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Safety evaluation on navigation environment of Xiazhimen Channel based on cloud mode

Pengpeng Ye

WORLD MARITIME UNIVERSITY

Dalian, China

Safety Evaluation on Navigation Environment of Xiazhimen Channel Based on Cloud Model

By

Ye Pengpeng

China

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Declaration

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

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

Signature: Ye Pengpeng

Date: July 18, 2013

Supervised by:

Dr. Zhang Xianku

Professor of Dalian Maritime University

Assessor:

Co-assessor:

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Title: **Safety Evaluation on Navigation Environment of Xiazhimen Channel Based on Cloud Model**

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Abstract

The research paper is a study on the safety of navigation environment of Xiazhimen (XZM) channel by using the synthetical evaluation method based on cloud model. Through that, this paper analyses and evaluates the main hazards and harmful factors existing in navigation environment according to the specific circumstance of XZM channel. After that, find out the risk degree of the channel, so as to provide scientific basis for making preventive measures and management decisions for local maritime authorities.

First of all, a brief overview is taken at the main characteristics of navigation environment of XZM channel and the introduction of natural conditions and traffic environment behind them. After that, the definition of safety evaluation is presented and the advantages and disadvantages of the evaluation methods commonly used in navigation environment domain are discussed. On the basis of that, cloud model, a new synthetical evaluation which can overcome those shortcomings, is introduced and used as the evaluation method of the paper.

During the establishment of cloud model of navigation environment safety evaluation, the evaluation indicator(EI) system is built and the risk criteria are identified based on the relevant materials and expertise. After that, the indicator set and evaluation set are developed and Delphi method is selected to obtain the weights of indicators after their risk value is confirmed. Then it uses the algorithms of cloud model to calculate indicators from low layer to high layer recursively and get the ultimate risk degree of XZM channel. Furthermore, on the basis of that, it takes a brief analysis and puts forward some relevant recommendations to the competent authorities.

The concluding chapter provides some findings and achievements of this thesis, discusses the feasibility of application of the cloud model in the domain of navigation evaluation. Also some improvements and proposals of future work are presented.

KEYWORDS: XZM Channel, Navigation Environment, Safety Evaluation, Cloud Model

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List of Abbreviations

APH	Analytic Hierarchy Process
CAE	Chinese Academy of Engineering
DMU	Dalian Maritime University
EI(s)	Evaluation Indicator(s)
IMO	International Maritime Organization (London)
MB	Meteorological Bureau
MEC	Mathematical Expected Curve
MIS	Management Information System
MSA	Maritime Safety Administration
MSL	Mean Sea Level
NB	Ningbo
NBMB	Meteorological Bureau of Ningbo
NGD	Navigation Guarantee Department of the Chinese Navy Headquarters
NNE	North-Northeast
NNW	North-Northwest
NW	Northwest
SE	Southeast
VLCC	Very Large Crude Carrier
VTS	Vessel Traffic Service
TEU	Twenty-foot Equivalent Unit
XZM	Xiazhimen
ZS	Zhoushan
ZSMB	Meteorological Bureau of Zhoushan

Chapter 1
Introduction

1.1 Background

On January 1, 2006, the name “Ningbo-Zhoushan Port” (NB-ZS Port) was officially adopted. In 2011, annual cargo throughput of “NB-ZS Port” had reached 690 million tons and ranked as the largest port in the world. Among them, the annual throughput of container in 2006 was 1,375 million TEUs and had achieved 2,661 TEUs in 2011, which occupied the sixth in the world. Further more, in bulk commodity transportation; NB-ZS Port also plays a dominant role. The percentage of the amount of coal, crude oil, iron ore, grain imported by this port accounted for Yangtze River Delta region’s foreign trade at 24%, 100%, 59%, 25%, respectively(Wang, 2013, p.38).

XZM channel, as the portal of NB - ZS Port, is also the shortcut for large ship especially oil tanker for its good environmental conditions, especially in the aspects of less reefs, straight shoreline, deep water, etc. The artificial deepwater channel of navigating ships of 300,000 tons has founded the basis for developing NB and ZS port into deepwater port group, which has ended the embarrassed history that fully-loaded ships of 250,000tons could not enter into port(Mao, 2012, p.43). However, with the rapid development of NB-ZS Port and related industries, the navigation pressure of XZM channel is also increasing. In order to maintain sustainable and stable development, it is necessary to evaluate its navigation environment for acquiring a comprehensive understanding and providing a basis for port development as well as maritime safety management, and ultimately to achieve the purposes of ensuring the navigation safety, navigation efficiency and maritime environmental protection.

1.2 Research Objectives

The principal objectives of this research are:

(1) to select the main factors of navigation environment according to the specific circumstance of XZM channel, on basis of that, and to establish a scientific EI system.

(2)to demonstrate the advantages of cloud model theory compared to other commonly used theories and try to use it in the domain of navigation environment evaluation.

(3)to establish a cloud model of safety evaluation on navigation environment and illustrate the processes step by step.

(4)to obtain a rational and credible evaluation result, by which it can provide a valuable basis for the decision making of maritime authorities.

1.3 Scope and Methodology

This paper primarily focuses on evaluating the navigation environment of the scope of XZM channel and extends both ends of the range approximately 1 nautical mile, because the greatest impact of traffic flow to the waterway safety is nearby at the two ends. Specific evaluation includes hydro-meteorological conditions, waterway conditions and so on. In addition, because this evaluation concentrates on the assessment of navigation environment, the aspects of human factors of crewmembers on board are not included.

The main methods for this paper: By the way of looking up relevant nautical publications combined with consultation to experts and scholars, deck officers, pilots, to get the basic information of XZM channel. On the basis of analysis of those information and some research achievements, the EIs and their risk criteria are identified. Further more, EI system is established. Then Delphi method is used here for determining the weights of EIs. According to the relevant information form NB VTS center, questionnaires from NB pilot station and ZS pilot station, nautical publications to determine the risk value of each indicator. After that, with the cloud model theory to establish safety evaluation model, calculation and drawing by MATLAB software and finally get the evaluation results.

Chapter 2

The Navigation Environment of XZM Channel

XZM channel, located between Taohua island and Xiazhi island, and its east end connects with open sea while west end with Fodu waterway, is about 7 n miles long and direction with NW and SE. As a natural waterway, the width of east channel mouth is 1.5 n miles while West mouth is 0.6 n mile, and the narrowest is only 0.4 n mile nearby of Xialanshan area, the depth of the channel is 30 ~ 123 meters and bottom materials are mud and stone. The favorable natural environment and good hydrological condition, deep water, small waves and good navigational aids, which makes this channel the only one waterway for the vessel from high seas to enter NB-ZS Port of tonnage above 20,000 tons. More important, it is also the only way for super-large ships to enter port. At the same time, this channel can be available for ship navigation day and night and it is regulated as the main channel for foreign ships to enter and leave NB-ZS Port according to related provisions (NGD, 2006, pp. 115-120).

The Geographic overview can be seen at Figure 1 which copied from NB vessel traffic services (VTS) by author.

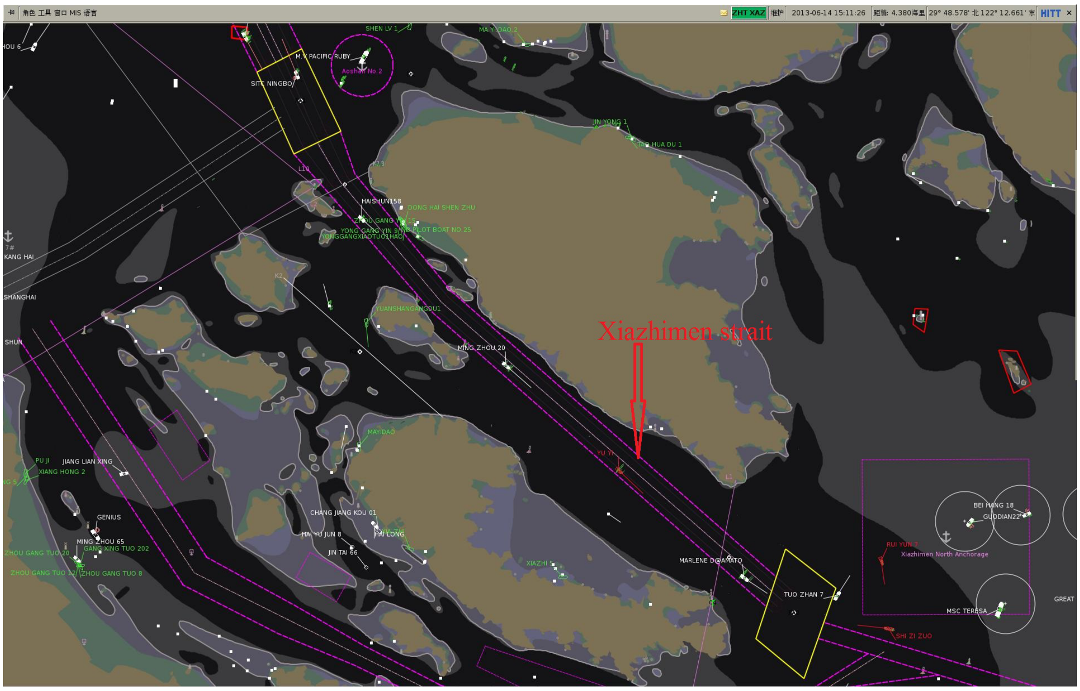

Figure 1 - The radar image of XZM channel copied from NB VTS
Source: The author

2.1 The Main Characteristics of XZM Channel

(1) High density vessel traffic. The vessel traffic volume of NB Port is very large and it results in greater impacts to the whole maritime vessel traffic conditions, especially the increasing number in vessels which form a huge dense traffic regions. As we know, if traffic density increases, the ship encounter rate and the operative difficulty to mariners will rise correspondently, which makes a great potential risk to collision or contacting between vessels.

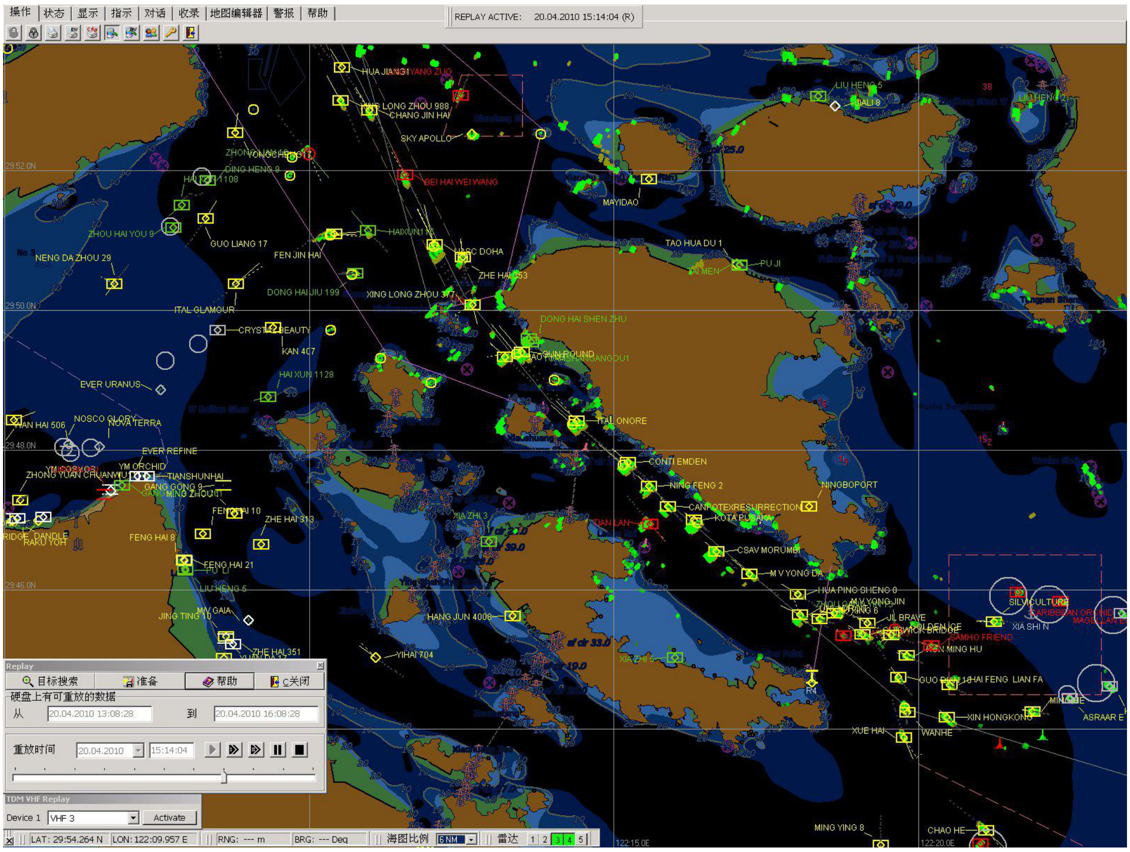

Figure 2-The radar image of gathering merchant fleet enter channel copied from NB VTS

Source: The author

(2)Heavy traffic flow. XZM channel, as a major waterway for large ships entering and leaving the port of NB and ZS, is used together by all kinds of ships, including merchant ships, fishing ships, war ships and so on. Therefore, the traffic flow is very heavy, and statistics form NB VTS well illustrate it: in 2009, there was a daily average of 70 inward vessels and 71.5 outward vessels, at totally 141.5, using XZM channel. It means that every 10 minutes there was a ship into this channel (Wang, 2010, p.25).

