8-25-2019

Safety assessment based on FAHP for marine traffic of important channel waters

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SAFETY ASSESSMENT BASED ON FAHP FOR MARINE TRAFFIC OF IMPORTANT CHANNEL WATERS

By

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

MASTER OF SCIENCE

In

Maritime Safety Environmental Management

2019

DECLARATION

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

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

Signature: ____________________________

Date: ____________________________

Supervised by:

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Dalian Maritime University

ACKNOWLEDGEMENTS

I am sincerely grateful to Dalian Maritime University for offering me this opportunity to study in MSEM.

I am profoundly thankful to my supervisor Prof. Wang Fengwu, for guiding me through this work and providing me with invaluable advice and insight into the subject matter. His rich knowledge and rigorous research attitude will benefit me in my future professional career and whole life. Deep thanks will also go to Ms. Bao Junzhong who made linguistic comments for this dissertation.

I also deeply appreciated all my colleagues and superiors in Dalian Maritime University (DMU), ad hoc, Vice President Prof. Liu Zhengjiang, Former Dean of Navigation College Prof. Dai Ran and Vice Dean Prof. Li Wei, for their continuous encouragement which has been a great source of inspiration and confidence for the completion of my studies.

Last but not least, I am everlastingly grateful to my beloved parents and parents-in-law who are always encouraging me by offering their full support especially my dear wife who is always taking my duties of caring for the whole family during my studies and helping me out of frustrations and sharing happiness at all times. The success and achievement which I made during my studies in Malmo would not have come true without her love and never-ending support.

ABSTRACT

Title of Dissertation: **SAFETY ASSESSMENT FOR MARINE TRAFFIC OF IMPORTANT CHANNEL WATERS**

Channel waters have the characteristics of high traffic density and complex navigation environment. They are also the areas where maritime traffic accidents occur frequently. Therefore, they are the focus of attention of maritime management departments and the hot spot of expert research in the maritime field. Firstly, the natural environment and traffic environment of channel waters are analyzed, the characteristics of marine traffic in channel waters are clarified, and the factors affecting ship navigation safety are obtained. Then, according to the method of fuzzy comprehensive assessment, the safety evaluation indices system is established. And based on the expert questionnaire, the weight of each index is obtained by FAHP method. Finally, a fuzzy comprehensive assessment model is established, and an example of Laotieshan Shuidao is used to verify the application of the model.

KEY WORDS: Marine Traffic, Safety Assessment, Channel Water, FAHP

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LIST OF ABBREVIATIONS

BDI	Baltic Dry Index
CBA	Cost and Benefit Analysis
CEA	Cost-Effectiveness Analysis
COP	Conference of the Parties
CMC	China Ministry of Commerce
C/P	Charter Party
DWT	Deadweight Tonnage
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EU	European Union
ETS	Emissions Trading System
FSC	Flag State Control
GHG	Green House Gas
GSP	Green Shipping Practice
IEA	International Energy Agency
IMO	International Maritime Organization
IOPC	International Oil Pollution Compensation Funds
IPCC	Intergovernmental Panel on Climate Change
LDCs	Least Developed Countries
LLDCs	Land Locked Developing Countries

CHAPTER 1

INTRODUCTION

1.1 The goal of China MSA: to make navigation safer and waters cleaner

With the sustained growth of China's economy, China's foreign trade is also increasing rapidly. According to statistics, in 2017, China's total import and export growth reached a six-year high, once again becoming the world's largest trading country. Due to the large capacity and low cost of marine transportation, at present, more than 90% of China's total import and export goods are completed by shipping, which has led to an increasing number of ships sailing on the sea. With the increasing number of ships, the increasing tonnage of ships, and the increasing density of ships in important waters and waterways, the marine traffic environment becomes more and more complex, thus marine traffic accidents occur from time to time. Serious maritime traffic accidents can cause huge personal injury and property losses, and may cause harm to the marine environment. For example, the collision between oil tanker Sanchi and cargo ship CF Crystal occurred in January 2018 in the Yellow Sea, which resulted in the explosion and final sinking, as well as 32 deaths/disappearances of Sanchi and serious damage to the CF Crystal.

In order to prevent and reduce the occurrence of maritime traffic accidents and achieve safe and efficient maritime transport, International Maritime Organization (IMO) has carried out a lot of work and adopted measures such as ship routing system, which has obvious effect on improving the safety of marine traffic. With the aim of safer shipping and cleaner oceans, China Maritime Administration has formulated a series of measures to ensure maritime traffic safety from the aspects of crew training and ship safety inspection. In addition, the scientific research on maritime traffic safety has been a hot topic for experts and scholars in the industry and a large number of research results applied to practice have played an important role in improving safety.

This dissertation focus on the marine traffic safety of channel waters, such as Laotieshan Shuidao in China, Singapore strait, etc., which have the characteristics of large traffic volume and complex navigation environment.

1.2 Objectives of research

The primary purpose of this research is to illustrate related factors affecting maritime traffic safety in passage waters and determine the safety level of channel waters. Based on the data of historical traffic accident and system safety engineering theory, this paper firstly identifies the risk of passageway waters and finds out the factors affecting maritime traffic safety. Then, the index system of maritime traffic safety in channel waters is created, and the weight of each index is determined according to the method of expert investigation. Finally, the fuzzy analytic hierarchy process (FAHP) is used to evaluate the maritime traffic safety of the channel waters, and the safety level of the channel waters is obtained.

1.3 Methodology

Firstly, on the basis of consulting relevant literature and related research results, this paper understands the research status of maritime traffic safety and other related fields at home and abroad. Through on-the-spot investigation and expert investigation, the characteristics of natural environment and traffic environment of channel waters are obtained. Based on the preliminary risk index system and questionnaire, the influencing factors of current maritime traffic safety are obtained and perfected through on-site interviews, and the key influencing factors are analyzed and screened. On the basis of literature review and expert interviews, expert questionnaires were issued, and the experts scored the indicators. The results of the questionnaires were used as the basis for determining the weight of indicators. The risk evaluation index system was improved according to the feedback of expert questionnaires.

Secondly, the evaluation index system of maritime traffic safety risk is constructed by using the mathematical method of fuzzy comprehensive evaluation, the connotation and evaluation criteria of the evaluation index are determined, and the mathematical model of risk evaluation is established based on FAHP method.

Finally, the data obtained from field research are used to verify the two evaluation methods, and the evaluation results are analyzed, and the corresponding suggestions and risk control measures are given.

1.4 Structure of dissertation

This dissertation consists of six chapters. Chapter two introduces the concept of marine traffic, marine traffic safety assessment and channel water in this paper, and by literature review, literature review, the current situation of maritime traffic safety assessment in corridor waters is understood. Chapter three analyses the factors affecting the safety of ships in passage waters, establishes the evaluation index system of maritime traffic safety in passage waters according to certain principles, and puts forward the evaluation criteria. Chapter four introduces the FAHP theory applied in this paper and calculates the weight of each elements. Chapter five establishes the safety assessment model and takes Laotieshan Shuidao as an example to verify the applicability of the model. Finally, the last chapter discourses the overall summaries and conclusions.

CHAPTER 2

Marine traffic safety and channel waters

2.1 Marine traffic

2.1.1 Marine traffic

Maritime traffic refers to the combination of individual ship movements or the overall behavior of all ships in the designated area, which reflects the interaction of ships, ship operators and marine traffic environment(Shao, 2000). According to the waters where ships are sailing, marine traffic can be classified into ship traffic in port, ship traffic in channel waters and ship traffic in coastal waters(Wu & Zhu, 2004). Ship is the main body of marine traffic, which is steered by people, including captain, officers, pilot, etc., in a certain environment. Therefore, the movement or behavior of a ship is strongly influenced by the ship's own characteristics and the characteristics of its navigators. Marine traffic can be illustrated as a human-ship-environment system.

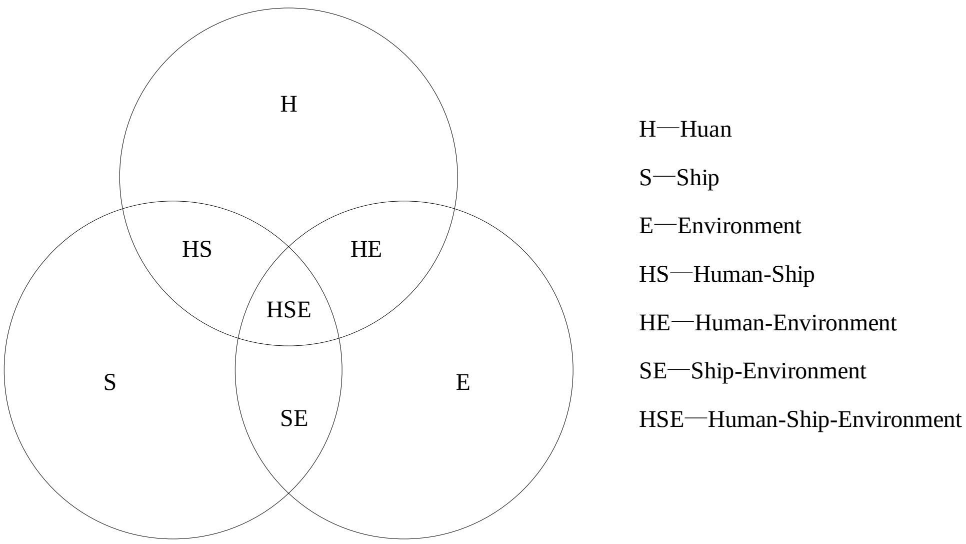

Fig 2.1: The relationship between human, ship and environment

2.1.2 Marine traffic elements

Marine traffic system consists of a wide range of subsystems, including human, ship and environment subsystems.

