**WORLD MARITIME UNIVERSITY**

Dalian, China

# Risk Assessment on Oil Spill in Dalian Port Sea Area

By

**Wu Yang**

**The People's Republic of China**

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

**MASTER OF Maritime Safety & Environmental Administration**

2016

**DECLARATION**

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

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

(Signature): 武洋

(Date):Aug-5 2016

**Supervised by: DR. LI WEI**
**Professor of Dalian Maritime University**

**Assessor:**
**Co-assessor:**

## ACKNOWLEDGEMENTS

I am sincerely grateful to WMU and DMU for offering me this opportunity to study for Maritime Safety and Environment Management. Meanwhile I wish to take this opportunity to express my appreciation to all the professors of WMU and DMU, who have tutored and supported me so much during the study course in Dalian. Please allow me to express my heartfelt appreciation to the Dalian MSA for so many years of cultivation.

I am profoundly thankful to my teachers, Mr. Bao Junzhong, Mrs Wang Yanhua and Mr Zhao Jian. During the study time they gave me so much help on study and living. I'm also grateful to Prof. Shuo Ma, Vice President of WMU, for teaching me and providing me with invaluable advice on the subject. Deep thanks will also go to Prof. Lee who is my supervisor on the research paper. He gave me so much help and lots of advice on the project.

I think I am lucky because I could meet such nice classmates. They are really cute and give me lots of help. I want to say it is so grateful to know these guys. At last I am everlastingly grateful to my family. They gave me so much and supported me to finish the course. I will never forget this experience, and I will miss the professors, the teachers and the classmates for ever.

**Abstract**

Dalian is located in the southernmost tip of the Liaodong Peninsula of China. And Dalian Port is an important access to the sea in the northeast of China, meanwhile Dalian Port is the the shipping center of Northeast Asia. With the development of China's economy, the demand for oil is increasing, the number of oil tanker gradually increased, and the oil tankers become larger, and the navigation environment is becoming more and more complex. Thus ship oil spill risk is also increasing. Dalian Port, as an important oil port in China, is responsible for the import and export of crude oil. Therefore, the risk of ship oil spill in Dalian Port has become one of the important risk sources of marine environment in the area.

In this paper, the risk of oil spill in the sea area of Dalian Port as the object of study, the use of AHP and fuzzy evaluation system analysis and evaluation of Dalian Port ship oil spill risk and the impact factors, trying to find out the corresponding countermeasures through the assessment of the oil spill risk in Dalian Port. Firstly, based on ships in Dalian port waters, overflow oil's dangerous source is identified, as well as the collision accidents to ship oil spill of high dangerous source, with ship collision as the main research object. Secondly, based on the AHP method and the fuzzy comprehensive evaluation method respectively, analysis and evaluation for the oil spill risk and the establishment of two-dimensional risk matrix are to be assessed. Finally, specific measures are to be found out to reduce the risk of oil spill.

**Key words: oil spill, risk assessment, AHP, fuzzy evaluation**

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background and significance

With the development of China's economy, the shipping industry and oil import volume have shown a good growing trend. In recent years, China's offshore oil transport is developing rapidly, but at the same time, the ship's oil spill has become an increasingly serious threat. Judging from the reality of the marine oil pollution accidents, the number of oil spill accidents in our country is in an upward trend. In 1993, China for the first time has become a net importer of oil; in 2009, China's crude oil import dependency degrees for the first time exceeded 50% over the internationally recognized warning line; in 2010, China's imports of crude oil reached 239 million tons, with an increase of 17.5%, dependence on foreign oil during the same period increased by 3%. By 2011, China had surpassed the United States as the world's largest oil importer and consumer. Then, official data show that China's crude oil dependence on foreign countries reached 55.2%, but also for the first time beyond the United States' 53.5%. At present, China's oil consumption being faster than the GDP growth rate is expected by 2020, and the total oil consumption will reach about 600 million tons. By 2030, 80% of China's oil consumption needs to rely on imports. In 2015, the country imported 330 million tons of crude oil. And Dalian Port as an important source of crude oil import in the north in 2015 have imported 27 million tons of crude oil. With the implementation of China's oil strategic reserve plan, the volume of oil imports in Dalian Port will continue to rise.

Because of the increase of the traffic density and the large scale of oil tankers, the risk of the oil spill accidents in the sea area of our country is increasing. According to statistics from Ministry of Transport of the People's Republic of China, from 1973 to

2014, along the coast of China, there were 3200 ship oil spill accidents, with a total amount of spill oil of about 42,936 tons (Zhao, W.J. & Qi, Z.X., 2015), in which there are 91 accidents leakage more than 50 tons. The biggest ship oil pollution accident occurred in 1983 in Qingdao — the Panama-registered tanker *FEOSOAMBASSADOR* oil spill accident, with a volume of more than 3,000 tons of oil spill.

Although the volume of marine spill oil is reducing stably as is shown the figure 1.1, marine oil spill accidents will still cause serious ecological disasters in coastal areas. On 13th November 2002, the Bahamas-registered tanker Prestige (42820 GT) with 76,972 tons of crude oil leaked off Spain. According to the ITOPF, this accident totally spilled 63,000 tons of crude oil, with a direct economic loss of more than 573 million €(ITOPF, 2007). The accident has made a heavy blow on the fishing and tourism of the coastal countries including Spain, France and Portugal. On 7th December 2007, the Hong Kong-registered tanker Hebei Spirit (146848 GT) was struck by the crane barge and leaked 10,900 tons of crude oil(ITOPF,2014). The oil spill accident polluted more than 300 kilometers coast, including 101 islands, 15 beaches, 3.5 million hectares of sea farm in South Chungcheong Province, South Jeolla Province, Luo North of South Korea. More than 10,000 family suffered great losses. For cleaning up the oil, reducing losses, and carrying out post disaster reconstruction work, since 7 December 2007 to 11 February 2008, the South Korean government mobilized 137 million people,15,757 ships, 274 helicopters, 1,198 heavy equipment, 1,113 pieces of washing equipment and 4,646 trucks.

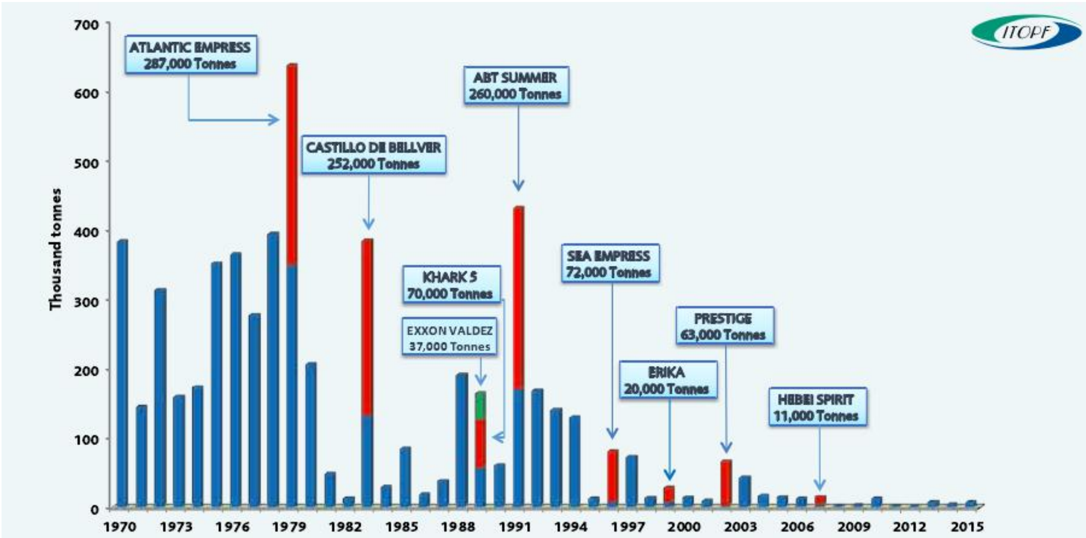



**Figure 1.1: Quantities of oil split 7 tons and over (rounded to nearest thousand), 1970 to 2015 (ITOPF, 2016, p.7)**

Under the background, it is important to use the quantitative and qualitative method on ship oil spill risk assessment, assess the risk occurrence probability, clear the impact of the accident on the marine environment and get reasonable and feasible risk prevention and treatment recommendations. It is also of great significance to protect the marine environment and ecological resources, and to establish an emergency response system of ship pollution.

### 1.2 The basic theory of risk assessment

Based on the severity of the oil spill accident, the risk assessment has been fully paid attention to. Scholars from around the world have used various methods of ship oil spill simulation and prediction, and oil spill accident risk assessment methods are mainly probability theory method, Analytical Hierarchy Process (AHP) method， artificial neural network method, and grey system theory.

### 1.2.1 Probability theory

Probability theory was first used to make risk assessment, and the method is usually used with the Poisson distribution. It is very important to study the occurrence probability of ship oil spill accident prediction, and to analyze the impact of the oil spill accident. Through study of the probability theory method of oil spill, we can predict the possibility of different scale of the oil spill occurred in different oil transport capacities or production.

### 1.2.2 Analytical Hierarchy Process(AHP)

The Analytic Hierarchy Process was proposed by Professor T. L. Saaty in the early 1970s. The method is a simple, flexible and practical multi-criteria decision making method. With decades of history, it is a kind of decision which is always related to the elements of the decomposition of the target, criteria, programs and other levels. On the basis of qualitative and quantitative analysis, the method would give the decision-making advice, using analytic hierarchy process to solve the problem.

### 1.2.3 Artificial neural network method

Artificial neural network is a network which is widely interconnected with a large number of processing units. It is an abstraction, simplification and simulation of the human brain, which reflects the basic characteristics of the human brain. The research is to study human's intelligent behavior from the physiological structure of human brain, and to simulate the function of human brain's information processing process. It is a technique based on neuroscience, mathematics, statistics, physics, computer science and engineering. The network is made up of the simple information processing units (neurons), and can accept and process information. Then the network information processing is realized by the interaction between the processing units, which is the expressed as processing unit between the "connections" to deal with.

### 1.2.4 Gray system theory

Grey system theory is a new theory which was formed in 1980s under the influence of the control theory, information theory and system theory. Professor Deng defined "the gray system as a system with known parameters and unknown parameters in the system." (Deng, 1983, p.1) Its characteristic is that the method could still make a quantitative analysis in the part of the unknown information of the system. It is a kind of theory which is applicable when there is lack of data and uncertainty. The feature is better to be analyzed in the case which lack information. In this situation, the method could reveal the law of the evolution of things, provide the basis for a harmonious relationship between man and nature. And the results could provide support for solving the concrete issues.

## 1.3 Structure and objective

The research objective of this paper is on the Dalian Port ship oil spill risk. Through analysis and study of the relevant literature on oil spill risk assessment and combined with Dalian Port sea area specific situation, the evaluation index system of oil spill risk assessment in Dalian Port is determined, and the fuzzy comprehensive safety evaluation is carried out to find out the hidden danger for safety. On this basis, it is important to put forward practical solutions to reduce the risk of oil spill in Dalian Port, improve the ecological security of the port. The main content of this paper is as follow:

Chapter one introduces the significance of the topic, the present situation of ship oil spill risk assessment, as well as the main research contents of this paper.

Chapter two introduces the general situation of Dalian Port sea area, including the nature condition and the port condition.

Chapter three is to analyze the hazard through the historical data to identity the hazard, and use the FTA model.

Chapter four is to determine the evaluation factors and evaluation criteria of oil spill risk in Dalian Port.

Chapter five makes a fuzzy comprehensive evaluation of oil spill risk in Dalian Port.

Chapter six gives some recommendations based on the assessment.

# CHAPTER 2

## General situation of Dalian Port sea area

### 2.1 natural condition of Dalian Port sea area

#### 2.1.1 Geographical area of Dalian Port sea area

“Dalian with three sides of sea, has 1,906 km of coastline and 226 distinctive islands. There are 23,000 $km^2$ territorial sea belonging to Dalian management.”(Shi, Z.G & Lin, H.X., 2007, p.47) There are 39 bays with total area of 1870.33 $km^2$ , 251 lump reefs of which the largest island is Changxing Island with an area of 223 $km^2$, being the fifth largest island in China. The total territorial sea area is approximately 29,000 $km^2$, accounting for 81% of Liaoning Province. On the other side, in Dalian the beach area is 1,121 $km^2$. On the marine organism aspect, there are three categories of marine organisms, including 209 families, 414 kinds, and 3 National Wildlife Refuges.

#### 2.1.2 Marine living resources

Dalian has rich marine biological resources, including sea cucumbers, sea urchins, abalone, fish, shrimp, shellfish, algae and other valuable seafood. More than 400 species of marine animals and plants and over 210 fish species.has been found. Wherein wrinkles abalone, sea cucumber, scallops, shrimp, wakame take a large amount of resources, with a high-quality reputation abroad. And the southern coast of Long Hill Islands group Rocky segment is the main origin of Seafood.

### 2.1.3 Coastal Tourism Resources

Dalian has many excellent harbors, which own 950 km long section of the base rocky coast. Mountains, seas, islands, reefs, and other wonders of the landscape form a rather unique natural landscape in Dalian. Because of that, Dalian also has a large number of coastal parks, beach, resort areas and other valuable tourism resources. The famous Xinghai Bay, Ocean Polar Museum, Sun Asia Ocean World, Coastal Road, Tiger Beach Park, Golden Pebble Beach landscape create a strong maritime culture. Dalian's long coastline has created more than 60 excellent natural bathing beaches. Here is an ideal summer resort with flat soft sand beaches, sunny, pleasant climate, fresh air.

### 2.1.4 Beach resources

Dalian has vast beach areas, with an area of 660 $km^2$, accounting for 5.2% of the total land area. And the beach distributes half and half on the Yellow Sea side and Bohai Sea coast. Good tidal water exchange conditions are conducive to the development of shrimp and shellfish farming. Dalian also has 220 $km^2$ of salt beach.