(3)Much Ship meeting situations and complicated navigable circumstance. The location of XZM channel objectively leads to complex traffic situations. As can be seen from the Figure 3, there are four traffic streams sharing the greatest impact on the whole navigation safety of the waters respectively.

Traffic stream 1: northward vessels from south enter into XZM channel; Traffic stream 2: ferry line between Xiazhi island and Taohua island; Traffic stream 3: vessels navigated at Fodu waterway which cross the main traffic flow at a right angle located at the western mouth of the channel; Traffic stream 4: passenger vessels navigated between Xiazhi island and Dinghai city. Due to the complex navigable circumstance, it is very easy for ships to generate the crossing and head-on situations in this waters and format of close-quarters situation, or even immediate danger.

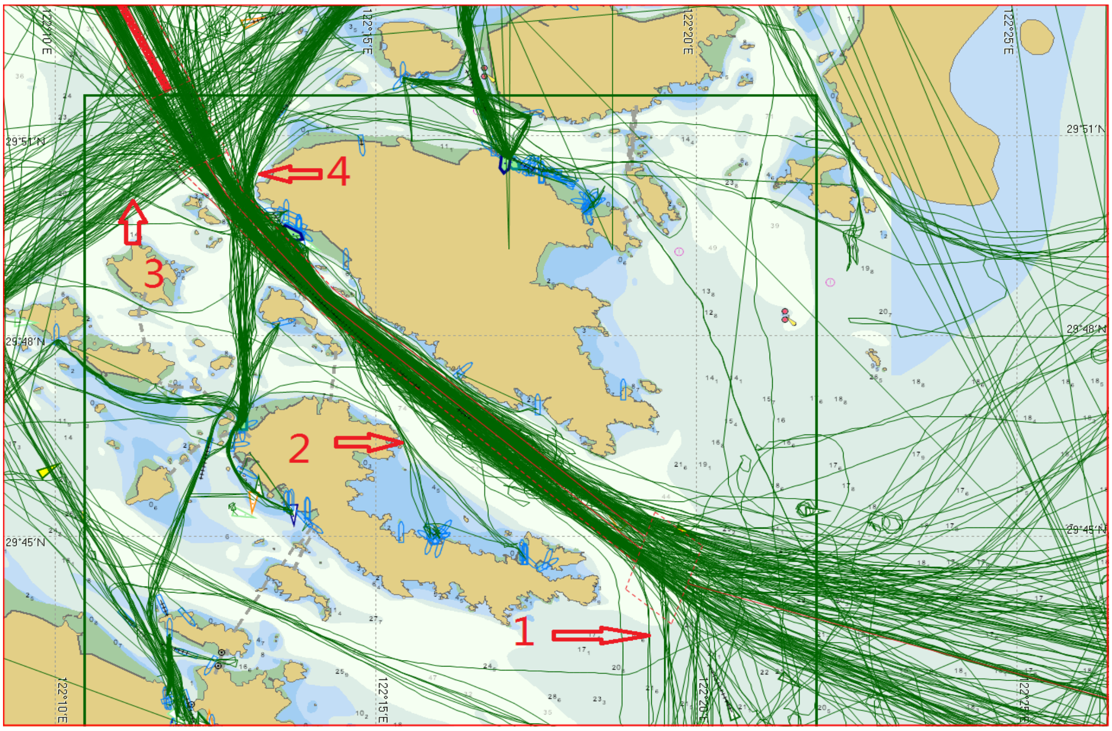

Figure 3-The Geographic Information System (GIS) image of vessel traffic flow of XZM channel copied from NB VTS

Source: The author

(4)The impact of fishing ships in fishing season. During the fishing season, there are usually groups of dragnet fishing vessels crossing the channel or staying in the channel. Further more, those fishing boats in larger quantities usually do not comply with relevant navigation regulations, which increase the danger degree of channel and affect the merchant normal voyage(Liu&Zhang, 2008, p.23).

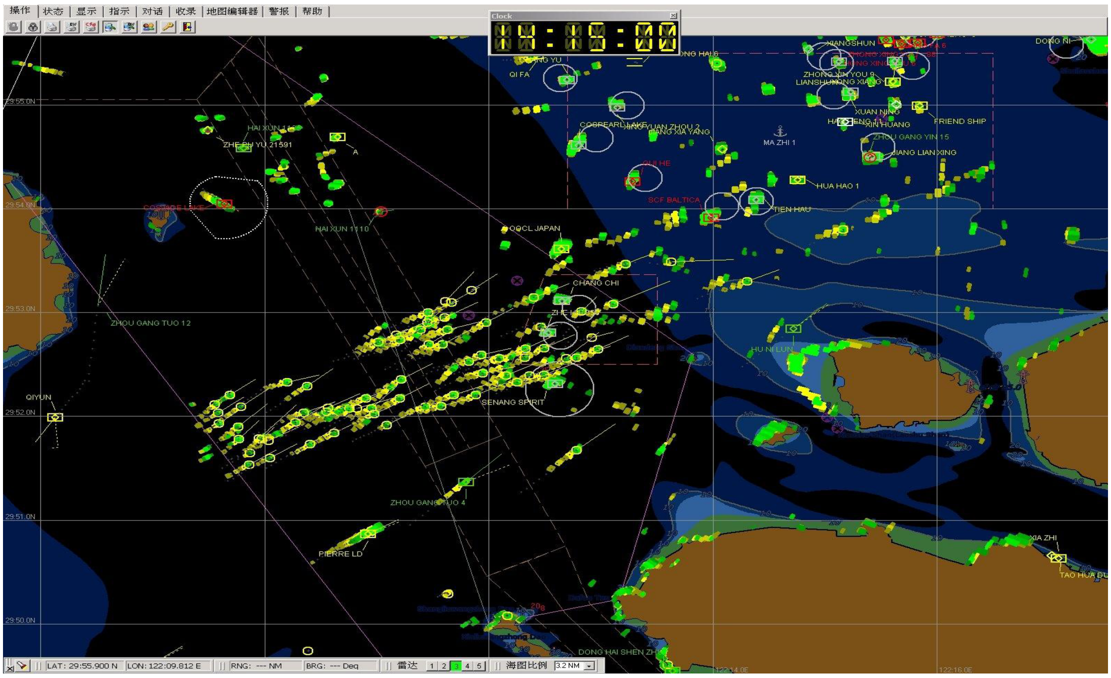

Figure 4-The radar image of fishing vessels crossing channel at fishing season copied from NB VTS

Source: The author

2.2 Natural Conditions of XZM Channel

2.2.1 Temperature

The annual average temperature is 18 ℃; maximum temperature is 32.1 ℃while minimum temperature is 1.4 ℃ (February)(Li, 2008, p.29). Detailed data are shown in Table 1:

Table 1-The average tiptop (low) temperature(℃)

Month	-6	7	8	9	10	11	12	1	2	3	4	5
Average temperature	23.0	27.6	27.9	26.2	20.9	18.6	12.7	8.0	8.5	11.1	13.8	18.3
Maximum temperature	31.8	31.7	32.1	30.8	25.7	23.2	19.0	17.0	12.8	17.2	18.8	22.6
Minimum temperature	19.4	26.2	25.7	20.4	14.4	14.8	7.2	4.8	1.4	5.6	8.4	13.6

Source:Li, G.S. (2008). *Study on the Traffie Ability and Saturation of Xiazhimen Channel.* Unpublished master's thesis, Dalian Maritime University, China,Dalian.

2.2.2 Winds

(l)Wind characteristics

The sea area here has obvious features of monsoon climate, and winds are characterized as predominantly SE and SSE in spring and summer while in autumn and winter they are prevailing NW and NNW directions.

Annual mean wind speed: 6.2m/s

Maximum monthly average wind speed: 7.9m/s(October)

Minimum monthly average wind speed: 4m/s (June)

Maximum wind speed, direction: 23.8m/s NNE(October)

High wind days≧force 6(10.8m/s)41 days

≧force 7(13.9m/s)14days

≧force 8(17.2m/s)5days(Wang, 2010, p.25)

(2)Typhoon

Typhoon season is from July to September every year and there are average 3.9 typhoons landing here per year, of which 82% are strong. Typhoons usually lasted for 2 or 3 days. Typhoons seriously affecting the NB sea area are mainly divided into two categories: one landing at the south area of Zhejiang province, usually going to northeast and demising at sea or shifting to northwest and disappearing at inland; The other sweeping type typhoon, whose center is closed to NB and usually goes to northward(Wang, 2010, p.25).

2.2.3 Fog Days

Totally, there are 32 fog days in an average year, and usually 26 fog days from March to June, accounting for 81% of annual fog days(Li, 2008, p.29).

Table 2-The statistics of fog days

month	6	7	8	9	10	11	12	1	2	3	4	5
days	7					2	4			3	8	8

Source:Li, G.S. (2008). *Study on the Traffie Ability and Saturation of Xiashimen Channel.* Unpublished master's thesis, Dalian Maritime University, China,Dalian.

2.2.4 Visibility

Table 3 demonstrates the frequency of visibility over 10 km in each month throughout a year on average. From the table, we can find that the days of mist in March are more than 27 days, with visibility always below 10km. In addition, the visibility of other months is more than 10 km(Li, 2008, p.29).

Table 3-The visibility frequency month by month (%)

month	6	7	8	9	10	11	12	1	2	3	4	5
≧10km frequency	51	60	81	72	76	61	41	61	65	9	60	81

Source:Li, G..S. (2008). *Study on the Traffie Ability and Saturation of Xiashimen Channel.* Unpublished master's thesis, Dalian Maritime University, China,Dalian.

2.2.5 Thunderstorm

According to Beilun Port statistics, generally, thunderstorm appears from March to October and with a record of 19 days per year(NBMB, 2012).

2.2.6 Humidity

Annual average relative humidity: 83%
Maximum mean monthly relative humidity: 91%(December)
Minimum mean monthly relative humidity: 74%(September)(ZSMB, 2013)

2.2.7 Ice and Snow

There are no icing phenomenon in the sea waters here, according to the Beilun statistics, and snowfall generally appears in December, January and February.