2.1.2.1 Ship

Ships are the main body of maritime traffic safety and an important part of maritime traffic safety system. Because different types of ships have different structural and operational characteristics, these characteristics make different types of ships face different risks. For maritime traffic safety, ship factors are mainly manifested in its seaworthiness, ship structure and equipment, ship maneuverability, cargo stowage and so on(Hu, 2014). According to relevant research, ship size, ship speed, ship maneuverability and ship age are closely related to maritime traffic safety.

2.1.2.2 Crew members

In the work of ship operation, the human factor such as ship duty Officer/Engineer is the most active and the most important one. It have been widely recognized that human factors are the main cause of accidents at sea(L. Zhang, Lu, & Ai, 2014) and more than 80% of marine accidents are related to human factors according to the statistics(Nagendran, 1994). Among the factors of crew, the responsibilities, knowledge, skills, experience, healthy passengers and psychological, physiological and behavioral characteristics of the ship's duty personnel are directly related to the safety of navigation.

2.1.2.3 Evironment

Ships sailing at sea will be affected by the surrounding environmental conditions, such as storm, poor visibility and dense traffic. Environmental factors have a great impact on people's working conditions and ship performance, and even threaten ship safety. Therefore, for navigators, understanding and mastering the characteristics of various traffic environments is an important guarantee for navigation safety(Hu, 2014). Maritime traffic environment refers to the space and conditions in which ships move, including navigation waters, natural conditions and traffic conditions in the waters(Wu & Zhu, 2004). As far as maritime traffic system is concerned, the navigational waters consist of ports and routes. And due to the dense traffic, frequent marine accidents and high traffic risk, more attention has been paid to the port and its adjacent waters, important channel waters and so on.

2.2 Marine traffic safety assessment

2.2.1 Marine safety

In safety engineering, safety is defined as a state in which no accidents or disasters such as casualties, damage to equipment or property, environmental damage, etc. occur and no dangers such as accidents or disasters occur. For the marine safety, Kopacz et al. has defined it as “such desirable conditions of human activity at sea that do not endanger human life and property, and are not harmful to the maritime environment.”(Baalisampang, Abbassi, & Khan, 2018) It consists of four parts, namely the safety of the technical and operational ship, the safety of navigation, the safety of persons in distress and the prevention of environmental pollution from the ship, as shown in Figure 2.2.

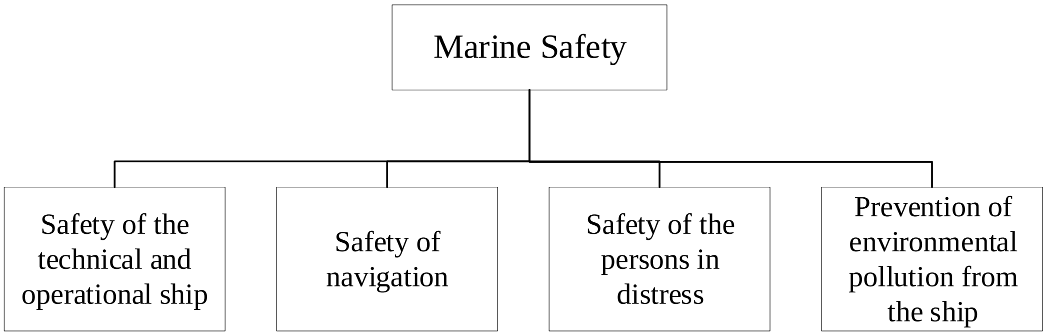

Fig 2.2: Four major components of marine safety

Source: Kopacz, Z., Morgas, W., & Urbanski, J. (2001). The Maritime Safety System, its Main Components and Elements.

2.2.2 Safety assessment(SA)

SA is the quantitative and qualitative assessment and evaluation of the system's safety situation(Wu & Zhu, 2004). Because safety is expressed by danger usually, SA is to estimate and evaluate the risk situation of accidents and disasters in the system. Therefore, safety evaluation is also called risk assessment(RA). The basic purpose of SA is to judge whether the system has reached the specified safety objectives or meets the safety requirements. Based on the results of SA, some measures are taken to improve and strengthen the safety of the system. According to the formal safety assessment(FSA) recommended by IMO, SA should include five steps: hazard identification, risk assessment, risk control options, cost-benefit assessment and decision making recommendations(IMO, 2018). The specific contents of FSA are shown in Figure 2.3.

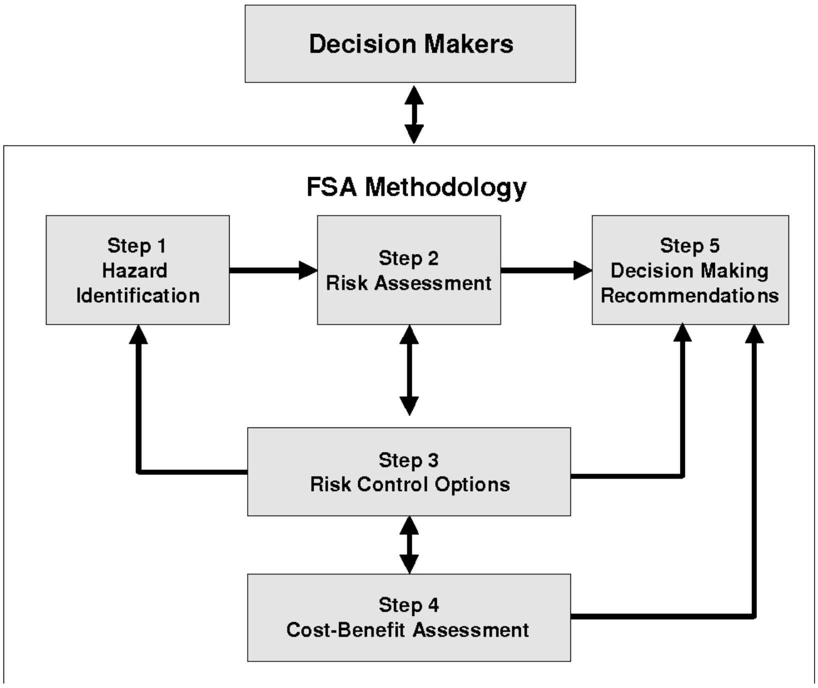

Fig. 2.3: FSA Flowchart

Source: https://www.semanticscholar.org/paper/Qualification

2.2.3 Marine traffic safety assessment

The assessment of maritime traffic safety should be based on the viewpoint, method and theory of safety system engineering. Maritime traffic system is a complex system which is composed of many parts. The system safety may be affected by the problems of any part, and each part will affect each other. By applying the safety system engineering method, the danger of each element of the ship traffic system, which is related to each other, can be identified, and the safety state can be evaluated and predicted.

Since the 1970s, researchers at home and abroad have carried out extensive and in-depth research on the issue of water traffic safety. In recent years, the theories of fault tree analysis(FTA)(Yao, Liu, & Wu, 2009), fuzzy mathematics(Zou & Han, 2013), grey theory(Shenping & Zhou, 2008), artificial neural network, cloud models(X. Zhang, Liu, & Jia, 2010) and FSA(Shen-Ping, Fang, Zhang, & Cai, 2012) have been gradually applied to the analysis and assessment of accidents.

2.3 Channel waters

In the marine traffic, the traffic of important channel is a hot spot that people pay close attention to and study. The channel water in this research refer to those waters where the navigable waters of ships are restricted to a certain extent due to their special geographical location and large marine traffic flow. Due to the influence of topography, hydrological conditions, traffic conditions and other factors, the navigable environment of channel waters is more complex and the marine traffic risk is larger, such as Chengshanjiao water area, Laotieshan Shuidao, Singapore Strait and so on.

2.3.1 characteristics of channel waters

When ships navigate in channel waters, where the environment is relatively complex, environmental factors have a significant impact on traffic safety. Compared with maritime traffic in port waters, vessel traffic in channel waters has the following characteristics.

Firstly, Vessel traffic volume and ship density are very large in channel waters. According to the statistics of the past 10 years, the average number of ships passing through Singapore Strait is over 64,000, including 23,000 container ships and 21,000 oil tankers, and more than 2,000 per day(Weng, Meng, & Qu, 2012). Although the width of navigable waters of channel is larger than the port waters, the ship's navigation behavior is more standardized due to the routing system, except for the waters in the precautionary zone.

Secondly, the ship's speed is usually faster and the speed difference between different types of ships is larger. Maritime authorities in some channel waters have restricted the speed of ships in the waters, such as Laotieshan Shuidao in which the ship’s speed limit is 10 kn.

Thirdly, in some special waters, such as precautionary areas, there are often routes crossing, complex navigation environment and high traffic risk.

Finally, due to terrain restrictions, the tidal current in channel waters is often larger than other waters, which will affect the safe navigation of ships.

