take the degree of importance (refer to table 1) to the tables as requirements.

Meaning	Evaluation
C_i is the same important with C_j	C_{ij} gets the value of 1
C_i is slightly important than C_j	C_{ij} gets the value of 3, oppositely, 1/3
C_i is important than C_j	C_{ij} gets the value of 5,oppositely, 1/5
C_i is more important than C_j	C_{ij} gets the value of 7,oppositely, 1/7
C_i is the most important than C_j	C_{ij} gets the value of 9,oppositely, 1/9
Value 2,4,6,8 and their reciprocal mean the middle values between values above	

"×"means need not to fill. We will calculate then.

For example：

	P_1	P_2	P_3	P_4
P_1	1	3	6	9
P_2	×	1	8	4
P_3	×	×	1	5
P_4	×	×	×	1

Primary index	Ship safety U1	Channel safety U2	Shipping safety U3	Channel safety management U4
Ship safety U1	1			
Channel safety U2	×	1		
Shipping safety U3	×	×	1	
Channel safety management U4	×	×	×	1

Secondary index	Ship tonnage U11	Ship age U12	Ship structure strength U13	Ship equipment U14	Ship emergency reaction level U15
Ship	1				

tonnage U11					
Ship age U12	×	1			
Ship structure strength U13	×	×	1		
Ship equipment U14	×	×	×	1	
Ship emergency reaction level U15	×	×	×	×	1

Secondary index	Relative depth U21	Relative width U22	Curvature degree U23	Barriers U24	Channel intersection U25
Relative depth U21	1				
Relative width U22	×	1			
Curvature degree U23	×	×	1		
Barriers	×	×	×	1	

U24					
Channel intersection U25	×	×	×	×	1

Secondary index	Visibility U31	Wind U32	Current U33	Traffic volume U34
Visibility U31	1			
Wind U32	×	1		
Current U33	×	×	1	
Traffic volume U34	×	×	×	1

Secondary index	Traffic management service U41	Navigation support information U42	Emergency reaction ability U43
Traffic management service U41	1		
Navigation support information U42	×	1	
Emergency reaction ability U43	×	×	1

APPENDIX: B

There are the final results of the tables in appendix A.

Primary index	Ship safety U1	Channel safety U2	Shipping safety U3	Channel safety management U4
Ship safety U1	1	2/3	4/5	4/3
Channel safety U2	3/2	1	6/5	2
Shipping safety U3	5/4	5/6	1	5/3
Channel safety management U4	3/4	1/2	3/5	1

Secondary index	Ship tonnage U11	Ship age U12	Ship structure strength U13	Ship equipment U14	Ship emergency reaction level U15
Ship tonnage U11	1	2	3/2	3/5	4/3
Ship age	1/2	1	2/5	4/3	5/4

U12					
Ship structure strength U13	2/3	5/2	1	3/5	2/3
Ship equipment U14	5/3	3/4	5/3	1	5/3
Ship emergency reaction level U15	3/4	4/5	3/2	3/5	1

Secondary index	Relative depth U21	Relative width U22	Curvature degree U23	Barriers U24	Channel intersection U25
Relative depth U21	1	3/2	2	5/3	4/3
Relative width U22	2/3	1	1/2	5/4	2/3
Curvature degree U23	1/2	2	1	3/2	5/2
Barriers U24	3/5	4/5	2/3	1	6/5
Channel intersection	3/4	3/2	2/5	5/6	1

U25					

Secondary index	Visibility U31	Wind U32	Current U33	Traffic volume U34
Visibility U31	1	3/4	3/2	3/5
Wind U32	4/3	1	2	4/5
Current U33	2/3	1/2	1	2/5
Traffic volume U34	5/3	5/4	5/2	1

Secondary index	Traffic management service U41	Navigation support information U42	Emergency reaction ability U43
Traffic management service U41	1	3/2	4/5
Navigation support information U42	2/3	1	1/2
Emergency reaction ability U43	5/4	2	1