2.2.8 Hydrology

(1)Datum Plane

The relationships of the datum Plane of XZM are shown in Figure 5:

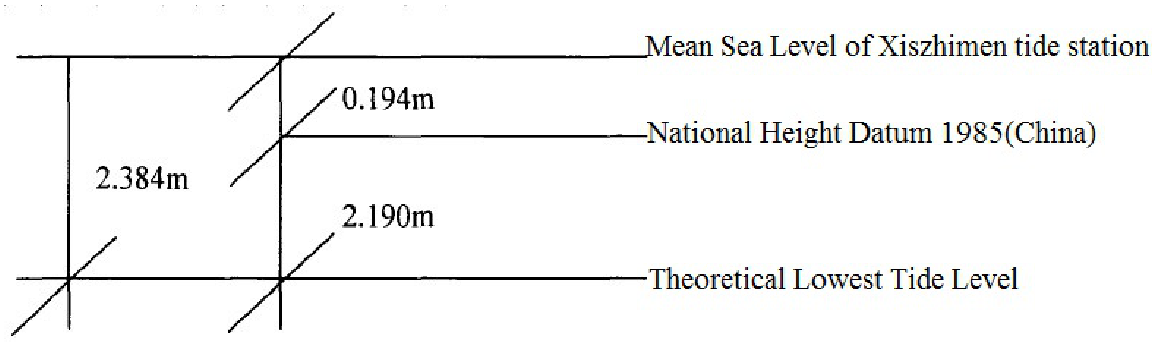

Figure 5-The relation of the datum Plane of XZM channel
Source: Navigation Guarantee Department of the Chinese Navy Headquarters. (2003). *LUO JIASHAN to XIANGSHANGANG*. Tianjin: Author.

(2)Tide

The tidal characteristic values in XZM sea waters are shown as follows(based on Theoretical Lowest Tide Level)(NGD,2003):

The highest high water level 5.12m（1994.8.21）

The lowest low water level -0.0lm（1994.12.4）

Average high tide: 3.89m

Average low tide: 1.14m

Maximum tidal range: 4.73m

Minimum tidal range: 0.55m

Mean tide range: 2.75m

Mean flood tidal duration: 5h55min

Mean ebb tidal duration: 6h30min(NGD,2003)

(3)Tidal Current

The sea area near XZM belongs to regular semidiurnal tide, with mean high water interval as 09h 29 min and turning around 4 hours after high tide, spring rise 4.1 meters, neap rise 3.1 meters, mean sea level(MSL) 2.3 meters. The direction of flood tide flow near the east entrance of XZM channel is northwest and at the rate of 1.8 knots while the ebb flow goes to southeast at 2.8 knots. Correspondently, flood tide flow nearby the west mouth is northwest flow at the rate of 4.4 knots, the ebb flow goes to southeast and the rate is 4 knots. In addition, the tide here begins to rise 3 hours before the high tide time of Dinghai Port and ebb tide flow 2hours later. In the center of the channel there is a rotary current, with maximum rate of 2.2knots. Ship navigation in channel is easily influenced by the current. The main reason is due to ship's speed increased by current and drift angle will increase while the rudder effect will reduce. There is a classic record illustrating that a ship proceeded at XZM channel with speed growth by current at 5 knots and the drift angle up to 6°(Zang, 2011, p.29).

2.3 The Traffic Environment of XZM Channel

2.3.1 The Traffic Flow Volume

Using the data statistical function of the management information system(MIS) of NB VTS, the traffic volume information of XZM channel form 0000 hour May 1,2013 to 2400 hour March 31,2013 was got in Table 4:

Table 4-The traffic volume information of XZM channel form 0000 hour May 1,2013 to 2400 hour March 31,2013 get from MIS system of NB VTS

Ships' type	volume	Total	Daily

		volume	volume
LNG and LPG	**165**	**16677**	**181.27**
Oil thanker	**726**		
Chemical thanker	**434**		
Container ship	**4428**		
bulk freighter	**4614**		
Others (including fish vessels and unidentified vessels)	**6310**		

Source: The author

2.3.2 Aids to Navigation

From the open sea proceeding inbound the channel, port hand lateral marks are listed: XZM No.2,4,6,8 buoy, Xiaoshuanshan light buoy, Dashuanshan light beacon, Laohuzui light buoy, Xialiuwangzhong light beacon; Starboard hand lateral marks: XZM No.1,3,5,7 buoy, Taohuadao lighthouse. The port hand lateral mark is red pillar and top mark is single red can, accordingly, the starboard hand lateral mark is green pillar while top mark is green can. Taohuadao Lighthouse as the most important navigational aids of XZM channel, located at the southeast corner of Taohua island, concrete cylinder covered by tiles with black and white horizontal stripes, equipped with radar transponder and signal code for the Z. Xiaoshuanshan, Xialanshan, Shangliuwangzhong light beacon, white concrete conical, equipped with radar transponder and signal code of T(NGD, 2006, pp. 115-120).

Table 5-Main lateral marks in XZM channel

Lateral marks	Position	Character	Range

Taohuadao Lighthouse	29° 46.3´N, 122° 18.5´E	Fishing. 12sec	15M
Xiaoshuanshan light beacon	29° 47.8´N, 122° 14.4´E	Fishing. 6sec	10.5M
Xialanshan light beacon	29° 48.7´N, 122° 14.3´E	Fishing. 4sec	10.5M
Shangliuwangzhong light beacon	29° 50.0´N, 122° 12.2´E	Fishing. 6sec	9M

Source: The author

2.3.3 VTS

NB VTS, the first VTS system of China, built in 1982, now has experienced three upgrades, the lasted completed in 2011. Now it is expanded to an advanced traffic service center with five monitoring desks and two exclusive VHF channels. NB VTS Center includes “seven stations and a center”, namely: Beilun Shan, Yu Shan, Daxie Island, Xiazhi Island, Dapeng Shan, Zhitou, Chuanbi Island seven radar stations and Beilun VTS centers. Meanwhile, it is a high-tech system which combines radar, communications, navigation, computer data processing and displaying. Since its opening, the NB VTS Center has been working uninterrupted 24 hours a day to provide safety navigation information, traffic organization, navigation assistance, organization of search and rescue, disposal emergencies and so on. Now, it is regarded as one of the busiest and the most efficient VTS systems in China(NB VTS, 2012).

Chapter 3
The Methods of Safety Evaluation on Navigation Environment and its Selection

3.1 Overview of Safety

From the absolute safety perspective, safety is no danger, no threat and no accident. In Safety Engineering, safety is defined as a certain condition that there is no death, no equipment or property losses and environmental damage and any other accidents or disasters. However, in fact, safety is a relative and ambiguous term, and it is to establish a circumstance in which people live and work, and in such a circumstance the hazard or danger perceived is known, cleared and controlled at an acceptable level. Therefore, safety is often described quantitatively by risk value or acceptable risk probability(IMO, 1995, pp. 187-190).

Hazard is an objective item of potential losses that may occur, and it can not be changed(IMO, 1995). Further more, hazard is the precondition of risk, in other words, if there is no hazard, there is no risk. In a technical perspective, risk refers to two variables: First, the probability of hazardous events; Second, the severity of the consequences or the extent of the losses to which the danger has happened. Fortunately, risk can be changed to a great extent by people' will, which means that, in accordance with our purpose, the likelihood of hazard occurrence or accident happening can be changed. And once it happens, we can reduce the extent of the damage by improving the protection measures.

Usually, risk is characterized by the accident situation because any accidents not only have the differences on the extent of damage but also the likelihood of its occurrence. Therefore, risk can be expressed by two factors: the damage degree and probability of accident occurrence, i.e., risk index=damage degree*probability of occurrence (Ma, Zhao&Hu, 2005, p.10).

3.2 The Definition of Navigation Environment

Navigation environment refers to the space and conditions of the ship's motion, mainly including the following three aspects:

(1)The place or space composed by the ports and waterways in which ship moves. Port waters include harbors, berthing areas, anchorages, turning areas, etc.; waterway is a certain water area of which depth, width, air draft as well as bending radius can provide safety navigation for ships, usually marked with navigation aids.

(2)Natural conditions. Referring to the meteorological conditions, hydrological conditions, terrain conditions, sediment conditions and other conditions of the navigable waters. Meteorological and hydrological conditions include visibility, wind, water depth, tides, waves, ice, etc.; Terrain conditions involve the width of waterway, evenness of the bottom, curvature degree, shallow as well as reefs and so on; Sediment condition is related to the impacts to the depth of navigable waters caused by the sediment sources and erosion and deposition to the port and fairway.

(3) Traffic conditions. Referring to the arrangement of ports and waterway location, navigational aids and facilities, traffic flow and density, traffic scheduling and management(Xu, 2008, p.23).

3.3 The Definition of Safety Evaluation

Safety evaluation is known as safety assessment or risk assessment, and it focuses on achieving the system safety as the destination, applying the theories and methodologies of safety systems engineering to identify and analyze the potential and existing hazards of the systems, on the basis of that, and to determine the possibility and the damage degree of the hazards and accidents which would occur in the system. Further more, it provides a reliable foundation for the development of preventive measures and management measures. In addition, assessment theories and practical experiences should be combined together during processing safety evaluation(Su, 2000, p.20)

3.4 The Principles of Selecting Safety Evaluation Method

In choosing a safety evaluation method, for the propose of making sure that the method selected is suitable, five principles should be followed (Zhang, 2007, p. 26):

(1)Sufficiency. Before safety evaluation, we must make adequate preparations and full analysis to the target system, do sufficient estimate work, based on its characteristics, and to make sure the approach is rational and effective.

(2)Adaptability. Adaptability refers to the fact that the methods must adapt the system when conducting safety evaluation. For each part of the system, respectively, by using appropriate evaluation methods, the results will be accurate and targeted.

(3)Systematicness. It means that we should rely on the systematic research and analysis to get the data and information comprehensively. At the same time, we also need a systematic estimation to achieve a reliable, rational, scientific, credible assessing result.

(4)Targeted. This principle means that the purpose must be clear and the assessment should be targeted. The aim of the evaluation, on one hand, is to check the occurrence of hazard and its damage degree. On the other hand, is to determine the likelihood of risk as well as the root causes to eliminate the hazards at their sources. Safety evaluation purposes, safety evaluation methodology and safety evaluation results should correspond to each other and be coordinated.

(5)Rationality. Rationality is known as the fact that people should select reasonable methods when they carry out safety evaluation. The calculation process in the methods chosen should be simple and the data should be less, so as to ensure the assessment workload is moderate and not too difficult to operate. However, there is no doubt that the precondition of this assessment method is to meet our requirement and do evaluation effectively. Besides that, we should avoid doing something useless as possible as we can.

3.5 Commonly Used Methods of Safety Evaluation on Navigation Environment

Navigation safety evaluation is a multidisciplinary course which requires common use of a lot of knowledge, not only statistics, but also safety engineering. Besides, it needs knowledge in professional maritime domain. However, the most essential is to coordinate uses of those knowledge. There are many safety evaluation methods commonly used: General Statistical Analysis and Mathematical Statistics Analysis, Fuzzy Comprehensive Evaluation, Analytic Hierarchy Process, Gray

System Theory, Cloud Model and so on.

3.5.1 General Statistical Analysis and Mathematical Statistics Analysis

In General Statistical Analysis, the number of each cause of maritime accidents, or number by weighted translation (such as the level of the accident given by weights), will be calculated to get the percentage accounting for the total number of accidents. Mathematical Statistical Analysis mainly analyzes all causes of accidents by using regression analysis, principal component analysis and correlation analysis. Currently, in China, when determining the danger level of inland navigable waters, many scholars and maritime administration usually use this method for risk projections. However, a certain number of samples are required when using Mathematical Statistical methods, because only when the sample quantity reaches a certain number, the frequency distribution can be presented stable, in which case, the model is reliable(Lin, 1995, p.51).

The method has played a great effect in the risk assessment field, but there are still some deficiencies: Firstly, only the number of accidents can not illustrate well the relationship between accidents and causes; Secondly, it requires a large number of data of very good distribution. In practice, sometimes it is very hard to do it(Zhang, 2010, p.26).

3.5.2 Fuzzy Comprehensive Evaluation

Fuzzy mathematics theory is proposed by American scholar L.A.zadeh in 1965. By introducing the concept of degree of membership and the mathematical model established by fuzzy set theory, the fuzzy information can be quantified, changing the point of view of traditional precise mathematics “not right is wrong”. As we know, There are many uncertain factors in the objective environment unable to carry out the analyses and evaluation with the traditional way, but fuzzy mathematics theory can deal with them quantitatively, so it has been widely applied in practice(Hu, 2004, pp.198-218).

The navigation environment safety itself is a fuzzy concept, and influenced by many factors. Therefore, a lot of research about navigation environment safety evaluation have adopted this method.