2.3.2 literature review of marine traffic safety assessment of channel waters

Many scholars have studied the traffic safety of channel waters. Li Huimin used the theory and method of water traffic conflict to evaluate the traffic risk of Chengshanjiao waters, considering the impact of different severity of conflict on traffic safety, and selected the grey clustering evaluation model, so as to effectively determine the risk of each area in the waters(H. Li, 2012). Li Tao has counted the maritime traffic accidents in Qiongzhou Strait in recent years, and has deeply analyzed the characteristics and causes of these maritime traffic accidents in order to improve the traffic safety of the Qiongzhou Strait(T. Li, 2013). Liang Hao used data mining technology to analyze AIS data in Laotieshan Shuidao, and obtained the temporal and spatial distribution of ship collision risk in the navigation of the waterway(Liang, 2017). Based on the AIS data, Qu Xiaobo et al. put forward three kinds of ship collision risk indices, including index of speed dispersion, degree of acceleration and deceleration, and number of fuzzy ship domain overlaps, to quantitatively assess the collision risk of ships in Singapore Strait(Xiaobo, 2011). Weng Jinxian estimates the collision frequency of ships in Singapore Strait by using the product of the number of vessel conflicts and the causation probability derived from real-time ship movement data from Lloyd's MIU database(Weng et al., 2012). Based on FSA, Ömer Faruk Görçün analyzed the risk of maritime traffic in the Istanbul Strait from 2001 to 2010 and different factors are selected for risk analysis, such as ship specifications, accident location, accident time, accident types and causes in practice(Görçün & Burak, 2015).

CHAPTER 3

Marine traffic safety assessment indices system

3.1 Principles of Establishing Indices System

In order to make the results of risk assessment scientific, reasonable and effective, it is necessary to select the indices system of assessment scientifically and reasonably. There are many factors affecting maritime traffic safety. How to select the appropriate factors is very important for the accurate assessment of maritime traffic safety. In determining the indices system, the following principles are mainly followed in this paper.

3.1.1 Completeness of factors

Completeness means that the evaluation index system should reflect and measure the evaluated objects as completely and comprehensively as possible. When the values of all factors in the system are determined, the evaluation results will not change with other variables.

3.1.2 Independence of factors

When designing the evaluation factor system, some factors often have a certain degree of correlation. Therefore, we should adopt a scientific method to deal with the factors with a large degree of correlation in the factor system, so that each factor can only appear once in the system, avoid duplication, and enable the factor system to reflect the actual situation of the evaluation object scientifically and accurately.

3.1.3 Representation of factors

When evaluating a specific object, we should not only comprehensively analyze its relevant factors, but also seize the main contradictions and select the factors that best reflect the level of the evaluation object, so as to make the evaluation factors representative.

3.1.4 Operability of factors

The factor system should be designed according to different evaluation requirements to make it concise and concise, and the required data can be acquired, easy to operate and measure, avoid complicated calculation, so as to facilitate the implementation of the evaluation.

3.1.5 conciseness of factor system

The factor system should be concise, the minor factors can be omitted, and the mathematical model should be easy to operate.

3.1.6 Principle of Combining Qualitative with Quantitative

Qualitative research can grasp the development law of the system, quantitative research can make the system clearer and clearer. The principle of combining qualitative and quantitative research is to embody all the influencing factors of the system.

3.2 Factors Affecting Maritime Traffic Safety

According to the characteristics of traffic environment in channel waters, based on the analysis of the literature on maritime traffic safety in recent years, the factors affecting traffic safety in channel waters are studied.

3.2.1 Human factors

Man-made factors are closely related to maritime traffic safety, and have a greater impact on ship navigation safety in traffic-intensive channel waters. According to some reports in recent years that human factors account for 75-80% of marine accidents. In a narrow sense, human factors refer to the factors of shipping personnel. Human Factors covers a range of issues including perceptual, physical and mental capabilities, the interaction and effects on individuals of their job and working environments, the influence of equipment and system design on human performance and finally the organizational characteristics which influence safety related behavior at work.

According to the characteristics of human factors, they can be divided into four categories, namely, physical factors, mental factors, intellectual factors and ability factors. In this paper, combined with the actual situation of maritime traffic safety, three indices of competence, responsibility and fatigue are used to evaluate the impact of human factors in maritime traffic safety risk.

3.2.1.1 competence of crewmembers

Competency is a comprehensive reflection of human ability, intelligence and physical factors. The competency of the crew on board should be reflected not only in their possession of effective competency certificates, but also in their professional and technical level, including theoretical level and practical work experience.

Seafarers holding qualifications certificates for senior seafarers have undergraduate, tertiary or technical secondary education in navigation. Statistical data show that the higher the education level, the less the possibility of mistake in practice, and the less the possibility of marine accidents.

Working experience on board a ship is the knowledge acquired by the crew through direct contact with objective things through their senses in long-term voyage practice, and then rises to special knowledge and skills of navigation through reflection and summary. Therefore, sea age is the reflection of the crew's working experience on board. Statistics show that the longer the age of the sea (within the legal working age), the less the possibility of error in actual operation, and the less the possibility of marine accidents.

3.2.1.2 responsibility of duty watchman

Responsibility refers to a person's conscious attitude toward the common activities, behavior norms and tasks of the group he belongs to, involving responsibility awareness and responsibility behavior. Responsibility is an important part of the crew's quality. Statistics on maritime accidents show that 80% of maritime traffic accidents are caused by human factors, and 80% of all human factors accidents are caused by insufficient responsibility. The main reason of the oil spill from the Exxon Valdez oil tanker in 1989 was that the captain was drunk and left third officer on the bridge, which eventually led to yaw and the ship hit the reef.

3.2.1.3 fatigue

During the long working period, seafarers are likely to be overtired due to excessive pressure and insufficient rest. Brain fatigue of drivers is characterized by dull sensation, inaccurate movements and reduced sensitivity. It is also characterized by mental distraction, slow thinking, slow reaction and restlessness, which often lead to traffic accidents. Therefore, fatigue is a state that reduces people's working level, dulls the reaction of body and mind, and weakens the ability to make reasonable judgments. As a result, unsafe behavior increases, ship handling quality decreases, and collision avoidance reaction speed slows down, leading to an increase in accidents. According to statistics, 88 grounding accidents occurred in the Norwegian sea in 2006, most of which were related to fatigue factors of duty officers and the direct cause of 8 accidents was that duty officers slept during duty(Akhtar & Utne, 2014).

3.2.2 Ship factors

Considering the acquisition of data, three indicators, namely ship type, seaworthiness and ship size, are used to evaluate the impact of ship factors on maritime traffic safety risk.

3.2.2.1 Ship type

According to the definition of High Risk Ship in Port State Control(PSC), referring to the "Four Types of ships" determined by the Ministry of Communications of China, this paper takes the scale of passenger ships and dangerous goods vessels, such as oil tanker, LNG carrier and so on, as an index to evaluate the navigable ship type of maritime traffic safety. Once an accident happens on a passenger ship, it will lead to serious casualties and casualties, which will have a greater social impact; while an accident on a dangerous goods ship may lead to huge marine environmental pollution, resulting in significant social impact and economic and property losses. In the book, the proportion of passenger ships (ro-ro passenger ships) and dangerous goods ships (ro-ro passenger ships) in the port area to the total number of ships entering and leaving the port is taken as the evaluation index to evaluate the maritime traffic safety of the port.

3.2.2.2 Ship size

Ships size is an important factor affecting the safety of ships. Especially when sailing in channel waters, because the natural conditions of port waterways are more complex and far less abundant than the open waters, the maneuverability of ships will be limited to varying degrees. According to the relevant statistics and research, ship tonnage is closely related to water traffic accidents. The larger the ship tonnage (scale), the greater the possibility of water traffic accidents.

***3.2.2.3 ship's* seaworthiness**

Marine traffic accidents are often related to the unseaworthiness of ships. According to traffic accident statistics, the main causes of collision are the failure of main engine, steering gear, auxiliary engine and power supply. Damage of ship hull, failure of navigation equipment, failure of main engine and steering gear are the causes of grounding/reef accident.

The main purpose of ship safety inspection, including PSC and Flag State Inspection(FSC) is to restrict and exclude low-standard ships, to ensure the safe navigation of ships and to prevent the pollution of the marine environment caused by ships. The results of some studies show that the data of ship safety inspection (types and quantities of defects) are directly related to ship safety status and ship traffic accidents.

In this paper, seaworthiness of ship is used as an index of ship factors to evaluate maritime traffic safety. In this paper, ship detention in PSC and FSC is used as the basis for ship's unseaworthiness, and ship detention rate is used as the criterion for evaluating ship seaworthiness in port waters.

3.2.3 Environment factors

3.2.3.1 Natural environment

Natural environmental factors affecting ship navigation in channel waters mainly include visibility, wind, tidal current and depth of water and obstacles to navigation.

(1) Visibility

Sea fog is the main threat factor to ship navigation safety. When the visibility is poor, it will be difficult to observe. Ships sailing and entering and leaving the harbor are guided by navigation aids such as radar. It is more intuitive and accurate to observe the ship directly with the help of navigation aids such as radar. When the radar warns, it is likely that the ship has missed the best time to avoid or receive warnings in time, which will lead to the occurrence of the failure to avoid or receive warnings in time. Collision accidents and even grounding accidents. In maritime traffic accidents, a considerable part is due to poor visibility. According to incomplete statistics, in the waters with poor visibility for a long time, the proportion of collision accidents in traffic accidents is as high as 50%. It is obvious that the harm of poor visibility is serious.

Some scholars believe that the relationship between the number of ship accidents and visible distance is as follows: when the visible distance is less than 4 km, it has a certain impact on navigation safety; when the visible distance is less than 1 km, the number of accidents increases sharply, which is regarded as dangerous visible distance.

