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Safety assessment of navigational environment in Dalian Beiliang Port

Miao Wang

WORLD MARITIME UNIVERSITY

Dalian, China

Safety Assessment of Navigational Environment in Dalian Beiliang Port

By

Wang Miao

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: Wang Miao

Date:

Supervised by:

Dr. Li Wei

Professor of Dalian Maritime University

Assessor:

Co-assessor:

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Abstract

Vessel traffic accident occurs mostly at the harbor water, in addition, port construction will bring certain influence to ship navigation around the harbor, so the port navigation safety assessment is necessary. Beiliang Port Area of Dalian Port is a relatively busy port, the traffic is more. For the safety of the port, the judgment is mostly emotional, this article is based on this, will give a quantitative assessment of the safety of navigation, for providing the reference for the follow-up development planning of port.

After analysising on a variety of navigation safety assessment method, this article will use fuzzy comprehensive assessment in Fuzzy Mathematics to establish the navigation safety assessment model. In this article, firstly, give a brief introduction of fuzzy comprehensive assessment, and process the experts questionnaire data, then, introduce each impact factor and establish the corresponding membership function; Secondly, integrate these factors together to establish a fuzzy comprehensive assessment model; thirdly, introduce the basic information of Beiliang Port Area of Dalian Port, in accordance with the relevant theory of AHP, respectively establish factor set, assessment set, weight set; Finally evaluate using the established Port navigable waters navigation safety fuzzy comprehensive evaluation model, then get the evaluation results.

This study provides a theoretical and practical reference for safety operation of Beiliang waters of Dalian port.

Key Words: Navigation environment; Safety assessment; Fuzzy comprehensive assessment

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List of Abbreviation

UK	the United Kingdom
AHP	Analytic Hierarchy Process
SCL	Safety Check List
PHA	Preliminary Hazard Analysis
FMEA	Fault Type and Effect Analysis
LEC	Probabilistic Risk Assessment Method
PSA	Probability Safety Assessment
ETA	Event Tree Analysis
FTA	Fault Tree Analysis
FSA	Flag State Assessment
VTS	Vessel Traffic Services

Chapter 1 Introduction

1.1 Background

In recent years, with the rapid development of China's economy, the cargo throughput of the port has increased dramatically, which boost the rapid development of shipping economy and port economy and provides more space for the development of the port. What followed was an increase in throughput of ship and ship traffic, so that the ship meeting rate is bound to increase, thus navigable water environment becomes more complex, and the risk of navigable waters could be higher. However, it is necessary to take appropriate measures so as to improve the navigation environment through evaluating these risks and drawing the main factors. Beiliang Port is located in the south of Dalian City Economic and Technological Development Zone, east longitude 121 ° 48 ′ 38 ″, latitude 38 ° 58 ′ 35 ″, which face Dalian district across the sea. The construction of Beiliang Port began in 1996. After port facilities, bulk grain transport capacity greatly improved, and Beiliang Port has become the hub for transporting grain from the north to south in China and also become one of the world's largest and most technologically advanced specialized food transit ports.

Berths are currently in use in Beiliang Port which include 4 bulk grain berths (3 are loading berths, 1 is discharging berth), 2 general cargo berths, with the design capacity of 11000000 tons in total . In 2009 and 2010, the throughput of Beiliang Port are 9910000 tons and 10420000 tons respectively.

In China's grain transportation pattern, the grain shipments of Northeast region is (including exports) about 57.1 million tons, accounting for about 63%, while Dalian Beiliang Port has become a major grain output in Northeast China transit. With the increasing number of arriving ships, port traffic environment is changing, which caused some impact on safe navigation of the ship. Therefore, it is necessary to carry out security environment comprehensive evaluation on navigable waters of Dalian Beiliang Port .

1.2 Purpose and Significance of the Study

According to the related theories of marine traffic engineering, 80% of reason for marine traffic accidents are caused by each is human factors, but as environmental factors have great impact on human factors, environmental factors can not be ignored. Sailing in the port area, vessel traffic density is much higher, and traffic flow situation is complex, hence, obstruction and other factors should be considered, and more attention should be paid to navigation environment in port water area should pay. Therefore, we should carry out analysis on navigational environment of port waters area and make comprehensive evaluation, and put forward the corresponding countermeasures and methods for improvement. It has very important significance for the safe navigation of the port water areas. Based on comprehensive safety evaluation on navigational environment of the Dalian Beiliang Port the present study, obtains main factors affecting navigation safety in this water area and takes quantitative approach to each factor acquire the factors that impact on the overall safety navigational environment, which can remind ships sailing in this port water area to pay attention to these environmental factors and make corresponding preventive measures so as to reduce the accident rate, and also can provide a theoretical reference to the relevant administrative departments.

1.3 Research Status at Home and Abroad

Japan has done a lot of research in the evaluation of the safety of maritime traffic environment, "quantitative assessment of ship burden" written by Inoue, potential risk of navigable water areas as indicators of potentially dangerous levels of ship navigation is studied quantitative analysis is done on the following two aspects :one is ship meeting probability in this navigable water area; the other is burden increase of ship operator after ships meeting each other.(Inoue,1992) Inoue also proposed degree of difficulty of ship-operating evaluation method based on environmental stress model, which is obtained by quantitative calculation of ship-operating environmental pressure value and the navigational environment pressure value(Inoue & Wataru , 1998). Kobayashi listed influencing factors about ship operation, such as length of ship, type of ship, depth of water area, wind, and gives a quantitative analysis and evaluation of the degree of ship-operating difficulty of entire port water areas(Kobayashi, 1992). Yasuo quantifies natural elements affecting the ships' ability to maneuver. He gives index values, then he gives the relationship between subjective feeling and index values, which can improve assessment on navigation safety and navigational environment(Arai,1992). In the UK, Vladimir and Barry established the port navigation safety management system based on risk(Vladimir & Barry, 2000). S.T.Ung used the method of combining the theory of fuzzy mathematics and artificial neural network to establish port navigation safety risk prediction model (Williams & Bonsal, 2006).

In China, experts and scholars have done a lot of work in this area. Vessel Traffic investigation and Safety Evaluation Team which is lead by Professor Wu proposes "security index" method. This method takes ratio of the number of ship accidents in certain water areas that occur within a certain time and quantity of ship activity during the period as indicators, which can measure traffic safety situation in these water area during the period (Wu & Zhu, 2004). Now the method has been applied to safety evaluation of many of our coastal port water area, and achieved satisfactory results. Hoong and Ashim established the orderly probability regression model for collision risk on waterway fairway areas (Hoong & Ashim, 2009). Wing and Ching used the simulation test method to establish evaluation model (Wing & Ching, 2006). Zhao introduced the Fuzzy Comprehensive Assessment Model into maritime security assessment, and conducted a comprehensive evaluation of the accident for several domestic shipping companies by applying the mathematical model, which fully reflects the superiority of the model (Zhao & Wu & Wang, 1991). Fuzzy Theory and Gray Theory proposed by Li are combined to create fairways Safety gray Fuzzy Assessment Model (Li, 2010). Zhang using gray system theory to establish navigational risk of ships in waterway fairway areas base on the situation of Qingdao Port waterway fairway areas (Zhang, 2007). Gao established Fuzzy Comprehensive Assessment Model of navigation safety in port water areas in his master's thesis “analysis and evaluation of risk of navigational environment of Xiamen fairway”, and used the Fuzzy Comprehensive Model to conduct evaluation of Xiamen port water area (Gao, 2000). Tan and Dai selected respectively the gray correlation analysis and Fuzzy Comprehensive Assessment method in their master's thesis, and established assessment model of degree of traffic safety of ships (Tan, 2002). Zhang used fuzzy mathematics to establish fuzzy comprehensive evaluation model of navigational safety of ports according to Yantai vessel traffic situation (Zhang, 2007). Professor Zhao presented fuzzy comprehensive evaluation method of risk of marine traffic in his “Fuzzy comprehensive evaluation method of risk of marine traffic”, and achieved very good assessment results (Zhao, 1997) Professor He proposed a concept of risk of maritime traffic environment, combining AHP and analytical methods to established comprehensive risk assessment model of traffic environment (He & Wu & Fang, 1997). Xu Et al. considered about navigational risk of Taizhou port, using the theory of set pair analysis and combined with the theory of fuzzy mathematics and creating set of evaluation model based on fuzzy entropy (Xu & Xuan & You, 2012). Ma applied gray clustering theory and statistical evaluation methods to carry out a quantitative analysis of risk of ship-operating environment in navigational water areas of port (Ma & Wu, 1998). Weng and Wu Applied security systems engineering principles to obtain environmental factors and their degree of importance through the construction of the fault tree method (Weng & Wu, 2001). Professor Zheng conducted a analysis of environmental factors of fairway and traffic accident by using in the method of gray correlation and factor analysis (Zheng & Huang & Wu, 2006). Another article “Grey risk assessment model of port navigational environment” written by Professor Zheng applied indicators fixed weight method of index theory grey clustering system theory, and analyzed and selected the eight environmental indicators of ports influenced navigation safety, and carried out risk assessment of navigational environment of ten ports for ships (Zheng & Wu, 1988). Chen of the Shanghai Maritime University in the “combined evaluation mode for navigational environment of port”, used 5 kinds of evaluation methods for the evaluation of China’s ten coastal security situation of ports, and he used the combination evaluation method, and achieved satisfactory results (Chen & Hao & Qin, 2005). “Unascertained measure mode of safety assessment on navigable waters”, Wang applied unascertained measure model to safety assessment in port water areas (Wang & Li & Zhong, 2009). Li Et al. used information entropy theory to establish evaluation index weights and applied a unknown mathematical theory to build unknown ship port navigable waters unknown measurable mathematic risk assessment model of port water areas for ships (Li & Hu & You, 2009). Shao in his doctoral thesis “maritime traffic safety evaluation model and simulation applied research”, based on control theory and fuzzy inference system ideas and methods, established maritime traffic safety evaluation FIS model and provides a practical model to achieve dynamic maritime traffic safety evaluation and improve the process of evaluation from static assessment to a dynamic assessment (Shao, 2000).