The method is characterized by: clear results, easily to master, especially considering the fuzziness of a system. However, when determining the index weight, too much reliance on subjective judgments, and due to the commonly used algorithm of “take large or small”, some information is lost and the model often becomes invalid. Further more, the basis of fuzzy set theory is the membership function. As we know, the membership function of a fuzzy set is a one-point to one-point mapping from a space U to the unit interval[0, 1](Zadeh, 1975, pp.199-249). After mapping, the uncertainty of an element belonging to the fuzzy concept becomes certain to that degree, a precise number. The uncertainty of the original concept is not passed on to the next step of processing at all. Therefore, they produce certain results and can not really simulate human being’s fuzzy thinking. This is the intrinsic shortage of the fuzzy set theory, which was often criticized by probabilists and experts in relevant fields(Di, 2001, p.26). In other wards, once uses an accurate membership function to depict the fuzzy sets, the fuzzy concept will be incorporated into the precise areas of traditional mathematics, which shows lack of thoroughness.

3.5.3 The Analytic Hierarchy Process(AHP)

The starting point of this approach is: according to the system engineering theory, as a whole, the complex system is reconstructed, the objectives of the system is decomposed into multiple sub-objectives(criteria, constraints), and decided by each sub-system objectives (criteria, constraints). By using fuzzy method to quantify the qualitative indicators and then sort the subsystems, this method is considered as a system approach to optimize a system's objectives(Jin&Wei, 2004, p.2004).

In AHP method, the uncertainty qualitative analysis and certainty quantitative analysis are combined effectively. By comparing the scaling value pairwise, the qualitative expertise can be quantified. In this case, the whole evaluation contains not only subjective logic judgment and analysis but also objective accurate calculation, so it is applied in a broader range of fields.

However, in practice, sometimes the hierarchy is oversimplified and does not consider the influences deriving from subjective judgment and preferences, so it has great randomness and hides some important dependencies. Therefore, it is difficult to apply to deal with the problem which needs higher quantitative analysis(Liao&Wu, 2007, pp. 56-61).

3.5.4 Gray System Theory

Gray system theory, a discipline developed originally by a Chinese professor Deng Julong based on the Information Theory, Cybernetics and Systems Theory. In this theory, if the relationships between different factors in a system are clear, those factors will be defined as "white", similarly, some fuzzy links are defined as "gray", and this kind of system is called gray system. This method is used in case of less data and they are unclear, making full use of the information already existing by "whitening" approach to predict or decisions. The advantage is that under the condition of some information is unknown; the system is still able to conduct quantitative research and analysis. The item "whitening" means converting the insufficient information into the materials that are easier to deal with(Zheng &Wu, 1997, pp. 61-64).

For safety evaluation to maritime traffic environment, due to historical reasons, cognitive factors, and its own characteristics of maritime traffic, made us accumulate less knowledge about maritime accidents. Further more, marine traffic environment is not fully familiar to people and many factors can not be completely quantified. These shortcomings just can be compensated by using gray system theory and be able to get a more realistic conclusion. Thus, in recent years, some scholars gradually introduced this theory into the field of maritime traffic safety. For instance, in the paper "Analysis model of accident's main causes on port vessels incidence by Gray System Theory", Zheng zhongyi and Wu Zhaolin used this theory for evaluating the navigation environment of ten main Chinese ports(Zheng &Wu, 1997, pp. 61-64).

3.6 Cloud Model

Cloud model, proposed by the academician Li Deyi of Chinese Academy of Engineering(CAE) in 1995, has been applied successfully in many fields, such as intelligent control and prediction, data mining, large system evaluation and so on(Zhang, Liu&Wu, 2010, p.65). Cloud model, as an important theory and tool of artificial intelligence with uncertainty, integrates the fuzziness and randomness of spatial entity, and to a certain extent, overcomes the limitation of the above methods.

At the same time, this theory can be used to properly deal with the conversion between qualitative and quantitative information, reduce the manual intervention as much as possible, and provide a powerful tool for the combination of qualitative and quantitative in information processing(Li, Cheng&Shi, 1998, pp.99-123). The essence of the theory is the flexible transformation qualitative linguistic terms and quantitative representation, solve the difficult balance between randomness and fuzziness. The advantages are as follows:

(1)The linguistic terms(qualitative data) from expertise are expressed by cloud model, which greatly reduces the subjectivity of expertise;

(2)The traditional evaluation method often can only use the determined membership or scale, and the cloud model is not under this restriction. Its membership is not indicated by the value determined, instead of that, using the softening interval to provide better tools to solve the complex qualitative evaluation;

(3)The fuzziness and randomness can be quantitatively calculated by the fuzzification of linguistic term, which can improve the accuracy of qualitative evaluation and provide a more objective reference criterion for decision making.

3.7 Identify the Method of Safety Evaluation to the Navigation Environment of XZM Channel

As mentioned above, although traditional evaluation techniques can carry out the quantitative calculation on qualitative evaluation, however, it can not take into account the fuzziness and randomness at the same time. Thus, solving the problem above has become the key point of safety evaluating the navigation environment scientifically. For the purpose of getting a more scientific and reasonable evaluation, this paper will attempt to the evaluation method based on cloud model and make further exploration on this issue, using uncertainly artificial intelligence to solve the above problems. Cloud model is universal in many areas, and also has strong scientificalness and operability. Currently, the usage of cloud model has a certain development in the field of intelligent control and prediction, large-scale system assessment, evaluation and decision analysis and other fields, however, it has not yet been applied in the studies of navigation safety evaluation. This paper will analyze deeply the characteristics of navigation safety, further more, on the basis of that, trying to establish a cloud model to evaluate navigational safety of XZM channel so as to obtain a more accurate and consistent with human thinking result. The specific approach is to use the cloud model method to create a model of navigation safety evaluation safety of XZM channel, and as a basis for calculation, finally, to put forward the specific result of the evaluation.

3.8 The Basic Theory and Algorithm of Cloud Model

Cloud model, proposed by a member of the CAE named Li Deyi, which is derived from traditional concept of fuzzy set theory and probability statistics theory and with the idea of membership function to establish a model by which it can achieve the uncertainty conversion between qualitative and quantitative items. In the process of uncertainty reasoning, the fuzziness and randomness of uncertainty concept are integrated together, generating a mapping between qualitative and quantitative and achieving the natural transition between uncertain linguistic terms and quantitative numbers(Li, 2010, p.26), which is consistent with the characteristics of navigation safety evaluation because it includes both qualitative indicators and quantitative indicators.

The linguistic items of qualitative concept in navigation safety evaluation can be transformed by cloud model into the points in the universe of discourse, which are called cloud drops. Every cloud drop is described as random event distributed by probability, and its degree of certainty is random as well. Therefore, the cloud model, which will be applied in quantifying the qualitative concept in navigation safety evaluation, has a great intuitive feature and operability. Cloud model, as a uncertain transition model of qualitative concepts and their quantitative values, uses probability theory to express the randomness and takes the advantage of fuzzy set theory to indicate the fuzziness. From this point, it reflects the character of combination of fuzziness and randomness.

3.8.1 Basic Concepts of Cloud Theory

Suppose U is a universe of discourse then set U = {u}, A is a linguistic term of U and is a quantitative concept. If $x \in U$, a random number with a stable tendency, and the memberships of x to the linguistic term A. In other words, x is a random event of the quantitative linguistic term A. Then, the membership degree μ of x to A, takes values in [0, 1], can be expressed by: $\mu(x) \in [0, 1]$. That is, $\mu : U \rightarrow [0, 1]$, $\forall x \in U, x \rightarrow \mu(x)$

Then the distribution of x in the universe of discourse is called cloud. And a cloud can reflect the evaluation situation of a indicator in the navigation safety evaluation, every x is named cloud drop(Li, 2005, pp.143-151). According to the basic definition of cloud model, it is not hard to see that the cloud has the following characteristics:

(1)According to the cloud geometry, the universe of discourse U can be one-dimensional, two-dimensional, even multi-dimensional.

(2)Cloud model explains the associativity of fuzziness and randomness by probability theory and fuzzy set theory.

(3) $x \in U$, the mapping from x to the interval [0, 1] is one-point to multi-point, producing a membership cloud, rather than a membership curve.

(4) The membership degree of x to the linguistic term A is a probability distribution function.

(5) The more the cloud drops generate, the more able to reflect the overall characteristics of the qualitative concept described.

Therefore, from the above characteristics of cloud, in describing the quantitative transition of qualitative indicators in the navigation environment, cloud reflects the multiple mapping of concept C from the universe of discourse U to the interval [0,1], and the mapping from a element in a domain to its membership for concept A is one to many relationship. This shows that each cloud drop generated is the point mapped from qualitative concept to a universe of discourse, and it is a quantitative conversion of qualitative indicators. At the same time, the cloud model generated can show the membership degree of qualitative indicators represented by drops. In addition, after understanding the overall distribution characteristics of the cloud drops accumulating to a certain number, the uncertainty qualitative analysis and certainty quantitative analysis can be integrated effectively. Thus, the distribution tendency of qualitative indicators in navigation environmental will be obtained(Li, Guo&Qiu, 2011, pp.2561-2567).

3.8.2 The Digital Characteristics of Cloud Model

A normal cloud is mainly characterized by three digital parameters, expected value E_x, entropy E_n and hyperentropy H_e (Fig.6).

(1) The expected value E_x is the central value of the linguistic term in the universe of discourse, which means that it represents the position at universe corresponding to the center of gravity of the cloud and its membership is 1, completely compatible with the linguistic term;

(2)The entropy E_n is used to measure the fuzziness of the qualitative concept. Entropy can reflect acceptable value range of the concept in the universe of discourse. In other words, the magnitude of E_n indicates the acceptable range of the concept and the bigger the E_n is, the fuzzier the concept is. In fact, E_n is defined by the bandwidth of the mathematical expected curve (MEC) of the normal cloud showing how many elements in the universe of discourse could be accepted to the linguistic term. The MEC of the normal cloud to a linguistic term may be considered as its membership function from the point of view of fuzzy set theory(Deng, Li&Li,1998, pp. 544-555).

(3) The hyperentropy H_e is the entropy of the entropy E_n, used to characterize the degree of dispersion of cloud drops. The greater H_e is, the degree of membership to a point will be more random, and cloud drops tend to be more discrete, the cloud thickness will be greater as well.

Thereby, Cloud model integrates fuzziness and randomness together through the E_x, E_n and H_e instead of a precise function. Cloud represents a qualitative concept by the overall shape of the cloud and every drop reflects a quantified qualitative concept, and it is more flexible, elastic, tolerant and human like than the traditional fuzzy set model.

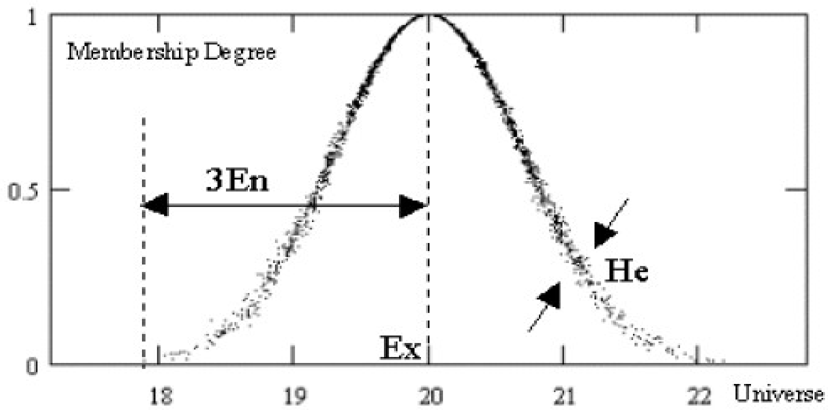

Figure 6-The digital characteristics of cloud model

Source: Li, D.Y.&Li, D.R.(2010), An integrated cloud model for measurement errors and fuzziness. In Singapore, *The 12th International Symposium on Spatial Data*. Global Spatial Data Infrastructure

3.8.3 The Algorithms of Cloud Model

The cloud can be generated by relevant algorithms, and we call this algorithm or hardware a cloud generator. It includes forward cloud, backward cloud, X conditional and Y conditional cloud generator. This thesis mainly uses the forward cloud generator to generate clouds.