## 2.2 Port status

Dalian Port's geographical coordinates is 121° 39 '17 "E, 38° 5' 44" N. Located in the center of the Pacific Northwest, is the center of the emerging Northeast Asia economic circle, the region into the Pacific Ocean, the world's maritime gateway. Natural conditions are very superior. Thus, Dalian port is the most convenient transportation port for the Far East, South Asia, North America and Europe. Free port area is 346 square kilometers, with a land area of more than 10 square kilometers. Existing port special railway line is more than 150 kilometers, warehouse has more than 30 million square meters, goods yard 180 million square meters, all kinds of loading and unloading machines are 1000 times larger than Taiwan. Besides Port Dalian Authority have container, crude oil, refined oil, grain, coal, bulk minerals, chemical products, ro-ro passenger ship's modern specialized berths.

### 2.2.1 Port development

Dalian Port is located in the southern tip of the Liaodong Peninsula. And Dalian Port is a deep, ice-free port. Dalian is the end of the Harbin -Dalian train line, which is the gate of northeastern of China. As economic window of the northeast of China, Dalian is the gateway and also the most important foreign trade port in the northeast region. In 2015, Dalian Port is the eighth largest port of cargo handling capacity in China, and the eleventh in the world.

Dalian Port Group has established relationship with more than 160 of the world's countries and regions, more than 300 ports of maritime shipping and trade relationships. It opened 75 international routes of container, and the container rail transport has become one of the main transit sea ports in China.

Dalian Port Group has the largest 300,000 ton crude oil dock (tankers can unload 450,000 tons) and China's largest crude oil tank port group, with the annual capacity of 8,000 tons, which is an important oil and liquids in Northeast China chemicals storage transfer distribution base. Dalian Port Group was also the first company which had the crude oil, refined oil bonded warehousing business qualification.

The container terminal berthing of Dalian Port Group could berth 3E level 18,000 TEU container ships. The Group has more than 100 container liner routes, and the domestic and international route network covers more than 100 ports. It is the Northeast's largest container hub port, foreign trade container throughput accounting for 97% of that in the northeastern part of China.

Dalian Port group has the best water depth condition, and the highest comprehensive efficiency of the ore special terminal. It has 35 million tons in specialized ore terminal, 15 million tons to turn water wharf, 55 million square meters rear yard, and 8.5 million tons of non-renewable stockpiling ore.

The car dock of Dalian Port Group is fastest growing professional team, berthing of the largest RORO, with an annual capacity of close to 50 million units, accounting for more than 90% of the business market share in Northeast Harbor.

Dalian Port Group general cargo terminal is one of the major bulk cargo transit centers in Northeast China, which is committed to building quality steel, bagged grain, coal transshipment base.

Dalian Port Group is becoming northeast China's most competitive grain transfer hubs with building the system which contain producing area, train, harbor, ship and sale.

Dalian is located in the north end of the Bohai Sea "golden fairway", and has opened several passenger routes from Dalian to Yantai, Weihai, Penglai, Dongying, Tianjin, Changhai islands. Furthermore, Dalian Port Group has the international passenger route from Dalian to Incheon routes. The passenger business scale has become the largest in China for a long time.

### 2.2.2 Loading and unloading capacity of Dalian Port Authority

The loading and unloading capacity of Port Dalian Authority is growing steadily. In 2015, in the face of the international economic situation in the doldrums, with the continuous decline in foreign trade and slow economic growth in the hinterland and other unfavorable situation, Dalian Port Authority tried its best to achieve a smooth throughput growth. From the port of Dalian and the Port Bureau, in 2015, Port Dalian Authority completed 336.6 millions of tons of cargo throughput, thereinto the loading and unloading capacity of container 9301 thousand TEU. What's worth mentioning, the sea-rail combined transportation completed the throughout of 349 thousand TEU, ranking number 1 in the country's coastal ports.

# CHAPTER 3

## Hazard identification

Hazard identification is the first step of oil spill risk assessment, and it is also the foundation of ship oil spill risk analysis. Oil spill hazard identification is in the comprehensive identification of the study area potential ship spilled oil dangerous source, influencing factors and distribution of traffic accident, and then determine the high risk source, the impact of the accident scene of larger factors and accident. For the Dalian Port's sea area oil spill risk recognition, first of all, we should survey ship spilled oil accident classification. Second, in reference to a great deal of data based on the high risk accident type identification and further identification of oil spill influence factors. Finally, the contribution of the factors to the oil spill is ranked, which provides a basis for the implementation of risk assessment measures.

### 3.1 Accident identification

The identification of oil spill risk sources is to determine the potential accident occurrence frequency and the consequence of high risk accidents in the sea area by collecting a large amount of oil spill data. Marine oil pollution accident is divided into accident oil spill, operational oil spill accident and intentional discharge oil spill. The accident oil spill accidents include collision, contact, grounding, fire, explosion and the ship hull damage, etc. These accidents could lead to the ship's oil spill accident. Operational oil spill accidents include loading and unloading of cargo oil, the installation of fuel oil and other operations with oil. The intentional discharge oil spill is that the seafarers spill the oil into the sea deliberately. Based on the statistics of the oil spill, there are over 50 tons of oil in Bohai sea during the year 1976-2005, the results are as follows: from 1976 to 2005, the total oil spill occurred in 20 cases, of which 18 accidents are the accident oil spill. The number of accident oil spill accounts for 90% in all oil spills. Meanwhile, the collision takes the account of more than a half in the total accidents. The Dalian Port sea area is located at the junction of the Yellow Sea and Bohai Sea. However, due to the fact that the number of oil spill accident in Bohai is small, the accident oil spill should be classified as a high risk source that should also refer to the international and domestic ship oil spill data.

The International Tanker Owner pollution Federation Limited (ITOPF) in accordance with the different levels of the accident and the causes of 9,697 tankers' oil spill accidents between 1970 and 2015, as table3.1. According to the analysis of the oil spill accident statistics table, 91% of operational oil spill accidents have an oil spill volume of less than 7 tons. On the other hand, in 2000s, the largest 10 oil spill accidents spilled the oil for 75% of the total number of spilled oil as is shown in figure 3.1.

**Table 3.1 :International Oil Spill Accident statistics from 1970 to 2015 (ITOPF,2016)**

| | <7 tons | 7-700 tons | >700 tons | Total |
|---|---|---|---|---|
| Collision | 188 | 361 | 136 | 685 |
| Grounding | 240 | 270 | 150 | 660 |
| Hull Failure | 577 | 101 | 60 | 738 |
| Equipment Failure | 1692 | 207 | 18 | 1917 |
| Fire/Explosion | 174 | 47 | 52 | 273 |
| Other | 1815 | 175 | 30 | 2020 |
| Unknown Reason | 3188 | 203 | 13 | 3404 |
| Total | 7874 | 1364 | 459 | 9697 |

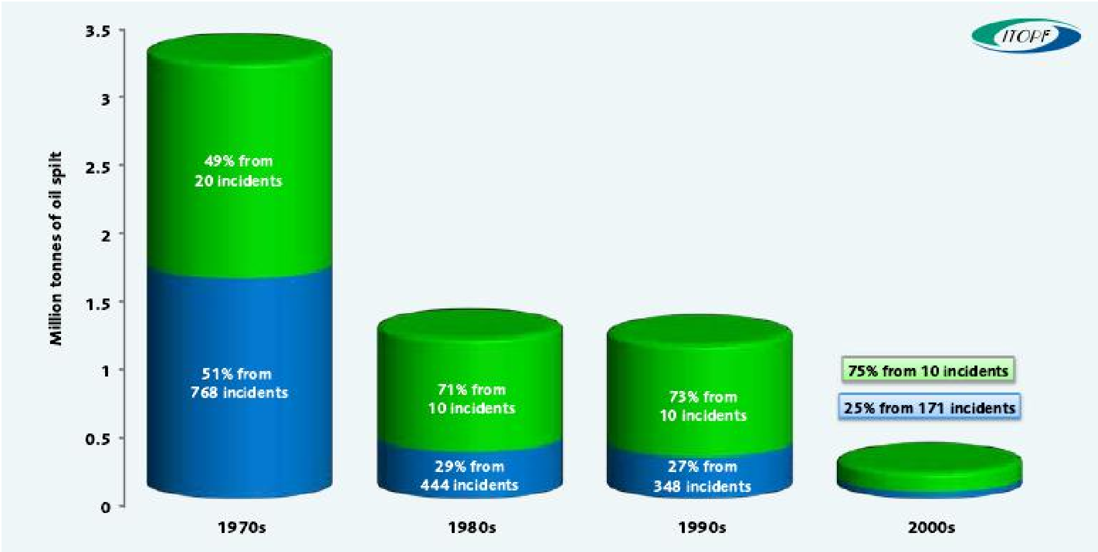



**Figure 3.1: Spills 7 tons and over per decade showing the influence of a relatively small number of comparatively large spills on the overall figure (ITOPF, 2016, p.7)**

It is evident that the accident oil spill is the hazard of the risk assessment. There are several kinds of casualties for the tankers, including collision, contact, grounding, fire, etc. Among them, the collision, contact, grounding, fire, explosion and non-accidental structural failure (NASF) could lead to oil spill. This research paper will find the influencing factors through these casualties.

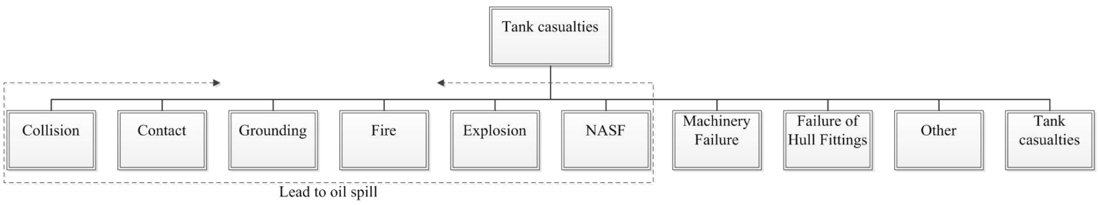



**Figure 3.2: Tanker Casualties Distribution**

From the figure, there are six kinds of accidents that could lead to the oil spill pollution. But these accidents are not in the same risk level. Firstly, the NASF is a kind of random event. It has nothing to do with the objective factors and operation. So the NASF is not in the assessment area. From the statistics, the oil spill accident covered period 1990-2005 in China, with the mainly pollution resource being the collision.

**Table 3.2: China's oil spill accidents with more than 50 tons from 1990 to 2005**

| | No. | Percent | Oil Spill Volume | Percent |
|---|---|---|---|---|
| Collision | 27 | 57 | 9821 | 57 |
| Grounding | 5 | 11 | 2560 | 15 |
| Equipment Failure | 2 | 4 | 330 | 2 |
| Fire/Explosion | 1 | 2 | 1000 | 6 |
| Overturn | 5 | 11 | 730 | 5 |
| Others | 5 | 11 | 2283 | 14 |
| Operation accident | 2 | 4 | 150 | 1 |
| total | 47 | 100 | 16874 | 100 |

### 3.2 Accident analysis based on Fault Tree Analysis(FTA) model

Fault tree is one kind of models to describe the causal relationship of the accident, and it is one of the important methods in system safety engineering. The FTA can not only analyze the direct cause of the accident, but also further indicate the potential cause of the accident. It can be used for both qualitative and quantitative analysis, and has the characteristics of simplicity and visual representation. The FTA fully reflects the systematic, accurate and predictive quality of the system engineering method, so it is widely used in many fields. The FTA consists of event symbols and logic gate and analysis of the safety and functional problem of the system. Meanwhile it could reflect the relationship between each event and provide a most concise expression form.

### 3.2.1 Basic concepts

In FTA, there are many concepts and here we only introduce some basic ones:

FTA is a tree structure chart which uses logic gate to link the top event and bottom event. And it is used to describe the logical relationship between each event.

Top event is located on the top of the fault tree and represent the unexpected consequence.

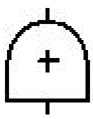
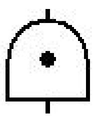
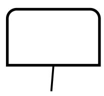
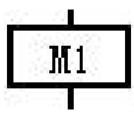
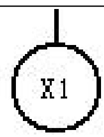
Bottom event is the cause of other events and is located at the bottom of the fault tree.

Middle event is link event between the top and the bottom event.

Or gate: The output occurs if any input occurs

And gate: The output occurs only if all inputs occur (inputs are independent).
The symbols are shown as follows (in table 3.3):

**Table 3.3: symbols of the fault tree**

| Event& Gate | Or Gate | And Gate | Top Event | Middle Event | Bottom Event |
|---|---|---|---|---|---|
| symbol |  |  |  |   |   |

### 3.2.2 FTA qualitative analysis

The qualitative analysis of the FTA could reveal the internal logical relationship in the process of accident. When FTA is used for a qualitative analysis, the Minimum Cut Set and Minimum Path Set would be used.

Cut Set: Set fault tree bottom event set $\{X_1, X_2, \ldots, X_n\}$, and structure function of fault tree is $\phi(X)$, if there is subset: $a = \{X_{a1}, X_{a2}, \cdots, X_{ap}\}$ and $\{X_{a1}, X_{a2}, \cdots, X_{ap}\} \in \{X_1, X_2, \cdots, X_n\}$, when the condition $X_{a1} = X_{a2} = \cdots = X_{ap} = 1$ is met, the $\phi(X) = 1$, so a is the cut set. Cut set is a collection of some of the bottom events in the fault tree. When these events occur at the same time, the top event must occur.

Minimum Cut Set : if the cut set $a = \{X_{a1}, X_{a2}, \cdots, X_{ap}\}$ and can not find another cut set $a'$, $a' \subset a$ but $a' \neq a$, the $a$ is just the Minimum Cut Set. The Minimum Cut Set is the cut set which could not remove any bottom event.

Path Set: Set fault tree bottom event set $b = \{X_{b1}, X_{b2}, \cdots, X_{bp}\}$, $b \subset \{X_1, X_2, \ldots, X_n\}$, if $X_{b1} = X_{b2} = \cdots = X_{bp} = 0$, the $\phi(X) = 0$ so the $b$ is the path set. Path set is a collection of some of the bottom events in the fault tree, when these events do not occur, the top event will not happen.