(2) Wind

Wind is another important natural environmental factor affecting the normal navigation of ships, and it is also a meteorological condition often encountered in the navigation of ships. Strong winds can induce big waves to a certain extent. Wind and waves often influence ships with each other. Heavy wind and waves have a high degree of impact on the safety of ship navigation, which can not only cause damage to the ship itself, but also bring great difficulties to the ship navigation. The influence of strong wind and waves on ships mainly includes the following aspects [22]: Firstly, strong wind and waves will cause ships to deviate from their course. Because the direction and size of the wind and waves are changeable, the degree and direction of the ship's course deviation are also changeable, which brings inconvenience to the ship's navigation; secondly, strong wind and waves will cause damage to the strength of the ship's hull structure, if the ship carries a large number of liquid cargo or rolling cargo, add The environment is harsh, the deck wave phenomenon is serious, and even the hull will be deformed and broken. Thirdly, due to the fluctuation of the wind and waves, the rudder efficiency of the ship will decrease, the speed of the ship will decrease, and the ship will be more difficult to operate. Finally, the cargo on the deck will be brought into the water by the strong wind and waves, resulting in cargo loss and so on.

(3) Tidal current

Tidal current factors will also affect the ship's own force conditions, and then affect the ship's maneuverability. In downstream current, the actual speed of ship is the sum of ship speed and current speed; in countercurrent, the speed is the difference between ship speed and current speed; when the direction and course are inconsistent, the ship will have a certain degree of yaw. In waters with obvious velocity, different flow conditions will bring different rudder efficiency, which is worse in downstream and better in countercurrent.

(4) Depth of water and obstacles to navigation

Generally speaking, the influence of water depth on ship navigation safety is mainly manifested in the decline of ship maneuverability. In shallow water, when D_w/H=1.2, the turning diameter is twice that of deep water, while when D_w/H=1.5, the turning diameter is almost the same as that of deep water. Therefore, it can be considered that when the excess water depth exceeds 50% of the draft of the ship, the change of water depth has no effect on the ship's maneuverability.

The Committee of the International Shipping Conference recommended that the total excess water depth in narrow channels should be set at about 15%. The coefficient takes into account the allowable draft of the ship, the range of vertical motion of the ship due to surge, the amount of stern seating caused by speed, the net excess water depth and other allowances. Therefore, it can be considered that when the surplus water depth is less than 15% of the ship's draft, it is shallow water, and when the surplus water depth is greater than 15% of the ship's draft, it is deepwater.

3.2.3.2 Traffic enviroment

Traffic environmental factors affecting ship navigation in channel waters mainly include ship traffic volume, routing system and conditions of ais to navigation, traffic confliction and impact of fishing vessels.

(1) Ship traffic volume

Vessel traffic volume directly reflects the scale and busy degree of ship traffic in navigable waters, and to a certain extent reflects the degree of congestion and danger of ship traffic in this waters. It can intuitively represent the dangerous situation of ship navigation in navigable waters and reflect the safety and efficiency of navigation in navigable waters. In addition, the distribution of ship traffic density or ship density is also the basic quantity of ship traffic environmental pressure in a water area. The density of ships can also reflect the busy and dangerous degree of ships in the waters and the crowded degree of ships in the channel waters. It is one of the important indicators in the safety evaluation process of navigable waters.

Because the navigable waters are limited to a certain extent, the large volume of ship traffic will inevitably lead to ship congestion and increase the risk of navigation. Therefore, the ship traffic volume has a significant impact on the maritime traffic safety in the channel waters.

(2) Routing system and conditions of ais to navigation

As an advanced maritime management concept, ship alignment system is an effective means of ship navigation order management in areas with heavy water traffic. In recent ten years, ship alignment system has been widely applied in many important waters in China. It has played an active role in regulating ship traffic flow, reducing ship collision and grounding accidents, and has been recognized by the shipping industry. However, due to the complex navigation environment or the imperfect design scheme, there may be some areas where the risk factors are concentrated, resulting in relatively frequent accidents in these sections. Therefore, whether the ship alignment system is established and whether the ship alignment system is perfect in the channel waters with dense traffic flow has obvious influence on navigation safety.

(3) Traffic confliction

Because of the limitation of navigable waters, the ship encounter rate is higher, so it is often accident-prone waters. The encounter situation of ships is related to the distribution of navigation routes in the channel. If the channel waters are separated, only one encounter situation can be overtaken in the separated navigation waters, and no encounter or cross encounter will occur. But the situation in the alert area will be more complex.

According to the AIS track chart of channel waters, the paper calculates the intersection of ship tracks of different routes, determines the number of intersection points of main routes, and analyses the ship encounter situation in channel waters.

(4) Impact of fishing vessels

With the continuous development of shipping industry and the continuous growth of marine economy, more and more vessels make the density of navigation on water increasing. The increase of the number of fishing vessels has brought great potential safety hazards to the navigation safety of merchant shipping. At the same time, collision accidents also bring catastrophic consequences to fishing vessels.

Fishing boats operate frequently, especially in the fishing season. Nearly 10,000 fishing boats operate in coastal waters every day. The activities of fishing vessels are mainly manifested in irregularity and directionality. They sail in groups, in scattered and circuitous ways, and work freely through traffic lanes or waterways, which seriously disturbs the order of maritime navigation.

Channel waters often have intensive fishing boat activities. For example, Chengshan Cape waters are important international navigation waters with high navigation density. At the same time, this waters is one of the relatively important fishing waters along the northern coast of China. When the peak fishing season comes, many fishing boats frequently engage in fishing activities in this waters. Therefore, the navigation environment of channel waters is relatively complex, and the collision between merchant ships and fishing vessels is more prominent.

3.2.4 Management factors

. IMO points out in ISM rules that about 80% of marine accidents are caused by human factors, and about 80% of human factors can be controlled by effective management, that is, by strengthening the internal management of the company and the safety management of ships. Only by effective management can all departments of the company, all links on board and different individuals be organically linked together, so as to coordinate the actions among departments, keep the motivation of individuals in line with the organizational goals, enhance the cohesion and combat effectiveness of the whole and reduce the occurrence of maritime accidents. The management factors related to maritime traffic safety in channel waters can be divided into the management of maritime departments and the management of shipping companies.

3.2.4.1 Maritime management level

Maritime management refers to all kinds of management actions carried out by maritime authorities to prevent maritime accidents or incidents, including maritime security incidents, or to mitigate the consequences of maritime accidents or incidents.

VTS plays an important role in information service and navigation aid management to improve water traffic safety. According to the statistical results, the implementation and implementation of good ship traffic management can reduce the number of water traffic accidents covered by VTS by 1/5-1/3. VTS plays an important role in improving navigation safety and port efficiency. For example, in 2006, the ship traffic flow of Tianjin Port reached 77,000 ships, more than three times that of 1995, while the rate of ship traffic accidents in Tianjin Port dropped from 0.29% to 0.06%. The role of safety and security is obvious.

In addition, the maritime traffic safety in channel waters is closely related to the local maritime traffic safety laws and regulations and the improvement of port navigation information, including ship entry and exit reporting system, nautical charts and navigation books, hydrometeorological information, etc.

3.2.4.2 Shipping company management level

The influence of maritime management level on maritime traffic safety in channel waters can be considered from three aspects: VTS, regulatory perfection and emergency response capacity, which are basically consistent with port waters.

(2) Management of shipping companies

The management of shipping company has certain influence on the safety of navigation at sea. It has become the consensus of the whole maritime community to enhance the safety of maritime transport by strengthening safety management. As the safe production of ships is directly under the management of the shipping company, and the safety situation of ships is closely related to the economic interests of the company, the safety management of the shipping company is direct and urgent. ISM rules have been in force for all international passenger ships and other ships with a gross tonnage of more than 500 tons since 1 July 2002. The implementation of this rule aims to improve the safety management consciousness of shipping companies and the actual management level of ships by standardizing the management of ship safety prevention and pollution prevention. ISM rules focus on improving the hardware equipments and management arts of shipping companies and their ships. Through the implementation of safety management system, strengthening crew training, improving navigation skills and work responsibility, thereby minimizing the risk of various accidents caused by human factors. However, the management of the shipping company is not satisfactory at present. The sinking of the Golden Harmony in 2012 and the sinking of the Years in 2014 are directly related to the negligence and loopholes in the management of the shipping company.

The management of shipping company is related to many factors, such as safety policy, communication channel and information management, quality and effectiveness of rules and regulations, operation rules, emergency response system and quality and ability of management personnel.

3.3 Evaluation criteria

Based on the factors affecting the safety of maritime traffic for analysis, from the human - Ship - Environment - a management system which start with the establishment of evaluation index system. For each index system, the determination of scientific and reasonable evaluation criteria is the basis for risk assessment. Therefore, based on the reference literature, the index evaluation criteria are determined for the data and data that can be collected.

For indicators that can obtain data, quantitative methods are used for evaluation; for indicators that cannot obtain data, qualitative methods are used for evaluation. For the index factors evaluated by the qualitative method, the evaluation results were obtained by means of expert survey data combined with reference literature.

3.3.1 Competency

The crew's competence is related to the crew's education, navigation experience, graduate school, company training, etc., and the competence of the crew in a region is difficult to describe with quantitative data. Therefore, qualitative methods are used for evaluation. The criteria for assessing competence are defined as five levels: good, good, average, poor, and poor.

The expert survey method is used to obtain relevant data and obtain the status of crew's competence in the channel waters. The survey mainly includes local VTS (responsible channel waters) attendants who are more familiar with the crew, as well as PSC inspectors and port pilots of the Maritime Bureau in neighboring jurisdictions (other ports around).