Forward cloud generator is the mapping of EIs from qualitative to quantitative, also a kind of uncertainty transition model to quantify the qualitative indicators. Entering three parameters (E_x, E_n, H_e) and the number of cloud drops, we can get the location of cloud drops distributed in domain space and the membership degree they represent.

The processes of generating cloud drops by forward cloud generator are shown as follows:

Enter: Three digital parameters (E_x, E_n, H_e) of a qualitative concept, the number of cloud drops N.

Output: N drop(x_i, μ_i), i=1, 2, 3...n.

(1)Create a random value E_n' satisfied with the normal distribution probability whose expected value is E_n and standard deviation is H_e;

(2)Produce a random value x_i, whose expected value is E_x and standard deviation is E_n'. Then the x_i is called a cloud drop in the space of universe of discourse U.

(3)Calculate $\mu_i = \exp\left[-(x_i - E_x)^2 / 2(E_n')^2\right]$, then μ_i is the membership degree of x_i to a qualitative concept C.

(4) Repeat the above steps (1) -(3) to generate N cloud drops(Li, 2005, pp.143-151).

3.8.4 The Concept of Virtual Cloud

Virtual cloud refers to the cloud constructed by other given clouds. There are several kinds of virtual clouds, such as floating clouds, synthesized clouds, resolved clouds, geometric clouds, etc. The role of floating cloud mechanism is gathering the linguistic terms in bottom level whose correlation is little or independent to a cloud. Meanwhile, synthesized cloud mechanism is used to synthesize linguistic terms into a generalized one. Therefore, if we use the mechanism of synthesized cloud construction recursively from low concept layers to high concept layers, we can get concept hierarchies for linguistic variables, which are very important in synthetic evaluation(Li, 2000, pp.3-14).

Chapter 4
The Establishment of Cloud Model of Navigation Environment Safety Evaluation

4.1 The Establishment of EIs System

4.1.1 The Importance of Establishment of EIs System

Navigation environment safety EIs system is an important part of navigation safety evaluation system. As we know, there are a lot of navigation environmental factors affecting safety navigation while they are complex, requiring the establishment of a scientific and objectively evaluation factors system by the analysis of those factors and their relationships. The importance of establishing an EIs system will be reflected in the following aspects:

Firstly, for the maritime safety managers, it contributes to a comprehensive and systematic understanding about environmental risk factors, and provides a factor-based safety knowledge.

Secondly, it is the prerequisite to establish a correct and reasonable evaluation model as well as a necessary step.

Thirdly, the EIs system can guide the implementation of a safety culture by the maritime department, providing a basis for the relevant departments making decisions in terms of safety planning and safety management and so on.

4.1.2 The Selection Principles of EIs

As mentioned above, the navigation system is a complex and large-scale system, navigation environment system is one of its subsystems. There are a lot of factors in navigation system affecting ship safety navigation. At the same time, only for navigation environment, its factors are also numerous, and some of these factors are independent while some factors are mutual restraint, more over, the influences to safety navigation caused by these factors are different. Therefore, we should classify and integrate those factors based on our perspective and the specific conditions, then the scientific EIs system should be in accordance with the principles listed as follows:

(l) Scientificity. Indicators system must be based on a scientific basis, and can fully reflect the intrinsic mechanisms of maritime safety system, especially objectively expressing the relationships between various subsystems and factors in the navigation environmental systems. Therefore, when selecting evaluation factors, we must consider: the comprehensiveness and reliability of the materials, the tendency and representativeness of evaluators. In other words, we do not only invite evaluators from a single party and ensure their freedom of expression, works without pressure; Guarantee the enough proportion of experts in the evaluation team.

(2) Relative independence. Choose relatively independent evaluation factors to avoid overlaps between indicators.

(3) Representativeness. In the evaluation process, we need a comprehensive analysis of the factors that affecting the evaluation object, which must involves many aspects. For the purpose of making indicators system as concise as possible, we

should choose those representative indicators that can best reflect the actual situation of the object to make sure the indicator system is simple and accurate.

(4) Comparability. The name, concepts and calculation methods of indicators should try to be the same with IMO adopted or common use. At the same time, the comparability with historical data should also be taken into account.

(5) Operability. The EIs selected should be measurable and easy to quantify. In practice, the factor data can be obtained or calculated through statistical materials, a smaller survey or questionnaires. Although some factors are very appropriate, however, they can not acquire, so those factors are not feasible and lack of maneuverability.

4.2 The Selection of EIs

Currently, the research to navigation environmental safety evaluation is still at an exploratory stage. Due to the differences in the research objectives and conditions among scholars, the division of navigation environment and the choice of evaluation factors made are different. Therefore, it has no uniform and appropriate EIs system to give a good reference to the shipping departments and other interested groups.

In the paper "A Grey Model for Evaluating Port Navigation Environment Risk Degree"(Zheng&Wu, 1998, p.319), professors Zheng Zhongyi and Wu Zhaolin of DMU identified eight major environmental factors: wind, current, ports visibility conditions, the length of main channel, the ratio of ship width to channel width, the number of crossovers made by main channel and sub-channel, the number of turning points, the ship traffic volume, ship traffic density. In the book "Marine Traffic

Engineering"(Wu, 1993, pp.214-218), Wu Zhaolin pronounced that: In the evaluation of ship operating environment based on the cognitions of danger, navigation environment can be divided into ship-operating environment and traffic environment, which ship-operating environment refers to natural environment, terrain environment and water facilities environment. In the "Study on Marine Safety Evaluation"(Wen, 2003, p.21), the environment safety indicators can be divided to: visibility, wind, stream, waterway conditions, traffic flow volume, navigation order, VTS systems, shipboard environment.

In this paper, the EIs are identified by consultation to experts(see Appendix 1). Through that, it established the EIs system composed of 4 first-layer indicators and 9 second-layer indicators.

Table 6-Indicators system of navigation environment safety evaluation based on cloud model

	First layer indicators	Second layer indicators
Indicators system of navigation environment safety evaluation based on cloud model	Hydrometeorological conditions	Winds
		Currents
		Visibility
	Navigational aids and assistances	Perfection degree of navigational aids
		Traffic management capability of VTS
	Waterway conditions	The width of channel
		The cross situation of channel
		The curvature of channel
	Traffic flow	The volume of vessel traffic flow

Source:The author

4.3 Analysis on the EIs and Identification of Evaluation Criteria

4.3.1 Winds

The impacts of winds on ships include deflection and drift. As we know, ship may deviate from the original course caused by deflection while the drift caused by wind may make the ship off waterway. And both of them may induce maritime accidents.

Due to small winds having little effects on the ships' voyage, it can be ignored. According to the relative materials, when the wind force is over 6 scale, it will have an obvious influence on ship maneuvering and navigation(Chen, 1993, pp.231-239). Further more, when a typhoon comes, the navigation in channel and berthing operations will be prohibited by maritime authority. Therefore, this thesis recognizes the 6 scale wind as standard wind, and converts the days of wind above 6-7 scale into the days of standard wind.

The annual number of standard wind days is calculated:

Annual days of standard wind = annual days of wind at 6-7 scale+ 1.5 * annual days of wind scale 8 and above(Chen, 1993, pp.231-239).

Table 7-The risk criteria of winds in XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
Annual days of standard wind	≤30	30-60	60-100	100-150	≥150

Source: The author

4.3.2 Currents

When ships navigate at channels, under the effect of currents, their speed will be decreased or increased. In addition, if there is a certain angle between the current direction and ships' course, it will generate deflection and drift.

The drift induced by current can be calculated by the following formula:

$$\Delta B_W = V_C T \sin\alpha$$

V_C : current speed

α : drift angle

T : drift time

$T = S / V_S$, S is the straight length of ship's voyage sailed in channel, take the times correspond to ship's length(Jiang, 2012, p.26). The effects caused by currents mainly reflected in two aspects: speed and direction. However, due to the impact of direction is very complex, the direction of current will not be considered in this article, and we take the maximum current speed as the evaluation criteria.

Table 8-The risk criteria of currents in XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
maximum current speed（knots）	0-1	1-2	2-3	3-4	4

Source:The author

4.3.3 Visibility

Visibility is defined as the maximum horizontal distance within which a person with normal vision could see or identify a targeted object under the particular weather conditions, it is usually indicated in km or n mile. (Zhu, 1999, p.20).

Visibility is an essential hydrometeorological factor that influences the safety navigation of ships. As we know, fog is the most important factor affecting the visibility at sea, and it can make the sight distance down to a few meters lasting for a long time, especially when a dense fog appears and visibility is very poor, it will bring a great difficulties to the navigation and it is very easy to cause collision or grounding. According to the statistics, there exist a exponential relationship between the maritime accidents happening in 1000 hours and visibility(Chen, Liu&Tang, 2001, pp.11-12).

The regression equation is: $N = 90 \cdot D^{-0.8}$

N is the quantity of maritime, D refers to the visibility (km).

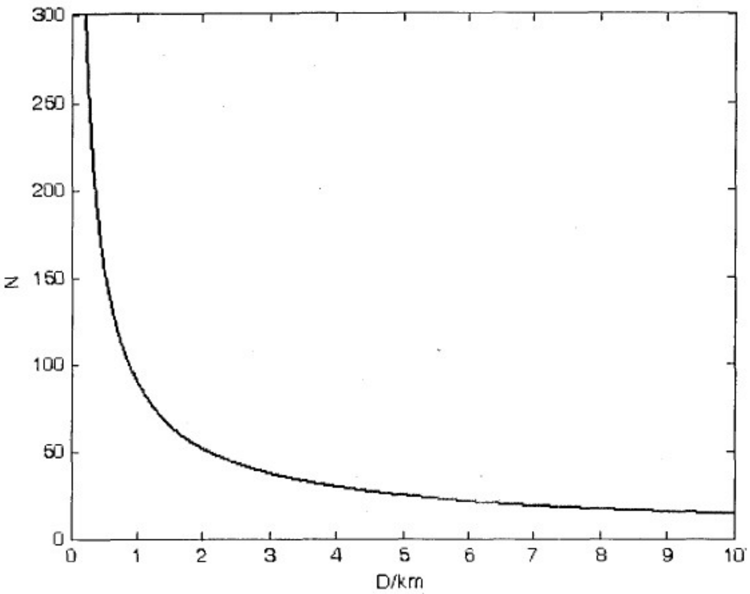

Figure 7-The relationship between visibility and accidents

Source: Chen, C.H.,Liu, X.P.&Tang, S.X.(2001). Waterway Engineering. Beijing:China Communications Press

As can be seen from the Figure 7, when the visibility is less than 4km, there are certain influences to navigational safety. When visibility drops to 1km, the numbers of accidents increase sharply, which is considered as dangerous visibility. According to the distance, the visibility is divided into 0-9 of 10 levels.

Fog and visibility scale		
Code number	Conditions	Visibility
0	Dense fog	Less than 1 cable *(50 m)*
1	Thick fog	*(50 - 200 m)*
2	Fog	1 - 2.5 cables *(200 - 500 m)*
3	Moderate fog	2.5 - 5 cables *(500 - 1000 m)*
4	Mist or haze, or very poor visibility	5 - 10 cables *(1 - 2 km)*
5	Poor visibility	1 - 3 n miles *(2 - 5 km)*
6	Moderate visibility	3 - 6 n miles *(5 - 10 km)*
7	Good visibility	6 - 12 n miles *(10 - 20 km)*
8	Very good visibility	12 - 30 n miles *(20 - 50 km)*
9	Excellent visibility	Over 30 n miles *(50 km)*

Figure 8-Fog and visibility scale
Source: Fog and visibility scale. Retrieved June 25, 2013 from the World Wide Web: http://www.defence.gov.au/sydneyii/RAN/RAN.002.0139.pdf

The paper "Evaluation on Danger Degree of Ship-operating Environment in Navigable Waters" demonstrates the reasonableness of visibility of 2km as a standard to measure the visibility(Zhang, 2007, p.36). Therefore, combining the actual fog conditions of XZM channel, the author selected the average annual days of visibility less than 2km (in units of days / year) in the latest two years as the EI. Finally, we identified the evaluation criteria of visibility in XZM channel:

Table 9-The risk criteria of visibility in XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
Days of poor visibility	≤15	15-25	25-40	40-50	≥50

Source: The author

4.3.4 Navigational Aids

In order to achieve the role of aids to navigation, generally, there are four functions of navigational aids, namely positioning function, hazard warning function, confirm function and instruction function. Navigational aids are an important factor in evaluation port area navigation environment.