Minimum Path Set: if $b = \{X_{b1}, X_{b2}, \cdots, X_{bp}\}$ is a path set, and could not find a path set $b'$ which $b' \subset b$ and $b' \neq b$, the $b'$ is the minimum path set. The Minimum Path Set is the path set which could not remove any bottom event.

FTA is mainly to find out the system failure and all the causes which lead to the top event, and qualitatively to find out the weak link in the system and to take corresponding remedial measures, guarantee system reliability and safety. Qualitative analysis is done by solving the minimal cut sets of the fault tree.

### 3.2.3 FTA model building

And the model needs to consider all kinds of possibilities. Through previous analysis, we know that the collision accident is the main source of the ship's oil spill, so the top event of this model is the result of collision. There is also a key to the success of the model that is closely related to the logic, and it should be said that the impact of the ship collision accidents, as well as the relationship between them is very complicated. The author mainly adopts an analysis of a large number of typical cases, and consults experts on the model to modify and improve the final set up as is shown in the figure of the FTA model.

The top event is expressed by the letter “T”, and in this fault tree, the top event is the oil spill accident caused collision. Ship collision accident is the basic causes of oil spill accident, including directly hull damaged by the collision and the fire or ship overturn by the collision.

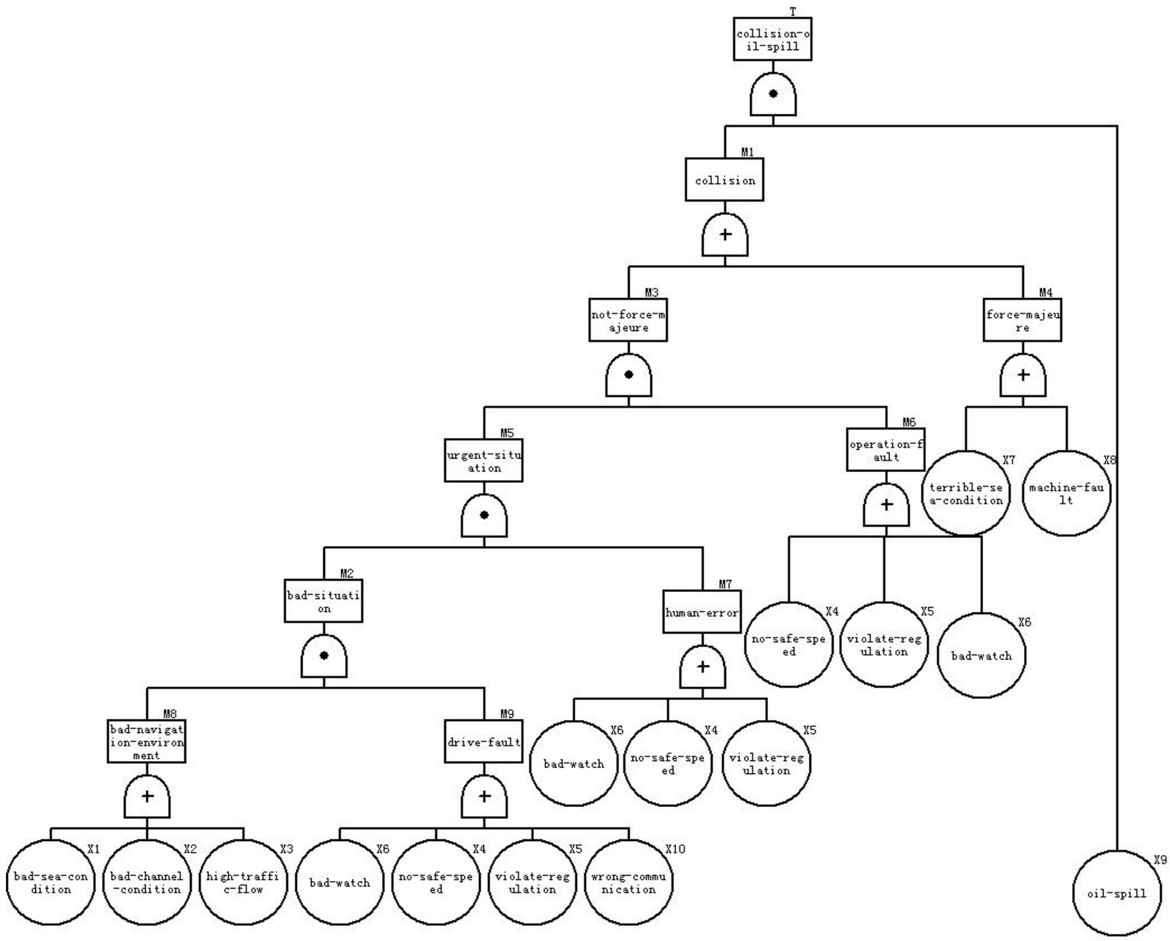



**Figure 3.3: The fault tree of the oil spill accident caused by collision**

Through the calculation, there are total 11 minimum cut sets: {X7,X9},{X1,X6,X9}, {X8,X9},{X2,X6,X9}, {X3,X6,X9}, {X1,X4,X9}, {X1,X5,X9}, {X2,X4,X9}, {X3,X4,X9}, {X2,X5,X9} and {X3,X5,X9}. Because the bottom event X9 is the oil spill, the X9 is sufficient of the top event.

The most important bottom event is the X9 oil spill, which is caused by the collision of ship hull damage and oil leakage. Spill oil accident is the objective of study, in order to find effective measures to reduce the occurrence of is research target. Through previous analyses, we know that the ship's oil spill accidents, especially big accidents, are caused mainly by marine accident, so we regard the oil spill accident as secondary accident. A lot of ship collision accidents are not directly caused by the occurrence of an accident of oil spill, while others are caused by the occurrence of an accident of oil spill. The difference between them is that the collision caused damage to the hull damage, which directly determines whether the ship will be spilled oil. Therefore, in order to cope with the increasingly serious marine environment protection pressure, the top priority for us is to improve the hull strength, especially oil tanker. In addition, because the collision is inevitable, it is needed to consider the location of the collision point, in order to prevent damage of the ship's storage compartments.

From the fault tree, it is clear the traffic condition is equal to human factors. But through controlling the human factors, the accident will be reduced significantly. In the minimum cut sets, the X1, X2, X3, X7 belong to the objective navigation environment. The main effective factors are visibility, wind, surge, current, tide, channel condition and so on. In the next chapter, this paper will further assess the oil spill risk in Dalian Port sea area.

During the course of the voyage, the ship will be influenced by many factors, such as the navigation environment, artificial operation, and the ship's malfunction. When one or more influencing factors are abnormal, it will cause the hidden dangers, and then cause the ship's oil spill accident. Therefore, first of all, we should identify the influencing factors of ship collision accident and then judge the degree of these factors on ship navigation safety, so as to provide a theoretical basis for the implementation of risk management measures.

### 3.3 Human factor

The IMO in the ISM instrument pointed that about 80% accidents was caused by human error. And the human factors related to the ship collision accident rate is as high as 89%-96%. So it is clear that the human factor is a key point in the collision accident. So it is necessary to make a separate analysis for the human factors. For the human factor, it is better to choose the SHEL model for analysis.

### 3.2.1 SHEL model

The SHEL model was first proposed by Edwards in 1972, which was modified by Hawkins Frank in 1987, and now is widely used in the study of human factors. The element of SHEL model is the software, hardware, environment and liveware, in which the liveware is the center of the model. There are four interfaces in the model, the L-S, the L-H, the L-E and the L-L. These interfaces respectively represent the relationship between the liveware with the other elements. Only when the liveware as the model center match the other neighboring elements, could the system work properly.

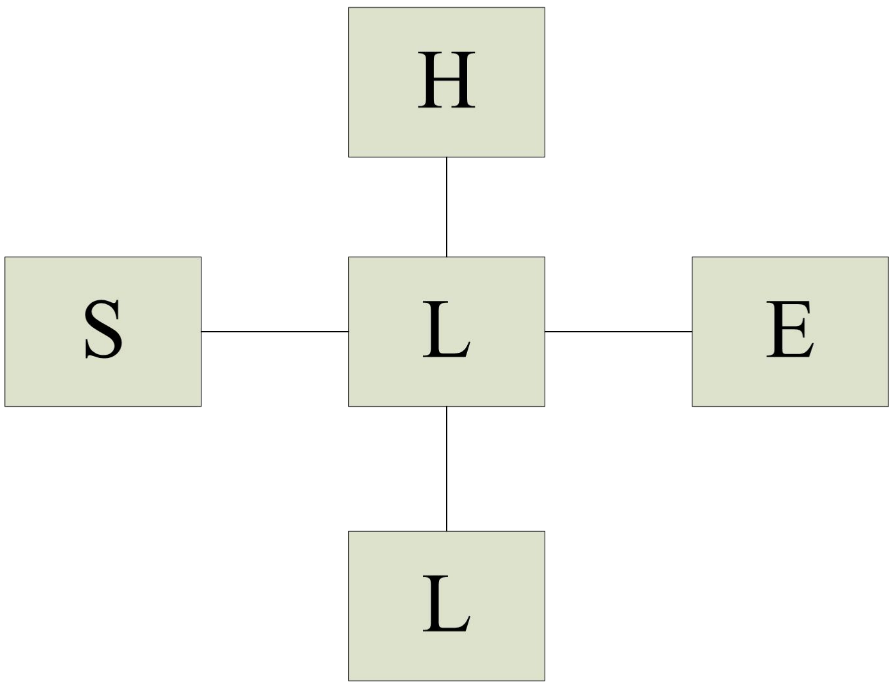



**Figure 3.4: SHEL model**

### 3.2.2 The element of SHEL model

Liveware: it refers to the element associated with the individual. As an organism, human beings have their own limitations. Human behavior is influenced by its character, physiology, psychology, social psychology and so on. Physical aspect includes physical characteristics, visual and auditory senses. Physiology aspect includes health, fatigue, medication, alcohol, and illusion. Psychological aspect includes perception, attention, emotion, attitude, personality, ability and other factors. Social psychology has other factors besides working, including family, social, interpersonal stress, and other factors. The system will be involved in a very wide range of personnel.

Hardware: it refers to the physical parts of the system, such as the ship, equipment, etc. Hardware is the physical component that is needed in navigation. Hardware factors are usually composed of workstations, displays, input devices, communication devices, measuring, radar systems and recording systems. The hardware should be used effectively, quickly and expediently. For example, the alarm button should be installed a cover, so that the seafarer could not make any false alarm. In addition, any button needs enough illumination in order to ensure operation on any occasion.

Software: it refers to the parts in the system which do not belong to the hardware. All the laws, regulations, navigation plan, operation procedures, emergency plan, manual, computer software belong to the software. The software should connect liveware with other elements well.

Environment: it refers to people, hardware, software interact in the environment. The weather, sea conditions, traffic density and visibility belonged to the environment. In a broad sense, the environment includes people's social environment, family environment.

### 3.2.3 The interface of SHEL model

Liveware-Hardware: It refers to the relationship between crew and ship and equipment. From the hardware's perspective, it should be designed to facilitate the operation, reduce the possibility of mistakes. Fundamentally speaking, the design of the hardware should be the core of human. The hardware development is for promoting safety, improving efficiency, and for being used easily. People have to adapt to hardware equipment to improve efficiency.

Liveware-Software: The various software provides guidelines and criteria for the crew members. The software can maximally reduce the randomness of the crew work to improve the working accuracy.

Liveware-Environment: The seafarers work in various environments. Different environment will give the seafarers different impacts. The poor visibility will affect the seafarer judgment, and the high traffic density also improve the difficulty of ship maneuvering. Correctly handling the environmental impact is the key to avoiding the accident.

Liveware-Liveware: It refers to the relationship between individuals, such as leadership, management, communication and cooperation between crew members. Navigation is a team work. Every department needs to work together, cooperate with each other, and finish the work. If the L-L interface has problems, the probability of an accident will be greatly increased.

### 3.2.4 SHEL model analysis

Liveware-Hardware: For the collision accident, the L-H interface fault is on two parts.

One is that the crew do not effectively use the navigational aids or identity the urgent situation in time. The other is the crew failed to operate ship to avoid the collision. All of these errors are caused by the crew who do not use the equipment effectively. The maritime administration should strictly carry out the assessment of the level of crew. Special simulator evaluation projects should be listed as the focus of the assessment project. Through lots of the simulator operation and on board operation drill, the operation level of the seafarers will be improved.

Liveware-Software: The human factors related to the ship collision accident rate is as high as 89%-96%. All the human factors are because the crews violate the regulations and rules. Among these regulations, the most important regulation is the International Regulations for Preventing Collisions at Sea（COLREGS）. All the actions of preventing collision should be in an accordance with the COLREGS. The COLREGS is used to deal with the urgent situation, but there are still mistakes in the operations. The crew's correctly performing the COLREGS is an important condition to avoid the collision. We should increase the training and examination of the COLREGS and other relevant laws and regulations. Important items should be trained in the form of manuals or graphics.

Liveware-Environment: The environment will interfere with the crew to make the right judgment. The internal environment includes equipment layout, information display, maintenance, degree of automation, noise and vibration. The external environment includes the weather, visibility, wind, current, tide, traffic flow and background light. All of these factors will cause interference to the crew. From the statistics, the visibility impacts the crew member most greatly.

Liveware-Liveware: There are many factors that affect L-L. Different cultures, different accents, different thinking patterns and different working methods all impact the L-L. If the two sides get different information from one point, the difference will cause hidden danger. On the other hand, the crew works on board and he is a member of the team. The crew needs to deal with the pressure from the work, family, social and the other aspect. The ship company as well as captain should find the problem in the L-L, and solve it timely. Only when the problem in the L-L is eliminated, the could accident be avoided.

# Chapter 4

## Evaluation factors and evaluation criteria of oil spill risk in Dalian Port

According to ship oil spill risk identification in chapter three, the main risk sources of ship oil spill accidents in Dalian Port sea area are identified as the ship collision accidents, so this chapter takes the ship collision accident as the research objective. Because of no comparability between human factors and the ship factors, it is difficult to determine the possibility influenced by the human factors of oil spill, so this chapter does not take the human factors into consideration.