Table 3.1 “Competency” evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Competency A1	Very good	Good	OK	Poor	Very poor

3.3.2 Responsibility

The crew's sense of responsibility is difficult to describe with quantitative data, but it can be seen from the crew's duty (navigation, anchoring, port cargo operations), inbound and outbound reports, attitudes and performance during the safety inspection process. Therefore, using qualitative methods for evaluation, the responsibility evaluation criteria are defined as five levels: good, good, average, poor, and poor.

Use expert survey methods to obtain relevant data and obtain the status of crew responsibility in the channel waters. The survey mainly includes local VTS (responsible channel waters) attendants who are more familiar with the crew, as well as PSC inspectors and port pilots of the Maritime Bureau in neighboring jurisdictions (other ports around).

Table 3.2 “Responsibility” evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Responsibility A2	Very good	Good	OK	Poor	Very poor

3.3.3 Degree of fatigue

The fatigue of the crew is difficult to describe with quantitative data, but it is reflected in the attitude and performance of the crew on duty (navigation, anchoring, port cargo operations), inbound and outbound reporting, and safety inspections. Therefore, using qualitative methods for evaluation, the fatigue level evaluation criteria are defined as five levels: good, better, average, poor, and poor.

Use expert survey methods to obtain relevant data and obtain the status of crew responsibility in the channel waters. The survey targets mainly the local VTS (responsible channel waters) occupants of the Maritime Safety Administration, and the PSC inspectors and port pilots of the maritime bureaus in the neighboring jurisdictions (other ports around).

Table 3.2 "fatigue" assessment on human criteria 7.24

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Fatigue degree A3	Very good	Good	OK	Poor	Very poor

3.3.4 Seaworthiness

Considering that the airworthiness of all ships in the channel waters cannot be expressed by accurate values, the ship's retention rate in the port PSC inspection and FSC inspection is used instead of the ship's airworthiness. Since the navigation vessels in the channel waters are transit vessels, it is difficult to fully calculate the corresponding safety inspection data. Therefore, the safety inspection data of one or more ports representative of the surrounding area can be selected as a reference. 2012 and 2014 with reference to China PSC inspection vessel retention ratio of 4.35% average (number of retention / the total number of check), determined according to the evaluation criteria as in Table 7.25 seaworthy ship.

Through the investigation of the navigation data of the ships by the maritime authorities, the ship detention rate of the ship safety inspection in the surrounding port waters is obtained, and the state of the seaworthiness of the ships in each channel is determined .

Table 3.4 ship "seaworthy" standard price

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Airworthiness status B1	<1%	1% to 3%	3% to 5%	5% to 10%	>10%

3.3.5 Ship type (high-risk ship size)

After expert investigation and reference to relevant literature, determine the evaluation criteria according to Table 7.26 as the scale of high-risk ships.

Through the investigation of the navigation data of the ships by the maritime authorities, the proportion of passenger ships and dangerous goods vessels in the traffic volume of the inbound and outbound vessels is obtained, and the scale of the high-risk vessels in each channel is determined .

Table 3.5 ship "navigable ship" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
High risk ship size B2	<5%	5% to 10%	10% to 20%	20% to 40%	>40%

3.3.6 Ship size

According to the classification of ship type when the VTS of the Maritime Safety Administration conducts statistics on passing ships in the channel waters (captain <200m, 200-300m, >300m, or draught<10m, 10~12m, >12m, or ship width <30m , >30m) up through the ship-type scale divided according to three levels, therefore, can not correspond with the book five risk levels. Refer to other literature [38]for the classification of ship scale and maritime traffic risk, and the risk level according to Table 7.27 as the evaluation standard of ship scale indicators.

Through the investigation of the navigation data of the ships by the maritime authorities, the ship's scale distribution of the navigable ships in the channel waters is obtained, and the condition of the ships in the channel waters is determined .

Table 3.6 ship "ship size" evaluation criteria:

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Ship scale B3			<200	200~300	>300

3.3.7 Wind

Refer to other references for the classification of stroke and maritime traffic risk, and evaluate the number of days above 6 winds as the evaluation index of wind, and determine the evaluation criteria of wind indicators according to Table 7.28 .

The weather of the winds above the 6th level in the port waters is obtained through the meteorological statistics of each place, and the wind conditions of the waters in each channel are determined .

Table 3.7 "wind" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Wind C11	<30	30~60	60 ~ 100	100~150	>150

3.3.8 Visibility

Reference other references and visibility in maritime traffic division of risk, determined in accordance with the evaluation criteria of visibility indicators Table 3.8.

Through the meteorological statistics of various places, the visibility of the visibility in the waters of the port is ≤1km, and the visibility of the waters in each channel is determined .

Table 3.8 "visibility" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Visibility C12	<10	10-20	20~30	30~40	>40

3.3.9 Current

Refer to the division of tidal current and maritime traffic risk in other references [16, 43] to determine the evaluation criteria according to Table 7.30 as the trend indicator. Acquisition trend in the waters of the port by port hydrological statistics or maximum flow rate chart data to determine the status of each channel tidal waters flow.

Table 3.9 "current " evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Trend C13	<0.5	0.5 to 1.5	1.5 to 2.5	2.5 to 4.0	>4.0

3.3.10 Water depth and obstacles

Reference and other references depth was divided hinders navigation and marine traffic risk, in order to determine the depth and distance from the ship's draft ratio was hinders navigation and the channel edge (unit: m) as the depth thereof and navigation-index evaluation standard, as shown in Table 3.9.

Completely unrestricted: the water depth in the navigable waters is 30m (satisfying the safe navigation of existing ships, ie ≥1.5d), and there are no obstacles that impede surface navigation;

Slightly affected: the water depth in the navigable waters is more than 30m, and there are some obstacles or shallow spots that hinder the surface navigation outside the 200m outside the navigable waters;

The impact is small: the water depth in the navigable waters is more than 30m, and there are some obstacles or shallow spots that hinder the surface navigation within 100~200m outside the navigable waters;

The impact is large: the water depth in the navigable waters is limited, and large ships need to slow down. There are some obstacles or shallow spots that hinder the surface navigation within 50~100m outside the navigable waters;

The impact is great: the water depth in the navigable waters is limited, and large ships need to pass through the tide. There are some obstacles or shallow spots that hinder the surface navigation within 50m outside the navigable waters.

The water depth and obstacle information are obtained from the chart data of the navigable waters to determine the water depth of the channel water and the condition of the obstacles.

Table 3.10 "Water depth and obstacles " Evaluation Criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Water depth and obstacles C14	Completely unrestricted	Slightly affected	Less affected	Greater impact	great influence

3.3.11 Ship traffic volume

The geographical location and navigation conditions of different channel waters are different, and the traffic volume of ships varies greatly. Refer to other references to determine the ship traffic volume as the ship according to Table3.11. Evaluation criteria for traffic volume.

Through the investigation of the navigation data of the ships by the maritime authorities, the traffic volume of the navigable ships in the channel waters is obtained, and the traffic volume of the ships in each channel is determined.

Table 3.11 "Ship traffic volume" Evaluation Criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Ship traffic volume	<50	50~100	100~200	200~300	>300

(ship/day) C21

3.3.12 Routeing system and navigation aids

It is difficult to describe the situation of the alignment system and the navigation aids with quantitative data. Referring to other literatures, the evaluation method is used by the expert scoring method. Theevaluation criteria for the alignment system and navigation aids are defined as five levels, which are determined according to Table 3.12 As an evaluation standard for the alignment system and navigation aidindicator.

The expert survey method is used to obtain relevant data, and the status of the alignment system and the navigation aid sign in the channel waters are obtained. The survey targets are mainly VTS attendants and liner crews of the Maritime Safety Administration.

Table 3.12 "Routeing and navigation aids" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Alignment system and navigation aids perfection rate C22	100 ~ 95	95 ~ 90	90 ~ 80	80 ~ 70	<70

3.3.13 Ship encounter situation

The traffic volume of the navigable ships in the channel waters is large, the ship encounter rate is high, and the risk of sea traffic increases. Referring to the track distribution of the AIS track map, the ratio of the number of intersections of different routes to the length of the intersection area of the ship is determined as the evaluation standard of the ship traffic volume, as shown in Table 3.13 .

FIG Get the number of intersections through the ship route chart information and AIS track channel water through the distribution channel condition is determined ship encounter water.

Table3.13 environmental assessment of "ship encounter situation" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Ship meeting condition C23	0	0.1 to 0.2	0.3 to 0.4	0.5 to 0.6	>0.6

3.3.14 Impact of fishing boats

It is a well-established fact that fishing boat activities have an impact on the safety of maritime traffic in access waters, but it is difficult to accurately grasp relevant data. This indicator appears to be less common in other literature on quantitative assessment of maritime traffic safety. Therefore, using qualitative methods for evaluation, the impact assessment criteria for fishing vessels are defined as five levels: small impact, good impact, general impact, large impact, and great impact.

Using expert investigation access to relevant data, combined with references conclusion, get fishing waters passage of ships sailing out of port security implications of the situation. The survey targets mainly include the VTS attendant of the Maritime Safety Administration and the crew of the liner ship.

Table 3.14 "fishing impact" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
The impact of fishing boats C24	no effect	Slightly affected	Greater impact	great influence	Great influence

3.3.15 Maritime supervision level

VTS difficult quantitative data description, with reference to other documents, the report of the expert scoring method was evaluated, evaluation criteria maritime control level is defined as five levels, is determined according to Table 3.15. The functions as evaluation standard maritime control level indicators.

The expert survey method was used to obtain relevant data. The survey subjects mainly included liner crews closely related to VTS and VTS attendants of the Maritime Bureau.