The influence to the safety navigation of ships caused by the imperfect arrangement or damage of navigational aids can not be ignored. However, unlike other factors, this factor is difficult to quantify. In order to describe the indicator objectively and reasonably, after consultation experts' opinion, we take the perfection rate as the evaluation criteria to navigational aids. Perfect navigational aids mainly refer to:

(1) The number is enough, configuration is reasonable and easily to be recognized;

(2) There are remarkable turning marks nearby the turning point of channel;

(3) There are marks on both sides of fairway to sign out the limitation;

(4) There are important marks on the main channel.

The perfection degree of navigational aids refers to "the number of the better navigational aids of the channel / total number" and its evaluation criteria are shown in Table 10. In the criteria, perfection degree 100% will be recorded as 100 and the rest can be done in the same manner.

Table 10-The risk criteria of perfection degree of navigational aids in XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
degree of perfection	95-100	90-95	80-90	70-80	≤70

Source: The author

4.3.5 VTS Traffic Management Capability

Vessel traffic services (VTS) refers to: A service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and respond to traffic situations developing in the VTS area(IMO,1997). So VTS is a service system. Further more, in this resolution the VTS is defined that: VTS should comprise at least an information service and may also include others, such as a navigational assistance service or a traffic organization service, or both(IMO,1997). Therefore, VTS is also management system to some extent.

Just like the indicator of Navigational Aids, this indicator is difficult to quantify too. Through consultation to experts, we decide to evaluate the VTS traffic management capability mainly in three aspects:

(1) The perfection degree of VTS system.

(2) The rationality degree of the arrangement of relevant equipments.

(3) The efficiency and ability of VTS personnel.

Finally, according to experts' recommendations, our evaluation criteria can be developed in Table 11:

Table 11-The risk criteria of VTS traffic management in XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
VTS traffic management capability	95-100	90-95	80-90	70-80	≤70

Source: The author

4.3.6 The Width of Channel

The magnitude of the channel width directly affects the safety navigation, the main reason is that when ship proceeds in narrow waters, there are usually the effect of narrow water, such as bank cushion and bank suction, which may result in collision, grounding and other accidents.

Therefore, the channel width has a very important role in safe navigation in narrow waters. Generally speaking, the width of channel usually can meet the requirements of safe navigation when it is designed. However, when considering the impacts of wind and current, the navigator should be very cautious, because the impacts may make ships deviate from channel and induce dangerous incidents.

In this paper, the evaluation criteria of width of channel refer to the ratio of ship's breadth to the channel width. Breadth means the average breadth value of the ship allowed navigation and channel width is the narrowest width of the fairway. Then, the evaluation criteria of channel width can be specified in Table 12:

Table 12-The risk criteria of the width of XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
breadth/the narrowest width of channel	≤0.05	0.05—0.10	0.10—0.30	0.3—0.5	≥0.5

Source: The author

4.3.7 Cross Situation of Channel

At the intersection of the fairway, because the traffic flow cross or merge, the ship meeting frequency and vessel density will increase, which easily leads to close-quarters situation and prone to collisions and groundings.

In the article "Evaluation and analysis on danger degree of port ship-operating environment by Grey System Theory", Professor Mahui and Wu Zhaolin take maximum intersection angle between channel and sub-channel as the EIs of waterway crossing(Ma&Wu, 1998, p.16). Combining the specific circumstances of XZM channel, the evaluation criteria of the cross situation can be set in Table 13:

Table 13-The risk criteria of cross situation of XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
The angle of crossover	≤20°	20°-45°	45°-60°	60°-70°	≥70°

Source: The author

4.3.8 The Curvature of Channel

When a ship navigates in bending channels, due to constraints of channel-scale and impacts of complex current, it brings great difficulties to ship's maneuvering, especially large fleet sails in acute bends. Therefore, in curved channel, safety navigation of ships is mainly affected by the magnitude of the steering angle. So in this paper, the maximum angle of channel camber is chosen as the EI, and its criteria are provided in Table 14.

Table 14-The risk criteria of the curvature of XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
maximum angle of channel camber	≤15°	15°-30°	30°-45°	45°-60°	≥60°

Source: The author

4.3.9 The Volume of Vessel Traffic Flow

Traffic volume is the total number of vessels passing through a particular place in a unit of time (year, month, day, hour), which is the basic indicator to reflect the traffic condition in waters especially in waterways. Traffic volume is the most important information of traffic engineering and easy to access, and it is a direct reflection of the magnitude and busyness of the vessel traffic in a certain water area, it also can indicate the congestion degree and danger degree to some extent. In addition, the volume of vessel traffic can not only restrict ship's movement in space but also impact the behavior of navigators in terms of psychology for it generates feeling of stress. Generally, the more traffic volume, the greater traffic density, the more traffic congestion, the worse the safety and the higher degree of management required.

According to the classification standards of management functions factors in the Port Management System of China: management degree level 1 means 16 vessels / day, management level 2 means 20 vessels / day, management level 3 means 24vessels / day, management level 4 means 70 vessel / day, 0 is the level that all ports should meet(Xu, 2008, p.36). Based on the above analysis and integrate traffic management classification standards, the evaluation criteria of vessel traffic volume can be provisioned in Table 15:

Table 15-The risk criteria of vessel traffic volume of XZM channel

risk criteria	Insignificant	low	moderate	high	Extremely high
Vessel traffic volume	≤10	10—15	15—25	25—70	≥70

Source: The author

Finally, for the facilitation of observation, we combine the 9 evaluation criteria into a single summary table-Table 16:

Table 16- The risk criteria of 9 EIs

risk criteria	Insignificant	low	moderate	high	Extremely high
Annual days of standard wind	≤30	30-60	60-100	100-150	≥150
maximum current speed（knots）	0-1	1-2	2-3	3-4	4
Days of poor visibility	≤15	15-25	25-40	40-50	≥50
degree of perfection	95-100	90-95	80-90	70-80	≤70
VTS traffic	95-100	90-95	80-90	70-80	≤70

management capability					
breadth/the narrowest width of channel	≤0.05	0.05—0.10	0.10—0.30	0.3—0.5	≥0.5
The angle of crossover	≤20°	20°-45°	45°-60°	60°-70°	≥70°
maximum angle of channel camber	≤15°	15°-30°	30°-45°	45°-60°	≥60°
Vessel traffic volume	≤10	10—15	15—25	25—70	≥70

Source: The author

4.4 Establishment of Factor Sets and Evaluation Sets

4.4.1 Factor Sets

Factor set is the assemblage of various factors which affects evaluation object and can be expressed as U = {U1, U2, ..., Un} where U_i (i = 1,2, ... n), n is the number of factors on the same level, which constitutes a collection of EIs. Since the safety of navigation environment of XZM channel was recognized as the final goal, it identified the first-layer EIs set $U = \{U_1, U_2, ..., U_m\}$ and second-layer EIs set $U_i = \{U_{i1}, U_{i2}, ..., U_{in}\}$, (i = 1, 2, ..., n).

This thesis will layer the indicators and assess them hierarchically, the cloud model obtained from the lower-level will be continued to participate in the next evaluation of the higher level, this can avoid the distortion of indicators' weighting caused by the phenomenon that too many factors in a layer and each weight of them will be very small. In general, the importance of every element in factor set U is different, therefore each element U must be given different weights w according to their degree of importance. The weight can be expressed as $W = (w_1, w_2, ..., w_n)$, where w_i (i = 1,2, ..., n) represents the weight of U_i, which reflects the importance of each factors in the evaluation. Furthermore, the weights in every layer usually satisfy the normalization and non-negativity conditions, that is:

$$\sum_{i=1}^{n} w_i = 1, 0 \le w_i \le 1$$

$$w_i \ge 0$$

4.4.2 Evaluation Sets

Evaluation set is a collection of the evaluation results made to the evaluation object, which can be expressed as V = {V_1, V_2,..., V_t}, where V_t (t = 1,2,..., m), m represents the number of comment grade. This provides a set of evaluation results which can be selected to the evaluation factors, and the element of the result set can be a qualitative linguistic item or a quantitative score. Based on the domestic and foreign scholars' researches to the safety evaluation on navigation environment, evaluation results will be divided into five grades: Insignificant, Low, Moderate, High and Extremely high. Therefore, the evaluation set of this article can be:V={Insignificant, Low, Moderate, High, Extremely high}

In addition, the risk evaluation criteria will adopt the hundred percentage system, and five grades correspond to five intervals respectively: 0-20, 20-40, 40-60, 60-80, 80-100.

4.5 Identification of the Weights of EIs

In the evaluation process, the identification of EIs' weights plays a key role for the evaluation results. Currently, the most commonly used methods are Fuzzy Comprehensive Evaluation method, AHP method, Delphi method and so on. This paper adopts Delphi method to determine the weights of EIs. Depending on the weights given by experts, we obtained the indicator weights by the calculation of weighted average, and compared importance of second-layer EIs and first-layer EI for the navigation environmental safety of XZM channel (see Appendix 3). Finally, we identified the weights of indicators in different layers(Table 17).

Table 17-The weights of EIs

First-layer indicators U_i	Second-layer indicators U_{ij}	weights	
		w_i	w_{ij}
Hydrometeorological conditions U_1	Winds U_{11}	0.2067	0.1667
	Currents U_{12}		0.3667
	VisibilityU_{13}		0.4666
Navigational aids and assistances U_2	Perfection degree of navigational aids U_{21}	0.3016	0.5000
	Traffic management capability of VTS U_{22}		0.5000
Waterway conditions U_3	The width of channel U_{31}	0.2517	0.5500
	The cross situation of channel U_{32}		0.3000
	The curvature of channel U_{33}		0.1500
Traffic flow U_4	The volume of vessel traffic flow U_{41}	0.2400	1.0000

Source: The author

4.6 Identification of Risk Value of Each EI

According to Chapter 2 and Chapter 3 and relevant statistics, we can conclude the risk values of EIs:

(1) Winds

By researching on the statistics on "Duty Log of NB VTS" recorded by VTS Operators(NB VTS, 2012), the annual days of standard wind can be calculated: 41 days/year(6-7 scale) +5*1.5 days/year(scale 8 and above)=49 days/year, and risk criterion is Low.

(2) Currents

According to the Section 2.2.8 of Chapter 2, the Maximum current speed can be 4.4 knots, risk at Extremely High.

(3) Visibility

Through the statistics recorded on "Duty Log of NB VTS", in the past two years the number of average annual days of visibility less than 2km in XZM channel is 21(NB VTS, 2012), risk criterion belonging to Low.

(4) Perfection Degree of Navigational Aids

Due to the complexity of navigation environment of XZM channel and as one of the most important navigable waterway in NB waters, the local waterway authority pays great attention to the building of navigational aids on this area. Through the actual data and expertise, perfection degree of navigational aids arrives at 99%, Insignificant of risk.

(5) Traffic Management Capability of VTS

The risk value of this indicator was got by the method of Expert Survey (see Appendix 2). According to the questionnaires recycling from pilots, deck officers and VTS experts, we can get the degree of traffic management capability of the local VTS: 92%, risk criterion: Low.

(6) The Width of Channel

The narrowest part of XZM channel is located nearby Xialanshan area with channel width of 400 meters(NGD, 2006, pp. 115-120). Since the channel is the only way for VLCC inbound and outbound in NB and ZS port, assuming ship' type is VLCC and with breadth about 58 meters, then 58/400 = 0.15 and risk criterion is Moderate.

(7)The Angle of Crossover

According to Figure 3, the angle of crossover between main channel and sub-channel is about 80°, which belongs to Extremely high risk criterion.