1.4 The Main Research Contents and Research Methods of this Article

This paper firstly introduces the method of navigation safety assessment in fairway areas. Secondly, it lists affecting factors of safety assessment, and gives the evaluation standard and membership function one by one so that we can set up the waterway fuzzy comprehensive evaluation model concerning navigation safety in fairway areas. Thirdly, it introduces simply about the actual situation of Dalian port fairway area and uses fuzzy comprehensive assessment model to conduct assessment. Finally, we have drawn conclusions.

Chapter 2 The Relevant Methods of Safety Assessment on Environment in Navigational Fairway

2.1 Summary of Safety Assessment

Safety assessment, also known as risk assessment or hazard assessment, refers to assessment on safety of the system or dangerousness of the system according to the relevant standards based on risk identification and analysis, codes and indicators, which are divided by level of risk, and propose safety measures to control system risk due to current science, technology level and economic conditions (Wen, 2003). Thus, it is not difficult to draw the basic content of safety assessment which consists of the following three parts:

(1) Hazard identification, by finding the unsafe factors and quantitative it or carrying out qualitative analysis;

(2) Safety assessment, by assessing system risk and degree of possible happening, and drawing conclusion;

(3) Safety improvements, by proposing countermeasures to reduce the accident rate.

Safety assessment methods include qualitative assessment methods, semi-quantitative assessment methods and quantitative assessment method. Common qualitative assessment methods includes SCL (Safety Check List), PHA (Preliminary Hazard Analysis), FMEA (Fault Type and Effect Analysis), etc. Common semi-quantitative assessment methods include LEC (Probabilistic Risk Assessment Methods), scoring checklist method, MES method; common quantitative assessment methods include risk index method, Mond method, PSA (Probability Safety Assessment), ETA (Event Tree Analysis) and FTA (Fault Tree Analysis). These methods have their own characteristics and scope, so we should determine the appropriate assessment methods to minimize subjective factors to arrive at a more rational, more objective evaluation results for the relevant departments to develop preventive measures and management decisions according to the specific circumstances of the system to be assessed.

2.2 Environmental Safety Assessment Methods in Fairway Areas

Scholars put forward many methods about environmental safety assessment in fairway areas, including the mathematical assessment model method (safety index method, factor analysis method, gray theory method, artificial neural network method, Bayesian network method, set pair theory, the fuzzy comprehensive evaluation method, application of extenics assessment, mathematical statistics methods), computer simulation, simulate method of simulator. Now we give a brief introduction to the commonly used methods according to the above-mentioned methods

2.2.1 Gray Theory

Gray theory, first proposed by Professor Deng of a mathematical discipline, which is based on the systems engineering disciplines of mathematical theory. Main solution contains specific problems of unknown factors in the field. With regard to marine transport environmental assessment, each accident has its own unique particular, To assess them, there are many subjectivity and uncertainty, and it is also more difficult to collect accident data, and many factors are difficult to quantify. Combing these characteristics, Many scholars introduced gray theory into environmental safety assessment of marine traffic (Zheng & Wu, 1998).

2.2.2 Artificial Neural Network Theory

In 1943, psychologist Mcculloch and number logicians Pitts first proposed neuron mathematical model to provide a theoretical basis for the study of artificial neural network theory. Artificial Neural Networks, also called neural network for short, is mathematical model of parallel distributed information processing algorithm, which is characterized by imitating animals' neural network operating mechanism. This network is used to adjust the internal nodes' interconnected relationship for complex system to achieve the purpose of information processing (Shao, 2002).

2.2.3 Mathematical Statistics

Mathematical Statistics method is method that gathering statistics and analyzing of various causes of maritime accidents or the number of events being weighted, finally it obtains percentage of the total number of accidents of each accident cause. We need a certain number of samples and enough stable assessment results to achieve the assessment result when using mathematical statistical methods to assess. This approach has some limitations. It can only show the absolute value of percentage of the various causes that lead to accidents, but it does not reflect the correlation degree of various causes and accidents. In addition, mathematical statistics requires a lot of data, so the accumulation of data and accuracy of data is particularly important.

This paper adopts fuzzy comprehensive assessment method, and the details are to be introduced in the next section.

2.3 Fuzzy Comprehensive Assessment Method

2.3.1Overview of Fuzzy Comprehensive Assessment Method

The key step for Fuzzy Comprehensive Assessment is to determine fuzzy relationship, which is a special kind of fuzzy sets to determine. Fuzzy relation represented by fuzzy matrix can achieve the purposes of Fuzzy Comprehensive Assessment by the fuzzy matrix arithmetic. Fuzzy Comprehensive Assessment consists of three elements: factor set (all factors), assessment set (selected assessment index from factor set), single factor assessment. That is to say, we firstly need to identify the influencing factors, from which we can select the assessment index. Then we need to assess multiple factors and draw final conclusions. The basic steps are as follows:

(1) Establishing factor set

Combine each influencing factor into a set U， namely:

$$U = \{u_1, u_2, \cdots, u_n\}$$

Thereinto, $u_i (i = 1,2,\cdots,n)$, which are influencing factors.

(2) Establishing weight set

The degree of Importance of every influencing factors are not the same. There is a need for each one endowed with the corresponding factors weights (ie weights), and we need to create a factor weights set composition by each weight number, that is, fuzzy subsets of sets of factors , namely:

$$\tilde{A} = (a_1, a_2, \cdots, a_n)$$

Thereinto, $\tilde{A}$ is factorial power set consisting of each weight number;

$a_i (i = 1,2,\cdots,n)$ is a membership degree of factor u on A, it reflects the importance of various factors and usually meet the normalization and nonnegativity conditions,

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

(3) Establishing the assessment set

Assessment set is a set consisting of possible assessment results, which can be expressed as $V = \{v_1, v_2, \cdots, v_m\}$, element $V = \{v_1, v_2, \cdots, v_m\}$ is assessment results of each possible. Fuzzy assessment is obtained by an optimum assessment results from assessment set V.

(4) Single factor fuzzy assessment

Starting from a single factor that been assessed to determine the membership degree of judge object on elements of assessment set, called a single-factor fuzzy assessment. Assume judge object that being carried out from u_i of factor set, the membership degree of v_j of the jth is r_{ij}, the assessment result of u_i of the ith can be expressed as follow:

$$\widetilde{R_t} = (r_{t1}, r_{t2}, \cdots, r_{tm})$$

(5) Fuzzy Comprehensive assessment

We can get the multi-factor comprehensive assessment matrix according to the above single factor fuzzy assessment, namely:

$$\tilde{R} = \begin{bmatrix} \widetilde{R_1} \\ \widetilde{R_2} \\ M \\ \widetilde{R_n} \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \Lambda & r_{1m} \\ r_{21} & r_{22} & \Lambda & r_{2m} \\ & \Lambda & \Lambda & \\ r_{n1} & r_{n2} & \Lambda & r_{nm} \end{bmatrix}$$

Thereinto, $r_{ij} = \mu_R(u_i, v_j)$, $0 \leq r_{ij} \leq 1$ express that judge assessment obtain the degree of assessment result v_j considering u_i.

When the weight factor set $\tilde{A}$ and assessment matrix $\tilde{R}$ are known, we get fuzzy comprehensive assessment set $\tilde{B}$ in accordance with the fuzzy matrix multiplication, namely:

$$\tilde{B} = A \circ B = (a_1, a_2, \Lambda, a_n) \circ \begin{bmatrix} r_{11} & r_{12} & \Lambda & r_{1m} \\ r_{21} & r_{22} & \Lambda & r_{2m} \\ & \Lambda & \Lambda & \\ r_{n1} & r_{n2} & \Lambda & r_{nm} \end{bmatrix} = (b_1, b_2, \Lambda, b_m)$$

Thereinto, b_j called fuzzy comprehensive evaluation index, that is, taking into account all factors in the case, judge object carries out membership degree of the jth on assessment set V.