Table 3.15 "Maritime supervision leve" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Maritime supervision level D1	100 ~ 95	95 ~ 90	90 ~ 80	80 ~ 70	<70

3.3.16 Shipping company management

The management level of the shipping company is difficult to describe with quantitative data. Therefore, the evaluation method of the expert scoring method is adopted. The evaluation standard of the management level of the shipping company is defined as five levels, and the evaluation according to Table 3.16 as the management level index of the shipping company is determined. standard.

Relevant data were obtained by expert survey method. The survey targets mainly include crew members entering and leaving the surrounding ports and VTS attendants of the Maritime Bureau.

Table 3.16 "shipping company management" evaluation criteria

Risk level	Very low risk	Low risk	General risk	High risk	Very high risky
Shipping	100 ~ 95	95 ~ 90	90 ~ 80	80 ~ 70	<70

company management level D2	

CHAPTER 4

FAHP and the weight of each indice

4.1 Introduction to FAHP

AHP is a systematic analysis method which combines qualitative analysis with quantitative analysis proposed by Professor A. L. Saaty of the University of Pittsburgh in the 1970s. The key link of AHP is to establish the judgment matrix. Whether the judgment matrix is scientific and reasonable will directly affect the effect of AHP. Some scholars believe that there are some problems in AHP, such as the difference between judgment consistency and matrix consistency, the difficulty of consistency test and the lack of science. Based on Saaty's analytic hierarchy process, FAHP method is proposed.

Compared with ordinary AHP, FAHP has the following advantages:

(1) It is easier to verify the consistency of the fuzzy matrix than to check the consistency of the judgment matrix by calculating the maximum eigenvalue of the judgment matrix and its corresponding eigenvectors.

(2) Adjusting the elements of the fuzzy matrix can quickly make the fuzzy inconsistency matrix have the fuzzy consistency, which overcomes the shortcomings of the common AHP which needs several adjustments, tests, readjustments and re-tests to make the judgment matrix have the consistency.

(3) The criterion for checking the consistency of the fuzzy matrix is more scientific, accurate and simple than that for checking the consistency of the judgement matrix: $CR < 0.1$.

The steps of FAHP method mainly include the establishment of the fuzzy consistent judgment matrix and the calculation of the weight of each elements by the fuzzy consistent judgment matrix.

(1) Establishment of fuzzy consistent judgment matrix

The fuzzy consistent judgment matrix R represents a comparison of the relative importance of an element of the previous layer with respect to the element of the previous layer, assuming that the element C of the previous level is the same as the element a_1, a_2, ..., a of the next level. n is related, then the fuzzy consistent judgment matrix can be expressed as:

C	a_1	a_2	...	a_n
a_1	r_{11}	r_{12}	...	r_{1n}
a_2	r_{21}	r_{22}	...	r_{2n}
⋮	⋮	⋮	⋮	⋮
a_n	r_{n1}	r_{n2}	...	r_{nn}

The element r_{ij} has the following practical meaning: r_{ij} indicates that the element a_i and the element a_j are compared with respect to the element C , and the element a_i and the element a_j have a degree of membership of the fuzzy relationship "... much more important than ... " . In order to quantify the relative importance of any two schemes with respect to a criterion, the scale of 0.1 to 0.9 can be used to give the scale.

Table . 7 .38 0.1 - 0.9 Number of scale

Scaling definition	Description
0.5	
0.6	
0.7	

0.8

0.9 Equally important

Slightly important

Obviously important

Much more important

Extremely important Comparing the two elements is equally important.

One element is slightly more important than the other compared to the other.

Compared to two elements, one element is significantly more important than the other.

Compared to two elements, one element is much more important than the other.

Compared to two elements, one element is extremely important than the other.

0.1, 0.2

0.3, 0.4 Counter comparison If the element a_i is compared with the element a_j to obtain the judgment r_{ij} , the judgment of the element a_j compared with the element a_i is $r_{ji} =1- r_{ij}$.

With the above numerical scale, the elements a_1 , a_2 , ..., a_n are compared with the previous element C to obtain the following fuzzy judgment matrix:

R has the following properties:

1 $r_{ii} =0.5$, $i =1 , 2 , ... , n$;

2 $r_{ij} =1- r_{ji}$, $i , j =1 , 2 , ... , n$;

3 $r_{ij} = r_{ik} - r_{jk}$, $i , j , k =1, 2 , ... , n$.

That is, R is a fuzzy uniform matrix. The consistency of fuzzy judgment matrix reflects the consistency of people's thinking judgment, which is very important in constructing fuzzy judgment matrix. However, in the actual decision analysis, due to the complexity of the problem studied and the one-sidedness that people may know, the construction The judgment matrix that is produced often does not have consistency. At this time, the necessary and sufficient conditions of the fuzzy uniform matrix can be applied for adjustment. The specific adjustment steps are as follows:

The first step is to determine a certain element that is judged with the importance of the remaining elements, without losing the generality. The decision makers think that the judgments r_{11} , r_{12} , ... , r_{1n} are more certain .

In the second step, the corresponding element of the second row is subtracted from the first row element of R. If the obtained n differences are constant, the second row element is not needed to be adjusted. Otherwise, the second row element is adjusted until the difference between the first row element minus the corresponding element of the second row is constant.

In the third step, the corresponding element of the third row is subtracted from the first row element of R. If the obtained n differences are constant, then the elements of the third row need not be adjusted. Otherwise, the elements of the third row are adjusted until the difference between the first row element minus the third row corresponding element is constant.

The above steps continue until the difference between the first row element minus the corresponding element of the nth row is constant.

(2) Finding the weight values w_1 , w_2 , ..., w_n of the elements a_1 , a_2 , ... , a_n from the fuzzy uniform judgment matrix R

Let the fuzzy consistency matrix obtained by comparing the two elements of the elements a_1 , a_2 , ... , a_n be $R = (r_{ij})_{n \times n}$, and the weight values of the elements a_1 , a_2 , ..., a_n respectively For w_1 , w_2 , ... , w_n , it is known from the previous discussion that the following relationship holds [53, 54] :

Where: a is a measure of how different people perceive the perceived object. a larger sum of the weights of the different indicators smaller difference; a smaller, the greater the difference between the sum of weights, when a = (n- difference / sum of weights of 2:00 -1) is maximized. Therefore, A smaller shows that policy makers attach great importance to the importance of the difference between the elements, A higher number indicates a significant difference in the degree of policy makers is not between elements very seriously.

4.2 Application of FAHP

The FAHP method is a systematic analysis method combining qualitative and quantitative analysis. It uses AHP to represent a complex problem as an ordered hierarchical structure. According to the hierarchical analysis structure model and expert judgment information, the fuzzy of each level element is constructed. The matrix is judged so that a complex decision problem can be derived using a simple pairwise comparison. The FAHP method calculates the combined weights of the constituent elements of each level for the total target by establishing the hierarchical analysis structure model, the construction judgment matrix, the hierarchical single sorting and the hierarchical total sorting, so as to realize the importance ranking of different risk factors. The FAHP method is currently widely used in coal mine safety [55] , power safety [56] , pipeline risk [57, 58] and other comprehensive evaluation, multi-objective system decision-making, etc., maritime traffic safety risk assessment, Ji-Yeong Pak, etc. The FAHP method was used to process the data collected by the 21 captains with more than 10 years of experience in independently maneuvering the ship. The safety of the six ports in Korea was evaluated and the most important indicators affecting port safety were obtained. Sort.

CHAPTER 5

Marine traffic safety assessment

5.1 Model of marine traffic safety assessment

Based on the analysis of various factors affecting maritime traffic safety, AHP is used to construct a multi-level fuzzy comprehensive evaluation model to carry out multi-level risk assessment, so that the previous comprehensive evaluation vector obtained by low-level evaluation can continue to participate. A level of evaluation.

(1) Establishing a set of factors

According to the affiliation between internal factors of the system, the solution of a complex system is decomposed into solutions to multiple simple subsystems, and then integrated step by step. Determine the factors that influence the object or system, based on the object or system under study, to form a set of factors.

$A= \{ a_1 , a_2 , ... , a_n \}$

$a_i = \{ a_{i1} , a_{i2} , ... , a_{in} \}$

Where: the first level indicator $A = \{ a_1 , a_2 , ... , a_n \}$ is the various factors affecting the target layer A; the second level indicator $a_i = \{ a_{i1} , a_{i2} , ... , a_{in} \}$ To influence the various factors of the first level of indicators. According to the different second-level indicators a_{ij} of the research object, it can be further subdivided. For maritime traffic safety risk (port waters, the waters of the channel) to establish a 3 layer index evaluation system, as described in chapter 7. 1.2 and 7. Section 1.3 of Figure 7. 1 and 7. 2

(2) Determine the weight set

The importance of each factor in the factor concentration is different for the object of judgment. In order to reflect the importance of each factor, a corresponding weight w_i ($i =1 , 2 , ... , n$) is assigned to each factor a_i , and the factor weight set W composed of each weight is the blur on the factor set A Subset.

$W = \{ w_1 , w_2 , ... , w_n \}$

In the formula: the weight w_i is the membership degree of the factor a_i to A, that is, it reflects the importance degree of each factor in the comprehensive evaluation, and generally should satisfy the normalization and non-negative conditions.

The book uses the FAHP method (see 7. 2.1 for details) to process the expert questionnaire to determine the weight of each factor.

