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Analysis and evaluation of maritime traffic risk in circumjacent water of Dagushan Peninsula of Dalian

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Analysis and Evaluation of Maritime Traffic Risk in Circumjacent Water of Dagushan Peninsula of Dalian

By

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DECLARATION

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

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

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ABSTRACT

Title of Research Paper: **Analysis and Evaluation of Maritime Traffic Risk in Circumjacent Water of Dagushan Peninsula of Dalian**

Degree: **MSc**

This paper carries out analysis and evaluation of maritime traffic risk in circumjacent water of Dagushan Peninsula of Dalian, in ways of:

Combined with relevant references, giving a brief overview of risk evaluation and the research status in port waters. Based on this, proposing the issue of risk evaluation for Dagushan Peninsula waters;

Combined with the main factors affecting maritime traffic safety in port waters, based on the principle of scientificity, operability etc., based on experts' guidance and advice, establishing the index system under the framework of "human-ship-environment-management" to evaluate the risk in Dagushan Peninsula waters;

Based on the establishment of the index system, with reference to the relevant literature, combined with the data and experts' advice, and further determining the evaluation standards;

Based on Fuzzy Analytic Hierarchy Process (FAHP) and relevant references, establishing a comprehensive evaluation model for maritime traffic risk in port waters and finally applying it to Dagushan Peninsula waters.

KEYWORDS: Port Waters, Risk Evaluation, FAHP, Dagushan Peninsula.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
DL	Dalian
DLETDZ	Dalian Economic and Technological Development Zone
ETA	Event Tree Analysis
FMEA	Faliure Mode and Effect Analysis
FAHP	Fuzzy Analytic Hierarchy Process
FTA	Fault Tree Analysis
HAZOP	Hazard ans Operability Analysis
IMO	International Maritime Orgnization
MLEM	Maximum Likelihood Estimation Method
MSA	Maritime Safety Administration
NR	Nature Reserve
NTCT	Navigational Traffic Conflict Technique
PHA	Preliminary Hazard Analysis
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Assessment
PSC	Port State Control
SCA	Safety Checklist Analysis
TA	Tourist Attraction
VTS	Vessel Traffic Service

CHAPTER1

INTRODUCTION

1.1 Background

Maritime traffic safety has always been a matter of concern. Since the 21st century, economic globalization and the technological revolution has gradually arisen, the world trade has been developing, and the demand for maritime transportation is increasing. With the rapid development of marine industry and the increasing traffic flow density, navigation environment is becoming more and more complicated, and the factors affecting maritime traffic safety are increasing. It can be seen that economic development promoted the maritime industry, at the same time, it also increased maritime traffic risks and maritime traffic accidents. Therefore, it is necessary to evaluate these risks and get the main influencing factors and take corresponding measures.

Dagushan Peninsula is located in the southeast of the Dalian Economic and Technological Development Zone, and the Sanshandao Sea Treasures Nature Reserve is to the south of the peninsula. After years of construction, Dagushan Peninsula is gradually developing into the international container hub port , grain transshipment center as well as the distribution centre of oil, liquid chemical products and ore in the northeast of China.

The main types of ships calling to Dagushan Peninsula are bulk carriers, oil tankers, liquid chemical tankers and container ships. In 2009, there were totally 6324 ships calling to Dagushan Peninsula,assuming that 330 operating days per year, there were 19.2 ships calling to Dagushan per day on average, which means approximately 40 ships (arrival and departure) sailing in the Dagushan Peninsula waters, obviously the traffic density of this area is very large. What's more, there is an apparent trend of the increasing number of ships in large-scale. In 2005, there were 74 ships of more than 100,000 tons calling to Dagushan, and the number reached 277 in 2009, nearly 4 times as the one of 2005. In the future, the number for the year of 2020 and 2030 will be 11000 and 13000 respectively. (Dalian MSA, 2017)

In summary, with the construction of the Dagushan Peninsula as well as the increasing traffic density and ships' scale, the maritime traffic risk is also rising in Dagushan Peninsula waters. Therefore, it is necessary to evaluate the risk of maritime traffic safety in this water comprehensively.

1.2 Objective

The objective of this paper is to evaluate the risk of maritime traffic safety in Dagushan Peninsula water quantitatively and comprehensively, and provide a maritime safety judgment and recommendation for Dalian Maritime Safety Administration (MSA). Based on the literature review, the researches about Dagushan Peninsula are mainly in the field of hydrology, biology, environmental protection, petrochemical, geology and so forth, but rarely involving risk of maritime traffic safety. However, as discussed above, the traffic density in this water has been always growing over time, the potential maritime traffic risk should not be ignored. Furthermore, as there are some coastal tourist attractions and nature reserve near Dagushan Peninsula, it can trigger economic and environmental losses in case of marine accidents in this water. Thus, this paper aims to arouse more attention to the maritme safety of this water from the academia, government and public.

1.3 Methodology and structure

The maritime traffic risk evaluation of Dagushan Peninsula waters is a complicated system engineering, which contains a large amount of uncertain and unascertained information, bringing great difficulties to the evaluation. Hence, the methodology adopted in this paper is Fuzzy Analytic Hierarchy Process (FAHP).

First of all, on the basis of the literature review, the author established the objective, content and methodology of this paper. Secondly, the author obtains the influencing factors of Dagushan Peninsula waters through the on-the-spot interview and expert consultation etc. Thirdly, the author analyzes and selects the key influencing factors, establishes and perfects the evaluation system and standards of maritime traffic risk in Dagushan Peninsula water according to the feedback of the experts and the questionnaires, moreover, the results of the questionnaire are as a basis for calculating and determining the weight of each index. Finally, an evaluation model based on FAHP is established and applied to Daguashan Peninsula water to analyze the risk, and the author gives the recommendation.

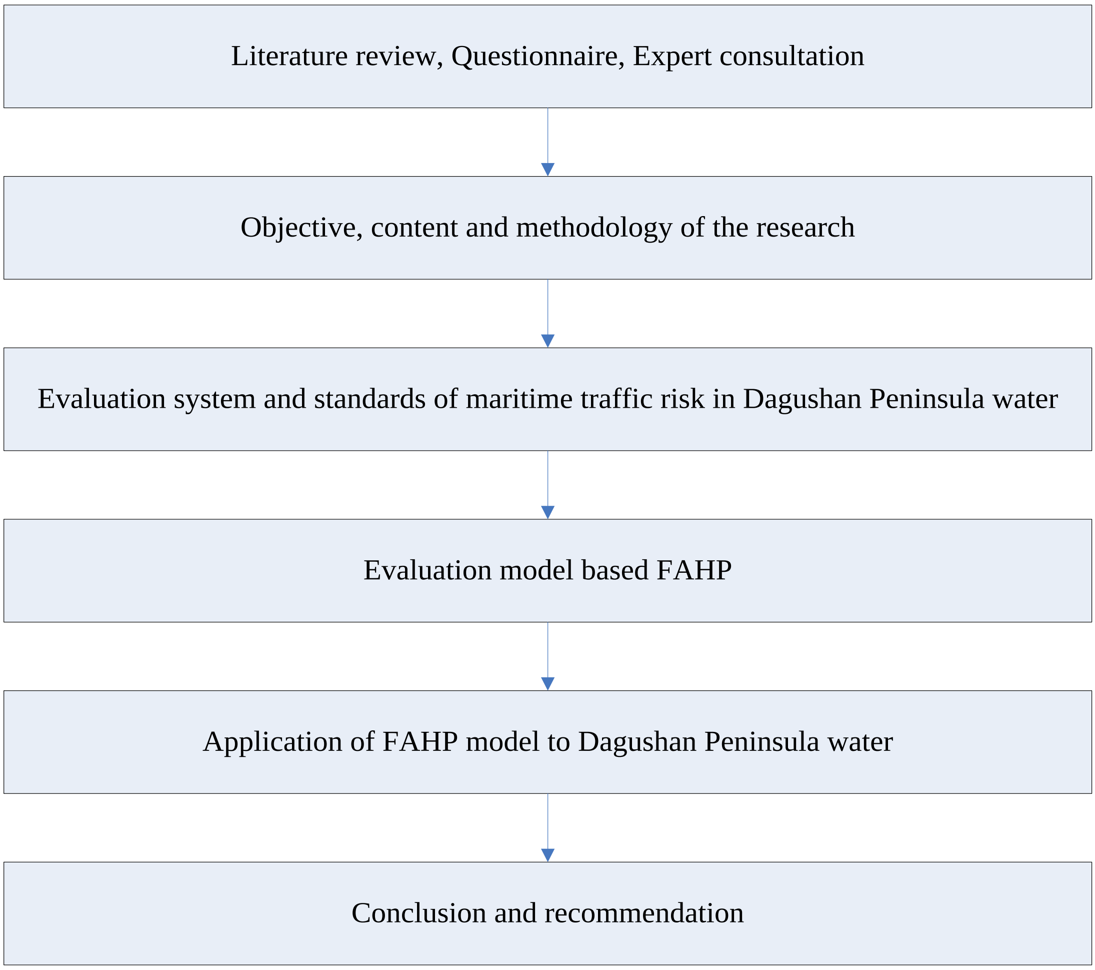

Figure 1.1 Structure of the research
Source: Compiled by the author

CHAPTER 2

OVERVIEW

2.1 General

“Risk” and “Safety” seem to be a pair of twins, because they are always mentioned together. Different scholars or organizations gave broadly similar definitions of safety, such as: “*Safety is the freedom from unacceptable risk*. ” (The American National Standards Institute). “*Safety is the freedom from accidental injury.* ” (U.S. Agency for Healthcare Research and Quality). “*Safety is the state in which harm to persons or of property damage is reduced to, and maintained at or below, an accepable level through a continuing process of hazard indentification and risk management.* ” (Intennational Civil Aviation Organization). In one word, safety is defined as “ *a condition where noting goes wrong*”. (Hollnagel, 2014, pp. 435-439). In the maritime industry, risk is defined as “*The combination of the frequency (the number of occurrences per unit time) and the severity of the consequence (the outcome of an accident), in which ‘accident’ means ‘An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage’*.” (IMO, 2013).

