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Safety assessment of Qinhuangdao anchorage

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SAFETY ASSESSMENT OF QINHUANGDAO ANCHORAGE

By

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DECLARATION

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

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

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ABSTRACT

Title of the research paper: **Safety assessment of Qinhuangdao anchorage**

Degree: **MSc**

Anchorage is an important part of port because it affects the port's operating and directly influences the safety and economic benefit of the port, so analysis and research safety of anchorage is very important. The unascertained measurement evaluation has been widely used in coal mine production domain, environmental quality assessment and other aspects, but it was less used in anchorage safety research. Anchorage is a system that has many factors, in this system in addition to natural conditions with uncertain information, VTS management services and the level of navigation aids facility outfit also with uncertainty.

This paper applies the unascertained measurement evaluation to the anchorage safety research, and set up the multi-level safety evaluation index system of anchorage through by analyzing the factors that affect anchorage safety. Subsequently, this paper utilizes improved AHP to determine the weight of evaluation indexes, and use unascertained mathematics methods to make the qualitative indexes via quantization process, which makes the weight more reasonable. Finally, this unascertained measure evaluation method is used in safety assessment of Qinhuangdao anchorage.

Application of the evaluating method of unascertained measure to the safety assessment of anchorage can improve the accuracy and reliability of the anchorage safety evaluation system, and it is practical for the safety evaluation of anchorage.

KEY WORDS: Anchorage, Unascertained Measurement Evaluation, Analytic Hierarchy Process, Safety Evaluation Model

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LIST OF ABBREVIATIONS

AHP	Analysis Hierarchy Process
C.R.	Conformance Rate
MABM	Multi-agent based modeling
MSA	Maritime Safety Administration
QHD	Qinhuangdao
UMM	Unascertained Measure Model
VTS	Vessel Traffic Service

Chapter 1 Introduction

1.1 Background

With the continuous development of world's economy, especially in the shipping industry, port capacity and port construction scale have been increased rapidly in coastal areas, in order to meet the needs of a modern port development, which makes traffic more and more congested in coastal waters. But due to the restricted range of harbor waters or natural conditions of harbor waters, the anchorage can not be randomly expanded or changed. As a result, the anchorage becomes increasingly tense, and a lot of ships entering into port waters cannot find proper anchoring place. In some condition, the anchoring ship is too close to the port and the main fairway which can seriously affect the safety of the ship entering into the port, which increases collision, grounding and dragging.

The plan and design of port anchorage must be carefully and properly made. In order to achieve this goal, it is necessary to make a comprehensive safety analysis and evaluate navigable anchorage.

There are several assessment methods, such as Principal Component Analysis Method, Data Envelopment Analysis, Fuzzy Comprehensive Evaluation Method, Gray Cluster Analysis Method, AHP and Gray Theory and Fuzzy Theory combining evaluation methods and so on. Fuzzy Comprehensive Evaluation Method is often used, but it still has a lot of problems; fuzzy membership as a state set function in Fuzzy Comprehensive Evaluation often can not meet the "additive principle" or "normalization conditions" (Zhao, 2007, pp. 36-38). Therefore, the evaluation results are less reliable. On the other hand, the operation of fuzzy sets "take smaller", "take greater" also misses a lot of useful information, often causing unclear consequence and unscientific results.

In order to solve the above problems, Unascertained Measure Model is a very effective solution. Unascertained Measure Model has been widely used in many areas and achieved satisfactory results. It is a high resolution assessment model and more applicable to assessment comprehensive ordered space problems (Liu, 1998, pp.41-44). In anchorage safety assessment, quantitative and visual system is the important theoretical research. Science safety assessment of anchorage involves many uncertain information, this dissertation will use Unascertained Measure Model to deal with this problems.

1.2 Purpose and significance of this research

1.2.1 Purpose of this research

In this dissertation, assessment of anchorage, deals with the traffic factors, natural conditions, weather conditions, guide services and other navigational aids. The concept of unascertained information is introduced into safety assessment of anchorage. Through analysis of factors affecting the safety of anchorage, setting up a safety assessment model for anchorage, using improved Analytic Hierarchy Process (AHP) to determine the evaluation factors weight, processing evaluation of qualitative indicators with unascertained mathematical knowledge, it is a more scientific and rational assessment result. Finally, the study of Unascertained Measure Model will be applied to safety assessment of Qinhuangdao anchorage to verify the feasibility and accuracy of Unascertained Measure Model in anchorage safety assessment.