(6) The selected assessment results

We have already obtained the final assessment results of the assessment index through the above five steps. The following should be screened for these evaluation results, and mainly has following methods:

- Maximum membership degree method

  Considering corresponding assessment set V_j of the maximum assessment index $max_j\, b_j$ as assessment results

- Weighted average method

Taking b_j as the weights and carrying out weight average ,then we can regard value that obtained as assessment results, namely:

$$v = \frac{\sum_{j=1}^{m} b_j v_j}{\sum_{j=1}^{m} b_j}$$

If the assessment index b_j has been normalized, namely, $\sum_{j=1}^{m} b_j = 1$, then

$$v = \sum_{j=1}^{m} b_j v_j$$

- Fuzzy distribution method

Directly considering $\tilde{B}$ as assessment result, or regarding assessment index $\tilde{B}$ been normalized as assessment result, assuming $b = \sum_{j=1}^{m} b_j$, then

$$B' = \left(\frac{b_1}{b}, \frac{b_2}{b}, \Lambda, \frac{b_m}{b}\right) = (b_1', b_2', \Lambda, b_m')$$

In summary, this paper uses fuzzy comprehensive assessment model is as follows:

- Designing and determining the assessment index;
- Determining the assessment index weights;
- Determining the membership degree of each assessment;
- Determining the results of comprehensive assessment.

2.3.2 Reasons for the Selection of the Fuzzy Comprehensive Evaluation Method

First of all, we should make clear the characteristics of safety assessment of navigation environment. The system is a complex system, influenced by many factors, and the concept of each factor is fuzzy, so it is difficult to accurately quantify, and also classification criteria for each factor are not unified. Each factor restraints and influences each other, different emphases can obtained completely different assessment results. If we assess single factor, sometimes there are two kinds of different results on the same system, thus a comprehensive assessment of the system is needed to solve the problem of relationship between various factors. After clearing about problems influencing factors, we should also clearly realize that the concept of navigational environment safety concept is fuzzy, and the concepts of connotation and denotation of safety and dangers is unclear. The usual practice is using expert survey based on the experience; however, these experiences are often summed up from particular incidents, so universality has some problems, and these experiences are very difficult to be quantified.

In addition, we need to make clear the advantages and disadvantages of Fuzzy Comprehensive Assessment (Liu & Wu, 1998). First, Fuzzy Comprehensive Assessment is suitable for the quantitative evaluation of qualitative indexes, which is widely applied. Application of fuzzy comprehensive assessment can process quantitatively of complex large system existing in non-human added various fuzzy factors, so the evaluation results are more in line with the objective reality. Second, the Fuzzy Comprehensive Assessment results are usually unique. As far as an assessment of the same object is concerned, general results of the assessment are unique as long as the weight of evaluation factors is the same, synthesis operators are the same. Third, the fuzzy comprehensive evaluation mathematical model is simple, intuitive, and easy to operate. Fuzzy Comprehensive Assessment is not only used for the comprehensive evaluation of subjective indicators but also been used for the comprehensive assessment of objective indicators.

This thesis selects the Fuzzy Comprehensive Assessment method by combining the advantages and disadvantages of the characteristics of the navigation environmental safety assessment and Fuzzy Comprehensive Assessment.

Chapter 3 Environmental Safety Assessment Model of Fairway areas

3.1 Establishing Hydro Meteorological Factors and Membership Function of Each Indicator

3.1.1 Establishing Visibility and Membership Functions

3.1.1.1 The Definition of Visibility and Assessment Criteria

Visibility is an indicator of atmospheric transparency. It generally refers to that people with normal eyesight can see the object contour at the maximum distance at that weather conditions (Chen, 1999). Main factors affecting the visibility are rain, snow, fog, etc. in the fairway areas, Table 1 show visibility level under the influence of various factors.

Table 1 visibility scale table

Visibility level	Visibility （unit：km）	Description of visibility level	Description of weather conditions corresponds to each level
0	<0.05	poor visibility	dense fog
1	0.05-0.2		dense fogor fog storm
2	0.2-0.5		heavy fog or heavy snow
3	0.5-1.0	restricted visibility	fog or moderate snow
4	1.0-2.0		thin fog or snow storm
5	2.0-4.0	moderate visibility	slight snow, heavy rain ,thin fog
6	4.0-10.0		moderate rain, slight snow ,thin fog
7	10.0-20.0	good visibility	drizzle, sprinkle
8	20.0-50.0	very good visibility	fog water

9	>50.0	excellent visibility	clear air

The visibility is an important factor affecting the safety of navigation of the ship. We can consider the continuous days of visibility state for each year as assessment index of degree of risk in navigational safety assessment in fairway areas. Assessment index table is shown in Table 2.

Table 2 Evaluation standard of danger of visibility

Degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Poor visibility days / year	<10	10-20	20-30	30-40	>40

3.1.1.2 Membership Function of the Visibility

According to the analysis, membership function of visibility of the degree of risk will be determined as follows:

$$u_2^1(x) = \begin{cases} 0 & x \leq 140 \\ \frac{x-140}{20} & 140 < x < 160 \\ 1 & x \geq 160 \end{cases}$$

$$u_2^2(x) = \begin{cases} 0 & x \leq 90 \ or \ x \geq 160 \\ \frac{x-90}{20} & 90 < x \leq 110 \\ 1 & 110 < x \leq 140 \\ \frac{160-x}{20} & 140 < x < 160 \end{cases}$$

$$u_2^3(x) = \begin{cases} 0 & x \leq 50 \; or \; x \geq 110 \\ \frac{x-50}{20} & 50 < x \leq 70 \\ 1 & 70 < x \leq 90 \\ \frac{110-x}{20} & 90 < x < 110 \end{cases}$$

$$u_2^4(x) = \begin{cases} 0 & x \leq 20 \text{ or } x \geq 70 \\ \frac{x-20}{20} & 20 < x \leq 40 \\ 1 & 40 < x \leq 50 \\ \frac{70-x}{20} & 50 < x < 70 \end{cases}$$

$$u_2^5(x) = \begin{cases} 0 & x \geq 40 \\ \frac{40-x}{20} & 20 < x < 40 \\ 1 & x \leq 20 \end{cases}$$

3.1.2 Establishing Wind and Membership Functions

3.1.2.1 The Definition of Wind and Assessment Criteria

Wind has a huge impact on ship-operating and navigational safety, especially in the narrow fairways. Due to action of deflection of wind, the ship navigating in the fairway affected by strong winds will produce wind pressure, resulting in deflection of the ship, therefore, the ship underway will predict the wind pressure in advance in order to make the ship navigating in the plan routes. In addition, wind has a greater influence in shallow waters, sometimes it makes the ship run aground, or strand. Wind can be divided into different levels according to wind conditions, as shown in Table 3.

Table 3 wind scale table

Rank	Name	Wind velocity （m/s）	Sea condition
0	calm	0-0.2	calm
1	light wind	0.3-1.5	very smooth sea
2	breeze	1.6-3.3	Smooth sea
3	gentle breeze	3.4-5.4	slight sea， Crests begin to break
4	soft breeze	5.5-7.9	slight sea， half of Crest turn into white spray
5	cool breeze	8.0-10.7	moderate sea， Almost all white spray
6	strong breeze	10.8-13.8	Rough sea, white spray rise up
7	high wind	13.9-17.1	Very rough sea, droplets begin to form stripes along the direction
8	strong wind	17.2-20.7	Very rough sea， water surface Filled with droplets
9	Very strong wind	20.8-24.4	high sea, crest started shaking, tumbling
10	fierce wind	24.5-28.4	very high sea， large areas of White spray slashed by wind
11	storm wind	28.5-32.5	Abnormal very high sea， white spray completely cover the water surface
12	hurricane	32.6-36.9	precipitous sea， The sky is full of white spray and droplet

From the table 3 above, we may take wind of level 6 as a dividing line. Wind above level 6 can be divided into three grades: the strong breeze of level 6-7, strong wind of level 8-9 and the typhoon gale above level 10. We need to convert different wind levels into standard wind days (Michel, 2000). In assessing the impact of wind on the safety of navigation, we will consider wind with level 6 as standard wind which can be converted, standard wind formula is as follows:

The days of annual average standard wind = days annual average wind of level 6 +1.5 times (level 7 and above) days of the annual average number of wind.(Kobayashi & Tanaka, 1999)

The number of annual standard wind days are obtained by above formula can get the wind risk assessment criteria. Finally, we can finalize this wind risk assessment criteria, details you can see Table 4.