Risk evaluation is also known as safety assessment, which takes the safety of the system as the goal, uses the relevant principles and methods of the safety system engineering, carries on a qualitative or quantitative analysis to the systematic or the latent risk factors, and finally obtains the appraisal of the system risk possibility and the consequence severity. Risk evaluation mainly include the following 3 parts:

Risk identification: to find unsafe factors for quantification or qualitative analysis;

Safety assessment: to evaluate the system risk and draw a conclusion;

Safety improvement measures: to reduce the incidence of accidents.

2.2 Status of research on maritime traffic risk evaluation in port waters

2.2.1 In the world

Lehikoinen and Luoma etc. (2015) assessed the collision risk of oil accident in the Gulf of Finland based on Bayesian Network. Dong and Dan (2015) computed the probability of ship collision and assessed the sustainability with the consideration of risk attitudes. Gemelos and Ventikos (2008) analyzed human reliability in the risk assessment of Greek coastal shipping. Yip (2008) used a negative binomial regression model to study the port traffic risks in Hong Kong waters. Kumar, Chor and Mazharul (2011) anallyze the collision risk of the Singapore port fairways based on Maximum Likelihood Estimation Method (MLEM). Hoongchor (2009) utilized an ordered probit regression model to study the collision risks in port water navigation. Fang and Hu (2008) established a comprehensive evaluation model and "human-ship-environment-management" evaluation system to study the risk of ship pilotage in Shanghai port based on Faliure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA) and Hazard ans Operability Analysis (HAZOP). Debnath and Chin (2010) proposed Navigational Traffic Conflict Technique (NTCT) and Surrigate Analysis Approach as alternatives to the collision-based analysis of risk evaluation in port waters. Montewka and Hinz etc. (2010) introduced a geometrical model to their paper and used "Monte Carlo and genetic algorithms" to assessed the ship collision risk compared with the data of the Gulf of Finland. ErsanBaÅar (2010) simulated different traffic conditions of Canakkale (Dardanelle) Strait, identified the risky areas, and revealed the relationship between traffic flow and waiting ships/time. Pak and Yeo etc. (2015) carrid out a quantitative analysis based on FAHP to evaluate the safety of 6 Korean ports, by using the data collected from 21 captains who have over 10 years experience in operating ships individually (Pak,Yeo, Oh, & Yang. 2015).

2.2.2 In China

Zhao (2010) analyzed the features and causes of the accidents in the port waters, assessed the risk with cost-effectiveness in order to improve the safety of maritime traffic and proposed risk control measures. Zheng and Huang etc. (2006) analyzed the relationship between traffic accidents and environment factors in 9 port waters of

China by factor analysis method. Xuan and Li etc. (2013) adopted Probabilistic Risk Assessment (PRA) and Bayesian Network to assess the environment risk in port waters and to predict the traffic volume as well as the trend of risk in Guanzhou port. Zhang (2008) assessed and forecasted the risk of Tianjin port by grid-based method, and Fan etc. (2008) utilized the same method to evaluate the risk of port waters and make a dynamic prediction of the risk. Cao (2010) evaluated the oil port storage and transportation of Nanjing by hazard identification, warning model, summarizing the problems of oil port storage and transportation in China, and proposing the measures such as emergency rescue, what's more, he also built evaluation model based on the theory of Delphi and fuzzy theory. Wang (2011) performed risk assessment of 8 ports in China on the point of natural disaster, and established a framework and system of hazard identification and natural disaster prevention in port. Gao (2010) took a safety evaluation in port waters based on Bayesian Network, the paper analyzed the cause of accidents and potential dangerous factors, and built a practical evaluation index system for port safety. Yang (2011) analyzed ship collision risk in 30 ports of China based on Artificial Neural Network, and set up a framework as well as a mathematical model of collision risk.

2.3 Reason for adopting FAHP in this paper

There are numerous kinds of risk evaluation models, methods, or theories, such as ETA, Artificial Neural Network, FMEA, Bayesian Network, FTA, HAZOP, Safety Checklist Analysis (SCA), Monte Carlo, Preliminary Hazard Analysis (PHA), MLEM, Grey theory, Probabilistic Safety Assessment (PSA), NTCT, PRA, Delphi theory, Analytic Hierarchy Process (AHP) and so on. Nevertheless, all of them can be summarized as 3 categories: Qualitative analysis, Semi-quantitative analysis and Quantitative analysis. Evaluation of maritime traffic risk in port waters is a system engineering, and it consists of many factors influencing the system, some of which can be quantified, but some not. In addition, the evaluation standards of those factors are not same. Therefore, it calls for a semi-quantitative and comprehensive analysis method to evaluate the maritime traffic risk in port waters, and FAHP is one of the suitable means. It can be more convincing after the discussion of Chapter 4 and 5.

CHAPTER 3

DAGUSHAN PENINSULA WATER

3.1 Location

Dagushan Peninsula is located in the southeast of the Dalian Economic and Technological Development Zone (DLETDZ), and the Sanshandao Sea Treasures Nature Reserve is to the south of the peninsula. Dagushan Peninsula is about 25 kilometers from the downtown of Dalian City, about 20 kilometers from Dalian airport, about 23 kilometers from Dalian railway station, about 8 kilometers from the expressway entrance. After years of construction, Dagushan Peninsula is gradually developing into the international container hub port , grain transshipment center as well as the distribution centre of oil, liquid chemical products and ore in the northeast of China.

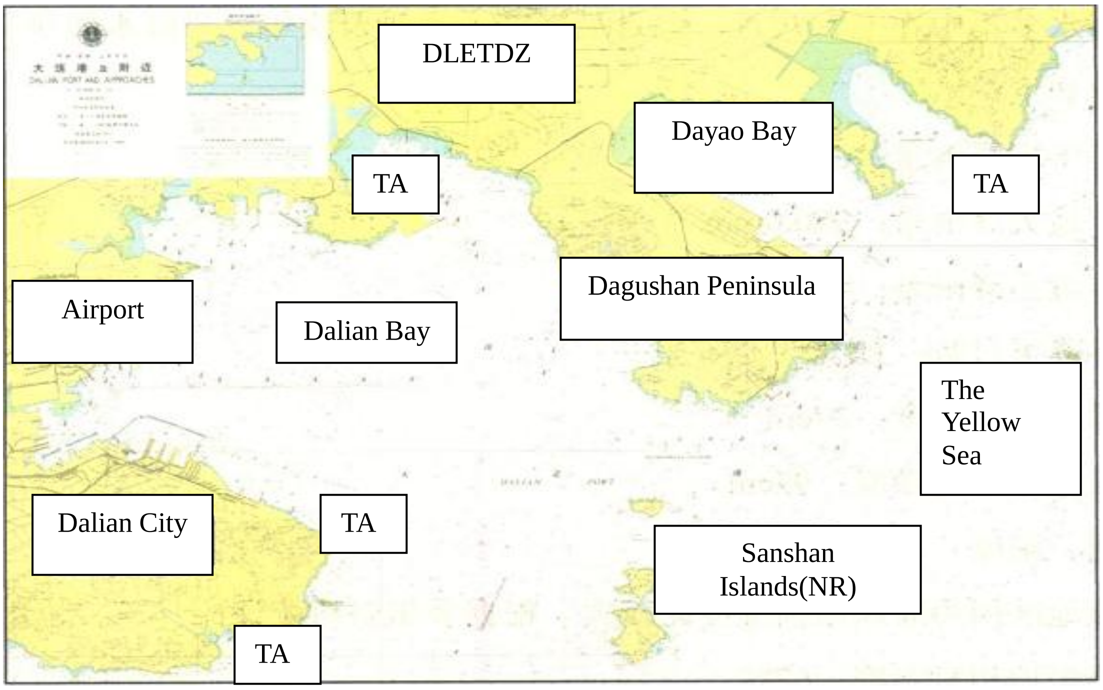

Figure 3.1 Location of Dagushan Peninsula
Source: Made by the author based on Zhang (2014)
* TA: Tourist Attraction; NR: Nature Reserve.

3.2 Nature (Meteorology and Hydrology)

3.2.1 Air temperature

Table 3.1 Air temperature of Dagushan Peninsula

Annual average temperature	10.4 ℃
Average minimum temperature	6.5 ℃
Average maximum temperature	14.8 ℃
Extreme minimum temperature	-21.1 ℃
Extreme maximum temperature	35.5 ℃

Source: Zhang, 2014

3.2.2 Ground temperature

Generally the ground temperature stabilizes at 0℃ below after December, the soil begins to freeze in early January and the surface of the soil begins to thaw in the next February. The average depth of freezed soil is 69 cm and the maximum is 93 cm. The average number of freezed-soil days is 105, the maximum thickness of snow is 37 cm. (Wang, 2009).

3.2.3 Precipitation

Precipitation concentrated in July or August, the most in July, little from November to the next March. The main data is as follows:

Table 3.2 Precipitation of Dagushan Peninsula

Annual average rainfall	677.1 mm
Annual maximum rainfall	950 mm
Annual minimum rainfall	425.9 mm
Number of snowfall days	12
Maximum thickness of snowfall	37 cm
Maximum depth of frozen line	93 cm

Source: Zhang, 2014

3.2.4 Humidity

The humidity of this area is relatively big due to the sea breeze.

Table 3.3 Humidity of Dagushan Peninsula

Annual average relative Humidity	67%
Winter Humidity	53%
Summer Humidity	77%
Monthly average maximum humidity	84.7%
Monthly average minimum humidity	56. 7%

Source: Zhang, 2014

3.2.5 Wind

This area is mainly affected by the monsoon: more southerly in summer, and more in winter. The major direction of wind is north, with the frequency of 19. 45%. The annual average wind speed is 5.8 m/s, the frequency of gale (mainly the northerly) at 6 above is 8.4%. (Ding, 2011). The typhoon appears from July to September and the most in July. In history, the thphoon affected Dagushan Peninsula approximately 20 times in total, about once every two years.