1.2.2 Significance of this Research

Currently, unascertained measure methods have been widely used in safety production of coal mine, assessment of environmental quality and grade and other aspects. But are less used in the specific application in terms of anchorage security. anchorage system is a multi-factor, multi-variable, multi-level system. In this system, in addition to the natural conditions of uncertainty, nearby navigable factors and navigation aids services are results of unascertained (Kara, 1991). Therefore, introducing the comprehensive unascertained measure method to safety analysis of the anchorage can improve the accuracy and reliability of the safety evaluation of anchorage; it has a important practical and significance for the existing safety evaluation methods for anchorage.

1.3 Research objectives and research methodology

1.3.1 The organization of the thesis

Unascertained rational and blind number theory of unascertained mathematics are used as the theoretical basis for research of this article, then establishing safety anchorage assessment model is established, through research and analysis of various indicators weights and values of safety indicators, constructing a comprehensive safety evaluation method for safety of anchorage. It includes four parts:

Investigating the safety conditions of navigable anchorage, finding the main factors affecting the safety, consulting relevant experts and establishing a practical safety evaluation model for anchorage.

The concept of index weight consistency verification process is introduced to Analytic Hierarchy Process, establishing an improved AHP measure model, using this model applied to finalize the description of anchorage evaluation as weight layers index .

Establishing safety assessment for anchorage with unascertained measure models. In unascertained rational and within the scope of unascertained information, analysis credibility of expert in anchorage safety assessment and index expert assignment safety issues.

Using Qinhuangdao anchorage, for an example, uses the unascertained measure model as principle to assess safety level of anchorage. Verification the feasibility and scientific of unascertained measure model for the safety assessment of anchorage.

1.3.2 The main research methods and technical route

(1) Investigation

By investigating Qinhuangdao Maritime Safety Administration, Qinhuangdao Pilot Station, Qinhuangdao Port Co., Ltd. and other relevant departments, consult literature,search online and other methods to collect relevant information of Qinhuangdao Anchorage.

(2) Consulting experts

Consulting, collecting and analyzing experts' opinions, listing various factors that affect the safety of anchorage, determining the unascertained measure model for safety anchorage assessment.

(3) Theoretical analysis

The professional field of knowledge and theories in-depth analysis are used in this research. With a system of scientific theories and ideas, research object is put in the form of the system from the overall views, unified opposition from relational systems and elements, functions and structure as well as the environment and the system. Inspecting, researching and analysis of each research object to solve problems and get optimum method (Liu, 2005, pp97-99).

(4) Quantitative analysis and qualitative analysis

Qualitative analysis is used as a prerequisite and basis for quantitative analysis, then quantitative analysis is used to disprove the results of qualitative analysis. Qualitative analysis can reduce the complexity of the quantitative analysis. The quantitative analysis can play a role in the results of qualitative research evidence to the contrary and amended, or may even counterproductive qualitative analysis and overthrow of the original conclusion to make new conclusions. Similarly, if only use the quantitative research will be hard to find the source of risk (Zhou, 2007, pp.47-53). Therefore combined with the quantitative research and qualitative research will avoid the greatest degree of error occurred, continue to make discoveries and advancing.

1.3.2.5 Recommendations

Unascertained measure model is used to assess the safety of Qinhuangdao anchorage and making relevant recommendations.