Table 4 the risk assessment standards of wind

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Standard wind days /year	<30	30-60	60-100	100-150	>150

3.1.2.2 Membership Function of Wind

Accordance with the above standards, the membership function of the wind is as follow:

$$u_2^1(x)=\begin{cases}0 & x\le 140\\ \frac{x-140}{20} & 140<x<160\\ 1 & x\ge 160\end{cases}$$

$$u_2^2(x)=\begin{cases}0 & x\le 90\ or\ x\ge 160\\ \frac{x-90}{20} & 90<x\le 110\\ 1 & 110<x\le 140\\ \frac{160-x}{20} & 140<x<160\end{cases}$$

$$u_2^3(x)=\begin{cases}0 & x\le 50\ or\ x\ge 110\\ \frac{x-50}{20} & 50<x\le 70\\ 1 & 70<x\le 90\\ \frac{110-x}{20} & 90<x<110\end{cases}$$

$$u_2^4(x)=\begin{cases}0 & x\le 20\ or\ x\ge 70\\ \frac{x-20}{20} & 20<x\le 40\\ 1 & 40<x\le 50\\ \frac{70-x}{20} & 50<x<70\end{cases}$$

$$u_2^5(x)=\begin{cases}0 & x\ge 40\\ \frac{40-x}{20} & 20<x<40\\ 1 & x\le 20\end{cases}$$

3.1.3 Establishment of Membership Function and Flow

3.1.3.1 The Concept of Flow and Assessment Criteria

Flow has a certain impact on safe navigation of the ships, which is mainly reflected in the impact on the rudder, and making the ship yawing. In a narrow fairway, it is likely to have the vessel wall effect because of the stream function. Two ships may make the vessels suction intensify because of the stream function resulting in collision. The role of flow on the ship includes two aspects: flow direction and flow velocity. When the ship navigating down along with the current, stopping performance will deteriorate; when ship under the role of cross flow is easy to yaw. With the increase of velocity of flow, the included angle between the bow and stern line becomes larger, resulting in an increase of flow pressure and making course-keeping ability deteriorate.

This paper will regard maximum flow velocity in fairway as the assessment index according to the literature, the assessment criteria shown in Table 5.

Table 5 the risk assessment standards of current

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Maximum flow velocity （kt）	<0.5	0.5-1.5	1.5-2.5	2.5-4.0	>4.0

3.1.3.2 Membership Function of Drift

In accordance with the above standards, membership function of drift and tidal is as follows:

$$u_3^1(x)=\begin{cases} 0 & x\le 3.8 \\ \frac{5x-19}{2} & 3.8<x<4.2 \\ 1 & x\ge 4.2 \end{cases}$$

$$u_3^2(x)=\begin{cases} 0 & x\le 2.3\ or\ x\ge 4.2 \\ \frac{10x-23}{4} & 2.3<x\le 2.7 \\ 1 & 2.7<x\le 3.8 \\ \frac{21-5x}{2} & 3.8<x<4.2 \end{cases}$$

$$u_3^3(x)=\begin{cases} 0 & x\le 1.3\ or\ x\ge 2.7 \\ \frac{10x-13}{4} & 1.3<x\le 1.7 \\ 1 & 1.7<x\le 2.3 \\ \frac{27-10x}{4} & 2.3<x<2.7 \end{cases}$$

$$u_3^4(x)=\begin{cases} 0 & x\le 0.3\ or\ x\ge 1.7 \\ \frac{10x-3}{4} & 0.3<x\le 0.7 \\ 1 & 0.7<x\le 1.3 \\ \frac{17-10x}{4} & 1.3<x<1.7 \end{cases}$$

$$u_3^5(x) = \begin{cases} 0 & x \geq 0.7 \\ \frac{7-10x}{4} & 0.3 < x < 0.7 \\ 1 & x \leq 0.3 \end{cases}$$

3.2 Each Index of Fairway Conditions and the Establishment of Membership function

3.2.1 The Fairway Width and Establishment of Membership Function

3.2.1.1 The Concept of Fairway Width and Assessment Criteria

According to the requirement of “Port general graphic design specification”, the fairway width mainly includes the following three kinds of width: track width, the surplus width between ships, the surplus width between ship and fairway bottom. Fairway width will directly affect the safe navigation of the ship: Collision rate between the fairway width and ships navigating in the fairway take two respective logarithmic, these two values are almost a linear relationship (Kuroda, 1981).

Different maneuverability of ships has different requirement on fairway width so that this assessment index of fairway width can be determined from this point of view, which can be taken as the ratio between the allowed average ship breadth value of specific port and narrowest value of specific fairway width. Specific criteria are shown in Table 6.

Table 6 the risk assessment standards of fairway width

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Fairway width	<0.3	0.3-0.5	0.5-0.8	0.8-1.0	>1.0

3.2.1.2 The Membership Function of Fairway Width

Accordance with the above standard, we can get the membership function of fairway width as follows:

$$u_4^1(x) = \begin{cases} 0 & x \leq 0.95 \\ 10x - 9.5 & 0.95 < x < 1.05 \\ 1 & x \geq 1.05 \end{cases}$$

$$u_4^2(x) = \begin{cases} 0 & x \leq 0.75 \ or \ x \geq 1.05 \\ 10x - 0.75 & 0.75 < x \leq 0.85 \\ 1 & 0.85 < x \leq 0.95 \\ 10.5 - 10x & 0.95 < x < 1.05 \end{cases}$$

$$u_4^3(x) = \begin{cases} 0 & x \leq 0.45 \ or \ x \geq 0.85 \\ 10x - 4.5 & 0.45 < x \leq 0.55 \\ 1 & 0.55 < x \leq 0.75 \\ 8.5 - 10x & 0.75 < x < 0.85 \end{cases}$$

$$u_4^4(x) = \begin{cases} 0 & x \leq 0.25 \ or \ x \geq 0.55 \\ 10x - 2.5 & 0.25 < x \leq 0.35 \\ 1 & 0.35 < x \leq 0.45 \\ 5.5 - 10x & 0.45 < x < 0.55 \end{cases}$$

$$u_4^5(x) = \begin{cases} 0 & x \geq 0.35 \\ \frac{7-10x}{4} & 0.25 < x < 0.35 \\ 1 & x \leq 0.25 \end{cases}$$

3.2.2 Fairway Depth and the Establishment of Membership Function

3.2.2.1 The Concept of Fairway Depth and Assessment Criteria

The waterway depth is another important factor affecting the safe navigation of the ship. If the ship is maneuvering in shallow water, the control performance will be severely limited, mainly as follows: speed decreasing, sliding and steering difficulties, the hull sinking intensified, being exacerbated by changes in the hull trim, ship severe vibration and so on.(Zhao, 2002) However, navigating in the water of same depth, ships with different draft will produce different effects. Therefore, this paper will consider the ratio of the actual depth and maximum draft of ship in fairway as standard value of assessment of fairway depth.

Table 7 the risk assessment standards of fairway depth

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Minimum water depth/ maximum draft that ships can pass through	>10	4-10	2.5-4	1.5-2.5	<1.5

3.2.2.2 Membership Function of Fairway Depth

In accordance with the above standards, you can get the membership function of fairway depth as follows:

$$u_5^1(x) = \begin{cases} 0 & x \geq 1.7 \\ \frac{17-10x}{4} & 1.3 < x < 1.7 \\ 1 & x \leq 1.3 \end{cases}$$

$$u_5^2(x) = \begin{cases} 0 & x \leq 1.3 \ or \ x \geq 2.7 \\ \frac{10x-13}{4} & 1.3 < x \leq 1.7 \\ 1 & 1.7 < x \leq 2.3 \\ \frac{27-10x}{4} & 2.3 < x < 2.7 \end{cases}$$

$$u_5^3(x) = \begin{cases} 0 & x \leq 2.3 \ or \ x \geq 4.2 \\ \frac{10x-23}{4} & 2.3 < x \leq 2.7 \\ 1 & 2.7 < x \leq 3.8 \\ \frac{21-5x}{2} & 3.8 < x < 4.2 \end{cases}$$

$$u_5^4(x) = \begin{cases} 0 & x \leq 3.8 \ or \ x \geq 10.2 \\ \frac{10x-38}{4} & 3.8 < x \leq 4.2 \\ 1 & 4.2 < x \leq 9.8 \\ \frac{51-5x}{2} & 9.8 < x < 10.2 \end{cases}$$

$$u_5^5(x) = \begin{cases} 0 & x \leq 9.8 \\ \frac{7-10x}{4} & 9.8 < x < 10.2 \\ 1 & x \geq 10.2 \end{cases}$$

3.2.3 Fairway Bending and Establishment of Membership Function

3.2.3.1 The Concept of Fairway Bending and Assessment Criteria

As we all know, the ship navigating in fairway bending has more difficult than ship navigate in the direct fairway. The ship will be limited by fairway size when navigating in the fairway bending corner. In addition, the incorrect flow will also affect the steering of ships.

As long as specific fairway are concerned, the fairway bending includes the number of turning points and each size of the steering angle turning points. The bigger steering angle is the greater impact it will have on ship's steering operation. Table 3.8 shows the risk assessment standards of fairway bending.