Table 3.4 Wind of Dagushan Peninsula

Wind direction	Average speed (m/s)	Maximum speed (m/s)	Frequency (%)
N	8.0	34.2	19.5
NNE	5.6	20.0	2.8
NE	2.7	17.0	1.2
ENE	5.7	17.0	2.9
E	4.8	15.0	4.9
ESE	4.2	11.5	6.8
SE	3.8	22.0	6.4
SSE	4.2	12.0	6.8
S	4.9	12.0	9.0
SSW	5.7	13.0	3.8
SW	5.5	14.0	4.5
WSW	5.5	13.0	2.6
W	5.5	17.0	4.0
WNW	6.6	20.0	3.4
NW	6.5	24.4	8.8
NNW	7.5	33.8	5.8
C			6.8

Source: Zhang, 2014

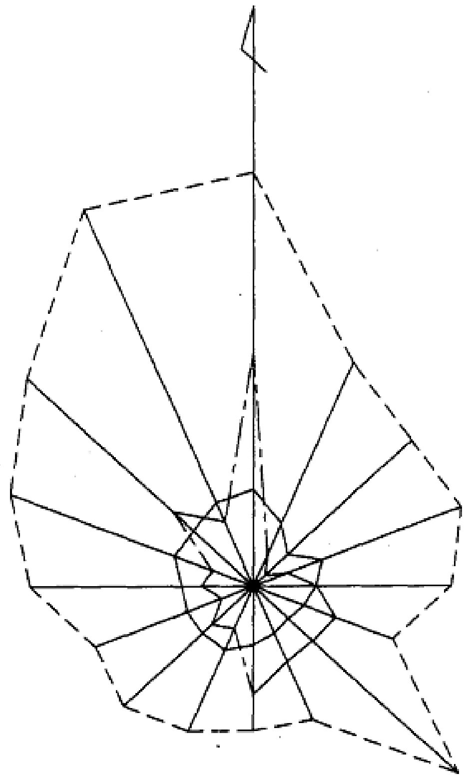

Figure 3.2 Wind rose of Dagushan Peninsula

Source: Zhang, 2014

3.2.6 Tide

Table 3.5 Tide of Dagushan Peninsula

Highest tide level	2.47 m
Lowest tide level	-2.79 m
Average high tide	1.04 m
Average low tide	-1.05 m
Average tidal range	0.46 m
Average sea level	0.02 m

Source: Zhang, 2014

3.2.7 Wave

The average annual wave height is 0.4 m to 0. 5 m, higher from July to November. The maximum wave height is 8.0 m (in August 1972) and the average monthly height is 3. 1 m to 4. 6 m. (Wang, 2009).

Table 3.6 Wave of Dagushan Peninsula

	Frequency (%)						
Wave direction	0.5 m below	0.6 to 0.8 m	0.9 to 1.0 m	1.1 to 1.5 m	1.6 to 2.0 m	2.1 m above	Total
N	2.90	0.42	0.11	0.07			3.50
NE	3.62	0.66	0.14				4.42
NNE	3.33	0.63	0.11	0.07	0.04		4.18
ENE	3.90	0.77	0.07	0.07	0.11		4.92
E	4.67	0.63	0.21	0.25	0.07		5.83
ESE	6.85	1.44	0.24	0.07			8.60
S	6.36	1.76	0.42	0.76	0.04	0.04	9.38
SE	11.55	2.98	0.65	0.67	0.11	0.07	16.03
SSE	8.39	2.74	0.84	0.63	0.04		12.64
SW	5.65	0.98	0.28	0.14			7.05
SSW	6.07	1.26	0.24	0.18	0.18	0.04	7.97
W	2.31	0.21	0.04	0.04			2.60
WSW	2.60	0.31	0.07	0.04			3.02
WNW	1.72	0.27	0.07	0.04			2.10
NW	2.21	0.46	0.25	0.10			3.02
NNW	2.95	0.42		0.04			3.41
C	1.33						1.33

Source: Zhang, 2014

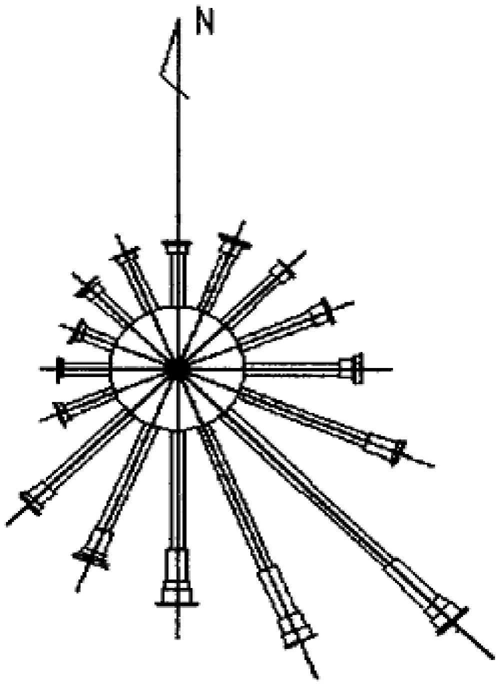

Figure 3.3 Wave rose of Dagushan Peninsula

Source: Zhang, 2014

3.2.8 Current

The current is usually a regular half-day trend, which is NNW at the mouth of the bay with the speed of 2.3 kn when tide is rising, and is the direction of S at the mouth of the bay with the speed of 1.2 kn when tide is dropping. (Ding, 2011).

3.2.9 Ice

The freezing period of Dalian Bay is usually from early January to early March, with the thickness of about 5 to 10 cm and a maximum of 45 cm.(Ding, 2011) Most of the sea ice is in the vicinity of the coast line, and it will not affect the navigation in normal years.

3.3 Sensitive target

Sanshan Islands, Bangchui Island, Jinshitan Bathing Beach and Fujiazhuang Bathing Beach etc. in the surrounding seas are sensitive targets for the risk of seaborne leakage.

3.4 Fairway

There are 4 fairways in Dagushan Peninsula waters:

Table 3.7 Fairways in Dagushan Peninsula waters

Ganjingzi Fairway	9 m in depth, 180 m in width
Xingang Fairway	17.5 m in depth,300 m in width
Dayao Bay Fairway	10.7 m in depth, 210 m in width
Dalian Bay Fairway	9.5 m in depth, 100 m in width

Source: Zhang, 2014

3.5 Traffic condition

3.5.1 Traffic flow

The main types of ships calling to Dagushan Peninsula are bulk carriers, oil tankers, liquid chemical tankers and container ships. In 2009, there were totally 6324 ships calling to Dagushan Peninsula,assuming that 330 operating days per year, there were 19.2 ships calling to Dagushan per day on average, which means approximately 40 ships (arrival and departure) sailing in the Dagushan Peninsula waters, obviously the traffic density of this area is very large. What’s more, there is an apparent trend of the increasing number of ships in large-scale. In 2005, there were 74 ships of more than 100,000 tons calling to Dagushan, and the number reached 277 in 2009, nearly 4 times as the one of 2005. In the future, the number for the year of 2020 and 2030 will be 11000 and 13000 respectively. (Dalian MSA, 2017)

3.5.2 Navigation service

The navigation aids, equipments and other supporting facilities in Dagushan Peninsula waters are complete, and the navigation mark has been basically able to guarantee the navigation safety of the passing ships in the water. VTS system constructed by Dalian MSA has been in operation for years, with a VTS centre and several radar traffic control stations. The surveillance scope of Dalian VTS centre can cover Dagushan Peninsula waters, and can meet the maritime traffic safety requirements.

.

CHAPTER 4

EVALUATION SYSTEM AND STANDARDS OF MARITIME TRAFFIC RISK IN DAGUSHAN PENINSULA WATER

4.1 Principle and Method

4.1.1 Principle

In order to make a scientifical, reasonable, feasible and effective risk evaluation, it is necessary to select evaluation factors scientifically and rationally. The research methods selected by different researchers are different, and the focus of research is also different. There are many factors that affect the safety of maritime traffic, and how to choose the appropriate influencing factors is of crucial importance for the accurate assessment of traffic safety in the port waters. This paper mainly follows the principles in determining system of the maritime traffic risk evaluation for the Dagushan Peninsula waters as below: (Wang, 2011)

Completeness

A complete index system should reflect and measure the assessed objects as completely and comprehensively as possible.

Independence

Independence refers to the use of scientific methods to deal with factors that are highly related to each other in a factor system, so that it can scientifically and accurately reflect the actual situation of the assessed objects.

Representativeness

When evaluating a specific object, it should comprehensively analyze its relevant factors, seize the main factors, and make assessed factors representative.

Operability

According to different evaluation requirements, the system of factors should be designed to be concise and the required data can be obtained, in order to facilitate the implementation of the evaluation.

Conciseness

The system should be concise with the omission of minor factors, and the established mathematical model should be easy to operate.

Combination of qualitative and quantitative evaluation

The combination of qualitative and quantitative principles can effectively reflect all the influencing factors of the system.

4.1.2 Method

The author established the evaluation system and standards by numerous relevant references and consulting experts in related fields, including on-spot interviews (Liaoning MSA, Dalian MSA, ships berthing in terminals of Dagushan Peninsula etc.) and on-line questionnaires (website: www.wenjuan .com, a total of 190 questionnaires recovered).

The widely used Expert Survey Method is the best way to gather information for scientific decision making. The experts mentioned here refer to the scholars, officers and project technicians who have a wealth of theoretical knowledge in the shipping field, as well as captains and other senior officers who are engaged in shipping and have accumulated a great deal of experience. It mainly includes professors in relevant fields, Liaoning MSA (e.g. Navigation Department, Seafarers Department, Ship Supervision Department, Legislation Department etc.), Dalian MSA (e.g. VTS, PSC Office, Seafarers Department and branches in Dagushan Peninsula etc.), senior crew, and other related personnel.

4.2 Evaluation system of maritime traffic risk in Dagushan Peninsula waters

As Fang and Hu (2008) established a comprehensive evaluation model and "human-ship-environment-management" evaluation system to study the risk of ship pilotage in Shanghai port, this paper uses their experience for reference to eatablish the system and standards under the framework of "human-ship-environment-management" to evaluate the risk in Dagushan Peninsula waters.