For harbor waters, the larger the risk of the ship in the process of transportation, the greater the possibility of the occurrence of oil spills. Then how much danger about the navigation and how much people can accept the safety level should also be taken into account. All these need to take the risk assessment into evaluation. The traffic safety of the port is a fuzzy concept, and the factors that affect the evaluation of the object are numerous, and have strong fuzziness. In this paper, the fuzzy comprehensive evaluation method is adopted to analyze the possibility of oil spill in Dalian Port sea area

### 4.1 Dalian Port's oil spill risk safety evaluation index system

This paper is to assess Dalian Port's oil spill risk. Through the analysis and research on related literature, combined with the actual situation of Dalian Port navigation sea area, the safety assessment factors are determined, and established Dalian Port oil spill risk assessment index system are shown in Figure 4.1:

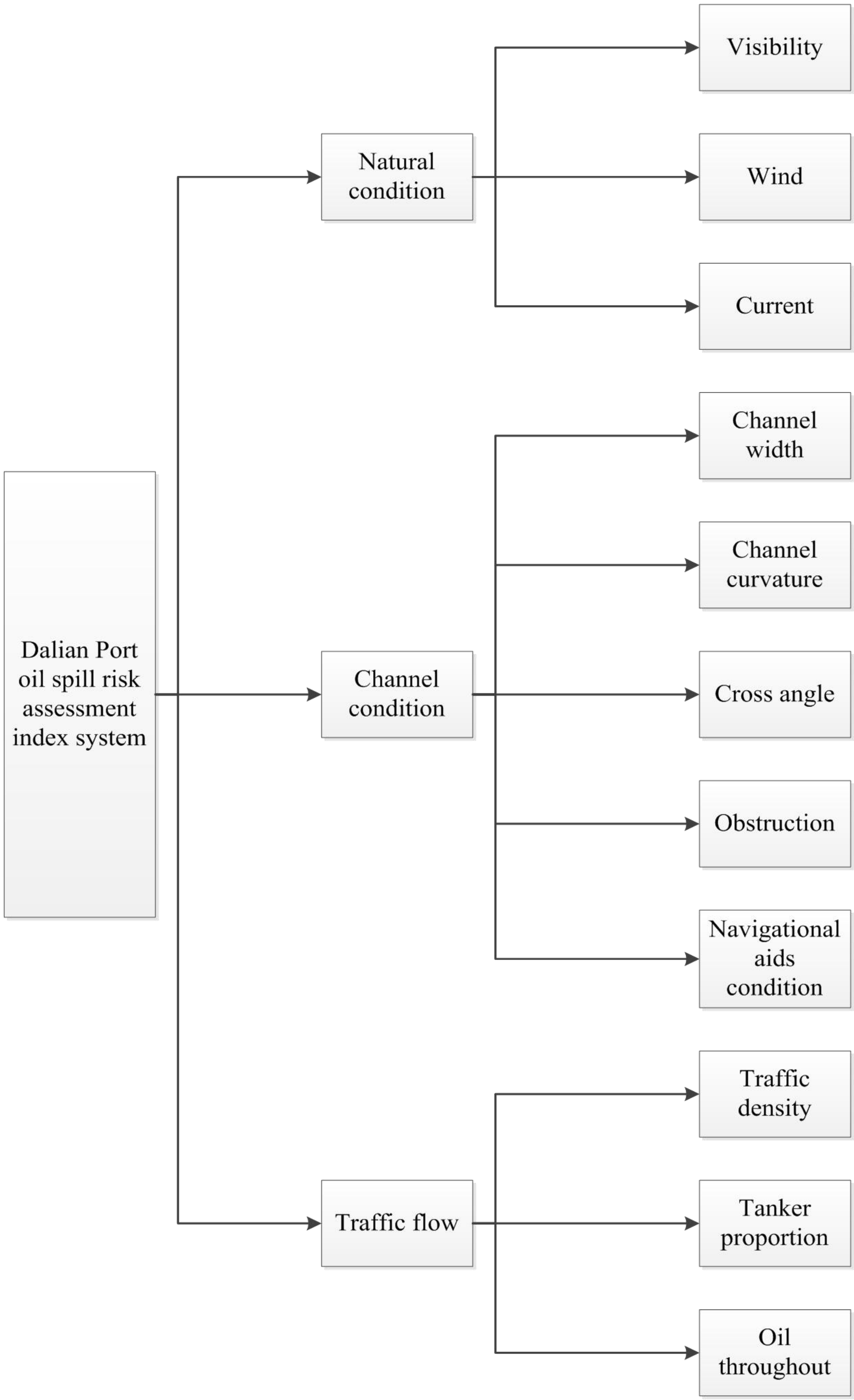



**Figure 4.1: Dalian Port oil spill risk assessment index system**

By figure 2.1, the establishment of Dalian Port oil spill risk assessment index system of comprehensive the relevant research at home and abroad can be seen to establish a similar index system, and on the basis of the actual situation in Dalian Port as the corresponding adjustment. The ultimate factors are selected natural environment, channel conditions and traffic flow for the safety assessment. In which the natural environment factors include three subordinate indexes visibility, wind and current. The waterway conditions include channel width, channel bends, crossing angle and obstacle of four subordinate indicators. There are three subordinate indexes in the traffic flow factor. The following will be a detailed analysis of each of the indicators.

## 4.2 Analysis of Dalian Port oil spill risk safety evaluation index and determination of its evaluation criteria

### 4.2.1 Visibility

On the sea, visibility refers to the normal visual sight which can be seen in the maximum horizontal distance. In another word, the visibility is the distance to the contour of the object from the sky background distinction. The direct influencing factor is the fog which is the most important factors in the marine traffic safety of the visibility in Dalian Port see area. The visibility scales are shown in table 4.1:

**Table 4.1: Visibility Scale**

| Scale | Fog Degree | Visual Range | |
|---|---|---|---|
| | | nm | m/km |
| 0 | Dense FOG | 0-0.03 | 0-50m |
| 1 | THICK FOR | 0.03-0.1 | 50-200m |
| 2 | FOG | 0.1-0.25 | 200-500m |

| | | | |
|---|---|---|---|
| 3 | MODERATE FOG | 0.25-0.5 | 500-1000m |
| 4 | MIST | 0.5-1.0 | 1-2km |
| 5 | POOR VISIBILITY | 1.0-2.0 | 2-4km |
| 6 | MODERATE VISIBILITY | 2.0-5.0 | 4-10km |
| 7 | GOOD VISIBILITY | 5.0-10.0 | 10-20km |
| 8 | VERY GOOD VISIBILITY | 10-30 | 20-50km |
| 9 | EXCELLENT VISIBILITY | >30 | >50km |

Poor visibility is an important factor that threatens the safety of ships in the hydrological and meteorological conditions, and it has a great influence on the traffic safety and traffic efficiency. Statistical analysis showed that the traffic and visibility distance is inversely proportional to the degree of risk. Here, the number of days in the condition of poor visibility is regarded as an index to evaluate the visibility of the navigation environment in the channel, and the evaluation criteria are listed in Table 4.2.

**Table 4.2: Visibility risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| poor visibility days/year | <10 | 10-20 | 20-30 | 30-40 | >40 |

### 4.2.2 Wind

Wind impact on the safety of ship navigation is particularly large, strong winds and typhoons will result in the ship's yaw, grounding, and the risk of dragging, especially in restricted waters yaw will lead to greater danger. Also ship roll which is caused by strong wind will affect the observation of the seafarers and the surface waves and waves often interfere with radar and visual observation, especially for some small targets that are not easy to identity, and the ship maneuverability are restricted. The wind is one unfavorable factor of the marine accidents and is recognized as an important factor of safety assessment of navigation environment.

Different grades of wind influence on ship navigation will produce different unfavorable effects: the larger speed of wind, the greater the probability of the accident. Wind scale table are shown in table 4.3.

**Table 4.3: Wind Scale**

| Force | WMO Classification | Appearance of Wind Effects On the Water |
|---|---|---|
| 0 | Calm | Sea surface smooth and mirror-like |
| 1 | Light Air | Scaly ripples, no foam crests |
| 2 | Light Breeze | Small wavelets, crests glassy, no breaking |
| 3 | Gentle Breeze | Large wavelets, crests begin to break, scattered whitecaps |
| 4 | Moderate Breeze | Small waves 1-4 ft. becoming longer, numerous whitecaps |
| 5 | Fresh Breeze | Moderate waves 4-8 ft taking longer form, many whitecaps, some spray |
| 6 | Strong Breeze | Larger waves 8-13 ft, whitecaps common, more spray |
| 7 | Near Gale | Sea heaps up, waves 13-19 ft, white foam streaks off breakers |
| 8 | Gale | Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks |
| 9 | Strong Gale | High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility |
| 10 | Storm | Very high waves (29-41 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility |

| | | |
|---|---|---|
| 11 | Violent Storm | Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced |
| 12 | Hurricane | Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced |

According to the previous experience on wind effects on the safety of navigation, usually wind of class 6 (strong breeze) is adopted as a standard wind, and is used in Dalian port sea area for nearly 5 years as the annual standard wind for evaluation index value, because there is almost no ship in navigation on the channel when the typhoon is coming. Taking into account in general typhoon passage there is almost no ship, the typhoon days will merge to windy days and windy day is divided into 6 to 7, 8 levels and above 8 levels. Then the level 8 and above windy days are converted into 6 ~ 7 standard wind days, to accurately reflect the ports and channel of water environment risk. Standard wind days conversion method is as follows:
Standard wind days/year=No of 6&7 level days/year+1.5*(above 7 level) wind days/year. And the evaluation criteria are listed in Table 4.4.

**Table 4.4: Wind risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| standard wind days/year | <30 | 30-60 | 60-90 | 90-120 | >120 |

### 4.2.3 Current

The influence of the current (including tidal current, ocean current, etc.) on the motion of the ship in the harbor area is mainly affected by the control performance. In many ports, the large and small ships need to rush out of the tide, resulting in a large increase in traffic flow within the channel, but the situation is very easy to cause the accident. In the narrow channel, the current will accelerate the flow of the relative velocity of the upstream vessels side and bottom water, and make the ship quay wall effect occur, strengthening the interaction between the ships, increasing the probability of  the ship collision, grounding and other accidents. Therefore, in general, the greater the current of a particular port, the more difficult the ship's voyage, and the greater the possibility of the occurrence of traffic accidents. Therefore, the current is an important indicator of the degree of safety of navigation environment. Because the influence of current is mainly determined by the flow rate and flow direction, this paper only uses the maximum flow rate of the channel as its evaluation criteria, and the evaluation criteria are shown in Table 4.5:

**Table 4.5: current risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| current speed (nm) | <0.5 | 0.5-2.0 | 2.0-5.0 | 5.0-7.0 | >7.0 |

### 4.2.4 Channel Width

Channel width directly affects the safety of navigation. When the ships navigate in narrow channel, it will be easily prone to shore, shore ceiling and wave damage phenomenon, resulting in ship collision, bank contact, or grounding. And also it is likely to affect the ship's encounter rate.

For the standard channel width, the waterway bureau and water transport bureau have different opinions. From the waterway bureau, the definition of channel width is the design width of the channel which refers to the standard width of the channel; when designing the lowest navigable water level, which is the minimum width of the navigable channel. In this paper, the width of the channel is equal to the average value of the width of the ship/the width of the channel width. The standard is shown in table

4.6:

**Table 4.6: channel width risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| channel width (nm) | 0-0.3 | 0.3-0.5 | 0.5-0.8 | 0.8-1.0 | >1.0 |

### 4.2.5 Channel Curvature

Ships navigating in curved channels are more dangerous than those in the straight channels. Because of the limitation of the channel scale and the non positive flow of the ship in the channel, the operation difficulty is increased, so that the accident is easier to happen in the curved channel. The influence of channel curvature on the safety of ship navigation is mainly reflected in the direction of the steering angle. This paper chooses the maximum steering angle as a risk evaluation index, and the prescribed standard is shown in table 4.7:

**Table 4.7: channel curvature risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| maximum steering angle | <15° | 15°-30° | 30°-45° | 45°-60° | >60° |

### 4.2.6 Cross Angle

At the crossing of the channel, because of the intersection of the traffic flow, the convergence of the number of ships will be increased, and the density of the ship increased. So it is easy to form urgent situation and the accident is hard to be avoided. According to Professor Zhong Yi Zheng and Wu Zhaolin in the port navigation environment risk degree of gray evaluation model, the risk of the cross channel evaluation status and the main channel intersection number mainly refer to the main channel and navigable water depth greater than 1m channel of the cross angle is larger than 20° in number. Due to the fact that the number of Dalian Port channel cross point is not much, and the size of the intersection angle of the main channel and the second channel affect the safety of navigation is relatively large, therefore, selecting the main channel and second channel cross angle as the evaluation standard is reasonable, and the vertical cross state as high risk. According to the specific conditions of the Dalian Port channel, the specific evaluation criteria of the factors of the intersection of the channel can be set as follows in table 4.8.

**Table 4.8: cross angle risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| cross state | <20° | 20°-45° | 45°-60° | 60°-70° | >70° |

### 4.2.7 Obstruction

In the course of navigation, there are obstacles in channel or near the channel, which makes the operation of the ship restricted, and it is a direct threat to the safety of navigation. The influence of navigation obstruction on the safety of navigation is mainly related to the number of obstacles and the distance to the channel. Considering the navigation environment risk degree of mathematical evaluation of the operation, the distance from obstruction to the channel is selected as the evaluation factors. And the specific evaluation criteria of the factors of the obstruction as the following provisions, see the table 4.9:

**Table 4.9: Obstruction risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
| --- | --- | --- | --- | --- | --- |
| obstacle state (m) | >200m | 100-200 | 50-100 | 20-50 | <20 |

### 4.2.8 Navigational aids condition

Navigational aids conditions means the artificial channel conditions. This factor is different from other factors. It is difficult to describe quantitatively, and we can only use the linguistic variables to describe the advantages and disadvantages of them. The main navigational aids include lighthouse and lightship, buoy and VTS. The advantages and disadvantages of the navigation aids classification standards are shown in the table 4.10.