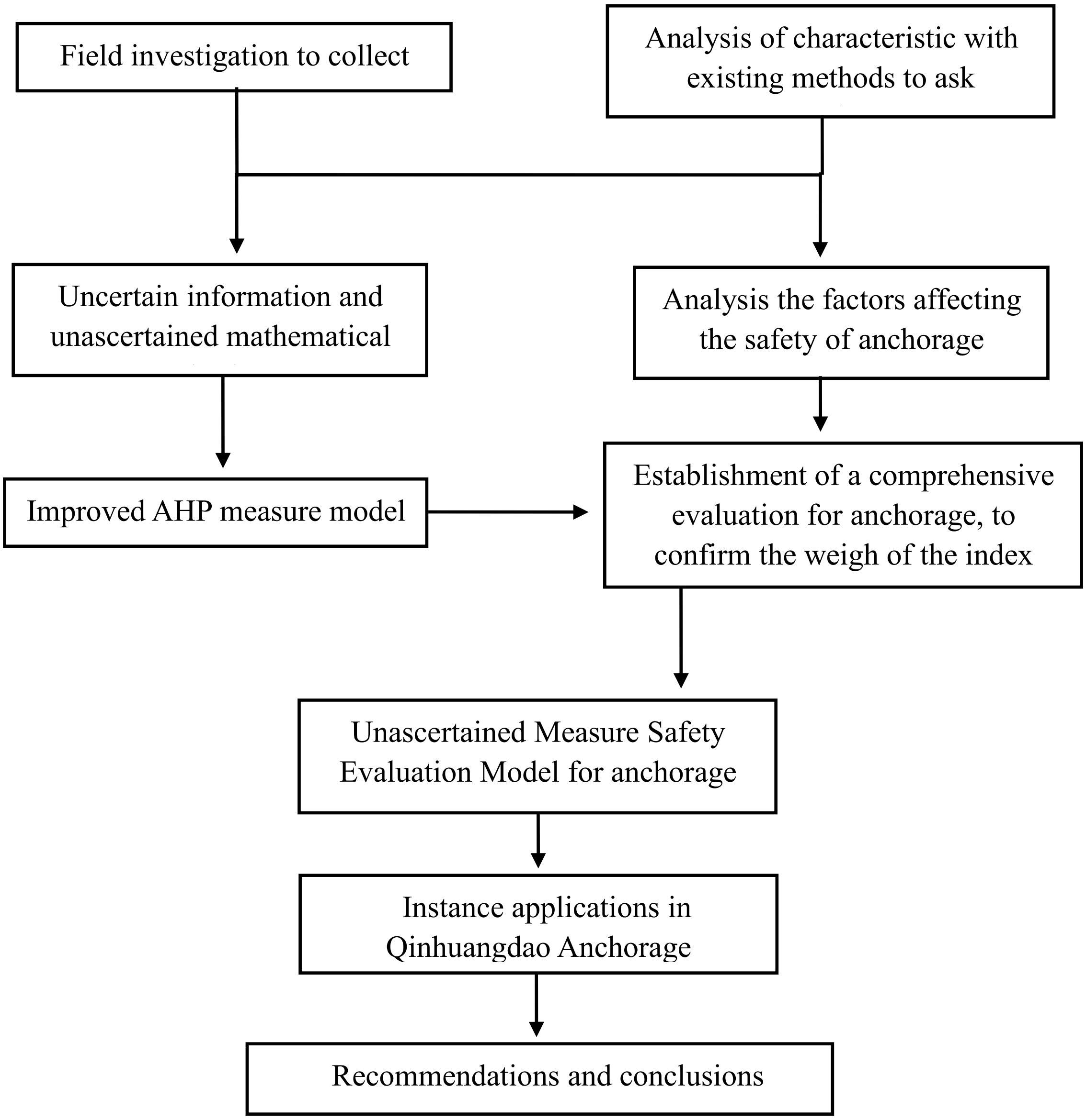

Figure 1.1 Flowchart of assessment technical route

Source: Author

1.4 Structure of dissertation

This dissertation consists of six chapters. Chapter One is an introduction, describing the research background, purpose and significance of several aspects, content and methods, the dissertation's organizational structure. Chapter Two introduces the basics of the unascertained information, highlighting the unascertained rational, unascertained collections and blind number. Description of the uncertain information may appear in pre-evaluation process, clear safety assessment process for the anchorage. Chapter Three made improvements for AHP model and determine the index weight, establishing a measurement model of AHP, and the calculated power layers target weight value, analyzed anchorage safety assessment factors with analytic hierarchy process, at the end establish the comprehensive safety assessment evaluation system for anchorage. Chapter Four is based on unascertained, combining the latest achievements of theoretical development of unascertained measure and blind number, establishing unascertained measure theory which for comprehensive anchorage safety assessment, and depending on the characteristics of the evaluation factors, constructed unascertained measure single index function. Chapter Five uses Qinhuangdao Port for an example, analysis of safety of the anchorage. Finally the last chapter, for concludes with recommendations.

Chapter 2 Unascertained information and unascertained mathematics

2.1 Unascertained information

2.1.1 Unascertained information and two unascertained information process methods

2.1.1.1 Concept of unascertained information

Research methods and speed of information processing is an eternal research project in the 21st century. For processing complete information, people already have rich knowledge and experience. For instance, the function has been established on the basis of classical mathematics and so on. However, incomplete information is uncertain; it was recognized relatively late, and emphasizes research and analysis of random information over a period of time. But some non-random information is also seen as a random information, using information statistical and probabilistic approach to deal with the non-random. Strictly speaking this is not appropriate (Ge, 2001).