4.2.1 Human

The level of academic qualifications, professional skills, and physiological conditions of the seafarers are directly related to the ability to complete transportation tasks safely and efficiently. Based on the principle of establishment of the index system and the interview with experts, this paper uses the three indicators of “Competency, Responsibility and Fatigue” to evaluate the impact of human factors in the assessment of traffic safety in Dagushan Peninsula waters.

Competency

Competency is a comprehensive manifestation of human ability, intelligence and physical factors. The competency of the personnel on board is not only reflected in holding an effective certificate of competency, but should also be reflected in the level of its professional skills, including theoretical level and practical work experience. With high professional skills and strong resilience, seafarers can deal with dangers in times of crisis. However, with low levels of expertise and weak resilience, seafarers prone to misjudgments and operational errors, resulting in a dangerous and urgent situation, which may cause failure to proper response to the voyages of ships.

Responsibility

Responsibility is an important part of the quality of the crew, which is the firewall of the ship's safety. Ships in operation may encounter unexpected situations at any time, and the crew should maintain a high degree of responsibility at all times to detect and handle unfavorable situations in a timely manner.

Fatigue

Fatigue can be divided into physical fatigue and mental fatigue, which is the embodiment of human physical and mental qualities. Due to the special nature of seafarers’ work, fatigue may be caused by stress, lack of rest, etc. during the long-term work. The seafarers’ brain fatigue is physiologically manifested as a feeling of dullness and a decrease in sensitivity, and psychologically manifested as inattention, slow response, slow thinking, and irritability, which often lead to traffic accidents. Therefore, fatigue will reduce people's working level, make the body and brain unresponsive, and reduce the ability to judge, resulting in increased unsafe behavior, slower collision avoidance and worse quality of the ship's manoeuvring, which lead to accidents.

4.2.2 Ship

This paper sets up three indicators of “Ship type, Ship scale, Seaworthiness” in ship factors.

Ship type

There are different risk levels in defferent types of ships. Taking the examples of passenger ships and oil tankers, in the event of an accident on a passenger ship, major casualties will be caused and social influence will be greater; accidents of oil tankers may trigger huge pollution of the marine environment, resulting in major social impact and loss of economic assets.

Ship scale

Ship scale (tonnage) is an important factor affecting the ship's own safety, because the natural conditions of port water area are more complex and are of more limitations than the open water, and the various handling performances of the ship will be limited to different extents.

Seaworthiness

Ship seaworthiness means that the ship is properly equipped with crew, equipment, and supplies, which can load the goods and transport them safely to their destinations, complete the scheduled voyage, and have the ability of anti-risk, navigation and cargo. And maritime traffic accidents are usually related to the ship's unseaworthiness, according to statistics of traffic accidents, main engines and power supply failures are the main causes of collisions. (Dalian MSA, 2017). The accidents caused by mechanical failures etc. trigger huge loss of life and property and serious environmental pollution. Thus, the use of seaworthiness status can better reflect the overall traffic safety status in port waters.

4.2.3 Environment

Environment factors are classified into two categories: Nature and Traffic, and there are four subfactors under each category respectively. That is, “Wind, Visibility, Tide, Water depth and obstruction” for “Nature”, and “Volume of vessel traffic, Aligment and navigation aids, Encounter situation of ships, Fishing boats” for “Traffic”.

Wind

Wind, as one of the important natural environmental factors that affect the normal navigation of a ship, is one of the meteorological conditions often encountered during navigation. The strong wind will cause a big wave to a certain extent, and the wind and waves will accompany each other to affect the safety of ships. The strong wind also has a relatively high degree of impact on ship’s navigation safety, which not only causes damage to the ship itself, but also brings great difficulties to the navigation of the ship.

Visibility

Visibility is an index that reflects the transparency of the atmosphere, which refers to the maximum distance a person with normal vision can see under the weather conditions at that time, and it is closely related to the weather conditions. Some scholars believe that the following relationship exists between the number of ship accidents and the visibility distance: When the visibility distance is less than 4 km, it has a certain impact on the safety of navigation; When the visibility distance decreases to 1 km, the number of accidents sharply increases, and the visibility distance is considered to be dangerous. (Gao, 2010).

Tide

This factor affects the force condition of the ship, thereby affecting the maneuverability and performance of the ship.

Water depth and obstruction

The impact of fairway depth on the safety of the ship's navigation is mainly reflected in the decline in the handling performance of the ship. Obstacles affecting the navigational safety of ships in port waters mainly include shallows, sunken ships and rocks, which poses great difficulties for the navigation of ships.

Volume of vessel traffic

The volume of vessel traffic reflects the scale and intensity of vessel traffic in navigable waters, and to a certain extent reflects the degree of traffic congestion and danger of ships in the waters, besides, it can intuitively characterize the dangerous conditions of ships in navigable waters. The traffic density, which can reflect the busy and dangerous degree of the ship in port waters, is one of the important indicators in the risk evaluation process of port waters. Due to certain restrictions on port waters, the large amount of vessel traffic will inevitably lead to congested ships and increase navigation risks. Therefore, the volume of vessel traffic has a significant impact on the safety of maritime traffic within port waters.

Alignment and navigation aids

Ship alignment is an advanced maritime management concept. In the past ten years, the ship alignment system has been popularized and applied in many water areas in China. It has played an active role in regulating ship traffic flow, reducing ship collisions and stranding accidents. However, due to the complicated navigation environment or incomplete design solutions, the ship alignment system may have some areas where risk factors are concentrated on the separation roads, resulting in relatively frequent occurrence of accidents (Fan, 2013). Therefore, whether the establishment of the ship alignment system and the improvement of the alignment system in the traffic-intensive waters has a significant impact on maritime traffic safety.

Encounter situation of ships

Due to the limited area of port waters, ships have a high rate of encountering, often making port waters accident-prone.

Fishing boats

There are many fishing activities near port waters, and Dagushan Peninsula is no exception. The Yellow Sea nearby Dagushan Peninsula is one of important fishing waters in the northeast coast of China, and there are many fishing boats frequently engaging in fishery activities in the fishing season, bringing certain impact to maritime traffic safety.

4.2.4 Manangment

Effective management can enable the organizaiton and different individuals to play a greater role, enhance the coordination of various departments and reduce the occurrence of maritime accidents. The management factors related to maritime traffic safety in port waters can be divided into “Maritime supervision and Company management”.

Maritime supervision

Maritime supervision refers to the general term used by maritime authorities to prevent the occurrence of maritime accidents or incidents (including maritime security incidents), or to mitigate the consequences of accidents at sea, and plays an important role in ensuring the maritime traffice safety.

Company management

Company management can be divided into two parts: port company and shipping company. It has become the consensus of the entire maritime industry to enhance the maritime traffic safety by strengthening company’s safety management. As the safe production of port or ships is directly under the management of the port or shipping company, and the safety of the port or ships is closely related to the company’s economic interests, the safety management of the port or shipping companies is direct and urgent.

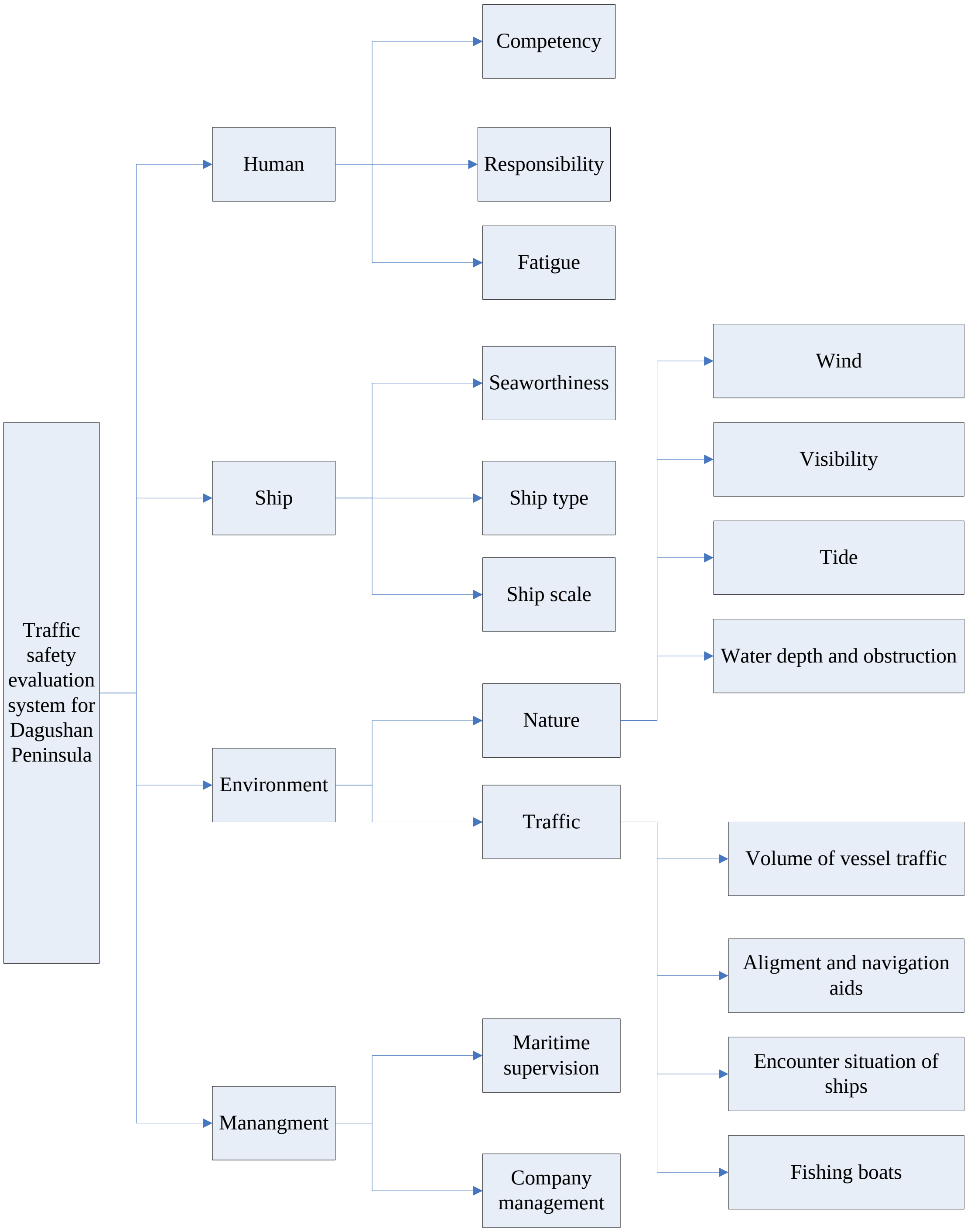

Figure 4.1 Evaluation system

Source: Made by the author

4.3 Standards of factors in the evaluation system

The scientific and reasonable evaluation standards are the basis for the risk evaluation. Therefore, based on the relevant references and the experts' suggestion, combined with the data that can be collected, this paper has determined the index evaluation criteria. For the factors of which data are available, quantitative methods are used for evaluation; for factors of which data are not available, qualitative methods are used for evaluation. Furthermore, these tables of evaluation standards are part of the questionnaire, of which the statistical results are utilized to calculate the membership degree.