Dalian Port for port maritime traffic safety risk assessment waters, a total of questionnaires 258 copies were issued including the Liaoning Maritime Safety Administration (Department of navigation, the crew, the ship Management Services), Dalian Maritime Bureau (VTS, PCS, the crew at), Dalian pilot Relevant personnel of the station (pilot), Zhonghai passenger ship (senior crew, sea affairs supervisor), Bohai Ferry (senior crew, sea affairs supervisor) and other units. A total of 234 questionnaires were retrieved, and 214 valid questionnaires, including 179 port waters (Dalian Port) and 35 waters in the channel waters (Laoshan Waterway).

The results are shown specific weight of Chapter 7. Section 4 authentication instance.

(3) Determine the evaluation set

The evaluation set is a collection of judgement results that may be judged by the judge. When determining the evaluation level, according to the characteristics of maritime traffic safety risks and referring to relevant researches of domestic and foreign experts and scholars [16, 50, 60, 61] , define the evaluation level and specify the score.

$V = \{ v_1 , v_2 , v_3 , v_4 , v_5 \} = \{1 , 2 , 3 , 4 , 5\}$

In the formula: 1 , 2 , 3 , 4 , and 5 represent fuzzy numbers, which represent the determined evaluation level: low risk, low risk, general risk, high risk, and high risk.

The level of risk is divided by the severity of the risk. The severity of the risk refers to the most serious consequences of the accident of the risk subject in general, and is determined by the casualties, pollution levels, economic losses, and social impacts that may result from the accident. Refer to the "Statistical Measures for Waterborne Traffic Accidents" on the classification criteria for water traffic accidents [62] and the mortality control indicators issued by the Maritime Safety Administration of the Ministry of Transport in recent years to the direct maritime affairs bureaus and the regulations on the management of water traffic safety risks of the Guangdong Maritime Safety Administration (Trial) The grading standards for safety risk sources are determined by the following specific criteria [62, 63] :

Low risk (point 1): It may cause death and disappearance of 3 persons and below, or the direct economic loss may be less than 10 million yuan.

Low risk (point 2): 4 to 10 people may be missing from the death, or the direct economic loss may be more than 10 million yuan, less than 30 million yuan.

The general risk (point 3): may cause death to disappear 11 to 20 people, or may cause direct economic losses of more than 30 million yuan, less than 60 million yuan.

High risk (point 4): 20 to 30 people may be missing from the death, or the direct economic loss may be more than 60 million yuan, less than 100 million yuan.

High risk (point 5): 30 people and more may be missing, or the direct economic loss may be more than 100 million yuan.

(4) Fuzzy comprehensive evaluation

The single factor fuzzy evaluation is judged separately from a factor a ij to determine the evaluation object for the evaluation set element v k (k =1, 2, 3, 4, 5) The process of membership r ijk . Of A ij ofEvaluation results R & lt ij of the fuzzy sets as a single factor evaluation.

The membership degree of each single-factor fuzzy evaluation set is taken as a single-factor evaluation matrix.

For the first-level fuzzy comprehensive evaluation, the comprehensive evaluation set Ei of the i-th factor can be obtained by multiplying the fuzzy transform R i by the factor weight set Wi according to the weighted average type fuzzy operator .

First-level fuzzy comprehensive evaluation model:

Multi-level fuzzy comprehensive evaluation model:

(5) Evaluation results

The final result of the fuzzy comprehensive evaluation is a fuzzy vector, that is, the membership object belongs to the membership degree vector of each evaluation level [19] . When determining the level of the object to be judged, the fuzzy vector needs to be defuzzified. The commonly used methods of anti-fuzzification are: the principle of maximum membership degree and the principle of weighted average.

1 Maximum membership degree principle determines evaluation results

The most large membership degree evaluation maritime traffic safety risks reviews set belongs to a risk value determination the conventional method [64] , i.e. a vector E , the maximum value of the comment corresponding to the comment set V J is the final rating scale.

2 Weighted average principle to determine evaluation results

The result of the fuzzy comprehensive evaluation is the membership degree vector of the judgement subject to each evaluation level. When determining the level of the object to be judged, the blur vector needs to be sharpened. The weighted average method is used for processing, and e k (k =1 , 2 , ... , 5) is regarded as a weight, and the evaluation set E is weighted and averaged:

Where: (k =1, 2, ... , 5) For each factor and the score corresponding to the evaluation set, the obtained E * is the result of the comprehensive evaluation.

5.2 Case verification

This paper evaluates Laotieshan Shuidao with FAHP method, and verifies the scientific rationality of the method.

Laotieshan waterway lies between Laotieshan in the southwest of Liaodong Peninsula and Beiweicheng Island in the north of Miaodao Islands. It holds the throat of the Bohai Sea. The navigable water area is 7.5 nautical miles wide and the water depth is 39-68 M. It is the only way for large vessels to enter and leave the ports around the Bohai Sea.There are many fishing boats in the past and in operation. The navigation density of waterway vessels is high, the flow direction of vessels is complex, and the encounter rate is high. There are strong winds, high waves, high currents and fog in the waters. There are military restricted zones on both sides. The navigable waters are restricted to a certain extent. The waters become the areas where collision accidents occur frequently at sea.Investigation and statistics show that from 1994 to 2004, 11 traffic accidents above grade occurred in Laotieshan waterway and its adjacent sea area, and all of them were collision accidents.Great loss of life and property has been caused, and the leakage of oil and liquid chemicals caused by the accident has polluted the marine environment [72].

Brief introduction of navigation environment in the waters near Lao Tie Shan Road

A. Natural Conditions

The Bohai Sea has obvious monsoon characteristics.Winter monsoon prevails from October every year to March next year. The prevailing period of about six months is mainly northerly wind.Among them, the northwest wind direction is dominant, the wind direction is stable and the wind force is strong.The summer monsoon is prevalent from May to August.July and August are the peak periods of summer monsoon.The wind direction is south and the southeast wind is the main wind direction.The wind is not strong and the wind direction is unstable.

Gale weather is the main disastrous weather in this region.The strong wind waves in the Bohai Sea mainly occur from October every year to March next year. The weather systems causing the strong wind are mainly cold high pressure, temperate cyclone and tropical cyclone.According to statistics, the average number of gale days above grade 8 can reach about 60 days per year, and the average number of gale days above grade 6 is about 100 days.

Sea fog is the main factor affecting visibility in the Bohai Sea.The foggy season is from March to July every year. Sea fog begins to appear in March, and also in February in some years. It gradually increases after that, with the maximum in June and July.The average foggy day is 20-24 days per year.Sea fog has a great influence on the safe navigation of ships at sea. More than half of collision accidents occur in weather conditions with poor visibility.

The flow velocity in the vicinity of the old iron mountain road is large, and the maximum flow velocity of the East and West flows is 6.25kn, and there are many undercurrents.

B. Traffic conditions

According to statistics, in the past 2010~2014 years, the annual average ship navigable traffic volume in the waters near the old iron mountain road is 83375 vessels, of which 93.75% are mainly transport ships, 4.60% are passenger ships, and 17.99% are dangerous goods vessels (including oil tankers).In 2014, the traffic flow of ships was 81,048, averaging 222 times a day.

According to the track distribution chart, the ship tracks in the western waters of Laotie can be divided into three parts.

Ship traffic flow to Yingkou Port and Jinzhou Port;

Ship traffic flow to Tianjin Port, Huanghua Port, Caofeidian Port and Jingtang Port;

Ship traffic flow to Qinhuangdao Port.

The traffic flow of each stock forms intersections in the waters near Laotieshan (mainly in the alert area of the fixed-line waters), forming multiple intersections.