**Table 4.10: Navigational aids condition risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
| --- | --- | --- | --- | --- | --- |
| navigational aids condition | excellent | better | good | not bad | bad |

### 4.2.9 Traffic Density

As Professor Wu Zhaolin's definition of the traffic density shows, "Traffic density refers to the number of vessels in the area of the unit area of a certain moment. It reflects the intensity of the ships in the waters." (Wu & Zhu, 2004, p.44) Traffic density is the most basic quantity to characterize the traffic situation of a water area (especially the water channel). Traffic density is one of the most important information and is easier to be collected. Its scale directly reflects the scale of the marine traffic and busy degree, and to some extent, reflects the waters of the ship traffic congestion and dangerous degree, more intuitive surface sign in navigable waters ships sailing a dangerous situation, and it has a great influence on ship navigation safety and traffic efficiency, traffic volume in the space constraints on the ship's action and the psychological impact of the operator's behavior.

In general, the greater the traffic density, the more traffic volume; the more congested traffic, the worse the degree of security, and the higher the degree of management. The evaluation criteria for the risk of traffic volume can be made as follows, as is shown in table 4.11.

**Table 4.11: Traffic density risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| traffic volume(No of ship/day ) | <10 | 10-15 | 15-25 | 25-70 | <70 |

### 4.2.10 Tanker proportion

Tanker proportion means the number of tankers that takes the proportion of the traffic flow. This paper mainly researches the oil spill risk assessment, so the tanker proportion is one of the most important factors. The higher tanker proportion in the traffic flow, the higher possibility of tanker accidents. Thus the evaluation criteria for the risk of tanker proportion can be made as follows, as is shown in table 4.12:

**Table 4.12: Tanker proportion risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| tanker proportion | <5% | 5%-10% | 10%-20% | 20%-35% | >35% |

### 4.2.11 Oil throughout

"Cargo throughout" means the total weight of all the ships in and out of the port., mainly from the point of view of the circulation of goods in the area of the description of the volume of shipping activities. The more import and export volume indicates that the more frequent the ship's activities, the greater the possibility of ship accident. Oil throughout means the total weight of the oil of all the ships in and out of the port. The size of the oil throughout could reflect the possibility of the oil spill. Thus the evaluation criteria for the risk of oil throughout can be made as follows, as is shown in table 4.13：

**Table 4.13: Oil throughout risk assessment criteria**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| oil throughout($10^4$ t) | <5 | 5-600 | 600-1200 | 1200-1800 | >1800 |

**4.3 Dalian Port oil spill risk assessment index system**

For better identity of the criteria for each evaluation factor, merging these tables into one table, risk assessment criteria for each evaluation factor are shown as follows in the table 4.14:

**Table 4.14: Risk assessment criteria for each evaluation factor**

| risk level | low risk | lower risk | general risk | higher risk | high risk |
|---|---|---|---|---|---|
| poor visibility days/year | <12 | 12-24 | 24-36 | 36-48 | >48 |
| standard wind days/year | <36 | 36-64 | 64-96 | 96-120 | >120 |
| current speed (nm) | <0.5 | 0.5-2.0 | 2.0-5.0 | 5.0-7.0 | >7.0 |
| channel width (nm) | 0-0.3 | 0.3-0.5 | 0.5-0.8 | 0.8-1.0 | >1.0 |

| | | | | | |
|---|---|---|---|---|---|
| maximum steering angle | <15° | 15°-30° | 30°-45° | 45°-60° | >60° |
| cross state | <20° | 20°-45° | 45°-60° | 60°-70° | >70° |
| obstacle state (m) | >200m | 100-200 | 50-100 | 20-50 | <20 |
| navigational aids condition | >80 | 60-80 | 40-60 | 20-40 | <20 |
| traffic volume(No of ship/day ) | <20 | 20-40 | 40-70 | 70-100 | <100 |
| tanker proportion | <5% | 5%-10% | 10%-20% | 20%-35% | >35% |
| oil throughout($10^4$t) | <5 | 5-600 | 600-1200 | 1200-1800 | >1800 |

# Chapter 5

## Fuzzy comprehensive evaluation of oil spill risk in Dalian Port

### 5.1 Evaluation index factors and determination of oil spill risk in Dalian Port

#### 5.1.1 Determination of factor set

The basis of risk assessment of oil spill in port water area is to establish an appropriate evaluation index. In the fourth chapter, the paper analyzes various factors that affect the safety of navigation in the navigation environment of Dalian Port waters., and establishes the risk evaluation index system, and determines the Dalian port waters navigation environmental risk degree evaluation index factors: visibility, wind, current, channel width, channel curvature, cross angle, obstruction, navigational aids condition, traffic density, tanker proportion and oil throughout. Therefore, according to the index factors set evaluation factors set:

$$U = \{u_1, u_2, u_3\} = \{Natural\ conditon, Channel\ condition, Traffic\ Flow\}$$

Inside:

$$u_1 = \{u_{11}, u_{12}, u_{13}\} = \{Visibility, Wind, Current\};$$

$$u_2 = \{u_{21}, u_{22}, u_{23}, u_{24}, u_{25}\} = \{Channel\ width, Channel\ curvature, Cross\ angel，Obstruction, Navigational\ aids\ condition\}$$

$$u_3 = \{u_{31}, u_{32}, u_{33}\} = \{Traffic\ density, \text{Tanker}\ proportion, Oil\ throughout\}$$

### 5.1.2 Determination of assessment level

An assessment set is a set of evaluation results that may be made by the evaluation object. The objective is to provide Dalian Port sea area an oil spill risk evaluation, with an index of risk, safety, description of the degree of the danger, and how to describe the risk degree. According to the foreign scholars' subjective evaluations of the oil spill risk degree value and operating pressure value of the ship environment related research, and our scholar related research results, the risk assessment standard is divided into five grades: low risk, lower risk, general risk, higher risk and high risk. Then the assessment set can be expressed as follows:

$$V = \{v_1, v_2, v_3, v_4, v_5\} = \{low\ risk, lower\ risk, general\ risk, higher\ risk, high\ \text{risk}\}$$

## 5.2 Determination of membership function of Dalian Port oil spill risk assessment index

Fuzzy mathematics is a mathematical theory and method to study and deal with the phenomenon of fuzziness. The key point is to seek the appropriate mathematical language to describe the fuzziness. Therefore, the membership functions of the identified is a basic problem of fuzzy mathematics in the application. And for the comprehensive assessment of the system or object, the membership function is based on the establishment of evaluation index membership degree of fuzzy relation matrix, which is equivalent to a fuzzy converter. Once the input is determined, it becomes the key to determining the output of the comprehensive evaluation results.

This paper is on Dalian port sea water area oil spill risk fuzzy comprehensive assessment. The factor set and assessment level has been identified above, so under this premise, impact assessment results depend on the determination of membership function. In the forth chapter of this paper, the indexes are discussed in detail about the effect of oil spill risk, and divided into five levels. According to the conclusion, this paper adopts the membership function type of the L semi-trapezoid distribution function, the Lower semi-trapezoid distribution function and the trapezoidal distribution, and determines the membership function of each evaluation index to the level of risk.

### 5.2.1 Visibility

According to the evaluation criteria for the visibility, the risk of visibility membership function formula is shown as follows. The function of the image is shown in figure 5.1:

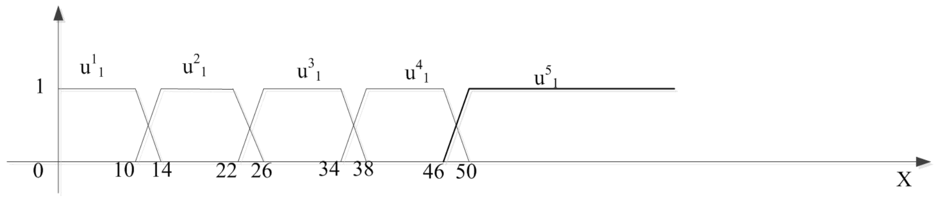



**Figure 5.1: The membership function of the visibility**

**Table 5.1:Membership function formula of the visibility**

| | |
|---|---|
| $u_1^1(x)=\begin{cases}1 & x\le 10\\ -\frac{1}{4}x+\frac{7}{2} & 10<x\le 14\\ 0 & x>14\end{cases}$ | $u_1^2(x)=\begin{cases}0 & x\le 10\ \&\ x>26\\ \frac{x}{4}-\frac{5}{2} & 10<x\le 14\\ 1 & 14<x\le 22\\ -\frac{x}{4}+\frac{13}{2} & 22<x\le 26\end{cases}$ |
| $u_1^3(x)=\begin{cases}0 & x\le 22\ \&\ x>38\\ \frac{x}{4}-\frac{11}{2} & 22<x\le 26\\ 1 & 26<x\le 34\\ -\frac{x}{4}+\frac{19}{2} & 34<x\le 38\end{cases}$ | $u_1^4(x)=\begin{cases}0 & x\le 34\\ \frac{x}{4}-\frac{17}{2} & 34<x\le 38\\ 1 & 38<x\le 46\\ -\frac{x}{4}+\frac{25}{2} & 46<x\le 50\end{cases}$ |

| | |
|---|---|
| $u_1^5(x)=\begin{cases}0 & x\le 46\\ \frac{x}{4}-\frac{23}{2} & 46<x\le 50\\ 1 & x>50\end{cases}$ | |

### 5.2.2 Wind

According to the evaluation criteria for the wind, the risk of wind membership function formula is shown as follows, and the function of the image is shown in figure 5.2:

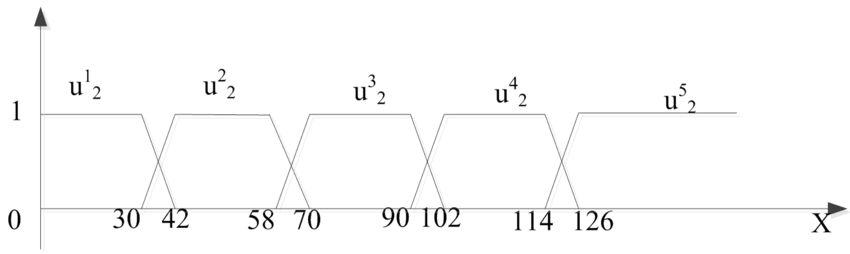



**Figure 5.2: The membership function of the wind**

**Table 5.2:Membership function formula of the wind**

| | |
|---|---|
| $u_2^1(x)=\begin{cases}1 & x\le 30\\ -\frac{x}{12}+\frac{7}{2} & 30<x\le 42\\ 0 & x>42\end{cases}$ | $u_2^2(x)=\begin{cases}0 & x\le 30\ \&\ x>70\\ \frac{x}{12}-\frac{5}{2} & 30<x\le 42\\ 1 & 42<x\le 58\\ -\frac{x}{12}+\frac{35}{6} & 58<x\le 70\end{cases}$ |
| $u_2^3(x)=\begin{cases}0 & x\le 58\ \&\ x>102\\ \frac{x}{12}-\frac{29}{6} & 58<x\le 70\\ 1 & 70<x\le 90\\ -\frac{x}{12}+\frac{51}{6} & 90<x\le 102\end{cases}$ | $u_2^4(x)=\begin{cases}0 & x\le 90\ \&\ x>126\\ \frac{x}{12}-\frac{15}{2} & 90<x\le 102\\ 1 & 102<x\le 114\\ -\frac{x}{12}+\frac{21}{2} & 114<x\le 126\end{cases}$ |

| | |
|---|---|
| $u_2^5(x)=\begin{cases}0 & x\le 114\\ \frac{x}{12}-\frac{19}{2} & 114<x\le 126\\ 1 & x>126\end{cases}$ | |

### 5.2.3 Current

According to the evaluation criteria for the current, the risk of current membership function formula is shown as follows, and the function of the image is shown in figure 5.3:

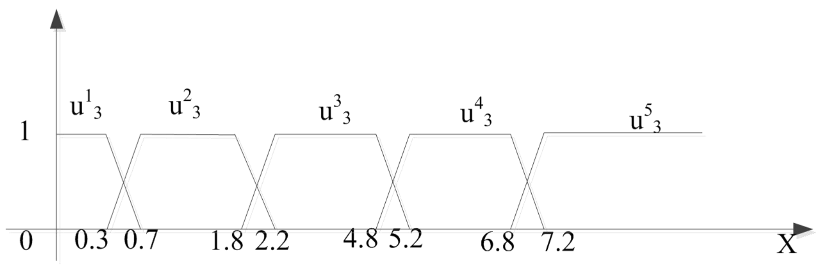



**Figure 5.3: The membership function of the current**

**Table 5.3:Membership function formula of the current**

| | |
|---|---|
| $u_3^1(x)=\begin{cases}1 & x\le 0.3\\ -\frac{5}{2}x+\frac{7}{4} & 0.3<x\le 0.7\\ 0 & x>0.7\end{cases}$ | $u_3^2(x)=\begin{cases}0 & x\le 0.3\ \&\ x>2.2\\ \frac{5}{2}x-\frac{3}{4} & 0.3<x\le 0.7\\ 1 & 0.7<x\le 1.8\\ -\frac{5}{2}x+\frac{11}{2} & 1.8<x\le 2.2\end{cases}$ |

| | |
|---|---|
| $u_3^3(x)=\begin{cases}0 & x\le 1.8\ \&\ x>5.2\\ \frac{5}{2}x-\frac{9}{2} & 1.8<x\le 2.2\\ 1 & 2.2<x\le 4.8\\ -\frac{5}{2}x+13 & 4.8<x\le 5.2\end{cases}$ | $u_3^4(x)=\begin{cases}0 & x\le 4.8\ \&\ x>7.2\\ \frac{5}{2}x-12 & 4.8<x\le 5.2\\ 1 & 5.2<x\le 6.8\\ -\frac{5}{2}x+18 & 6.8<x\le 7.2\end{cases}$ |
| $u_3^5(x)=\begin{cases}0 & x\le 6.8\\ \frac{5}{2}x-17 & 6.8<x\le 7.2\\ 1 & x>7.2\end{cases}$ | |