4.3.1 Human

Competency

The crew's competency is related to the crew's academic qualifications, navigation experience, company training, etc. However, it is difficult to describe the competency of seafarers within a region with quantitative data. Therefore, this paper uses qualitative analysis to define this factor as five levels: Good, Relatively good, Average, Relatively poor, Poor.

Table 4.1 Evaluation standards of competency

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Competency (A1)	Good	Relatively good	Average	Relatively poor	Poor

Source: Made by the author

Responsibility

The responsibility of the crew is difficult to describe with quantitative data. However, the degree of emphasis on the safety of the ship can be seen from the attitude, performance of the crew on duty (navigation, anchorage, cargo operations in port) and safety inspection etc. Therefore, this paper adopts the qualitative method to define this factor as 5 levels: Good, Relatively good, Average, Relatively poor, Poor.

Table 4.2 Evaluation standards of responsibility

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Responsibility (A2)	Good	Relatively good	Average	Relatively poor	Poor

Source: Made by the author

Fatigue

The degree of 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, cargo operations in port) and safety inspection etc. Therefore, this paper adopts the qualitative method to define this factor as 5 levels: Good, Relatively good, Average, Relatively poor, Poor.

Table 4.3 Evaluation standards of fatigue

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Fatigue (A3)	Good	Relatively good	Average	Relatively poor	Poor

Source: Made by the author

4.3.2 Ship

Seaworthiness

Considering that the seaworthiness status of all ships in the port waters can not be expressed with accurate numerical values, the rate of ship detention of PSC and FSC inspection in the port is used here to quantify the ship's seaworthiness status.

Table 4.4 Evaluation standards of seaworthiness

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Seaworthiness (B1)	<1%	1%-4%	4%-8%	8%-12%	>12%

Source: Made by the author

Ship type

The index of this factor is the percentage of ships in high risk level to all ships within Dagushan Peninsula waters.

Table 4.5 Evaluation standards of ship type

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Ship type (B2)	<5%	5%-10%	10%-20%	20%-30%	>30%

Source: Made by the author

Ship scale

The index of this factor is the Gross Tonnage of ships.

Table 4.6 Evaluation standards of ship scale

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Ship scale (B3)	<1000 GT	1000 GT-3000 GT	3000 GT-10000 GT	10000 GT-50000 GT	>50000 GT

Source: Made by the author

4.3.3 Environment

Wind

The number of windy days above level 6 is used as the evaluation index value of this factor.

Table 4.7 Evaluation standards of wind

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Wind (C11)	<30	30-60	60-100	100-150	>150

Source: Made by the author

Visibility

The index is determined by the number of days of visibility less than l km in the water area.

Table 4.8 Evaluation standards of visibility

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Visibility (C12)	<15	15-25	25-40	40-50	>50

Source: Made by the author

Tide

The maximum speed of the current is used as the index of this factor.

Table 4.9 Evaluation standards of tide

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Tide (C13)	<0.5	0.5-1.5	1.5-2.5	2.5-4.0	>4.0

Source: Made by the author

Water depth and obstruction

Table 4.10 Evaluation standards of water depth and obstruction

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Water depth and obstruction (C14)	Good	Relatively good	Average	Relatively poor	Poor

Source: Made by the author

Volume of vessel traffic

The index of this factor is expessed by the number of ships in and out of the port per day.

Table 4.11 Evaluation standards of volume of vessel traffic

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Volume of vessel traffic (C21)	<50	50-100	100-200	200-500	>500

Source: Made by the author

Alignment and navigation aids

It is difficult to describe the conditions of the alignment and navigational aids with quantitative data, hence, the index of this factor is determined by the method of expert scoring.

Table 4.12 Evaluation standards of alignment and navigation aids

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Alignment and navigation aids (C22)	100-90	90-85	85-80	80-75	<75

Source: Made by the author

Encounter situation of ships

The ratio of the number of intersections of different routes and the length of the ship's meeting area is used as the evaluation index of this factor.

Table 4.13 Evaluation standards of encounter situation of ships

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Encounter situation of ships (C23)	0	0.1-0.2	0.3-0.4	0.5-0.6	>0.6

Source: Made by the author

Fishing boats

It is difficult to describe the impact of fishing boats within a region with quantitative data. Therefore, this paper uses qualitative analysis to define this factor as five levels: Good, Relatively good, Average, Relatively poor, Poor.

Table 4.14 Evaluation standards of fishing boats

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Fishing boats (C24)	Good	Relatively good	Average	Relatively poor	Poor

Source: Made by the author

4.3.4 Manangment

Maritime supervision

It is difficult to describe the level of maritime supervision with quantitative data, hence, the index of this factor is determined by the method of expert scoring.

Table 4.15 Evaluation standards of maritime supervision

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Maritime supervision (D1)	100-90	90-85	85-80	80-75	<75

Source: Made by the author

Company management

It is difficult to describe the level of company management with quantitative data, hence, the index of this factor is determined by the method of expert scoring.

Table 4.16 Evaluation standards of company management

Risk ranking	Small risk	Relatively small risk	General	Relatively significant risk	Significant risk
Company management (D2)	100-90	90-85	85-80	80-75	<75

Source: Made by the author

CHAPTER 5

EVALUATION MODEL BASED FAHP

5.1 Overview of FAHP

FAHP is one of the methods to deal with weight, which refers to the importance of each evaluation index to the system in the comprehensive evaluation system, and it relates to the accuracy of the final evaluation result.(Shi, 1997). There are many methods to determine the weights, and AHP is a relatively mature one. This paper uses the improved method of AHP, that is, FAHP to obtain the weights and evaluate the maritime traffic risk.

AHP is a systematic analysis method combining qualitative analysis and quantitative analysis, which was proposed by professor Saaty in 1970s. The key to AHP is to establish a judgment matrix, and whether the judgment matrix is scientific or reasonable directly affects the result of AHP.(Saaty, 1980). In recent years, many scholars have used AHP to determine the weights and used the fuzzy comprehensive evaluation method to assess the risks of collision, stranding and sunken ships on marine traffic. Some scholars believe that there are some problems in AHP, such as: differences in the consistency of judgments and matrices, difficulties in consistency checking, and the lack of scientificity etc., thus, FAHP was proposed on the basis of AHP. (Zhang, 2000).

FAHP is also a systematic analysis method that combines qualitative analysis and quantitative analysis, which expresses a complex problem as an ordered hierarchical structure based on AHP. According to the expert judgment and structural model of hierarchical analysis, FAHP constructs a fuzzy judgment matrix for each level of elements, which in turn enables a complex decision problem to be derived by using a simple pairwise comparison. FAHP calculates the combined weights of the elements in each level to realize the importance ranking of different risk factors, via establishment of the hierarchy analysis structure model, construction of the judgment matrix, the hierarchical single ranking and the hierarchical total ranking. (Zhang, 2000).

5.1.1 Establishment of fuzzy consistent judgment matrix

The fuzzy consistent judgment matrix “R” represents the comparison of the relative importance between an element on the upper level and its related element in this level, assuming that the element “C” on the upper level is related to the elements “a_1, a_2, ⋯, a_n” on the lower level. If there is a link, 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 significance: “r_{ij}” indicates that, when element “a_i” is compared with element “a_j” on the relation to the element “C”, element “a_i” and element “a_j” have the membership degree of the fuzzy relation “⋯ is more important than ⋯”. In order to quantitatively describe the relative importance of any two schemes with respect to a certain criterion, the following quantitative scale may be used.

Table 5.1 Quantitative scale between two comparative factors

Quantitative scale	Comparison of importance
0.5	Equally important
0.6	Little more important
0.7	More important
0.8	Much more important
0.9	Extremely more important
0.1, 0.2, 0.3, 0.4	Reverse comparison

Source: Zhang, 2000

With the quantitative scale above, when the elements "$a_1, a_2, \cdots, a_n$" are compared with element "C" on the upper layer, the following fuzzy judgment matrix can be obtained:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix}$$

Where,

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

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

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

5.1.2 Calculate the weights from the fuzzy consistent judgment matrix

Assuming that, the fuzzy consistency matrix "$R = (r_{ij})_{n*n}$" is obtained by pairwise comparison of the elements "$a_1, a_2, \cdots, a_n$", and the weights of elements "$a_1, a_2, \cdots, a_n$" are "$w_1, w_2, \cdots, w_n$" respectively, thus, the following relational expression is established:

$$r_{ij} = 0.5 + a(w_i - w_j) \quad i, j = 1,2, \cdots, n$$

$$w_i = \frac{1}{n} - \frac{1}{2a} + \frac{1}{na} \sum_{k=1}^{n} r_{ik} \qquad i \in \{1,2, \cdots n\}$$

Where,

"a" is a measure of the degree of difference in perceived objects, when "a = (n-1) / 2", the difference of weights is the biggest. (Lv, 2002).

In order to reflect the differences in various indicators, combined with experts' advice, this paper lets "a = (n-1) / 2" in the following calculations of the next chapter.