The so-called uncertainty is that people are not able to make an accurate determination on development trends and results. The so-called "unascertained information" is that the decision-makers are not comprehensive enough of available information; they can not accurately determine the number of relationships and the real state of things. As a result, in decision-makers' pure subjective awareness is uncertainty. This subjective awareness of uncertainty caused by unascertained information is referred to as unascertainty. For example, the design of a structure, function, principles of a new product. But due to the current limit level of technological development, the future operating conditions of this product can not accurately grasp, and therefore generate unascertainty.

2.1.1.2 Two unascertained information process methods

If unascertained information has to be used in the decision-making process, in normal circumstances, there are two methods used to process it, after demonstration and analysis of the evidence related to the limited information.

The first is estimation subjective probability distribution. The so-called subjective probability is that of decision-makers make subjective probability judgment for an unascertained event in a possible situation. The event is already happening, so there is no randomness, and the event is a one-time event processing, so there is no statistical meaning for subjective probability. Therefore, although the method of processing random events is used, this subjective probability and statistical probability are essentially different; it reflects the randomness and unascertainty are essentially different.

The second is the estimation of subjective membership distribution The method of processing is to use the ambiguity of information to resolve the uncertain information. For example, through research, measurement and analysis, it estimates that anchorage area around $60km^2$. The answer is a simple amount of blur to estimate the deterministic water area of the anchorage. It is merely a subjective estimation of the specific amount of anchorage area, so it is called subjective membership distribution (Wang, 2000, pp.1-9).

2.1.2 Relationship between unascertained information and other uncertain information

2.1.2.1 Unascertained information and random information

Due to the interference of causal factors or insufficient objective conditions, some uncertainty result from certainty, which prevents us from determining what would result in one trial. Such trials are called randomized trials, information obtained in randomized trials are called random information (Wang, 2001).

Fundamentally speaking, random information and unascertained information are two different types of information expression:

Let S be non-empty set, x an object, A is "x in S, and a_e is the possibility of $e \in S$, $0 \leq a_e \leq l$", U is "x in S", U can be known from A, so A is information.

If $\Sigma a_e = 1$, A is a random information; if $\Sigma a_e = a < 1$, then A is unascertained information (Li, 2003).

Random information is information in the context of randomized trials. In general it is an objective description of future events. So random information is a special case belonging to unascertained information. The total confidence level is "1" indicating that the results of all tests are already known with certainty. If the test results are not completely known, the test can not be called a randomized trial, and this trial as the information will no longer be random information; it is unascertained information.

The background of unascertained information is that test results of the trial are not all known, regardless of objective things which are uncertain or determined, is not occurring or has occurred. If a decision-maker can not fully grasp number of relationships or real state of it, then it is the policy-makers' "uncertainty" thought, existing on such a subjective understanding of uncertainty is called "unascertained." For unascertained information, its total confidence should be less than 1, that is $\Sigma a_e < 1$. This is the mathematics difference between unascertained information and random information.

2.1.2.2 Fuzzy information and unascertained information

Because of the complexity in reality, while its boundary between fuzzy information and unascertained information is not distinct elements, the border is not clear, so it can not be given a definitive conceptual description or well-established evaluation criteria. The information provided for decision-makers is called fuzzy information.

Let X be object of study, S non-empty set, U is "x in S", A is "x in S, and a_e is a subordinate degree $e \in S$, $0 \le a_e \le 1$", clearly $A \subset U$, so A is called A fuzzy information. The element in fuzzy information "x is $e \in s$, a_e is subordinate degree" and in unascertained information or random information "x is $e \in s$, a_e is the possibility" is not the same mathematical sense. In fuzzy information, subordinate degree a_e means "indeed there is a_e in part of X, not limited by $\Sigma e_a \leqslant 1$, allow>1"; but in unascertained information or random information the possibility a_e and refers only to the existence of possible, which does not mean there must be e and a_e belonging to x. If in one trial, the possibility of x is 0.99, but this does not mean "the test" must occur, whereas a_e stringent satisfies the conditions $\Sigma e_a \leqslant 1$ (Zadeh, 1978).

2.1.2.3 Gray Information and unascertained information

Because of the complexity in reality, and due to the limited ability to receive and interference by other noise, as a result, that people can get probably or part of the information, but can not have precise information or all information. This information can not all be got, but some unknown information still exists, we can call it gray information.

Let x be element, S non-empty cantor set, S 'is a non-empty subset of S, N for the "x in S", A for "x in the S ", then A is gray information.