Table 8 the risk assessment standards of fairway bending

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Maximum steering angle	<15	15-30	30-45	45-60	>60

3.2.3.2 Membership Function of Waterway Fairway Bending

Accordance with the above standard, you can get membership function of fairway bending as follows:

$$u_6^1(x) = \begin{cases} 0 & x \leq 55 \\ \frac{x-55}{10} & 55 < x < 65 \\ 1 & x \geq 65 \end{cases}$$

$$u_6^2(x) = \begin{cases} 0 & x \leq 40 \ or \ x \geq 65 \\ \frac{x-40}{10} & 40 < x \leq 50 \\ 1 & 50 < x \leq 55 \\ \frac{60-x}{10} & 55 < x < 60 \end{cases}$$

$$u_6^3(x) = \begin{cases} 0 & x \leq 25 \ or \ x \geq 50 \\ \frac{x-25}{10} & 25 < x \leq 35 \\ 1 & 35 < x \leq 40 \\ \frac{50-x}{10} & 40 < x < 50 \end{cases}$$

$$u_6^4(x) = \begin{cases} 0 & x \leq 10 \ or \ x \geq 35 \\ \frac{x-10}{10} & 10 < x \leq 20 \\ 1 & 20 < x \leq 25 \\ \frac{35-x}{10} & 25 < x < 35 \end{cases}$$

$$u_6^5(x) = \begin{cases} 0 & x \geq 20 \\ \frac{20-x}{10} & 10 < x < 20 \\ 1 & x \leq 10 \end{cases}$$

3.2.4 Obstacle and Establishing of Membership Functions

3.2.4.1 The Concept of Obstruction and Assessment Criteria

There may be obstacles in fairway or around fairway when ships navigating in the fairway, these obstacles will restrict the maneuvering of ships and also threaten the safe navigation of ships. Obstacles affecting the maneuvering of ships that navigate in fairway are mainly reflected in the number of obstacles and distance between obstacles and fairway centerline. This article will consider the distance between obstacles and fairway as assessment standard of safety influence by obstacles on fairway, specific standards see table 9 (Inoue, 1994).

Table 9 the risk assessment standards of obstacle

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
The distance from obstacle to fairway（m）	>200	100-200	50-100	20-50	<20

3.2.4.2 Membership Function of Obstacle

In accordance with the above standard, you can get the membership function of obstacles as follows:

$$u_7^1(x)=\begin{cases}0 & x\geq 30\\ \frac{x-10}{20} & 10<x<30\\ 1 & x\leq 10\end{cases}$$

$$u_7^2(x)=\begin{cases}0 & x\leq 10\ or\ x\geq 60\\ \frac{x-10}{20} & 10<x\leq 30\\ 1 & 30<x\leq 40\\ \frac{60-x}{20} & 40<x<60\end{cases}$$

$$u_7^3(x)=\begin{cases}0 & x\leq 40\ or\ x\geq 110\\ \frac{x-40}{20} & 40<x\leq 60\\ 1 & 60<x\leq 90\\ \frac{110-x}{20} & 90<x<110\end{cases}$$

$$u_7^4(x)=\begin{cases}0 & x\leq 90\ or\ x\geq 210\\ \frac{x-90}{20} & 90<x\leq 110\\ 1 & 110<x\leq 190\\ \frac{210-x}{20} & 190<x<210\end{cases}$$

$$u_7^5(x) = \begin{cases} 0 & x \leq 190 \\ \frac{7-10x}{4} & 190 < x < 210 \\ 1 & x \geq 210 \end{cases}$$

3.3 Traffic Flow Factors and the Establishment of Assessment Index

3.3.1 The Concept of Traffic Flow and Assessment Criteria

The impact of traffic flow on navigational safety assessment on ships in fairway areas mainly manifested in traffic volume. Traffic flow mainly refers to ships that pass through one location within unit time, which indicate the most basic measurement of maritime traffic lively.(Wu, 1993). Traffic flow data are relatively easy to obtain in various data of marine traffic engineering, from which we can clearly see the degree of busy and scale of the marine traffic, in addition, the degree of traffic risk and degree of traffic congestion in the water area will be presented more intuitive, and can reflect the degree of risk of fairway.

The density of traffic flow will bring some pressure to ship operators, the greater the density the fairway is , the worse the level of safety the shipping operators have, and also bring greater psychological pressure to ship operator. This paper selects traffic flow factors as the assessment index is also based on this reason. Specific assessment criteria is shown in Table 10.

Table 10 the risk assessment standards of traffic volume

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
Traffic flow （Ship / day）	<10	10-20	20-40	40-80	>80

3.3.2 Membership Function of Traffic Flow

In accordance with the above standards, you can get the membership function of traffic flow as follows:

$$u_8^1(x) = \begin{cases} 0 & x \leq 78 \\ \frac{x-78}{4} & 78 < x < 82 \\ 1 & x \geq 82 \end{cases}$$

$$u_8^2(x) = \begin{cases} 0 & x \leq 38 \; or \; x \geq 82 \\ \frac{x-38}{4} & 38 < x \leq 42 \\ 1 & 42 < x \leq 78 \\ \frac{82-x}{4} & 78 < x < 82 \end{cases}$$

$$u_8^3(x) = \begin{cases} 0 & x \leq 18 \; or \; x \geq 42 \\ \frac{x-18}{4} & 18 < x \leq 22 \\ 1 & 22 < x \leq 38 \\ \frac{42-x}{4} & 38 < x < 42 \end{cases}$$

$$u_8^4(x) = \begin{cases} 0 & x \leq 8 \; or \; x \geq 22 \\ \frac{x-8}{4} & 8 < x \leq 12 \\ 1 & 12 < x \leq 18 \\ \frac{22-x}{4} & 18 < x < 22 \end{cases}$$

$$u_8^5(x) = \begin{cases} 0 & x \geq 12 \\ \frac{7-10x}{4} & 8 < x < 12 \\ 1 & x \leq 8 \end{cases}$$

3.4 Traffic Management Factors and the Establishment of Assessment Index

3.4.1 The Concept of Traffic Management Factor and Assessment Criteria

Systems engineering considers “people – environmental – management” as a whole, thus, so in the field of safety assessment, the growing importance of management factors are highlighted. Management factors are placed in very important position by many concepts proposed by FSA (Flag State Assessment) in maritime Comprehensive assessment.

The following are about various aspect of fairway management:

(1) Navigational aids

Navigational aids include channel marking, bear marking, obstacle marking, bacon etc. (Guo, 2009). Navigational aids provide positioning function for ships and also indicating a hazardous area. Therefore, the functional reliability of aids to navigation directly affects the safe navigation of the ship.

(2) Vessel Traffic Organization

Maritime transportation and land transportation have some similarities both need some rules and the management and guidance of the relevant departments. The department responsible for vessel traffic management is VTS (Vessel Traffic Services) center of Maritime Bureau, VTS center can monitor the ship dynamic through the radar, and correctly guide the ship import and port operation, anchoring operation and organization of the ship traffic flow after obtaining dynamic information of the ship out of port, wharf, pilot station information as well as other relevant information. This requires the related personnel on duty to be conscientious and responsible, and they need to timely report relevant departments in case of emergencies and coordination with these relevant departments to deal with the emergency.

As long as the impact of traffic management factors on safety assessment are concerned, this paper uses the complete rate of traffic management as the assessment index, which involves two major aspects the degree of perfection of navigational facilities and the efficiency of VTS center management: The paper uses the degree of perfection of navigational aids as assessment index of the complete rate of navigational facilities, that is, navigational aid of the fairway area can be expressed by the ratio of the total water area that is covered with navigational aids and total area of the fairway area.

With regard to the efficiency of VTS center management, many factors are involved in and difficult to quantify, thus, it is just considered as a reference. The paper put the two together and get the assessment of traffic management factors (In order to ease of subsequent calculations, here will be 100% credited to 100, 95% recorded as 95, other percentage conversion method are analogous), Specific assessment criteria are shown in Table 11.

Table 11 the risk assessment standards of traffic management

The degree of risk	Lower degree of risk	Low degree of risk	General low degree of risk	High degree of risk	Higher degree of risk
complete rate of traffic management	95-100	90-95	85-90	80-85	<80

3.4.2 Membership Function of the Traffic Management Factors

In accordance with the above standard, you can get the membership function of traffic management factors as follows:

$$u_9^1(x) = \begin{cases} 1 & x \le 78 \\ \frac{82-x}{4} & 78 < x < 82 \\ 0 & x \ge 82 \end{cases}$$

$$u_9^2(x) = \begin{cases} 0 & x \le 78 \ or \ x \ge 87 \\ \frac{x-78}{4} & 78 < x \le 82 \\ 1 & 82 < x \le 83 \\ \frac{87-x}{4} & 83 < x < 87 \end{cases}$$

$$u_9^3(x) = \begin{cases} 0 & x \le 83 \ or \ x \ge 92 \\ \frac{x-83}{4} & 83 < x \le 87 \\ 1 & 87 < x \le 88 \\ \frac{92-x}{4} & 88 < x < 92 \end{cases}$$

$$u_9^4(x) = \begin{cases} 0 & x \leq 88 \; or \; x \geq 97 \\ \frac{x-88}{4} & 88 < x \leq 92 \\ 1 & 92 < x \leq 93 \\ \frac{97-x}{4} & 93 < x < 97 \end{cases}$$

$$u_9^5(x) = \begin{cases} 0 & x \leq 98 \\ \frac{102-x}{4} & 98 < x < 102 \\ 1 & x \geq 102 \end{cases}$$

3.5 Fuzzy Comprehensive Environmental Assessment Model of Fairway Area

3.5.1 Establishment of the Fuzzy Comprehensive Evaluation System

Through the above analysis, we can get the comprehensive evaluation method of this paper using the two stage fuzzy comprehensive assessment, relationship between each level is shown in Figure 1