5.2 Evaluation model based on FAHP

5.2.1 The set of factors

According to the affiliation of the internal factors of the system, the solution of a complex system is decomposed into a solution to a number of simple subsystems, and then synthesized layer by layer. According to the research object or system, determine the factors that affect the object or system, and form a set of factors.

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

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

Where,

the indicators of the first layer “$A = \{ a_1, a_2, \cdots, a_n \}$” are the factors which influence the target level, namely, “Human, Ship, Environment, and Management”; the second-level indicators “$a_i = \{ a_{i1}, a_{i2}, \cdots, a_{in} \}$” are the factors affecting the first-level indicators, such as “Competency, Responsibility and Fatigue”, and the rest can be done in the same way.

5.2.2 The set of weights

The importance of different factors to the evaluated object is different. To reflect the importance of each factor, a corresponding weight value “w_i (i=l, 2⋯, n)” should be assigned to each factor “a_i”, and the weight set “W” composed by weight values of the factors is a fuzzy subset of the factor set “A”.

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

Where,

the weight value “w_i” is the membership degree of factor “a_i” to the factor set “A”, which reflects the degree of importance of each factor in the comprehensive evaluation, in addition, it meets the requirement as below:

$$\sum_{1}^{n} w_i = 1 \qquad w_i \geq 0$$

5.2.3 The evaluation set

The evaluation set is a set of possible evaluation results for the evaluation target. According to the five grades of evaluation standards discussed in last chapter, the evaluation grade is defined as below:

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

Where,

"1, 2, 3, 4, 5" represent the fuzzy numbers, which mean the grades of "Small risk, Relatively small risk, General, Relatively significant risk, Significant risk" repectively for the evaluation set.

5.2.4 The function of membership degree

The key to fuzzy mathematics is to seek appropriate mathematical language to describe the ambiguity of things. Zhang (2016) proposed the function of membership degree:

$$y = \begin{cases} 1 & x \geq x_{max} \\ \dfrac{x - x_{min}}{x_{max} - x_{min}} & x_{min} < x < x_{max} \\ 0 & x \leq x_{max} \end{cases}$$

Based on the research results of Zhang (2016) and the evaluation standards discussed in last chapter, under the guidance of experts, this paper proposes the functions of membership degree for the evaluation set as follows:

Seaworthiness: (x is the rate of ship detention of PSC and FSC inspection)

Small risk:

$$R_{21}^{1}(x) = \begin{cases} 1 & x \leq 0.6 \\ \dfrac{1.2 - x}{1.2 - 0.6} & 0.6 < x < 1.2 \\ 0 & x \geq 1.2 \end{cases}$$

Relatively small risk:

$$R_{21}^{2}(x) = \begin{cases} 0 & x \leq 0.6 \\ \dfrac{x - 0.6}{1.2 - 0.6} & 0.6 < x \leq 1.2 \\ 1 & 1.2 < x \leq 2.8 \\ \dfrac{3.6 - x}{3.6 - 2.8} & 2.8 < x \leq 3.6 \\ 0 & x > 3.6 \end{cases}$$

General:

$$R_{21}^{3}(x)=\begin{cases}0 & x\le 2.8\\ \dfrac{x-2.8}{3.6-2.8} & 2.8<x\le 3.6\\ 1 & 3.6<x\le 4.8\\ \dfrac{5.4-x}{5.4-4.8} & 4.8<x\le 5.4\\ 0 & x>5.4\end{cases}$$

Relatively significant risk:

$$R_{21}^{4}(x)=\begin{cases}0 & x\le 4.8\\ \dfrac{x-4.8}{5.4-4.8} & 4.8<x\le 5.4\\ 1 & 5.4<x\le 9.0\\ \dfrac{9.6-x}{9.6-9.0} & 9.0<x\le 9.6\\ 0 & x>9.6\end{cases}$$

Significant risk:

$$R_{21}^{5}(x)=\begin{cases}0 & x\le 9.0\\ \dfrac{x-9.0}{9.6-9.0} & 9.0<x<9.6\\ 1 & x\ge 9.6\end{cases}$$

Ship type: (x is the percentage of ships in high risk level to all ships)

Small risk:

$$R_{22}^{1}(x)=\begin{cases}1 & x\le 2\\ \dfrac{4-x}{4-2} & 2<x<4\\ 0 & x\ge 4\end{cases}$$

Relatively small risk:

$$R_{22}^{2}(x)=\begin{cases}0 & x\le 2\\ \dfrac{x-2}{4-2} & 2<x\le 4\\ 1 & 4<x\le 8\\ \dfrac{12-x}{12-8} & 8<x\le 12\\ 0 & x>12\end{cases}$$

General:

$$R_{22}^{3}(x)=\begin{cases}0 & x\le 8\\ \dfrac{x-8}{12-8} & 8<x\le 12\\ 1 & 12<x\le 18\\ \dfrac{24-x}{24-18} & 18<x\le 24\\ 0 & x>24\end{cases}$$

Relatively significant risk:

$$R_{22}^{4}(x)=\begin{cases}0 & x\le 18\\ \frac{x-18}{24-18} & 18<x\le 24\\ 1 & 24<x\le 36\\ \frac{42-x}{42-36} & 36<x\le 42\\ 0 & x>42\end{cases}$$

Significant risk:

$$R_{22}^{5}(x)=\begin{cases}0 & x\le 36\\ \frac{x-36}{42-36} & 36<x<42\\ 1 & x\ge 42\end{cases}$$

Wind: (x is the number of windy days of level 6 above)

Small risk:

$$R_{311}^{1}(x)=\begin{cases}1 & x\le 15\\ \frac{25-x}{25-15} & 15<x<25\\ 0 & x\ge 25\end{cases}$$

Relatively small risk:

$$R_{311}^{2}(x)=\begin{cases}0 & x\le 15\\ \frac{x-15}{25-15} & 15<x\le 25\\ 1 & 25<x\le 35\\ \frac{50-x}{50-35} & 35<x\le 50\\ 0 & x>50\end{cases}$$

General:

$$R_{311}^{3}(x)=\begin{cases}0 & x\le 35\\ \frac{x-35}{50-35} & 35<x\le 50\\ 1 & 50<x\le 70\\ \frac{90-x}{90-70} & 70<x\le 90\\ 0 & x>90\end{cases}$$

Relatively significant risk:

$$R_{311}^{4}(x)=\begin{cases}0 & x\le 70\\ \frac{x-70}{90-70} & 70<x\le 90\\ 1 & 90<x\le 110\\ \frac{130-x}{130-110} & 110<x\le 130\\ 0 & x>130\end{cases}$$

Significant risk:

$$R_{311}^{5}(x)=\begin{cases}0 & x\le 110\\ \frac{x-110}{130-110} & 110<x<130\\ 1 & x\ge 130\end{cases}$$

Visibility: (x is the number of days of visibility less than l km)

Small risk:

$$R_{312}^{1}(x)=\begin{cases}1 & x\le 4\\ \dfrac{8-x}{8\text{-}4} & 4<x<8\\ 0 & x\ge 8\end{cases}$$

Relatively small risk:

$$R_{312}^{2}(x)=\begin{cases}0 & x\le 4\\ \dfrac{x-4}{8-4} & 4<x\le 8\\ 1 & 8<x\le 12\\ \dfrac{18-x}{18-12} & 12<x\le 18\\ 0 & x>18\end{cases}$$

General:

$$R_{312}^{3}(x)=\begin{cases}0 & x\le 12\\ \dfrac{x-12}{18-12} & 12<x\le 18\\ 1 & 18<x\le 22\\ \dfrac{28-x}{28-22} & 22<x\le 28\\ 0 & x>28\end{cases}$$

Relatively significant risk:

$$R_{312}^{4}(x)=\begin{cases}0 & x\le 22\\ \dfrac{x-22}{28-22} & 22<x\le 28\\ 1 & 28<x\le 32\\ \dfrac{38-x}{38-32} & 32<x\le 38\\ 0 & x>38\end{cases}$$

Significant risk:

$$R_{312}^{5}(x)=\begin{cases}0 & x\le 32\\ \dfrac{x-32}{38\text{-}32} & 32<x<38\\ 1 & x\ge 38\end{cases}$$

Tide: (x is the maximum speed of the current)

Small risk:

$$R_{313}^{1}(x)=\begin{cases}1 & x\le 0.3\\ \dfrac{0.6-x}{0.6\text{-}0.3} & 0.3<x<0.6\\ 0 & x\ge 0.6\end{cases}$$

Relatively small risk:

$$R_{313}^{2}(x)=\begin{cases}0 & x\le 0.3\\ \dfrac{x-0.3}{0.6-0.3} & 0.3<x\le 0.6\\ 1 & 0.6<x\le 1.2\\ \dfrac{1.6-x}{1.6-1.2} & 1.2<x\le 1.6\\ 0 & x>1.6\end{cases}$$

General:

$$R_{313}^{3}(x)=\begin{cases}0 & x\le 1.2\\ \dfrac{x-1.2}{1.6-1.2} & 1.2<x\le 1.6\\ 1 & 1.6<x\le 2.4\\ \dfrac{3.2-x}{3.2-2.4} & 2.4<x\le 3.2\\ 0 & x>3.2\end{cases}$$

Relatively significant risk:

$$R_{313}^{4}(x)=\begin{cases}0 & x\le 2.4\\ \dfrac{x-2.4}{3.2-2.4} & 2.4<x\le 3.2\\ 1 & 3.2<x\le 3.8\\ \dfrac{4.2-x}{4.2-3.8} & 3.8<x\le 4.2\\ 0 & x>4.2\end{cases}$$

Significant risk:

$$R_{313}^{5}(x)=\begin{cases}0 & x\le 3.8\\ \dfrac{x-3.8}{4.2\text{-}3.8} & 3.8<x<4.2\\ 1 & x\ge 4.2\end{cases}$$

Volume of vessel traffic: (x is the number of ships in and out of the port per day)

Small risk:

$$R_{321}^{1}(x)=\begin{cases}1 & x\le 40\\ \dfrac{60-x}{60\text{-}40} & 40<x<60\\ 0 & x\ge 60\end{cases}$$