Because there is no missing information, "fuzzy", "random" belongs to the "complete information" category; due to the presence of missing information, "unascertained" and "gray" belong to the "incomplete information" category. Their difference is the range of gray information element is known, but the exact location is unknown. The missing information of unascertained information is completely unknown, and even their element scope is unknown. Of course, random information, also belongs to gray information; the essence of fuzzy information is determined, it can also be seen as a gray information (Wang, 1996). When overall credibility of unascertained information a_e= l it also belongs to gray, but when overall credibility of unascertained information it is much smaller than 1, it can no longer be used as gray information. This is because the missing information is not known, nor the scope of that the missing information belongs is completely unaware.

2.2 Unascertained mathematical basis

2.2.1 Unascertained Rational Number

We define the true of unascertained element as x_0, every possible values of unascertained element x_i are called elementary, and the set of all elementary constituted referred to as spatial X. F(x) indicates the number have additional range restrictions, known as "unascertained number".

Order a is an arbitrary real number, $0 \leq a \leq 1$, called [[a, b],φ(x)] is the first order unascertained rational number, in which:

$$\varphi(x) = \begin{cases} a, & \text{when } x=a \\ 0, & \text{when } x \neq a \text{ and } x \in [a,b] \end{cases}$$

The upper formula means an amount gets value in the closed interval [a, b], sets up a credibility as φ(x) =a. When a=1, it indicates that the credibility of amount is 1; when a=0, it indicates that the credibility of amount is 0. For any closed interval [a, b], $a = x_1 < x_2 < x_3 < \ldots < x_n = b$, if the function is satisfied:

$$\varphi(x) = \begin{cases} a_i, & \text{when } x=x_i\ (i=1,2,3\ldots,n) \\ 0. & \text{other} \end{cases} \qquad \text{And } \sum_{i=1}^{n} a_i = a,\ 0<a\leq 1,$$

Then [a, b] and φ(x) constitute an order unascertained rational number (Yue, 2001, pp.58-67).

2.2.2 Unascertained number

In the interval [a, b], and if the function F(x) satisfies the following conditions:

(1) $0 \leq F(x) \leq 1$;

(2) F(x) is range of $(-\infty, +\infty)$ unabated right continuous function;

(3) When $x < a$, $F(x) = 0$; when $x>b$, $F(x)=F(b) \leq 1$.

Then [a, b] and the function F (x) constitute a unascertained number, denoted as A= {[a,b], F (x)}. Range [a,b] is called value interval, the function F (x) is called the credibility of the distribution function on the subjective belong to range of [a, b], referred to credibility of distribution. The range of [a,b] is called unascertained distribution interval. The function F(x) is called distribution of unascertained number.

The unascertained number expressions are {[a,b], F(x)}, generally unascertained number is a number with additional contained range conditions (Yue, 2001, 58-67). Distribution function F(x) direct relevance to the true value of the credibility x_0 located $[-\infty, x]$. $F(x_i)$ -$F(x_j)$ represents true value of credibility within the range x_0 $[x_i, x_j]$.

2.2.3 Unascertained set

2.2.3.1 Concept of unascertained set

Set is called the foundation of mathematics, fuzzy mathematics and classical mathematics is based on the fuzzy set and cantor set . In order to research and Spread unascertained, combine the fuzzy set and cantor set, establish a "unascertained set". "Unascertained set" in unascertained mathematics role is equivalent to the fuzzy set in its respective system (Yue, 2001, pp.58-67). At the same time unascertained set is development and inheritance of the former .

If $a \geq 0$, $a \leq b \leq 1$, then unascertained number {[a, b], F(x)} is ≥ 0 and ≤ 1 unascertained number, all unascertained number like this composition the set, referred to as I [0,1], i.e.:

$$I = \{\{[a, b]\ F(x)\} \mid a \geq 0,\ a \leq b \leq l\}$$

Let N is one unascertained subset of domain U, referred to as unascertained set. Refer to N which is a subordinate function u: U→ I[0 , l], u→μ(u)∈ [0, l], u∈U, combined the each element u of subordinate function U and an number of unascertained set. The μ(u) is subordinate of N, put μ(u) as a subordinate function of unascertained set referred to $N_{\mu(u)}$. The essentially unascertained set of U is the collection values in function $I_{[0,1]}$.

2.2.3.2 Representation of unascertained set

First, the general representation. Nu expresses the subordinate function of unascertained set μ. Sometimes subordinate function of unascertained set μ can also be expressed by N_u.

Second, the fractional representation.

Set U={a, b}, then $N_{\mu(u)} = \{\frac{u(a)}{a} + \frac{u(b)}{b} + ...\}$, each molecule of fraction represents the subordinate function of elements of U for N.