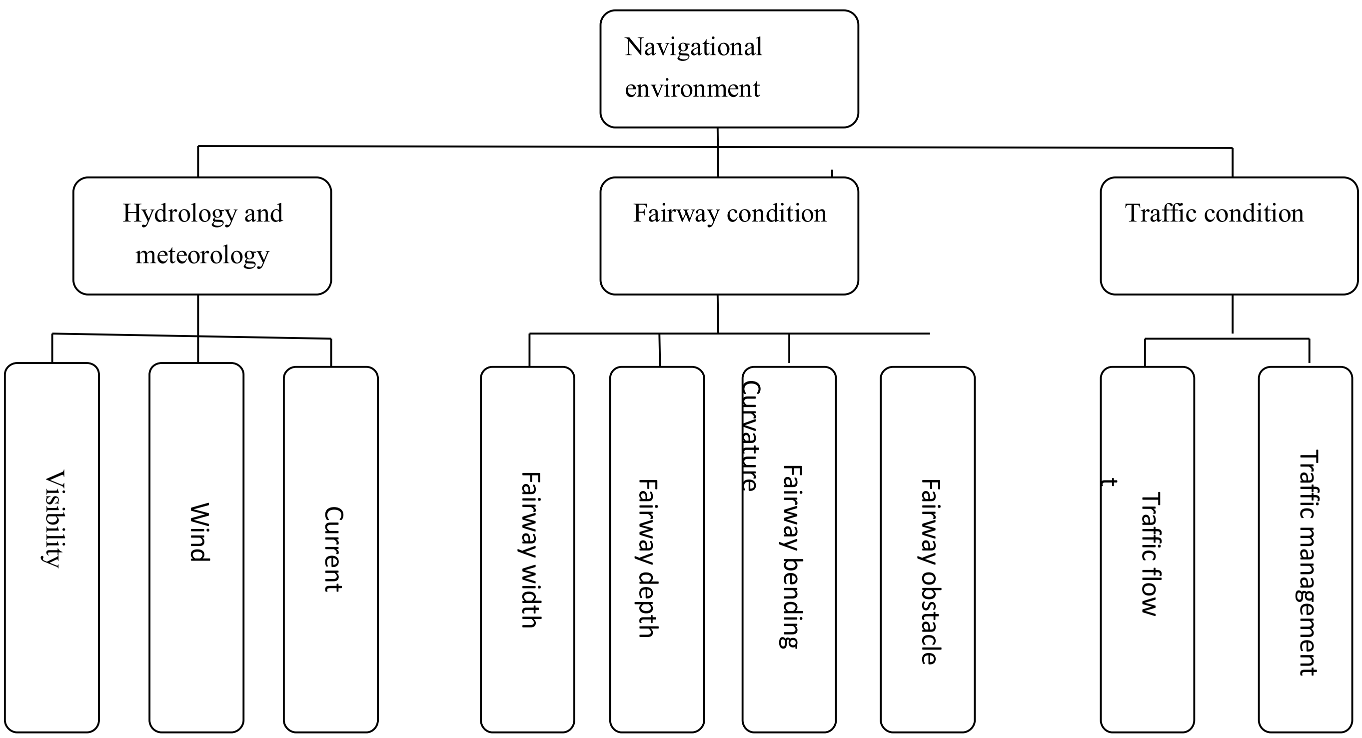

Figure 1 Dalian Beiliang Port area navigation safety assessment system

3.5.2 Establishment of the Factor Set

According to the multi-level fuzzy comprehensive assessment steps, factors set of every assessment factor need to be established after the establishment of the hierarchy of assessment factors.(Hu, 2010) The first level of factors set are as follows:

The safety of navigational environment = {hydrology and meteorology, fairway conditions, traffic conditions}, namely:

$$\mathrm{U} = \{\mathrm{u}_1, \mathrm{u}_2, \mathrm{u}_3\}。$$

The second level of factor set are as follows:

Hydrological and meteorological= {visibility, wind, drift}, namely:

$$\mathrm{u}_1 = \{\mathrm{u}_{11}, \mathrm{u}_{12}, \mathrm{u}_{13}\};$$

Fairway conditions={fairway width, fairway depth, fairway bending, obstacle in fairway}, namely:

$$\mathrm{u}_2 = \{\mathrm{u}_{21}, \mathrm{u}_{22}, \mathrm{u}_{23}, \mathrm{u}_{24}\}$$

Management conditions={Traffic flow, traffic management}, namely:

$$\mathrm{u}_3 = \{\mathrm{u}_{31}, \mathrm{u}_{32}\}。$$

3.5.3 Establishment of the Assessment Set

Chapter 2 has discussed about influencing factors, of which assessment standard can be divided into five levels, that is, lower degree of risk, low degree of risk, general low of degree of risk, high degree of risk, and higher degree of risk, Accordingly, we can create assessment set V={Lower degree of risk, Low degree of risk, General low of degree of risk, High degree of risk, Higher degree of risk},namely:

$$V = \{v_1, v_2, v_3, v_4, v_5\}$$

3.5.4 Establishment of the Weight Set

There are many kinds of determination methods of Weight value, which mainly include subjective assignment method, objective valuation method and the combination assignment method (Zhu, 2005). Some common subjective assignment methods are subjective assignment AHP, and expert judgment method; some common objective assignment methods are the coefficient of variation, principal component analysis.

These methods have advantages and disadvantages. The professional knowledge of each expert in expert assignment method have great differences, and entropy method and the results obtained by experts are less stable; objective assignment method has strong dependence on samples, as different sample will obtain different weight value. Analytic Hierarchy Process (AHP) is a simple method to make the decision of some complex and fuzzy problem, the method is especially suitable for the analysis of quantitative problems (Zhu, 2005). The core function of this method is determining the weight of factor, and the weight of factor is a fuzzy set. AHP has many advantages: first, it can simulate human decision-making process and combine quantitative and qualitative analysis to some extent; second, it can reduce the impact of subjective factors and make the evaluation results more objective (Michel, 2000).

To sum up, this paper uses AHP to determine the weight of each factor value. The method of determining the weight factors set is mainly divided into two steps: the establishment of judgment matrix and consistency test (Liu & Wu, 1998).

The biggest difficulty is that these weight values are difficult to quantify, when in determining each factor in the proportion of the entire evaluation system. In addition, when there are many influence factors, directly considering the degree of influence of each factor in whole assessment system, often appear inconsistent situation between the degree of influence value proposed by decision makers and the degree of importance value that decision makers believe in reality because of not comprehensive consideration and difficulty to reconcile the severity, or even there are a group of conflicting data proposed by decision makers. The solution to this problem is to establish judgment matrix, obtain the relatively objective weight vector after comparing with each other. The steps determining judgment matrix are as follows:

Step 1:

Seting n factors for comparison $X = \{x_1, x_2, \cdots, x_n\}$, we can use a_{ij} to express the ratio of each factor(x_i and x_j) and the overall effect sizes, and the comparison result is manifested with the matrix $A = (a_{ij})_{n \times n}$. The matrix is the judgment matrix. Judgment matrix A should satisfy:

(1) $a_{ij} > 0$; (2) $a_{ji} = \frac{1}{a_{ij}}(i, j = 1,2, \cdots, n)$; (3) $a_{ii} = 1, (i = 1,2, \cdots, n)$。

The value is used for Saaty's 1-9 dial, and its specific meaning is shown in Table 12.

Table 12 1-9 Dial method

dial	meaning
1	Two factors have same importance after comparing with each other.
3	The former is slightly important than the latter after comparing with each other.
5	The former is obviously important than the latter after comparing with each other.
7	The former is very important than the latter after comparing with each other.
9	The former is extremely important than the latter after comparing with each other.
2,4,6,8	The above intermediate value of adjacent judgment.
reciprocal	If the importance ratio of element x_i and x_j is a_{ij}, then the importance ratio of x_j and x_i is $a_{ij} = \frac{1}{a_{ji}}$.

Step 2: calculating the weight value of each assessment index according to the judgment matrix.

(1) The n-column vectors of judgment matrix A will be normalized, namely

$$(2)\ \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad (i,j = 1,2,\cdots,n) \tag{3.46}$$

(3) Calculating arithmetic mean of every row vector normalized after been normalized and considering these approximate values as weight vector, namely w_i

$$w_i = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad i = 1,2,\cdots,n \tag{3.47}$$

Step 3: consistency test

(1) calculating consistency index CI

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{3.48}$$

Thereinto, λ_{max} is the maximum characteristic root of judgment matrix。

(2) Finding the corresponding average random consistency index, values given by Saaty are shown in Table 13.

Table 13 Average random consistency index

n	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41
n	9	10	11	12	13	14	15	
RI	1.46	1.49	1.52	1.54	1.56	1.58	1.59	

(3) calculating consistency ratio CR

$$CR = \frac{CI}{RI} \tag{3.49}$$

When CR<0.10, the consistency of human judgment matrix is acceptable, or deal with the judgment matrix that we need to make adjustment.