### 5.2.4 Channel width

According to the evaluation criteria for the channel width, the risk of channel width membership function formula is shown as follows, and the function of the image is shown in figure 5.4:

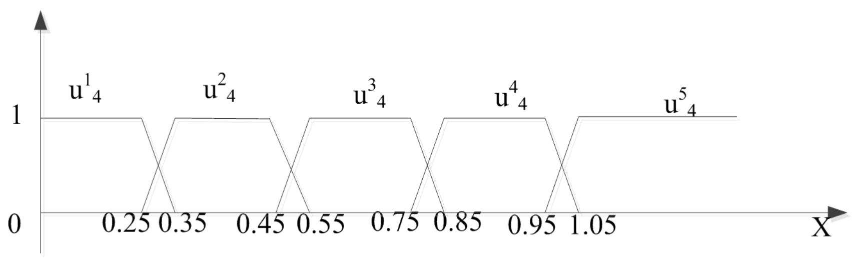



**Figure 5.4: The membership function of the channel width**

**Table 5.4:Membership function formula of the width**

| | |
|---|---|
| $u_4^1(x)=\begin{cases}1 & x\le 0.25\\ -10x+\frac{7}{2} & 0.25<x\le 0.35\\ 0 & x>0.35\end{cases}$ | $u_4^2(x)=\begin{cases}0 & x\le 0.25\ \&\ x>0.55\\ 10x-\frac{5}{2} & 0.25<x\le 0.35\\ 1 & 0.35<x\le 0.45\\ -10x+\frac{11}{2} & 0.45<x\le 0.55\end{cases}$ |
| $u_4^3(x)=\begin{cases}0 & x\le 0.45\ \&\ x>0.85\\ 10x-\frac{9}{2} & 0.45<x\le 0.55\\ 1 & 0.55<x\le 0.75\\ -10x+\frac{17}{2} & 0.75<x\le 0.85\end{cases}$ | $u_4^4(x)=\begin{cases}0 & x\le 0.75\ \&\ x>1.05\\ 10x-\frac{15}{2} & 0.75<x\le 0.85\\ 1 & 0.85<x\le 0.95\\ -10x+\frac{21}{2} & 0.95<x\le 1.05\end{cases}$ |
| $u_4^5(x)=\begin{cases}0 & x\le 0.95\\ 10x-\frac{19}{2} & 0.95<x\le 1.05\\ 1 & x>1.05\end{cases}$ | |

### 5.2.5 Channel Curvature

According to the evaluation criteria for the channel curvature, the risk of channel curvature membership function formula is shown as follows, and the function of the image is shown in figure 5.5:

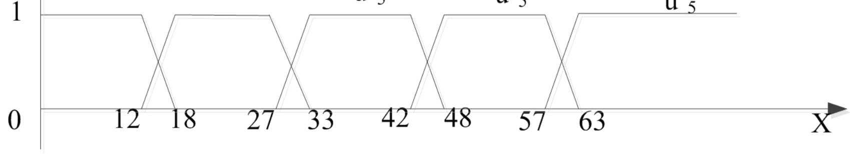



**Figure 5.5:The membership function of the channel curvature**

**Table 5.5:Membership function formula of the channel curvature**

| | |
|---|---|
| $u_5^1(x)=\begin{cases}1 & x\le 12\\ -\frac{1}{6}x+3 & 12<x\le 18\\ 0 & x>18\end{cases}$ | $u_5^2(x)=\begin{cases}\frac{1}{6}x-2 & 12<x\le 18\\ 1 & 18<x\le 27\\ -\frac{x}{6}+\frac{33}{6} & 27<x\le 33\\ 0 & x>33\ \&\ x\le 12\end{cases}$ |
| $u_5^3(x)=\begin{cases}\frac{x}{6}-\frac{9}{2} & 27<x\le 33\\ 1 & 33<x\le 42\\ -\frac{x}{6}+8 & 42<x\le 48\\ 0 & x>48\ \&\ x\le 27\end{cases}$ | $u_5^4(x)=\begin{cases}\frac{x}{6}-7 & 42<x\le 48\\ 1 & 48<x\le 57\\ -\frac{x}{6}+\frac{21}{2} & 57<x\le 63\\ 0 & x>63\ \&\ x\le 42\end{cases}$ |
| $u_5^5(x)=\begin{cases}0 & x\le 57\\ \frac{x}{6}-\frac{19}{2} & 57<x\le 63\\ 1 & x>63\end{cases}$ | |

### 5.2.6 Cross Angle

According to the evaluation criteria for the channel cross angle, the risk of channel cross angle membership function formula is shown as follows, and the function of the image isshown in figure 5.6:

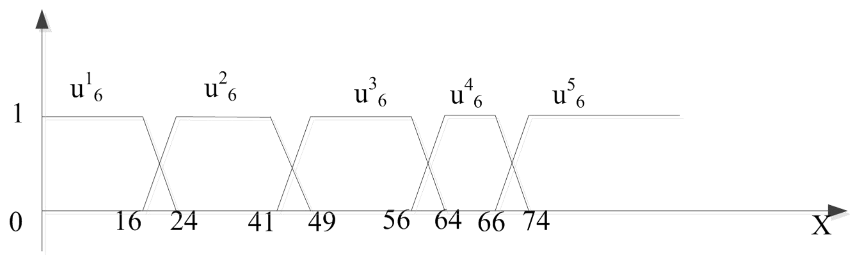



**Figure 5.6: The membership function of the cross angle**

**Table 5.6:Membership function formula of the cross angle**

| | |
|---|---|
| $u_6^1(x)=\begin{cases}1 & x\le 16\\ -\frac{x}{8}+3 & 16<x\le 24\\ 0 & x>24\end{cases}$ | $u_6^2(x)=\begin{cases}0 & x\le 16\ \&\ x>49\\ \frac{x}{8}-2 & 16<x\le 24\\ 1 & 24<x\le 41\\ -\frac{x}{8}+\frac{49}{8} & 41<x\le 49\end{cases}$ |
| $u_6^3(x)=\begin{cases}0 & x\le 41\ \&\ x>64\\ \frac{x}{8}-\frac{41}{8} & 41<x\le 49\\ 1 & 49<x\le 56\\ -\frac{x}{8}+8 & 56<x\le 64\end{cases}$ | $u_6^4(x)=\begin{cases}0 & x\le 56\ \&\ x>74\\ \frac{x}{8}-7 & 56<x\le 64\\ 1 & 64<x\le 66\\ -\frac{x}{8}+\frac{37}{4} & 66<x\le 74\end{cases}$ |
| $u_6^5(x)=\begin{cases}0 & x\le 66\\ \frac{x}{8}-\frac{33}{4} & 66<x\le 74\\ 1 & x>74\end{cases}$ | |

### 5.2.7 Obstruction

According to the evaluation criteria for the channel obstacle, the risk of channel obstacle membership function formula is shown as follows, and the function of the image is shown in figure 5.7:

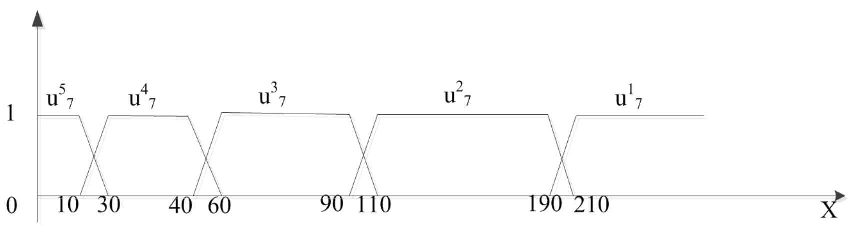



**Figure 5.7: The membership function of the obstruction**

**Table 5.7:Membership function formula of the obstruction**

| | |
|---|---|
| $u_7^1(x)=\begin{cases}0 & x\le 190\\ \frac{1}{20}x-\frac{19}{2} & 190<x\le 210\\ 1 & x>210\end{cases}$ | $u_7^2(x)=\begin{cases}0 & x\le 90\ \&\ x>210\\ \frac{1}{20}x-\frac{9}{2} & 90<x\le 110\\ 1 & 110<x\le 190\\ -\frac{x}{20}+\frac{21}{2} & 190<x\le 210\end{cases}$ |
| $u_7^3(x)=\begin{cases}0 & x\le 40\ \&\ x>110\\ \frac{x}{20}-2 & 40<x\le 60\\ 1 & 60<x\le 90\\ -\frac{x}{20}+\frac{11}{2} & 90<x\le 110\end{cases}$ | $u_7^4(x)=\begin{cases}0 & x\le 10\ \&\ x>60\\ \frac{x}{20}-0.5 & 10<x\le 30\\ 1 & 30<x\le 40\\ -\frac{x}{20}+3 & 40<x\le 60\end{cases}$ |
| $u_7^5(x)=\begin{cases}1 & x\le 10\\ -\frac{x}{20}+\frac{3}{2} & 10<x\le 30\\ 0 & x>30\end{cases}$ | |

### 5.2.8 Navigational aids condition

According to the evaluation criteria for the navigational aids condition, the risk of navigational aids condition membership function formula is shown as follows, and the function of the image is shown in figure 5.8:

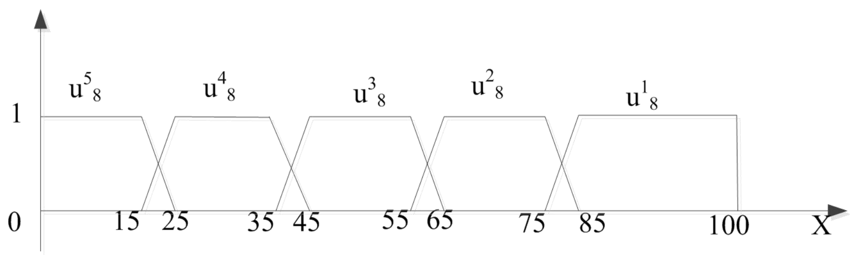



**Figure 5.8: The membership function of the navigational aids condition**

**Table 5.8:Membership function formula of the navigational aids condition**

| | |
|---|---|
| $u_8^1(x)=\begin{cases}0 & x\le 75\\ \frac{x}{10}-7.5 & 75<x\le 85\\ 1 & 85<x\le 100\end{cases}$ | $u_8^2(x)=\begin{cases}0 & x\le 55\ \&\ x>75\\ \frac{x}{10}-5.5 & 55<x\le 65\\ 1 & 65<x\le 75\\ -\frac{x}{10}+8.5 & 75<x\le 85\end{cases}$ |
| $u_8^3(x)=\begin{cases}0 & x\le 35\ \&\ x>65\\ \frac{x}{10}-3.5 & 35<x\le 45\\ 1 & 45<x\le 55\\ -\frac{x}{10}+6.5 & 55<x\le 65\end{cases}$ | $u_8^3(x)=\begin{cases}0 & x\le 35\ \&\ x>65\\ \frac{x}{10}-3.5 & 35<x\le 45\\ 1 & 45<x\le 55\\ -\frac{x}{10}+6.5 & 55<x\le 65\end{cases}$ |
| $u_8^5(x)=\begin{cases}1 & x\le 15\\ -\frac{x}{10}+2.5 & 15<x\le 25\\ 0 & x>25\end{cases}$ | |

**5.2.9 Traffic Density**

According to the evaluation criteria for traffic density, the risk of traffic density membership function formula is shown as follows, and the function of the image is shown in figure 5.9:

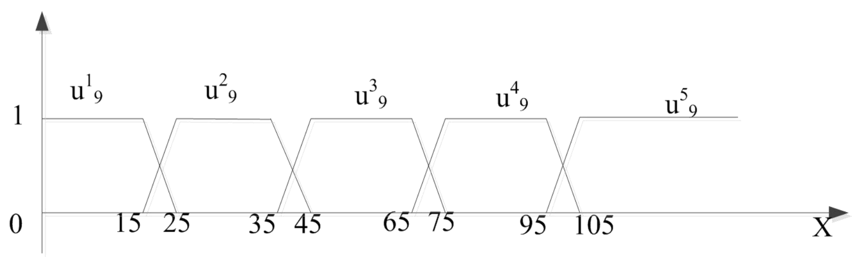



**Figure 5.9: The membership function of the traffic density**

**Table 5.9:Membership function formula of the traffic density**

| | |
|---|---|
| $u_9^1(x)=\begin{cases}1 & x\le 15\\ -\frac{x}{10}+2.5 & 15<x\le 25\\ 0 & x>25\end{cases}$ | $u_9^2=\begin{cases}0 & x\le 15\ \&\ x>45\\ \frac{x}{10}-1.5 & 15<x\le 25\\ 1 & 25<x\le 35\\ -\frac{x}{10}+4.5 & 35<x\le 45\end{cases}$ |
| $u_9^3(x)=\begin{cases}0 & x\le 35\ \&\ x>75\\ \frac{x}{10}-3.5 & 35<x\le 45\\ 1 & 45<x\le 65\\ -\frac{x}{10}+7.5 & 65<x\le 75\end{cases}$ | $u_9^4(x)=\begin{cases}0 & x\le 65\ \&\ x>105\\ \frac{x}{10}-6.5 & 65<x\le 75\\ 1 & 75<x\le 95\\ -\frac{x}{10}+10.5 & 95<x\le 105\end{cases}$ |
| $u_9^5(x)=\begin{cases}0 & x\le 95\\ \frac{x}{10}-9.5 & 95<x\le 105\\ 1 & x>105\end{cases}$ | |

### 5.2.10 Tanker proportion

According to the evaluation criteria for tanker proportion, the risk of tanker proportion membership function formula is shown as follows, and the function of the image is shown in figure 5.10:

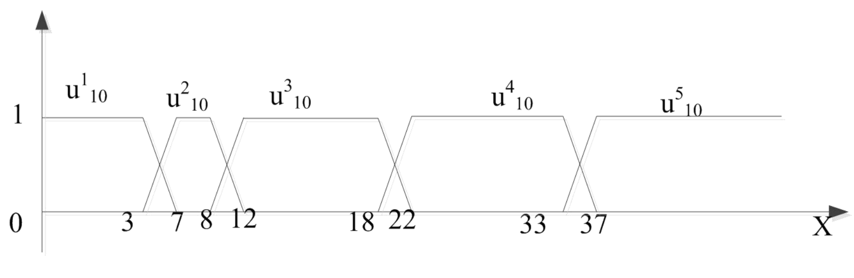



**Figure 5.10:The membership function of the tanker proportion**

**Table 5.10:Membership function formula of the tanker proportion**

| | |
|---|---|
| $u_{10}^{1}(x)=\begin{cases}1 & x\le 3\\ -\frac{x}{4}+\frac{7}{4} & 3<x\le 7\\ 0 & x>7\end{cases}$ | $u_{10}^{2}(x)=\begin{cases}0 & x\le 3\ \&\ x>12\\ \frac{x}{4}-\frac{3}{4} & 3<x\le 7\\ 1 & 7<x\le 8\\ -\frac{x}{4}+3 & 8<x\le 12\end{cases}$ |
| $u_{10}^{3}(x)=\begin{cases}0 & x\le 8\ \&\ x>22\\ \frac{x}{4}-2 & 8<x\le 12\\ 1 & 12<x\le 18\\ -\frac{x}{4}+\frac{11}{2} & 18<x\le 22\end{cases}$ | $u_{10}^{4}(x)=\begin{cases}0 & x\le 18\ \&\ x>37\\ \frac{x}{4}-\frac{9}{2} & 18<x\le 22\\ 1 & 22<x\le 33\\ -\frac{x}{4}+\frac{37}{4} & 33<x\le 37\end{cases}$ |
| $u_{10}^{5}(x)=\begin{cases}0 & x\le 33\\ \frac{x}{4}-\frac{33}{4} & 33<x\le 37\\ 1 & x>37\end{cases}$ | |

### 5.2.11 Oil throughout

According to the evaluation criteria for oil throughout, the risk of oil throughout membership function formula is shown as follows, and the function of the image is shown in figure 5.11:

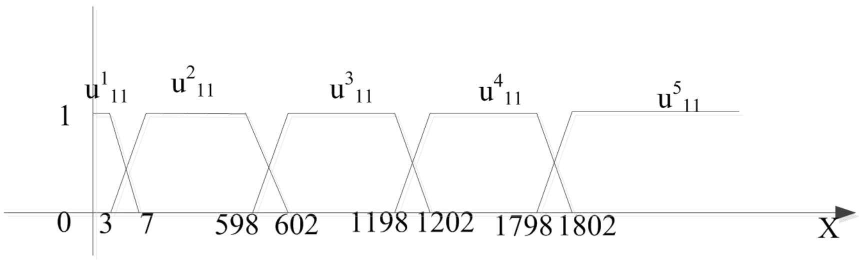



**Figure 5.11:The membership function of the oil throughout**

**Table 5.11:Membership function formula of the oil throughout**

| | |
|---|---|
| $u_{11}^{1}(x)=\begin{cases}1 & x\le 3\\ -\frac{x}{4}+\frac{7}{4} & 3<x\le 7\\ 0 & x>7\end{cases}$ | $u_{11}^{2}(x)=\begin{cases}0 & x\le 3\ \&\ x>602\\ \frac{x}{4}-\frac{3}{4} & 3<x\le 7\\ 1 & 7<x\le 598\\ -\frac{x}{4}+\frac{602}{4} & 598<x\le 602\end{cases}$ |
| $u_{11}^{3}(x)=\begin{cases}0 & x\le 598\ \&\ x>1202\\ \frac{x}{4}-\frac{598}{4} & 598<x\le 602\\ 1 & 602<x\le 1198\\ -\frac{x}{4}+\frac{1202}{4} & 1198<x\le 1202\end{cases}$ | $u_{11}^{4}(x)=\begin{cases}0 & x\le 1198\ \&\ x>1802\\ \frac{x}{4}-\frac{1198}{4} & 1198<x\le 1202\\ 1 & 1202<x\le 1798\\ -\frac{x}{4}+\frac{1802}{4} & 1798<x\le 1802\end{cases}$ |
| $u_{11}^{5}(x)=\begin{cases}0 & x\le 1798\\ \frac{x}{4}-\frac{1798}{4} & 1798<x\le 1802\\ 1 & x>1802\end{cases}$ | |

**5.3 Determination of weight set of Dalian Port oil spill risk assessment index**

Weight is the degrees of importance of the various factors in the evaluation system and the weight in this paper is referred to as the navigation environment factors of oil spill risk take the important degree in the oil tanker navigation. Therefore, the weight has the relative significance.

At the same time, the weight coefficient is very important for comprehensive evaluation system, which can directly affect the results of comprehensive evaluation. In this paper, the current domestic shipping safety evaluation studies are analyzed, based on the summary of the appropriate adjustments. Ultimately, the Dalian Port oil spill risk assessment index of the weight set is determined as follows:

The weight of the first layer is:

$$W^{(1)} = (0.244 \ \ 0.320 \ \ 0.436)$$

The weight of natural condition in the second layer is:

$$W_1^{(2)} = (0.506 \ \ 0.193 \ \ 0.301)$$

The weight of channel condition in the second layer is:

$$W_2^{(2)} = (0.442 \ \ 0.158 \ \ 0.162 \ \ 0.115 \ \ 0.123)$$

The weight of traffic flow condition in the second layer is:

$$W_3^{(2)} = (0.420 \ \ 0.387 \ \ 0.193)$$

**5.4 Establishment of oil spill risk assessment model in Dalian Port sea area**

The fourth chapter has summarized the factors system of evaluating the risk of oil spill in the sea area of Dalian Port, which can be seen in the two level evaluations.

The first layer: by the natural conditions $u_1$ of the three factors $u_{11}$, $u_{12}$ and $u_{13}$, we can evaluate the natural conditions of the comprehensive evaluation of the safety of the vector $B_1$; by the channel conditions $u_2$ of the five factors $u_{21}$, $u_{22}$, $u_{23}$, $u_{24}$ and $u_{25}$, we can evaluate the channel condition of the comprehensive evaluation of the safety of the vector $B_2$; by the traffic flow $u_3$ of the three factors $u_{31}$, $u_{32}$ and $u_{33}$, we can evaluate the traffic flow of the comprehensive evaluation of the safety of the vector $B_3$

The second layer: the comprehensive evaluation of the comprehensive evaluation vector $B$ by the above three evaluation vectors.

Comprehensive evaluation based on the steps of ??? :

The first layer evaluation: for the natural conditions, the natural conditions of the port channel parameters are substituted into their membership function determine the membership degree, so the formation of single factor evaluation matrix, and have determined the weights of the factors can be matrix operation evaluation vector $B_1$ of natural conditions. $B_1$ and other factors, which are tied together with the natural conditions, and continue to participate in the evaluation of the next layer.

$$\underset{\sim}{B_1} = \underset{\sim}{W_1}^{(2)} \circ \underset{\sim}{R_1} = (w_{11}\ w_{12}\ w_{13}) \circ \begin{bmatrix} r_{111} & r_{112} & r_{113} & r_{114} & r_{115} \\ r_{121} & r_{122} & r_{123} & \mathrm{r}_{124} & r_{125} \\ r_{131} & r_{132} & r_{133} & r_{134} & r_{135} \end{bmatrix}$$

That is:

$$\underset{\sim}{B_1} = (0.506\ \ 0.193\ \ 0.301) \circ \begin{bmatrix} r_{111} & r_{112} & r_{113} & r_{114} & r_{115} \\ r_{121} & r_{122} & r_{123} & r_{124} & r_{125} \\ r_{131} & r_{132} & r_{133} & r_{134} & r_{135} \end{bmatrix}$$

In the same way, the evaluation vector of channel condition $B_2$ can be obtained:

$$\underset{\sim}{B_2} = \underset{\sim}{W_2}^{(2)} \circ \underset{\sim}{R_2} = (w_{21}\ \ w_{22}\ w_{23}\ w_{24}\ w_{25}) \circ \begin{bmatrix} r_{211} & r_{212} & r_{213} & r_{214} & r_{215} \\ r_{221} & r_{222} & r_{223} & r_{224} & r_{225} \\ r_{231} & r_{232} & r_{233} & r_{234} & r_{235} \\ r_{241} & r_{242} & r_{243} & r_{244} & r_{245} \\ r_{251} & r_{252} & r_{253} & r_{254} & r_{255} \end{bmatrix}$$

$$\underset{\sim}{B_2} = \underset{\sim}{W_2}^{(2)} \circ \underset{\sim}{R_2} = (0.442\ \ 0.158\ \ 0.162\ \ 0.115\ \ 0.123) \circ \begin{bmatrix} r_{211} & r_{212} & r_{213} & r_{214} & r_{215} \\ r_{221} & r_{222} & r_{223} & r_{224} & r_{225} \\ r_{231} & r_{232} & r_{233} & r_{234} & r_{235} \\ r_{241} & r_{242} & r_{243} & r_{244} & r_{245} \\ r_{251} & r_{252} & r_{253} & r_{254} & r_{255} \end{bmatrix}$$

Then the evaluation vector of traffic flow $B_3$ can be obtained:

$$\underset{\sim}{B_3} = \underset{\sim}{W_3}^{(2)} \circ \underset{\sim}{R_3} = (w_{31}\ \ w_{32}\ w_{33}) \circ \begin{bmatrix} r_{311} & r_{312} & r_{313} & r_{314} & r_{315} \\ r_{321} & r_{322} & r_{323} & r_{324} & r_{325} \\ r_{331} & r_{332} & r_{333} & r_{334} & r_{335} \end{bmatrix}$$

$$\tilde{B}_3 = \tilde{W}_3^{(2)} \circ \tilde{R}_3 = (0.420\ \ 0.387\ 0.193) \circ \begin{bmatrix} r_{311} & r_{312} & r_{313} & r_{314} & r_{315} \\ r_{321} & r_{322} & r_{323} & r_{324} & r_{325} \\ r_{331} & r_{332} & r_{333} & r_{334} & r_{335} \end{bmatrix}$$

So the results of the two level evaluation can get the final evaluation vector B:

$$\tilde{B} = \tilde{W}^{(1)} \circ \tilde{R} = (w_1\ \ w_2\ w_3) \circ \begin{bmatrix} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \end{bmatrix} = (0.244\ \ 0.320\ \ 0.436) \circ \begin{bmatrix} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \end{bmatrix}$$

For the results of fuzzy comprehensive evaluation is a fuzzy vector, that is, the evaluation object belongs to each evaluation grade of membership vector $b_j$ (j=1,2,⋯, n), defuzzification is adopted to determine the final results of the evaluation, that is, to determine the evaluation object level when the vector is in precision. Usually, the method has the maximum membership degree method and the weighted average method (gravity method). Because the latter is more accurate than the former, this paper chooses the weighted average method to carry on the following calculation.

$$V = \frac{\sum_{j=1}^{n} b_j v_j}{\sum_{j=1}^{n} b_j}$$

If the $\sum_{j=1}^{n} b_j = 1$, so the $V = \sum_{j=1}^{n} b_j v_j$.

The resulting value is the level of the risk status of the Dalian Port sea area. This evaluation method takes into account the contribution of each element of the fuzzy subset, which can reflect the exact value of the whole fuzzy vector information.

## 5.5 Calculation of the risk assessment of oil spill in Dalian Port sea area

### 5.5.1 Hydrology and meteorology of Dalian Port sea area

#### 5.5.1.1 Tide

Tide of Dalian Port sea area belongs to the semidiurnal and irregular semidiurnal mixed tide, with the wind effect, the average tidal range is 2.1 meters. The maximum tidal range in the Dalian bay port area is approximately 3.9 meters. The average tidal epoch is 10 hours and 12 minutes when the spring rise 2.91 meters, 2.33 meters neap rise, mean sea level 1.63 meters. For Dalian Xingang port area and Dalian Dayaowan port area, the average tidal epoch is 10 hours and 2 minutes when the spring rises 3.3 meters, 2.6 meters neap rise, the mean sea level is 1.9 meters.

#### 5.5.1.2 Surge

In the Gulf of Dalian, there is generally little swell. When typhoon affects this area, the swell to southeast is a little larger. For Xingang port area, there are most waves to the south-southeast and the second is the waves to southeast. With the east or northeast wind, the waves could reach 3-5 meters.

#### 5.5.1.3 Wind

Every October to next March, there is mostly north and northwest wind; from April to August, there is mostly south and southeast wind. September is the wind conversion time, with north and northwest wind and southerly winds appearing alternately. In winter, the wind is heavy and the gust is very terrible. Sometimes the heavy wind is larger than grade 6, which could last more than three days. There are approximately 10 strong wind days in winter, and the wind is generally at the level of 6-8, sometimes 9-10. In summer, the wind is weak, with 4-5 strong wind days per month, and the wind is generally only 6 in scale.

### 5.5.1.4 Fog

Annually, Dalian Port has an average of 36 fog days. Though the fog appears in the whole year, yet it mostly occurred from March to August, especially in June and July. In June and July, there are on average 5-9 fog days monthly, even up to 17 days. In March, April, May and August, the average monthly fog days are 3-4 days, and in the rest of the year, the average fog days are 1-2 days monthly. The duration of the fog in June and July are generally 2-3 days, the most extreme condition the fog could continue for one week and the rest of the other month is only 1 day, but sometimes in March, it will also continue for a long time.

### 5.5.1.5 Visibility

The number of days when the visibility of Dalian Port is less than 1000 meters are on average about 40. And in July, the number is the largest, for about 14; while in October, there is almost none. The days of visibility which is less than 4,000 meters are on average 48. Also in July, the number of these days are the largest, for 15 days, while in October, there are few.