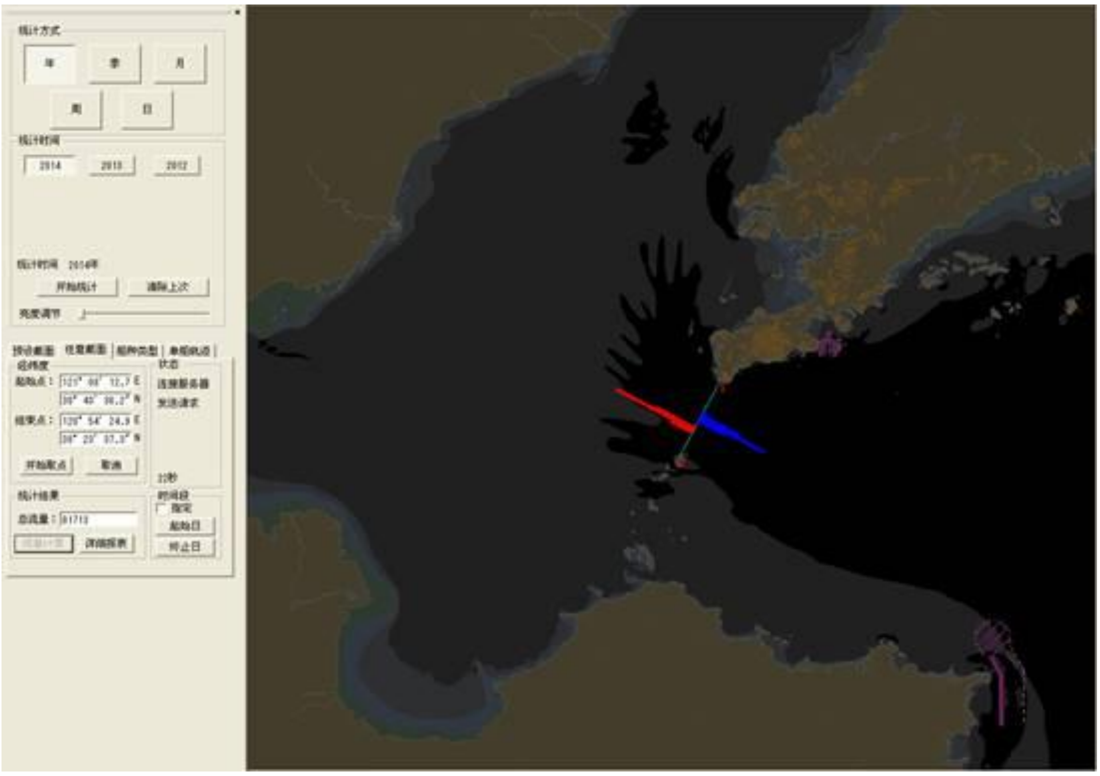

Figure 5.1 Vessel Traffic Statistics of Laotieshan Waterway Gate Line

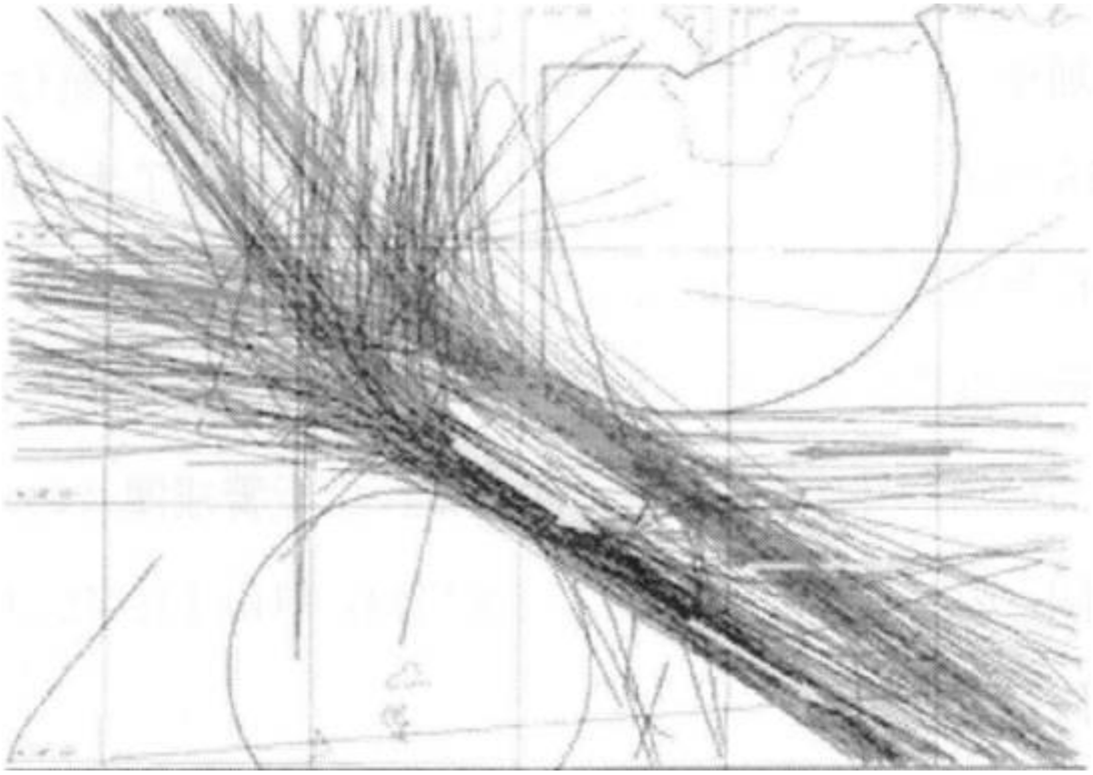

Figure 5.2 Track Distribution of AIS Ship in Laotieshan Waterway

(2) Weight acquisition

FAHP method was used to deal with the data collected from 35 experts' questionnaires, and the weight values of various factors that affected the risk of marine traffic safety in the old iron mountain area were obtained.

Table 7.45 Weight Table of Maritime Traffic Risk Assessment Index System in Laotieshan Waters

Layer 1 Indicators	weight	Layer 2 Indicators	weight	Layer 3 Indicators	weight
people	0.3276	competence	0.3273		
		Conscientiousness	0.4152		
		Fatigue degree	0.2576		
ship	0.2118	Seaworthiness	0.3936		
		Navigable hull form	0.3597		

		Tonnage of ships	0.2467		
Environmental Science	0.1906	natural environment	0.5727	wind	0.2813
				visibility	0.3252
				Trend	0.1851
				Depth of water and obstacles to navigation	0.2084
		Traffic environment	0.4273	Ship traffic volume	0.3610
				Routing System and Navigation Aid Signs	0.2613
				Ship encounter status	0.1968
				The Impact of Fishing Vessels	0.1810
Administration	0.2712	maritime management	0.4955		
		Shipping Company Management	0.5045		

(3) Obtain the membership degree of each index according to the navigation environment data of Laotieshan waters.

The author has carried out data research to Liaoning Maritime Safety Bureau for several times to obtain data on marine traffic safety risk indicators involved in Liaoning maritime safety administration area and Dalian old iron and water landscape area, including: high risk ship size, ship size distribution, seaworthiness status (safety check retention rate), ship traffic volume, etc.The data processing results of the system (old iron mountain water) "Questionnaire" and referring to the existing research results related to the old iron and water landscape area [72-74], obtained the membership table of the risk assessment index of the sea traffic risk in the old iron mountain waters, as shown in table 5.1.

Table 5.1 Subjection Degree of Maritime Traffic Risk Assessment Indicators in Laotieshan Waters

index			Degree of membership				
Layer 1 Indicators	Layer 2 Indicators	Layer 3 Indicators	**Low risk**	**Lower risk**	**General risk**	**Higher risk**	**High risk**
people	competence		0.0000	0.8667	0.0667	0.0667	0.0000
	Conscientiousness		0.0667	0.5333	0.3333	0.0667	0.0000
	Fatigue degree		0.0000	0.2368	0.5263	0.2105	0.0263
ship	Seaworthiness		0.0000	0.0000	0.4486	0.5514	0.0000
	Navigable hull form		0.0000	0.0000	0.3727	0.6273	0.0000
	Ship dimensions		0.0000	0.0000	0.8510	0.1331	0.0159
Environmental Science	natural environment	wind	0.0000	0.0000	0.5000	0.5000	0.0000
		visibility	0.0000	0.1000	0.9000	0.0000	0.0000
		Trend	0.0000	0.0000	1.0000	0.0000	0.0000
		Depth of water and obstacles to navigation	1.0000	0.0000	0.0000	0.0000	0.0000
	Traffic environment	Ship traffic	0.0000	0.0000	0.2800	0.7200	0.0000

		volume					
		Routing System and Navigation Aid Signs	0.0667	0.5333	0.3333	0.0667	0.0000
		Ship encounter status	0.0000	0.0000	0.6000	0.4000	0.0000
		The Impact of Fishing Vessels	0.0000	0.0571	0.1143	0.5143	0.3143
Administration	Maritime Management Level		0.0667	0.5333	0.3333	0.0667	0.0000
	Management Level of Shipping Company		0.0000	0.4667	0.3333	0.2000	0.0000

(4) Fuzzy comprehensive evaluation

A. Maximum Subordination Principle

According to the comprehensive evaluation results of marine traffic safety risk in the old iron mountain area:

$$E = \begin{bmatrix} 0.0421 & 0.3811 & 0.3536 & 0.2165 & 0.0068 \end{bmatrix}$$

According to the principle of maximum membership, the old iron landscape area is a "low risk" grade.

B. Weighted Average Principle

According to the comprehensive evaluation results of marine traffic safety risk in the old iron mountain area, it can be concluded that the sea traffic safety risk value in the old iron mountain area is between "low risk (2)" and "general risk (3)", and is closer to "general risk".

Main factors of C. affecting the safety of marine traffic in old iron and mountain area

According to the analysis of the single factor evaluation, we can find the main factors that affect the traffic safety risk of the old iron mountains and waters: human factors are the main factors that affect the traffic safety risks of the old iron mountains and waters. Poor visibility and strong wind weather have certain effects on maritime traffic safety. The main factors affecting the risk of maritime traffic safety in Lao Tie Shan waters are: fishing vessels have great influence on the safety of marine traffic in the Laotieshan Shuidao and adjacent waters.

CHAPTER 6

SUMMARY and CONCLUSIONS

On the basis of analyzing the characteristics of maritime traffic safety risk, the evaluation index system of maritime traffic safety risk in channel waters is established; the weight of each index evaluation factor is obtained by FAHP method through processing expert questionnaire; finally, the risk evaluation model of maritime traffic safety in channel waters is established and implemented. Example verification. The results show that:

(1) The marine traffic risk assessment model based on FAHP method and fuzzy comprehensive evaluation is suitable for the maritime traffic safety assessment in channel waters. The evaluation results can reflect the risk level of water area and the main risk factors affecting the risk, and have good practical value.

(2) Compared with traditional AHP and other methods, FAHP method has certain advantages and is suitable for determining the weight of the risk index system of maritime traffic safety.

(3) It is feasible to use the detention rate data of ship safety inspection as a standard to measure the seaworthiness of ships, which can reflect the overall safety situation of ships in a certain area to a certain extent.

(4) The scale of high-risk ships mainly considers the importance of life safety and environmental safety in the current society. Once a safety accident happens on passenger ships and dangerous goods ships, it will lead to tremendous social impact,

loss of life, property and environmental damage. Therefore, as an important index in the evaluation index system, the results of risk assessment are considered. It has good reference value.

(5) Because of the limitation of the collected data and the time, both the index system and the evaluation method have some limitations, which need to be further improved..

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