A total of 85 questionnaires were distributed, 67 were recovered, of which 61 were valid. Among them, 13 of them are pilots, 21 of them are Captains, 14 of them are chief officer, 13 of them are teachers in navigation colleges. Combined with the above method, we can obtain the weight of each influencing factors through statistical analysis on the data of questionnaire:

First level weight value of assessment index:

$$\lambda_{max} = 2.9640; \quad CR = 0.0165 < 0.10;$$

$$A = (0.1283, 0.4905, 0.3812)$$

Table 14 the weight of the first level

Assessment index	Hydrology and meteorology	Fairway condition	Traffic condition
Weight value	0.1283	0.4905	0.3812

Second level weight value of assessment index of hydro meteorological factors:

$$\lambda_{max} = 3.0640; \quad CR = 0.0125 < 0.10;$$

$$A_1 = (0.5623, 0.2513, 0.1874)$$

Table 15 the weight of hydro meteorological

Hydrological and meteorological	visibility	wind	flow
Weight value	0.5623	0.2513	0.1874

Second level weight value of assessment index of fairway condition:

$$\lambda_{max} = 3.9230; \quad CR = 0.0215 < 0.10;$$

$$A_2 = (0.1524,0.4613,0.2517,0.1346)$$

Table 16 the weight of fairway

Fairway condition	Fairway width	Fairway depth	Fairway bending	Obstacle in fairway
Weight value	0.1524	0.4613	0.2517	0.1346

Second level weight value of assessment index of traffic condition:

$$\lambda_{max} = 3.5214; \quad CR = 0.0201 < 0.10;$$

$$A_3 = (0.4816,0.5184)$$

Table 17 the weight of traffic condition

Traffic condition	Traffic flow	Traffic management
Weight value	0.4816	0.5184

After calculation, the overall ranking $CR = 0.0131 < 0.10$, the judgment matrix is acceptable.

3.5.5 Establishment of Fuzzy Comprehensive Assessment Model

We need to carry out a comprehensive assessment and second level comprehensive assessment after establishing the factor set, assessment set and weight set.

3.5.5.1 First level Comprehensive Assessment

Carrying out assessment on each element of each class, assuming the first level single element comprehensive matrix of each element is R_i, then fuzzy comprehensive assessment of I class is $B_i = A_i \circ R_i$.

3.5.5.1 Second Level Comprehensive Assessment

The single element assessment matrix of two level fuzzy comprehensive assessment is a first level fuzzy comprehensive assessment matrix :

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_s \end{bmatrix} = \begin{bmatrix} A_1 \circ R_1 \\ A_2 \circ R_2 \\ \vdots \\ A_S \circ R_S \end{bmatrix} \tag{3.50}$$

Thus, Second level comprehensive assessment is

$$B = A \circ R = A \circ \begin{bmatrix} A_1 \circ R_1 \\ A_2 \circ R_2 \\ \vdots \\ A_S \circ R_S \end{bmatrix} = (b_1, b_2, \cdots, b_p) \tag{3.51}$$

Finally, we can get the final results of the assessment according to the principle of maximum membership degree.

Chapter 4 Safety Assessment on Navigational Environment of Dalian Beiliang Port Water Area

4.1 Overview of Navigational Environment in Dalian Beijiang Port

Beiliang Port is located to the west of Dagu mountain Peninsula of Dalian Bay in Liaodong Peninsula (latitude 38 ° 58'5 ", longitude 121 ° 48'5"), which is across the sea from Dalian. Beiliang Port has good natural conditions, not silt and not frozen, the condition of natural covering is extremely advantageous, average water depth is -12.5m and also is a natural deep water harbor.

4.1.1 Hydrological and Meteorological Conditions of Dalian Beiliang Port

Meteorological data of Dalian Bay can be gotten from Dalian Meteorological Observatory, address: N3901, E12143, elevation of 62.4m, located in King County, beach of Dalian Nanshan Town, which is Dalian city meteorological observation station before 1969.

4.1.1.1 Temperature

Annual average temperature is 10.2 ℃, the highest temperature in August,24.1℃, and the lowest in January, -5.4 ℃, normal extreme maximum temperature is 34.4 ℃, which appeared in the August 1, 1968, extreme minimum temperature -19.1 ℃, appeared in 1966 on January 19th and the 20th. Annual temperature range is 29.5 ℃.

4.1.1.2 Precipitation

The average annual rainfall of waters for many years is 639.6mm, Thereinto, the largest rainfall of waters in these years is 938.9mm, the smallest rainfall of waters in these years is 318.7mm, and maximum daily rainfall is 149.4mm, appeared in August 21, 1967. Significant precipitation changes with the seasons. The rainfall of summer (June, July and August) is the largest in a year, which is 421.5mm, accounting for 66%. The rainfall of July is 195.7mm, accounting for 31% of the year, ranking the first of each month. The rainfall of winter (November, December, January, February) is the least in a year, which is 51.0mm, accounting for only 8% of the year. Spring and autumn have a similar rainfall.

4.1.1.3 Wind

The annual average wind speed of sea waters is 5.3m / s. Maximum wind speed is 34m / s, the direction is N, and it appeared three times in total, on November 22, 1960, April 6, 1964 and March 15, 1965. For the full year, N wind is very common, with a frequency of 19%; the second is SE wind, with a frequency of 12%. Wind has obvious seasonal variation. In summer prevails SE wind, frequency of which is 26%; N wind in autumn increases, and become the dominant wind direction, and its frequency is 22%. N direction occupies the absolute superiority, frequency up to 30%. In spring, SE wind gradually increases, the frequency is 14%. Annual average wind (level 8) days is 70.4 days, which occur most in winter, 34.1 days, accounting for 48%; the minimum is in summer, for 5.7 days, accounting for only 8%.

4.1.1.4 Typhoon

Typhoon affects the local area mainly in July to September, which has the most times in August. According to statistics of typhoon affecting the local area, there are 1.1 times in average, the year for the most times that typhoon occurred is 1964,which happened 4 times, The time for typhoon directly passing through the region annually is 0.51 times, Maximum wind of the typhoon that largely impacts on the region is up level 12 or more, lasting longer than 18 hours.

4.1.1.5 Fog conditions

Foggy days in this sea waters mostly concentrate in April to July. The foggy days of visibility less than 1km (including overcast and rain and snow) in Dalian Beiliang Port area is 55 days, accounting for 68.7% of the year, The number of days of the average delay of fog is 10.3 hours. The days of delaying for more than 12 hours account for 33.1% of the year, and the days of delaying for 6-11 hours account for 37.3%. The number of days affecting departure of ships approximately is 15 days.

4.1.1.6 Humidity

Annual average relative humidity is 68%. Monthly average relative humidity variation is obvious. Maximum humidity occurs in July, accounting for 89% of the year. Subsequently, the humidity decline monthly. The humidity of January is the smallest in the year, which occupies 57%, and then increases month by month. Monthly extreme minimum humidity is 47%, which appeared in March 1965.

4.1.1.7 Tides

The sea area is attributed to regular semidiurnal tide. We can use existing statistical data of Beiliang Port as Tidal data. But the existing data of Beiliang Port is not sufficient. This region in Dalian Port has very rich measured data. Based on the measured data synchronization comparison, we can find that the distance difference of mean sea level between Dagushan and Dalian port is 2cm, and the distance difference of mean tide level between Dagushan and Dalian port is 4cm. You can use can calculate tidal level by using the Dalian Port tidal data after comparing argument. The characteristic value of tidal level is as follow: the highest tide level is 4.10m (the highest tide level is affected by typhoon 9216 is 4.5m), the lowest tide level is -1.16m, the mean high level is 2.67m, mean low tide level is 0.58m, the average tidal range is 2.09m, and the mean sea level is 1.65m.

4.1.1.8 Wave

According to actual statistics from 1963 to 2005, the range of average height of wave in Beiliang Port range is 0.4m to 0.5m, and the wave is especially much higher from July to November. The maximum wave height is 8.0m (appeared in August,1972), the maximum wave height from 3.1m to the 4.6m. Wave direction is the SW, frequency of 14%, followed by SSE and SE, whose frequency is 13% and 10% respectively; the strong wave direction is SW.

4.1.1.9 Currents

The ocean current in Dalian Bay is dominant by tide current. The flood current mainly flows into the bay from Sanshandao waterways, and the ebb current mainly flows from Sanshandao to Huangbaizui waterway. The outflow direction is south of Sanshandao waterway and southeast of Huangbaizui waterway, namely, flood current and ebb current are in opposite direction, with the flood current slightly stronger than the ebb current, and they lasted roughly for equal time.

The area is restricted by the tidal current of coast, islands and submarine topography, the trend of mainstream of each station. Layer flood and ebb tidal current are almost consistent with that of isobath or shoreline. Flow rate value is small. The flow rate of maximum flood current is 0.21m/s, and flow rate of maximum ebb current is 0.35m/s.

The statistics of measured data shows that the ordinary wave direction in this area is in SW, the frequency was 8.04%; the second ordinary wave direction is NNW and SE, frequency was 6.81% and 6.65% respectively.