### 5.5.1.6 Ice condition

Dalian port is an ice-free harbor. But every year at the beginning of January and February, part of the pier area would have icing phenomenon, with thickness of 5-20 cm. The ship with steel hull could navigate without any difficulty. Freezing range is from north breakwater of the Dagang Port to the western of Haimao Island. And the Choushuitao sea area and Heizuizi sea area is the most serous, and the ice thickness is about 15-20cm, which may affect the small ship berthing the Heizuizi Port.

### 5.5.2 Channel condition of Dalian Port

Dalian port has three kinds of channels, the main channel, the sub channel and the special channel. In this paper, the main channel that is used by the tanker will be introduced.

The main channel includes Dagang port channel, Ganjingzi channel, Xianglujiao channel, Heshang Island channel, Xingang port channel, Dayaowan channel, Beiliang channel and COSCO channel.

The Dagang port channel is located on the east of Dagang port East District with N0.1 to No.4 buoy. The channel is from the north of Huangbaizui to the east gate of the Dagang port East District, which is approximately 2.6nm long , about 363.6m wide, and the depth is above 10m. At the end of the breakwater in Dagang port east district, there are two light beacons. The channel is muddy bottom channel.

Ganjingzi channel is located on the north of the Dagang port area, which is equipped with H3, H5, H7, H9 (on the right side) and H4, H6, H8 (on the left side). Located from H3 buoy to the south of Ganjingzi port area, the channel's direction is from 270° -090 °, 2.6nm long, 180m wide. From H2 buoy to the H1 buoy, the depth is 11m, the depth of west part is 8.6m, with a muddy bottom.

Xianglujiao channel is located from the west of Ganjingzi channel to Xianglujiao port area. On the both sides of the channel, the buoys are provided, and the H11 buoy is equipped on the northeast. The channel's direction is from 227°-047°, about 1.4nm long, 150m wide, 8.5m deep.

The Heshangdao channel is located on the north of H2, and the channel is equipped with No.10 to No.20 buoy, of which 7 are on the right side and 4 on the left. From No.11 buoy to the harbor, it is about 2.2 miles long, between No11-No15 buoy the channel direction is from 351°-171°,between No 15 to No 18, the direction is from 330°-150°, 9.5m depth. From No 13 to the harbor, the channel is a dredging channel, which is 130 meters wide.

Xingang port channel is located on the Nianyuwan port area, of which the No 1 to No 3 buoy is equipped on the entrance of the channel. The length from No 1 buoy to oil dock is approximately 8.5nm, and the width is about 350m, rock bottom. From the entrance to the waterway tanker anchorage for natural waterway, it is 7000 m long.

Dayaowan channel is located in Dayaowan port area, with 9 buoys from No 29 to No 37. In these buoys, No 29 and No 31 are on the left side and the others are on the right side. The channel is about 1650m long, 210 wide, 13.5 deep. The fairway from the entrance of the channel to the Dayaowan anchorage is the navigation waterway, about 4.5nm.

Beiliang channel is located in Beiliang port area, 1600m long, 250m width, channel depth of 13.3 meters, which is equipped with 8 channel buoys.

COSCO channel is located between COSCO Shipping yard and deepwater oil dock, which is more than 4600m long, 220 meters wide, and 6 meters deep, with 9 buoys.

### 5.5.3 Traffic flow

#### 5.5.3.1 Traffic density

Dalian Port has a huge cargo-handling capacity which ranks 11th in the world. Meanwhile, Dalian Port has a large traffic flow. In the traffic flow, there are all kinds of ships, including tanker, container, bulk, passenger ship, chemical tanker, etc. And these ships are of different sizes, not only VLCC and MSC Oscar with 19,224 TEU, but also small ships with 200 GT. All these ships constitute the traffic flow in Dalian Port sea area. Statistics were made on the number of the ships which import and export Dalian port between 2013 to 2015 by the Liaoning MSA office automatically. The table 5.12 shows the number of the traffic volume in the Dalian Port sea area.

**Table 5.12: The statistics of the import and export ship**

| | Arrival Number | Departure Number | Total |
|---|---|---|---|
| 2015 | 31348 | 31366 | 62714 |
| 2014 | 30284 | 30352 | 60636 |
| 2013 | 31036 | 31074 | 62110 |
| Average | 30889 | 30931 | 61820 |

#### 5.5.3.2 Tanker proportion

The tanker proportion is an important factor in the oil spill assessment. But it is different from the statistical method of traffic density, because the risk source is the cargo crude oil and the empty tanker is not in the assess area. So when the statistics of the tanker volume were made, the results should be half of the volume. The statistics were provided by the Liaoning MSA office automatically. The table 5.13 shows the number of tankers in Dalian Port sea area.

**Table 5.13: Statistics of the tankers in Dalian Port**

| | Tanker number | Tanker with cargo number | Total | Proportion |
|---|---|---|---|---|
| 2015 | 4912 | 2456 | 62714 | 3.92% |

| | | | | |
|---|---|---|---|---|
| 2014 | 6747 | 3373.5 | 60636 | 5.56% |
| 2013 | 6722 | 3361 | 61820 | 5.44% |
| Average | 6127 | 3063.5 | 61723 | 4.97% |

#### 5.5.3.3 Oil throughout

Dalian Port has two ports that can be docked by tanker's unloading operations: Xingang Port and Ganjingzi Port. The two ports use two channels: Xingang port channel and Ganjingzi port channel. And the oil throughout of Xingang port is much larger than that in Ganjingzi port. Author statistics are made by the Liaoning MSA office automatically. The table 5.14 shows the oil throughout from 2013 to 2015:.

**Table 5.14: Oil throughout in Dalian port**

| | Xingang port | Ganjinzi port | total |
|---|---|---|---|
| 2015 | 25291408(t) | 2137830(t) | 27429237(t) |
| 2014 | 23417970(t) | 1979472(t) | 25397442(t) |
| 2013 | 20607136(t) | 1570173(t) | 22177559(t) |
| Average | 23105505(t) | 1895825(t) | 25001413(t) |

### 5.5.4 Calculation of oil spill risk assessment model

As is mentioned above, the natural condition of Dalian Port hydrology, the channel condition and the general situation of the traffic flow are introduced, then the level of the oil spill risk is identified, which involves a comprehensive evaluation. Only a comprehensive evaluation can provide the policy-making basis for the future. In this chapter, we have established a good mathematical model to evaluate the risk of oil spill in Dalian Port, and the reliability and practicability of the model have to be further determined.

Through the investigation, evaluate and collate the relevant information on the waters of Dalian Port, the data are obtained with the evaluation criteria, which is shown in the table 5.15.

**Table 5.15: Dalian Port oil spill risk assessment data**

| Factor | Visibility | Wind | Current | Channel Width | Channel Curvature | Cross Angle | Obstruction | Navigational aids condition | Traffic Density | Tanker Proportion | Oil Throughout |
|---|---|---|---|---|---|---|---|---|---|---|---|
| X value | 42 | 102 | 0. 60 | 0. 2 | 70 | 0 | 200 | 75 | 169 | 4. 97% | 2500 |

Will the real data substitution to 2.2, the corresponding membership functions and membership vector of each evaluation factors are obtained as follows:

$$r_{11} = (r_{111}, r_{112}, r_{113}, r_{114}, r_{115}) = (0, 1, 0, 0, 0)$$

$$r_{12} = (r_{121}, r_{122}, r_{123}, r_{124}, r_{125}) = (0, 0, 0, 1, 0)$$

$$r_{13} = (r_{131}, r_{132}, r_{133}, r_{134}, r_{135}) = (0.25, 0.75, 0, 0, 0)$$

$$r_{21} = (r_{211}, r_{212}, r_{213}, r_{214}, r_{215}) = (1, 0, 0, 0, 0)$$

$$r_{22} = (r_{221}, r_{222}, r_{223}, r_{224}, r_{225}) = (0, 0, 0, 0, 1)$$

$$r_{23} = (r_{231}, r_{232}, r_{233}, r_{234}, r_{235}) = (1, 0, 0, 0, 0)$$

$$r_{24} = (r_{241}, r_{242}, r_{243}, r_{244}, r_{245}) = (0.5, 0.5, 0, 0, 0)$$

$$r_{25} = (r_{251}, r_{252}, r_{253}, r_{254}, r_{255}) = (0, 1, 0, 0, 0)$$

$$r_{31} = (r_{311}, r_{312}, r_{313}, r_{314}, r_{315}) = (0, 0, 0, 0, 1)$$

$$r_{32} = (r_{321}, r_{322}, r_{323}, r_{324}, r_{325}) = (0.508, 0.493, 0, 0, 0)$$

$$r_{33} = (r_{331}, r_{332}, r_{333}, r_{334}, r_{335}) = (0, 0, 0, 0, 1)$$

So the evaluation matrix is as follows：

$$\tilde{R}_1 = \begin{pmatrix} r_{11} \\ r_{12} \\ r_{13} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0.25 & 0.75 & 0 & 0 & 0 \end{pmatrix}$$

$$\tilde{R}_2 = \begin{pmatrix} r_{21} \\ r_{22} \\ r_{23} \\ r_{24} \\ r_{25} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{pmatrix}$$

$$\tilde{R}_3 = \begin{pmatrix} r_{31} \\ r_{32} \\ r_{33} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ 0.508 & 0.493 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

By calculation：

$$\tilde{B}_1 = \begin{pmatrix} 0.506 \\ 0.193 \\ 0.301 \end{pmatrix} \circ \begin{pmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0.25 & 0.75 & 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.075 & 0.226 & 0 & 0.699 & 0 \end{pmatrix}$$

$$\tilde{B}_2 = \begin{pmatrix} 0.442 \\ 0.158 \\ 0.162 \\ 0.115 \\ 0.123 \end{pmatrix} \circ \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.662 & 0.181 & 0 & 0 & 0.158 \end{pmatrix}$$

$$\tilde{B}_3 = \begin{pmatrix} 0.420 \\ 0.387 \\ 0.193 \end{pmatrix} \circ \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ 0.508 & 0.493 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 0.196 & 0.191 & 0 & 0 & 0.420 \end{pmatrix}$$

Accordingly：

$$\tilde{R} = \begin{pmatrix} \tilde{B}_1 \\ \tilde{B}_2 \\ \tilde{B}_3 \end{pmatrix} = \begin{pmatrix} 0.075 & 0.226 & 0 & 0.699 & 0 \\ 0.662 & 0.181 & 0 & 0 & 0.158 \\ 0.196 & 0.191 & 0 & 0 & 0.420 \end{pmatrix}$$

So:

$$\tilde{B} = \begin{pmatrix} 0.244 & 0.320 & 0.436 \end{pmatrix} \circ \begin{pmatrix} 0.075 & 0.226 & 0 & 0.699 & 0 \\ 0.662 & 0.181 & 0 & 0 & 0.158 \\ 0.196 & 0.191 & 0 & 0 & 0.420 \end{pmatrix} = \begin{pmatrix} 0.316 & 0.196 & 0 & 0.171 & 0.234 \end{pmatrix}$$

The above calculation results reflect the fuzzy distribution status of the oil spill risk degree in Dalian Port sea area on the evaluation set V. For the final evaluation results, this paper uses the weighted average method to obtain. In 1, 2, 3, 4, 5, respectively, on behalf of the low to high degree of risk (low risk, lower risk, general risk, higher risk and high risk), the evaluation set V can be expressed as

$$V = (v_1 \quad v_2 \quad v_3 \quad v_4 \quad v_5) = (1 \quad 2 \quad 3 \quad 4 \quad 5)$$

As the evaluation index B has been normalized, so:

$$v = \sum_{j=1}^{m} b_j v_j = 0.316 \times 1 + 0.196 \times 2 + 0 \times 3 + 0.171 \times 4 + 0.234 \times 5 = 2.558$$

By analyzing the above evaluation results, the risk of oil spill in Dalian Port is between lower risk and general risk. This result shows that the oil spill risk in Dalian Port is relatively low, but there are still some risks. The results are consistent with the historical data of Dalian Port. And in fact, there are some oil spill accidents in Dalian Port sea area. In the next chapter, the measures will be given which is used to evaluate the risk of oil spill in Dalian Port.

# Chapter 6

# Recommendation

## 6.1 Human factor control

Human factor is the core of accidents. So the seafarers' eligibility is the key to the ship safety. Improving the seafarer quality is the foundation of seafarer competency. Maritime administration should strictly control the training, examination, assessment and certification. On the other hand, the PSC and SMS audits also should focus on the quality of the seafarers in order to arouse the attention of the ship management companies to the human factor.

As the main body of the management of the crew, the ship company should always carry out professional moral education and strengthen the safety skills training for the crew. Crew management department should give full play to the role of administrative supervision and management, and carry out "safety education", "emergency drill" and other inspections.

The crew management institutions should establish a dynamic management mechanism, and record of the crew work, using the new equipment to reduce the human error such as the improper observation, instead of the use of safety speed. By improving the crew's professional information system, we can effectively improve the professional quality of the crew, so that the ship owners can control crew members more effectively.

### 6.2 Ship control

The administration should enhance the PSC for improving the standards of the ships. Especially for the high risk ships, the PSC should not omit any hidden problem. In addition, the maritime administration needs to establish and perfect the black list mechanism. When the ship on the black list is going to port, the maritime administration should take special actions for preventing accidents. Ship companies should do a good job in the maintenance of the ship, to ensure that the ship is in good condition.

### 6.3 Environment control

It is important to cooperate with the professional meteorological stations and establish communications, receive the weather forecast in time and track changes in the weather trend, and make full use of the existing hydrological and meteorological observation equipment. Close attention should be paid to the area of weather and sea change; summary will be based on the above information, through a comprehensive analysis of the area's meteorological information, VTS issue the navigation warnings and information of sea conditions.

Navigation mark is an important navigation aid facility. Especially in poor weather and bad sea conditions, whether beacon is working properly is very important to the navigation safety. Thus, the administration should collect the information of the navigation mark timely and the navigation mark management department should ensure the navigation mark is in good condition.

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