Relatively small risk:

$$R_{321}^{2}(x)=\begin{cases}0 & x\le 40\\ \dfrac{x-40}{60\text{-}40} & 40<x\le 60\\ 1 & 60<x\le 90\\ \dfrac{120-x}{120-90} & 90<x\le 120\\ 0 & x>120\end{cases}$$

General:

$$R_{321}^{3}(x)=\begin{cases}0 & x\le 90\\ \dfrac{x-90}{120-90} & 90<x\le 120\\ 1 & 120<x\le 180\\ \dfrac{240-x}{240-180} & 180<x\le 240\\ 0 & x>240\end{cases}$$

Relatively significant risk:

$$R_{321}^{4}(x)=\begin{cases}0 & x\le 180\\ \frac{x-180}{240-180} & 180<x\le 240\\ 1 & 240<x\le 280\\ \frac{320-x}{320-280} & 280<x\le 320\\ 0 & x>320\end{cases}$$

Significant risk:

$$R_{321}^{5}(x)=\begin{cases}0 & x\le 280\\ \frac{x-280}{320-280} & 280<x<320\\ 1 & x\ge 320\end{cases}$$

Encounter situation of ships: (x is the ratio of the number of intersections of different routes and the length of the ship's meeting area)

Small risk:

$$R_{323}^{1}(x)=\begin{cases}1 & x\le 0.075\\ \frac{0.125-x}{0.125-0.075} & 0.075<x<0.125\\ 0 & x\ge 0.125\end{cases}$$

Relatively small risk:

$$R_{323}^{2}(x)=\begin{cases}0 & x\le 0.075\\ \frac{x-0.075}{0.125-0.075} & 0.075<x\le 0.125\\ 1 & 0.125<x\le 0.25\\ \frac{0.275-x}{0.275-0.25} & 0.25<x\le 0.275\\ 0 & x>0.275\end{cases}$$

General:

$$R_{323}^{3}(x)=\begin{cases}0 & x\le 0.25\\ \frac{x-0.25}{0.275-0.25} & 0.25<x\le 0.275\\ 1 & 0.275<x\le 0.4\\ \frac{0.425-x}{0.425-0.4} & 0.4<x\le 0.425\\ 0 & x>0.425\end{cases}$$

Relatively significant risk:

$$R_{323}^{4}(x)=\begin{cases}0 & x\le 0.4\\ \frac{x-0.4}{0.425-0.4} & 0.4<x\le 0.425\\ 1 & 0.425<x\le 0.575\\ \frac{0.625-x}{0.625-0.575} & 0.575<x\le 0.625\\ 0 & x>0.625\end{cases}$$

Significant risk:

$$R_{323}^{5}(x)=\begin{cases}0 & x\le 0.575\\ \frac{x-0.575}{0.625-0.575} & 0.575<x<0.625\\ 1 & x\ge 0.625\end{cases}$$

5.2.5 Fuzzy comprehensive evaluation

The membership degree of each single-factor fuzzy evaluation set is used as a single-factor judgement matrix:

$$R_{ij} = \begin{bmatrix} R_{i1} \\ R_{i2} \\ \vdots \\ R_{in} \end{bmatrix} = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i15} \\ r_{i21} & r_{i22} & \cdots & r_{i25} \\ \vdots & \vdots & \cdots & \vdots \\ r_{in1} & r_{in2} & \cdots & r_{in5} \end{bmatrix}$$

Single-level fuzzy comprehensive evaluation model: the comprehensive evaluation set "E_i" of factor "i" can be obtained by multiplying the single-factor judgement matrix "R_i" and the factor weights set W_i:

$$E = W \times R = (w_1, w_2, \cdots, w_n) \times \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} = (e_1, e_2, \cdots, e_n)$$

Multi-level fuzzy comprehensive evaluation model:

$$E = W \times R = A \times \begin{bmatrix} A_1 \times R_1 \\ A_2 \times R_2 \\ \vdots \\ A_n \times R_n \end{bmatrix}$$

5.2.6 Evaluation results

The final result of the fuzzy comprehensive evaluation is a fuzzy vector, that is, the evaluation targets are subject to the membership degree vector of each evaluation grade. In order to determine the evaluation targets' grade, it is necessary to defuzzify the fuzzy vector, with the following two common methods: the principle of maximum membership degree and the principle of weighted average.

The principle of maximum membership degree

In Vector E, grade "v_j" of the evaluation set corresponding to the maximum value of "e_r =max{e_j} (j = l, 2, ···, 5)" is the final evaluation result.

The principle of weighted average

$$E^* = \frac{\sum_{k=1}^{n} e_k \times v_k}{\sum_{k=1}^{n} e_k}$$

Where,

"v_k (k = 1, 2, ⋯, 5)" is the grade for each factor corresponding to the evaluation set,

"E^*" is a number from 1 to 5, which is the final evaluation result.

CHAPTER 6

APPLICATION OF FAHP MODEL TO DAGUSHAN PENINSULA WATER

6.1 Evaluation system weight of Dagushan Peninsula

The calculations of this section are based on the formulas discussed in section 5.1.2 of last chapter, and the raw data used for calculations are from the on-line questionnaires (as discussed in section 4.1.2 of Chapter 4). Finnaly, the weights are as below:

Table 6.1 Evaluation system weight of Dagushan Peninsula

Evaluation system weight of Dagushan Peninsula					
Index of 1st tier	Weight	Index of 2nd tier	Weight	Index of 3rd tier	Weight
Human	0.3280	Competency	0.3281		
		Responsibility	0.4148		
		Fatigue	0.2571		
Ship	0.2121	Seaworthiness	0.3933		
		Ship type	0.3601		
		Ship scale	0.2466		
Environment	0.1898	Nature	0.5718	Wind	0.2901
				Visibility	0.3258
				Tide	0.1795
				Water depth and obstruction	0.2046
		Traffic	0.4282	Volume of vessel traffic	0.3637
				Alignment and navigation aids	0.2628
				Encounter situation of ships	0.1883
				Fishing boats	0.1852
Manangment	0.2701	Maritime supervision	0.4895		
		Company management	0.5105		

Source: Made by the author

6.2 Membership degree of evaluation index of Dagushan Peninsula

As discussed in section 4.3 of chapter 4, the evaluation standards are divided into two categories: quantitative and qualitative. For factors of which data are available, quantitative methods are used for determining the evaluation standards; for factors of which data are not available, qualitative methods are used for determining the evaluation standards. The results of membership degree are obtained in the similar way: for the factors with quantitative standards (e.g. seaworthness, wind, visibility, volume of vessel traffic etc.), this paper collected data via on-spot interviews as well as internal reports from Dalian MSA, combined with the on-line questionnaires, and calculated the membership degree based on the functions in section 5.2.4 of chapter 5; for the factors with qualitative standards (e.g. human, management etc.), this paper processed the data from the on-line questionnaires to obtain the membership degree. Finnaly, the results of membership degree are as below:

Table 6.2 Membership degree of evaluation index of Dagushan Peninsula

Membership degree of evaluation index of Dagushan Peninsula							
Index			Membership degree				
Index of 1st tier	Index of 2nd tier	Index of 3rd tier	Small risk	Relatively small risk	General	Relatively significant	Significant risk
Human	Competency		0.0000	0.6666	0.2333	0.1001	0.0000
	Responsibility		0.0666	0.6432	0.2333	0.0569	0.0000
	Fatigue		0.0000	0.2456	0.6168	0.1296	0.0080
Ship	Seaworthiness		0.0000	0.0000	0.8533	0.1467	0.0000
	Ship type		0.0000	0.1103	0.3725	0.5172	0.0000
	Ship scale		0.0000	0.0842	0.8623	0.0321	0.0214
Environment	Nature	Wind	0.0000	0.0000	0.7800	0.2200	0.0000
		Visibility	0.0000	0.1000	0.9000	0.0000	0.0000
		Tide	0.0000	0.4640	0.5360	0.0000	0.0000
		Water depth and obstruction	0.9000	0.1000	0.0000	0.0000	0.0000
	Traffic	Volume of vessel traffic	0.0000	0.0000	0.0000	0.2000	0.8000
		Alignment and navigation aids	0.0827	0.5310	0.2157	0.1706	0.0000
		Encounter situation of ships	0.0000	0.0000	0.4000	0.6000	0.0000
		Fishing boats	0.0000	0.0227	0.2148	0.4868	0.2757
Manangment	Maritime supervision		0.0411	0.7110	0.1986	0.0493	0.0000
	Company management		0.0000	0.3871	0.4896	0.1233	0.0000

Source: Made by the author

6.3 Fuzzy comprehensive evaluation

Comprehensive evaluation of “Human”

$$E_a = W_a \times R_a = \begin{bmatrix} w_{a1} & w_{a2} & w_{a3} \end{bmatrix} \times \begin{bmatrix} r_{a11} & r_{a12} & r_{a13} & r_{a14} & r_{a15} \\ r_{a21} & r_{a22} & r_{a23} & r_{a24} & r_{a25} \\ r_{a31} & r_{a32} & r_{a33} & r_{a34} & r_{a35} \end{bmatrix}$$

$$= \begin{bmatrix} 0.3281 & 0.4148 & 0.2571 \end{bmatrix} \times \begin{bmatrix} 0.0000 & 0.6666 & 0.2333 & 0.1001 & 0.0000 \\ 0.0666 & 0.6432 & 0.2333 & 0.0569 & 0.0000 \\ 0.0000 & 0.2456 & 0.6168 & 0.1296 & 0.0080 \end{bmatrix}$$

$$= \begin{bmatrix} 0.0276 & 0.5487 & 0.3319 & 0.0898 & 0.0021 \end{bmatrix}$$

Comprehensive evaluation of “Ship”

$$E_b = W_b \times R_b = \begin{bmatrix} w_{b1} & w_{b2} & w_{b3} \end{bmatrix} \times \begin{bmatrix} r_{b11} & r_{b12} & r_{b13} & r_{b14} & r_{b15} \\ r_{b21} & r_{b22} & r_{b23} & r_{b24} & r_{b25} \\ r_{b31} & r_{b32} & r_{b33} & r_{b34} & r_{b35} \end{bmatrix}$$