(8) The Curvature of Channel

According to the large scale Chinese chart of this area, we can identify maximum angle of channel camber is approximate 10°(NGD, 2010), in Insignificant risk.

(9) Vessel Traffic Volume

As shown in Table 4, the volume of traffic flow is at average 181.3 vessels a day, which belongs to Extremely high risk criterion.

4.7 Synthetic Evaluation Based on Cloud Model

As mentioned above, the EIs system is composed of two layers of indicators, so the evaluation of them belongs to the multi-level synthetic evaluation. According to the general multi-level synthetic evaluation calculation steps, firstly, the calculation should begin from the bottom (second layer) to carry out the first calculation of synthetic evaluation and obtain the current evaluation values of its parent layer. Then we take the results as the evaluation value of highest level (first layer) EIs and conduct the synthetic calculation of them to get the final evaluation results. Therefore, during the whole process, there should be proceeded two times of synthetic calculations. Due to the differences in correlation and independence between the elements of each level, the algorithms used in the calculation of each layer will be different.

4.7.1 The Cloud Model of Evaluation Criteria

The risk criteria of evaluation set have been already given above, five grade, and each standard has a corresponding value range with the form just like $[C_{\min,} C_{\max}]$. According to the digital characteristics of cloud model, we can use the following formula to calculate the parameters of each evaluation value.

$$\begin{cases} E_x = (C_{\min} + C_{\max})/2 \\ E_n = (C_{\max} - C_{\min})/6 \\ H_e = k \end{cases} \qquad (1)$$

Where k is a constant, we can make some specific adjustment according to the stability of the variable itself. For the evaluation value range only has one boundary ranges, like $[C_{\min,} + \infty]$ or $[-\infty, C_{\max}]$, we can determine the parameters of default boundary or the expected value firstly, then according to formula (1) to calculate the cloud parameters(Wang, 2012, p. 26).

4.7.2 Floating Cloud Calculation in the EIs of Second Layer

As the correlation between the EIs is little, and they are basically independent, so we can use the floating cloud method of virtual cloud to assemble those indicators, which can be carried out as follows:

$$\begin{cases} E_x = \dfrac{E_{x1} \times w_1 + E_{x2} \times w_2 + \cdots + E_{xn} \times w_n}{w_1 + w_2 + \cdots + w_n} \\ E_n = \dfrac{w_1^2}{w_1^2 + w_2^2 + \cdots + w_n^2} E_{n1} + \dfrac{w_2^2}{w_1^2 + w_2^2 + \cdots + w_n^2} E_{n2} + \cdots + \dfrac{w_n^2}{w_1^2 + w_2^2 + \cdots + w_n^2} E_{nn} \\ H_e = \dfrac{w_1^2}{w_1^2 + w_2^2 + \cdots + w_n^2} H_{e1} + \dfrac{w_2^2}{w_1^2 + w_2^2 + \cdots + w_n^2} H_{e2} + \cdots + \dfrac{w_n^2}{w_1^2 + w_2^2 + \cdots + w_n^2} H_{en} \end{cases} \quad (2)$$

Wherein, w_i(i=1, 2, ...,n) for the weight of EIs; (E_{xi}, E_{ni}, H_{ei}) are the cloud model parameters for the EIs, n is the number of EIs(Luo&Liu, 2008, p.125).

4.7.3 Synthesized Cloud Calculation in the EIs of First Layer

Since the cloud model of a single EI is a linguistic term, so we use the synthesized cloud construction method to integrate them from low concept layer to high concept level recursively, which assembles two or more cloud models into a generalized one. Calculation formula is shown as follows(Luo&Liu, 2008, p.125):

$$
\begin{cases}
E_x = \dfrac{E_{x1}E_{n1}w_1 + E_{x2}E_{n2}w_2 + \cdots + E_{xn}E_{nn}w_n}{E_{n1}w_1 + E_{n2}w_2 + \cdots + E_{nn}w_n} \\
E_n = E_{n1}w_1 n + E_{n2}w_2 n + \cdots + E_{nn}w_n n \\
H_e = \dfrac{H_{e1}E_{n1}w_1 + H_{e1}E_{n1}w_2 + \cdots + H_{en}E_{nn}w_n}{E_{n1}w_1 + E_{n2}w_2 + \cdots + E_{nn}w_n}
\end{cases} \quad (3)
$$

4.7.4 Specific Process of Calculation

By formula (1), we can obtain the conceptual cloud model of five risk criteria based on their value intervals: Extremely high (100, 20/3, 0.5), High (70, 10/3, 0.5), Moderate (50, 10/3, 0.5), Low (30, 10/3, 0.5), Insignificant (0, 20/3, 0.5). As the same manner, the cloud models of EIs in second layer are identified in Table 18.

Table 18-The cloud models' parameters of second layer EIs

Second layer indicators U_{ij}	Risk criteria					(E_x, E_n, H_e)
	0-20 Insignificant	20-40 Low	40-60 Moderate	60-80 High	80-100 Extremely high	
Winds U_{11}		√				(30,10/3, 0.5)
Currents U_{12}					√	(100, 20/3, 0.5)
VisibilityU_{13}		√				(30, 10/3, 0.5)
Perfection degree of navigational aids U_{21}	√					(0, 20/3, 0.5)
Traffic management capability of VTS U_{22}		√				(30, 10/3, 0.5)
The width of channel U_{31}			√			(50, 10/3, 0.5)

The cross situation of channel U_{32}					√	(100, 20/3, 0.5)
The curvature of channel U_{33}	√					(0, 20/3, 0.5)
The volume of vessel traffic flow U_{41}					√	(100, 20/3, 0.5)

Source: The author

By calculating formula (2), we can get the parameters of first layer in Table 19.

Table 19-The cloud models' parameters of first layer EIs

First layer indicators	(E_x, E_n, H_e)
Hydrometeorological conditions U_1	(55.6690, 0.5000, 4.5130)
Navigational aids and assistances U_2	(15.0000, 0.5000, 5.0000)
Waterway conditions U_3	(57.5000, 0.5000, 4.2369)
Traffic flow U_4	(100.0000, 0.5000, 6.6667)

Source: The author

Then, using synthesized cloud calculation method (formula (3)) to calculate the parameters of first layer, we get the parameters of synthetical evaluation cloud model: (57.9311, 20.4290, 0.5000), the parameters of ultimate cloud model. Due to the tedious calculations, we use the MATLAB software to facilitate the whole process (see Appendix 4).

By the forward cloud generator we can draw the Figure 9 to illustrate the digital characteristics of ultimate cloud model, which is also the cloud model of the safety evaluation on the navigation environment of XZM channel. In addition, this figure is also drawn by the MATLAB (see Appendix 5).

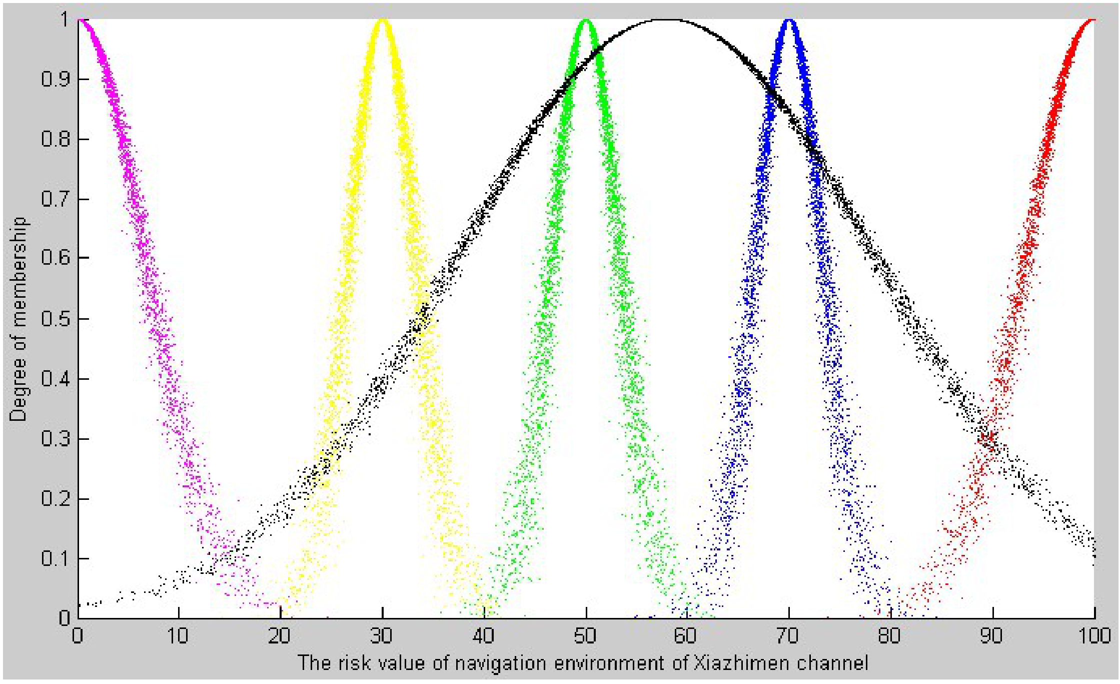

Figure 9-The digital characteristics of the cloud model of the safety evaluation on the navigation environment of XZM channel.

Source: The author

In Figure 9, the clouds color of pink, yellow, green, blue, red representing the five qualitative concept, namely: Insignificant, Low, Moderate, High and Extremely High five risk criteria, respectively, wherein the black cloud delegates the synthetical evaluation results. We can see that this figure directly reflects the distribution of the synthetical evaluation results in the concept cloud of five evaluation risk criteria. Although the black cloud covers the entire universe of discourse, the main part of the cloud locates at Moderate and High position. At the same time, the figure shows other parts of the black cloud drops are very sparse at the position of Insignificant, Low, and Extremely High, and the membership degree of those parts are very low, illustrating the probability of these parts is also very low correspondently. Turning to the parts at Moderate and High position, we can find that the cloud covers more parts at Moderate than High, and we know that the expected value E_n=57.9311, according to the cloud model theory we can make the following judgment: the risk standard of navigation environment of XZM channel is Moderate but very close to High.

4.8 Analysis and Recommendations Based on the Evaluation Result

As mentioned above, the risk degree of the navigation environment of XZM channel is at Moderate level but very close to High. Except for a collision of the death of 6 people in 2010 in XZM channel(NB MSA, 2010, p.16), reviewing “Annual Report of Ningbo MSA” for the last five years, there were no other casualties in this channel. So, the result of our evaluation is in accordance with the actual situation of XZM channel.

From Table 18, we find that the risk level of three indicators: currents, the cross situation of channel and the volume of vessel traffic flow are extremely high, which are the main causes of raising the risk value of XZM channel.

In recent years, with the rapid economy development in China, the shipping industry is also accompanied by a great growth and the high navigation pressure of XZM channel. From Table 4, we can see that the daily traffic volume of XZM channel has reached 181.27 vessel, and wherein container ship, bulk freighter about half. Such a large volume of traffic must bring great pressure to ship navigators, thereby enhancing the entire risk value of the waterway. Another important reason is the traffic flow cross the fairway. From Figure 3 we can see that nearby the waters, there are four sub-traffic flows affecting the main traffic. Ships crossing the waterway also will produce pressure on normal sailing vessels and raise the risk value.

So our suggestions are: For the traffic flow, from the recent, competent authorities especially local VTS should provide effective traffic organization service during peak periods and reasonable allocating vessel traffic flow. From long term perspective, we need to open up a new channel to fundamentally solve the problem caused by the growing traffic volume(Xu, 2006, p.8).

For ships crossing channel, the competent authority should develop a strong rule to regulate the behavior of ships and require the crossing vessels observe good seamanship and local regulations. By this we can reduce the entire risks value. As for the influence of current, because it belongs to the natural conditions, we do not consider here.