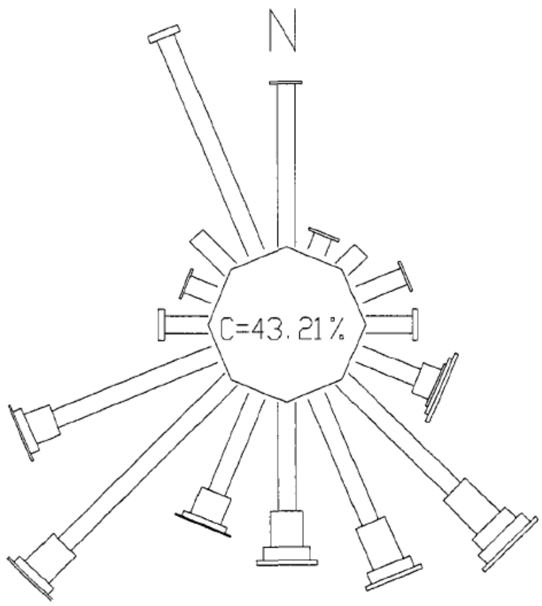

Figure 2 the roses of wave

4.1.1.10 Sea Ice

Beiliang Port is located at the southern tip of Liaodong Peninsula. This sea area has no serious glacial period. Beiliang Port stretches into interior. There are winter icing phenomenons with different degree in every winter. Glacial period measured is two months from January to March, the maximum thickness of the fixed ice inshore is 62cm, maximum stack height of ice inshore is 2m.

4.1.2 Overview of Dalian Beiliang Port

Dalian port current fairways mainly are Big Sanshan waterway, Small Sanshan waterway, Dagang fairway, Ganjingzi fairway, Xianglujiao fairway, the monk island fairway, Beiliang fairway, COSCO Shipyard fairway, petrochemicals (deep) fairway, 300,000-ton of ore fairway, 300,000-ton crude oil fairway, catfish Bay (Newport) and Dayao bay fairway. Beiliang Port fairway is located in the east of H2 light buoy. The fairway is about 1600 meters long, 250 meters wide, 13.8 meters water depth. After proceeding through Big Sansan waterway, ships will turn into the main fairway of Beiliang Port when they are approaching H2 buoy. With regard to ships that entering (or leaving) the Beiliang Port, they should consider influence of traffic in the fairway - that lots of ships enter or leave the Beiliang Port, because this kind of influence is relatively complex, it also needs to consider the each zone and fairway condition of Beiliang Port. Hence we only consider the Beiliang Port fairway. There are no obstructions in fairway. As far as the area with shallow depth outside the outer edge of fairway are concerned, we temporarily carry out assessment on this area of locating obstructions.

4.1.3 Traffic Flow Situation of Dalian Beiliang Port

With the increase of Beiliang Port cargo throughput, the number and tonnage of ship is also increasing. There were 2060 vessel-times in 2010, of which 1,661 vessel-times in ships below 5,000 tons, accounting for 80.6% of the total amount, 174 vessel-times in ships between 5,000-9,999 tons, accounting for 8.4% of the total amount; 125 vessel-times in ships between 12-29 thousand tons; 28 vessel-times in ships between 30-49 thousand tons; 68 vessel-times in ships between 50-70 thousand tons; 4 vessel-times in ships with 70 thousand tons, the largest ship that arrived at Beiliang Port was a ships of 100 thousand tons. Especially, 1,775 vessel-time in bulk grain ships, distribution of tons class and the overall situation is basically the same, 1,431 vessel-times in ships below 5000 tons, accounting for 80.6% of the total grain ship; 157 vessel-times in ships between 5,000-9,999 tons, accounting for 8.8% of the total grain ships; 89 vessel-times in ships between 10-29 thousand tons; 27 vessel-times in ships between 30-49 thousand tons; 67 vessel-times in ships between 50-70 thousand tons; 4 vessel-times in ships with 70 thousand tons. Comparison of statistical data of ships arriving at Beiliang Port over years show that port throughput increased year by year, but the total number of arriving ships decreased, and the increase of ship tonnage indicates that arriving ships are becoming larger.

The north-south traffic flow is more concentrated in Big Sansan waterway, the daily average flow is about 90 vessel-times, and the peak of daily traffic flow of ships navigating north and south reachs more than 100 second.

4.1.4 Overview of Dalian Beiliang Port Traffic Management

Navigation marks of Dalian Beiliang Port water area are under the jurisdiction of Maritime Bureau of Navigation Marks, With the continuous development and construction of Dalian port, waterway construction has been relatively complete, as well as aids to navigation, navigation equipment and other navigational facilities. The setting of navigation marks in fairway has basically guaranteed that the passing ships enter or leave the fairway safely. The construction of water traffic management system of Dalian Maritime Bureau (VTS) started early, which has built control center and several traffic control radar station. Monitoring range of Beiliang radar station can cover the waters where ships entering or leave the fairway and also can satisfy the safety requirements of ships going in or out of port and berthing.

4.2 Fuzzy Comprehensive Assessment on Safety of Navigational Environment in Dalian Beiliang Port

According to the description of navigable waters of Dalian Beiliang Port fairway in section 4.1, we can get the value of each assessment index. Specific values are as shown in table 18.

Table 18 objective index value assessment

Assessment index	Measure method of assessment index	assessment index value
visibility	poor visibility days/year	55
Wind	Standard wind days/year	32
Drift	The maximum velocity in fairway（knots）	1.5
Width of fairway	The ratio of the average breadth of the ship and the narrowest value width of specific fairway	0.59
Depth of fairway	The ratio of actual depth of fairway and maximum draft of ships navigating in fairway	2.1
Fairway bending	The maximum steering angle (degrees)	30
Obstacle in fairway	Distance to obstacles and fairway (meters)	125
Traffic flow	Traffic flow（vessel/day）	6
Traffic management	Complete rate of traffic management	95

According to fuzzy comprehensive assessment model that setting up in chapter three, we can get the fuzzy assessment vector of each factor after obtaining each assessment index value:

$$U_1 = (0 \quad 0 \quad 0 \quad 0 \quad 1)$$
$$U_2 = (0.4 \quad 0.6 \quad 0 \quad 0 \quad 0)$$
$$U_3 = (0 \quad 0.5 \quad 0.5 \quad 0 \quad 0)$$
$$U_4 = (0 \quad 0 \quad 1 \quad 0 \quad 0)$$
$$U_5 = (0 \quad 0 \quad 0 \quad 1 \quad 0)$$
$$U_6 = (0 \quad 0.5 \quad 0.5 \quad 0 \quad 0)$$
$$U_7 = (0 \quad 1 \quad 0 \quad 0 \quad 0)$$
$$U_8 = (1 \quad 0 \quad 0 \quad 0 \quad 0)$$
$$U_9 = (0 \quad 0.5 \quad 0.5 \quad 0 \quad 0)$$

Hydrological and meteorological factors assessment vector:

$$B_1 = A_1{}^\circ R_1 = (0.5623, 0.2513, 0.1874)^\circ \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix}$$
$$= (0.5623, 0.2513, 0.1874)^\circ \begin{bmatrix} 0 & 0 & 0 & 0 & 1 \\ 0.4 & 0.6 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \end{bmatrix}$$
$$= (0.1005, 0.2445, 0.0937, 0, 0.5623)$$

The assessment vector of fairway condition:

$$B_2 = A_2{}^\circ R_2 = (0.1524, 0.4613, 0.2517, 0.1346)^\circ \begin{bmatrix} U_4 \\ U_5 \\ U_6 \\ U_7 \end{bmatrix}$$
$$= (0.1524, 0.4613, 0.2517, 0.1346)^\circ \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$
$$= (0, 0.2604, 0.2783, 0.4613, 0)$$

The assessment vector of traffic situation :

$$B_3 = A_3{}^\circ R_3 = (0.4816, 0.5184)^\circ \begin{bmatrix} U_8 \\ U_9 \end{bmatrix}$$

$$= (0.4816, 0.5184)^\circ \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \end{bmatrix}$$

$$= (0.4816, 0.2592, 0.2592, 0, 0)$$

The assessment vector of safety of navigational environment in Dalian Beiliang Port water area:

$$B = A^\circ R = (0.1283, 0.4905, 0.3812)^\circ \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix}$$

$$= (0.1283, 0.4905, 0.3812)^\circ \begin{bmatrix} 0.1005 & 0.2445 & 0.0937 & 0 & 0.5623 \\ 0 & 0.2604 & 0.2783 & 0.4613 & 0 \\ 0.4816 & 0.2592 & 0.2592 & 0 & 0 \end{bmatrix}$$

$$= (0.1965, 0.2579, 0.2473, 0.2263, 0.0721)$$

In accordance with the principle of maximum degree of membership, the risk of Dalian Port Beiliang Port navigation environment is low risk, which can basically meet the demand of safety of navigation.

Chapter 5 Conclusion

Before writing this article, I read a lot of materials, including: assessment method of Beiliang Port, Dalian hydrological and meteorological and fairway conditions, and questionnaires, which provides sufficient data and basis for the writing of this article. Based on these preliminary work, we can establish a fuzzy comprehensive assessment model on environmental safety in navigable waters after conducting in-depth theoretical analysis and apply this model to conducted a comprehensive assessment on Dalian Beiliang Port area. Assessment results basically consistent with the actual navigation condition, which can provide a reference for the relevant departments.

In this paper, it may has great subjectivity for each factor setting because of the lack of experience. In addition, in dealing with the factor of complete rate of traffic management, treatment method is not very reasonable, these all need to gradually improved in the future's work and study.

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