$$= \begin{bmatrix} 0.3933 & 0.3601 & 0.2466 \end{bmatrix} \times \begin{bmatrix} 0.0000 & 0.0000 & 0.8533 & 0.1467 & 0.0000 \\ 0.0000 & 0.1103 & 0.3725 & 0.5172 & 0.0000 \\ 0.0000 & 0.0842 & 0.8623 & 0.0321 & 0.0214 \end{bmatrix}$$

$$= \begin{bmatrix} 0.0000 & 0.0605 & 0.6824 & 0.2519 & 0.0053 \end{bmatrix}$$

Comprehensive evaluation of “Nature”

$$E_{c1} = W_{c1} \times R_{c1} = \begin{bmatrix} w_{c11} & w_{c12} & w_{c13} & w_{c14} \end{bmatrix} \times \begin{bmatrix} r_{c111} & r_{c112} & r_{c113} & r_{c114} & r_{c115} \\ r_{c121} & r_{c122} & r_{c123} & r_{c124} & r_{c125} \\ r_{c131} & r_{c132} & r_{c133} & r_{c134} & r_{c135} \\ r_{c141} & r_{c142} & r_{c143} & r_{c144} & r_{c145} \end{bmatrix}$$

$$= \begin{bmatrix} 0.2901 & 0.3258 & 0.1795 & 0.2046 \end{bmatrix} \times \begin{bmatrix} 0.0000 & 0.0000 & 0.7800 & 0.2200 & 0.0000 \\ 0.0000 & 0.1000 & 0.9000 & 0.0000 & 0.0000 \\ 0.0000 & 0.4640 & 0.5360 & 0.0000 & 0.0000 \\ 0.9000 & 0.1000 & 0.0000 & 0.0000 & 0.0000 \end{bmatrix}$$

$$= \begin{bmatrix} 0.1841 & 0.1363 & 0.6157 & 0.0638 & 0.0000 \end{bmatrix}$$

Comprehensive evaluation of “Traffic”

$$E_{c2} = W_{c2} \times R_{c2} = [w_{c21} \quad w_{c22} \quad w_{c23} \quad w_{c24}] \times \begin{bmatrix} r_{c211} & r_{c212} & r_{c213} & r_{c214} & r_{c215} \\ r_{c221} & r_{c222} & r_{c223} & r_{c224} & r_{c225} \\ r_{c231} & r_{c232} & r_{c233} & r_{c234} & r_{c235} \\ r_{c241} & r_{c242} & r_{c243} & r_{c244} & r_{c245} \end{bmatrix}$$

$$= [0.3637 \quad 0.2628 \quad 0.1883 \quad 0.1852] \times \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 & 0.2000 & 0.8000 \\ 0.0827 & 0.5310 & 0.2157 & 0.1706 & 0.0000 \\ 0.0000 & 0.0000 & 0.4000 & 0.6000 & 0.0000 \\ 0.0000 & 0.0227 & 0.2148 & 0.4868 & 0.2757 \end{bmatrix}$$

$$= [0.0217 \quad 0.1438 \quad 0.1718 \quad 0.3207 \quad 0.3420]$$

Comprehensive evaluation of “Environment”

$$E_c = W_c \times R_c = [w_{c1} \quad w_{c2}] \times \begin{bmatrix} r_{c11} & r_{c12} & r_{c13} & r_{c14} & r_{c15} \\ r_{c21} & r_{c22} & r_{c23} & r_{c24} & r_{c25} \end{bmatrix}$$

$$= [0.5718 \quad 0.4282] \times \begin{bmatrix} 0.1841 & 0.1363 & 0.6157 & 0.0638 & 0.0000 \\ 0.0217 & 0.1438 & 0.1718 & 0.3207 & 0.3420 \end{bmatrix}$$

$$= [0.1146 \quad 0.1395 \quad 0.4256 \quad 0.1738 \quad 0.1464]$$

Comprehensive evaluation of “Management”

$$E_d = W_d \times R_d = [w_{d1} \quad w_{d2}] \times \begin{bmatrix} r_{d11} & r_{d12} & r_{d13} & r_{d14} & r_{d15} \\ r_{d21} & r_{d22} & r_{d23} & r_{d24} & r_{d25} \end{bmatrix}$$

$$= [0.4895 \quad 0.5105] \times \begin{bmatrix} 0.0411 & 0.7110 & 0.1986 & 0.0493 & 0.0000 \\ 0.0000 & 0.3871 & 0.4896 & 0.1233 & 0.0000 \end{bmatrix}$$

$$= [0.0201 \quad 0.5456 \quad 0.3472 \quad 0.0871 \quad 0.0000]$$

Comprehensive evaluation of “Maritime traffic risks in Dagushan Peninsula waters”

$$E = W \times R = [w_a \quad w_b \quad w_c \quad w_d] \times \begin{bmatrix} r_{a1} & r_{a2} & r_{a3} & r_{a4} & r_{a5} \\ r_{b1} & r_{b2} & r_{b3} & r_{b4} & r_{b5} \\ r_{c1} & r_{c2} & r_{c3} & r_{c4} & r_{c5} \\ r_{d1} & r_{d2} & r_{d3} & r_{d4} & r_{d5} \end{bmatrix}$$

$$= [0.3280 \quad 0.2121 \quad 0.1898 \quad 0.2701] \times \begin{bmatrix} 0.0276 & 0.5487 & 0.3319 & 0.0898 & 0.0021 \\ 0.0000 & 0.0605 & 0.6824 & 0.2519 & 0.0053 \\ 0.1146 & 0.1395 & 0.4256 & 0.1738 & 0.1464 \\ 0.0201 & 0.5456 & 0.3472 & 0.0871 & 0.0000 \end{bmatrix}$$

$$= [0.0362 \quad 0.3666 \quad 0.4282 \quad 0.1394 \quad 0.0296]$$

Evaluation score

$$E^* = \frac{\sum_{k=1}^{n} e_k \times v_k}{\sum_{k=1}^{n} e_k} = \frac{0.0362 \times 1 + 0.3666 \times 2 + 0.4282 \times 3 + 0.1394 \times 4 + 0.0296 \times 5}{0.0362 + 0.3666 + 0.4282 + 0.1394 + 0.0296} = 2.7596$$

6.4 Evaluation results

The principle of maximum membership degree:

According to the result: E = [0.0362, 0.3666, 0.4282, 0.1394, 0.0296], e_r =max{e_j} (j = l, 2, ···, 5) = 0.4282, hence, the risk evaluation grade of Dagushan Peninsula is “Small risk”.

The principle of weighted average:

The evaluation score E* =2.7596, thus, the risk evaluation grade of Dagushan Peninsula is between “Relatively small risk (the score is 2)” and “General (the score is 3)”.

CHAPTER 7

CONCLUSION AND RECOMMENATION

7.1 Conclusion

This paper carries out analysis and evaluation of maritime traffic risk in circumjacent water of Dagushan Peninsula of Dalian, in ways of:

Combined with relevant references, giving a brief overview of risk evaluation and the research status in port waters. Based on this, proposing the issue of risk evaluation for Dagushan Peninsula waters;

Combined with the main factors affecting maritime traffic safety in port waters, based on the principle of scientificity, operability etc., based on experts' guidance and advice, establishing the index system under the framework of "human-ship-environment-management" to evaluate the risk in Dagushan Peninsula waters;

Based on the establishment of the index system, with reference to the relevant literature, combined with the data and experts' advice, and further determining the evaluation standards;

Based on FAHP and relevant references, establishing a comprehensive evaluation model for maritime traffic risk in port waters and finally applying it to Dagushan Peninsula waters.

Nevertheless, there are still some drawbacks in this paper:

The framework or system of "human-ship-environment-management" seems like a "twice-told story", from this point, this paper lacks of some innovation. Apart from that, due to the author's limited ability, the evaluation system can hardly cover all the factors affecting the maritime safety in Dagushan Peninsula waters;

There is a certain degree of subjectivity in the determination of the evaluation standards, weights, and membership degree functions etc.;

Due to the limitation of time and other objective conditions, the sample of respondents is not large enough.

7.2 Recommenation

As discussed in chapter 2, “Risk” and “Safety” seem to be a pair of twins, because they are always mentioned together. The purpose that we study risk is to make things safe, because we deem that safety is the acceptable risk. However, Professor Erik Hollnagel has a different view about safety. He names current ideas on safety as “Safety-I” and proposes the concept of “Safety-II”: “*Safety-I is the condition where the number of adverse outcomes (for example, accidents, incidents and near misses) is as low as possible. Safety-I is achieved by trying to make sure that things do not go wrong, either by eliminating the causes of malfunctions and hazards, or by containing their effects*. ”. “*Safety-II is the condition where the number of acceptable outcomes is as high as possible. It is the ability to succeed under varying conditions. Safety-II is achieved by trying to make sure that things go right, rather than by preventing them from going wrong.* ”. (Hollnagel, Leonhardt, Licu, & Shorrock, 2013).

Table 7.1: The basic differences between Safety-I and Safety-II

	Safety-I	Safety-II
Definition of safety	That as few things as possible go wrong	That as many things as possible go right
Safety management principle	Reactive, respond when something happens or is categorised as an unacceptable risk.	Proactive, continuously trying to anticipate development and events.
View of the human factor in safety management	Humans are predominatly seen as a libility or hazard. They are a problem to be fixed.	Humans are seen as a resource necessary for system flexibility and resilience. They provide flexible solutions to many potential problems.
Accident investigation	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify the causes.	Things basically happen in the same way, regardless of the outcome. The purpose of an investigation is to understand how things usually go right as a basis for explaining how things occasionally go wrong.
Risk assessment	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify causes and contributory factors.	To understand the conditions where performance variability can become difficult or impossible to monitor and control.

Source: Hollnagel, 2015, p. 153

It is obvious that these two ideas are of big difference: safety-I, which is the main idea about safety, is to learn how things go wong and avoid it; safety-II, focuses on how things go right. This paper believes that this new view deserves more attention and to be studied more.

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