Chapter 5
Conclusion and Future Work

5.1 Conclusion

The purpose of this paper is to understand the risk level of XZM channel, and to identify the main factors impact of navigation environmental safety of this channel simultaneously. Further more, on the basis of that, it puts forward some relevant recommendations to the competent authorities for decision making. At the same time, this thesis chooses to use the cloud model to carry out this safety evaluation, and to achieve a better transition between qualitative and quantitative concepts which required in the safety evaluation. It ensures the objectivity and rationality and improves the credibility of the evaluation. Meanwhile, detailed findings can be summarized as follows:

(1)Reviewing main navigation environmental characteristics and natural conditions of XZM channel, including: Hydrometeorological conditions, Navigational aids and assistances, Waterway conditions, etc. On the basis of that, we find the main navigation environmental factors which influence the navigation safety best. They are: Winds, Currents, Visibility, Perfection degree of navigational aids, Traffic management capability of VTS, The width of channel, The cross situation of channel, The curvature of channel, The volume of vessel traffic flow, respectively.

(2)By introducing the concept of safety and risk, we have learned that safety is a relative and ambiguous term. It is to establish a circumstance in which people live and work, and in such a circumstance the hazard or danger perceived is known, cleared and controlled at an acceptable level. And, safety is often described quantitatively by risk value or acceptable risk probability. So, we need a tool which can do well in terms of transformation between the ambiguous concept and quantitative term.

(3)Through the analysis of the methods of navigation environment safety evaluation commonly used, we know their shortcomings embodied in the aspects of mutual transformation between qualitative and quantitative concepts. However, the cloud model can deal with this challenge very well, consistent with human thinking and suitable for using in the domain of safety evaluation wherein both qualitative and quantitative concept exist.

(4)Establishing a multi-layer EI system is very useful in safety evaluation, because it can avoid the distortion of model effectively caused by the phenomenon that if there are too many factors then each weight will be too small.

(5)The risk degree of the navigation environment of XZM channel is at Moderate level but very close to High. The cause is that the risk level of three indicators: currents, the cross situation of channel and the volume of vessel traffic flow are extremely high.

(6)Due to the current belonging to natural condition and is a uncontrollable factor, for the purpose of reducing the risk degree, we mainly need to take prevention action from other two aspects, and in particular it should be reflected at strengthening the management of vessel traffic flow and regulating the ships' behaviors of crossing through the channel.

5.2 Future Work

This thesis provides a new synthetical evaluation method for the safety assessment on navigation environment. At the same time, the evaluation achieves a reliable result, indicating the effectiveness and the advantages compared to other traditional methods. Thus, it is suitable for the application in the domain of navigation evaluation. Also, it is possible that problems and improvements involved in this thesis need to be analyzed and discussed more specifically. Therefore, there are proposals for further studies as follows:

(1) In this paper, the establishment of risk criterion of each EI is on the basis of consideration of the specific circumstance of XZM channel, and also in reference to the research of some scholars and consultation to several experts. Inevitably, there is a certain degree of subjectivity. Therefore, we need do further studies to get a more scientific and rational EI system.

(2) Due to the complexity of current, the current's direction is not taken into account in this paper. Therefore, it is necessary for application of a new method which can reflect both the impact of speed and direction. At the same time, when evaluating the traffic management capability of VTS, this thesis fully adopts the method of asking experts, to some extent, is oversimplified. Therefore, we have to make more in-depth research.

(3) In determining the weight of each EI we use the Delphi method to do it. However, this method also has a certain degree of subjectivity. So a better and more scientific way is needed.

(4) As we know that the majority of maritime accidents are caused by human factors. Therefore, it is necessary in the next study to take into consideration on the crew factors, so as to get overall risk values of XZM channel.

(5) This thesis is the first time of application of the cloud model theory to navigation safety evaluation, and it is necessary to use some other methods to verify and compare.

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Appendix

Appendix 1: Survey on the Safety Evaluation on the Navigation Environment of Xiazhimen Channel (1)

Dear Experts：

Due to the needs for researching of safety evaluation on navigation environment of Xiazhimen channel, so carry out this survey. Please on the basis of your own experience and requirements of the table, fill in the required content. Thank you for your support!

When carry out safety evaluation on navigation environment of Xiazhimen channel, we should consider a lot of factors. To highlight the main factors, ignoring the impacts of minor factors, this table provides 12 factors (table below) to choose. Please according to the principles of operability and guarantee relative scientific, select the factors that you think should be included, and to explain its reasons; If there are some other factors which need to be added in, please also explain the reasons.

Factors	Reasons of include	Reasons of exclude
1.Visibility		
2.Rain		
3.Wind		
4.Current		
5.The width of channel		
6.The length of channel		
7.The depth of channel		
8.The cross situation of channel		
9. the volume of traffic flow		
10. The density of traffic flow		
11. Navigational aids		
12.Traffic management capability of VTS		

Appendix 2: Survey on the Safety Evaluation on the Navigation Environment of Xiazhimen Channel (2)

Dear Experts：

Due to the needs for researching of safety evaluation on navigation environment of Xiazhimen channel, so carry out this survey. Please on the basis of your own experience and requirements of the table, fill in the required content. Thank you for your support!

Vessel Traffic Service (VTS) constructed by four elements “personnel - equipment -environment (water environment) - Management”. Its vessel traffic management capabilities and management performance primarily depends on VTS management soft science, shore-based facilities and water environmental factors. For the completed VTS, management capability and performance mainly depends on the people management degree on the VTS. VTS management degree mainly depends on the following three aspects (weights 1:1:1): (1) The perfection degree of VTS system. (2) The rationality degree of arrangement of relevant equipments. (3) The efficiency and ability of VTS personnel. please based on your experience and observations, score the three elements of traffic management which affecting Xiazhimen waters in following table(100 points for each option).

Factors	score
The perfection degree of VTS system	
The rationality degree of arrangement of relevant equipments.	
The efficiency and ability of VTS personnel	

Appendix 3: Survey on the Safety Evaluation on the Navigation Environment of Xiazhimen Channel (3)

Dear Experts:

Due to the needs for researching of safety evaluation on navigation environment of Xiazhimen channel, so carry out this survey. Please on the basis of your own experience and requirements of the table, fill in the required content. Thank you for your support!

Mainly fill weights of indicators (The sum of the weights at each layer should equal to1. For example, at the first layer: $w_1+w_2+w_3+w_4=1$; At the second layer, the three sub-indicators of hydrometeorological conditions: $w_{11}+w_{12}+w_{13}=1$, others indicators at second layer should be done at the same manner) . Thank you for your cooperation!

First-layer indicators U_i	Second-layer indicators U_{ij}	weights	
		w_i	w_{ij}
Hydrometeorological conditions U_1	Winds U_{11}		
	Currents U_{12}		
	VisibilityU_{13}		
Navigational aids and assistances U_2	Perfection degree of navigational aids U_{21}		
	Traffic management capability of VTS U_{22}		
Waterway conditions U_3	The width of channel U_{31}		
	The cross situation of channel U_{32}		
	The curvature of channel U_{33}		
Traffic flow U_4	The volume of vessel traffic flow U_{41}		

Appendix 4: MTALAB Program of Formula (2) and Formula(3)

```
clear;

  wij1=[0.1667,0.3667,0.4666];Exi1=[30,100,30];Eni1=[10/3,20/3,10/3];Hei1=[0.5,0.5,0.5];
  wij2=[0.5,0.5];Exi2=[0,30];Eni2=[20/3,10/3];Hei2=[0.5,0.5];
  wij3=[0.55,0.3,0.15];Exi3=[50,100,0];Eni3=[10/3,20/3,20/3];Hei3=[0.5,0.5,0.5];
  wij4=[1];Exi4=[100];Eni4=[20/3];Hei4=[0.5];
  wi=[0.2067,0.3016,0.2517,0.2400];

ww=0;a=0;b=0;c=0;d=0;
for i=1:length(wij1)
        ww=ww+wij1(i)^2;
end
for i=1:length(wij1)
        a=a+(Exi1(i)*wij1(i));
        b=b+wij1(i);

        c=c+(wij1(i)^2*Eni1(i))/ww;
        d=d+(wij1(i)^2*Hei1(i))/ww;
end
Ex(1)=a/b;
En(1)=c;
He(1)=d;

ww=0;a=0;b=0;c=0;d=0;
for i=1:length(wij2)
        ww=ww+wij2(i)^2;
end
for i=1:length(wij2)
        a=a+(Exi2(i)*wij2(i));
        b=b+wij2(i);

        c=c+(wij2(i)^2*Eni2(i))/ww;
        d=d+(wij2(i)^2*Hei2(i))/ww;
end
Ex(2)=a/b;
En(2)=c;
He(2)=d;
```

```
ww=0;a=0;b=0;c=0;d=0;
for i=1:length(wij3)
    ww=ww+wij3(i)^2;
end
for i=1:length(wij3)
    a=a+(Exi3(i)*wij3(i));
    b=b+wij3(i);

    c=c+(wij3(i)^2*Eni3(i))/ww;
    d=d+(wij3(i)^2*Hei3(i))/ww;
end
Ex(3)=a/b;
En(3)=c;
He(3)=d;

ww=0;a=0;b=0;c=0;d=0;
for i=1:length(wij4)
    ww=ww+wij4(i)^2;
end
for i=1:length(wij4)
    a=a+(Exi4(i)*wij4(i));
    b=b+wij4(i);

    c=c+(wij4(i)^2*Eni4(i))/ww;
    d=d+(wij4(i)^2*Hei4(i))/ww;
end
Ex(4)=a/b;
En(4)=c;
He(4)=d;

a=0;b=0;c=0;x=0;n=4;
for i=1:length(Ex)
   x=x+En(i)*wi(i);
   a=a+Ex(i)*En(i)*wi(i);

   c=c+He(i)*En(i)*wi(i);
end
Exx=a/x;
Enn=x*n;
Hee=c/x;
```

Appendix 5: MTALAB Program of the Cloud Drawing

```
n=6000;
En=20/3;
He=0.5;Ex=100;
hold on;
X=zeros(1,n);Y=zeros(1,n);
X(1:n)=normrnd(En,He,1,n);
for i=1:n
En1=X(1,i);
X(1,i)=normrnd(Ex,En1,1);
Y(1,i)=exp(-(X(1,i)-Ex)^2/(2*En1^2));
end
plot(X,Y,'r.','markersize',2);

En=10/3;
He=0.5;Ex=70;
X=zeros(1,n);Y=zeros(1,n);
X(1:n)=normrnd(En,He,1,n);
for i=1:n
En1=X(1,i);
X(1,i)=normrnd(Ex,En1,1);
Y(1,i)=exp(-(X(1,i)-Ex)^2/(2*En1^2));
end
plot(X,Y,'b.','markersize',2);

En=10/3;
He=0.5;Ex=50;
X=zeros(1,n);Y=zeros(1,n);
X(1:n)=normrnd(En,He,1,n);
for i=1:n
En1=X(1,i);
X(1,i)=normrnd(Ex,En1,1);
Y(1,i)=exp(-(X(1,i)-Ex)^2/(2*En1^2));
end
plot(X,Y,'g.','markersize',2);

En=10/3;
He=0.5;Ex=30;
X=zeros(1,n);Y=zeros(1,n);
```

```
X(1:n)=normrnd(En,He,1,n);
for i=1:n
En1=X(1,i);
X(1,i)=normrnd(Ex,En1,1);
Y(1,i)=exp(-(X(1,i)-Ex)^2/(2*En1^2));
end
plot(X,Y,'y.','markersize',2);

En=20/3;
He=0.5;Ex=0;
X=zeros(1,n);Y=zeros(1,n);
X(1:n)=normrnd(En,He,1,n);
for i=1:n
En1=X(1,i);
X(1,i)=normrnd(Ex,En1,1);
Y(1,i)=exp(-(X(1,i)-Ex)^2/(2*En1^2));
end
plot(X,Y,'m.','markersize',2);


En=20.429080780664860;
He=0.5;Ex=57.931147636075714;
% En=16.949501442170295;
% He=0.5;Ex=86.213369281120390;
X=zeros(1,n);Y=zeros(1,n);
X(1:n)=normrnd(En,He,1,n);
for i=1:n
En1=X(1,i);
X(1,i)=normrnd(Ex,En1,1);
Y(1,i)=exp(-(X(1,i)-Ex)^2/(2*En1^2));
end
plot(X,Y,'k.','markersize',2);

xlim([0, 100]);
xlabel('The risk value of navigation environment of Xiazhimen channel');
ylabel('Degree of membership');
```