Third, the vector representation. The vector representation of unascertained: set U= {a, b ...}, then $N_{\mu(u)}$ = {μ ((a), a), μ ((b), b),} (Zhao, 2007, 36-38).

2.3 Uncertainties of safety assessment process of anchorage

2.3.1 Uncertainty safety of anchorage

Safety of anchorage has significant uncertainty, lying in the following two points:

First, the factors involved in evaluation are more, such as: location factors, ship characteristics and hydro-meteorological factors. While these factors interact and constraint with each others. So we can not just simply make a judgment from one aspect;we must consider all factors and make a evaluation closer to the real in order to avoid blind-sided and the other.

Second, there are more uncertainty concepts. When conducting safety assessment, we often encounter similar anchorage sediment, ship condition is good or bad, regulatory is comprehensive or not and other issues, these issues are all uncertainty. How to quantify these uncertainties, and resolve our safety assessment based on scientific rational is in a complex and difficult issue for us.

Overall, the characteristics of unascertained are the information it generated is not objective, but generated by the subjective uncertainty of the decision-makers. The issues itself may be determined, happened and something already exists, or may be uncertain, such as the future of issues, the number of relationships and the real state can not be recognized because of objective or subjective reasons. Virtually, any system both have behavioral factors and state factors, the information provided basically belong to unascertained information. We must consider the uncertainty information based on its unascertained nature, and we shouldn't simplify it as determined information (Ao, 2008, pp.21-25).

2.3.2 Safety assessment procedures of anchorage

Safety assessment is a kind of human cognitive activity, and anchorage is a special and complex system. Safety assessment of anchorage is a difficult and complex task. The implementation process of safety assessment generally accords with the following procedures:

1. Determine evaluated anchorage.
2. Get familiar with anchorage environment and collect variety of information on anchorage. Investigating anchorage and its surroundings. Evaluate the weather, traffic flow and hydro logical conditions of anchorage in full based on the fully investigate environment and ship navigation around the anchorage.
3. Identify the risk factors of anchorage. Analysis risk of anchorage based on weather

conditions, hydro logical conditions, traffic conditions, navigation conditions, navigation service guide and so on (Brusendorf, 2002).

2.4 Summary

This chapter introduces the basics of unascertained information, which focuses on the relevant knowledge of unascertained number, unascertained set and unascertained information.

According to characteristics of the unascertained information, analysis factors may occur during the evaluation of anchorage. At the end, determine the safety assessment procedures of anchorage.

Chapter 3 Establishment of a comprehensive evaluation system of anchorage

In the safety assessment process, if we want to establish a comprehensive and objective system reflection of the basic conditions and risk factors of anchorage, we must establish a scientific safety assessment system and determine the weight of each index reasonably. This chapter analyzes the principle of establishing safety evaluation and based on the Analytic Hierarchy Process to establish a safety assessment system. Improved AHP method is used to determine the each index weight of layers of assessment system.

3.1 Basic principles for establishing evaluation system

The content of safety assessment of anchorage involves so many factors, which means different factors should be considered. The key of safety assessment is to select the appropriate evaluation. Whether safety assessment system is scientific and reasonable or not, affects whether the level of safety can be improved through safety assessment. In order to establish a reasonable, complete, scientific evaluation system, we must follow principles of systematic, purposeful, scientific, feasible and qualitative and quantitative (Fang, 2002, pp.10-15).

3.2 Establishing safety evaluation index system of anchorage

Based on anchorage planning principles, through searching data, consulting the captain, pilot and maritime experts, and investing extensive officer. At the end through detailed summary and analysis, this paper summarized the factors as: anchorage factors, traffic factors, weather factors, hydro-logical factors, adjacent facilities and navigation service six key factors. Including the anchorage area, sediment, water depth, sheltered nature, traffic flow, traffic composition complexity, wind, visibility, current, waves, distance to the fairway, distance to breeding areas, distance to other obstacles, VTS management level and navigation aids level totally fifteen secondary factors (Zeng, 2004, pp.41-47).

In accordance with the Analytic Hierarchy Process, the safety factors are divided into three layers, the first layer is called overall evaluation, the second layer is first index indicator of safety anchorage assessment system, third layer is the detailed indicators of first index of safety anchorage assessment system. In safety assessment, we need to analysis the third layer index of assessment system. Getting different indicators value after processing associated methods (Duan, 2007, 8-11).

The Index System is showed in Figure 3.1

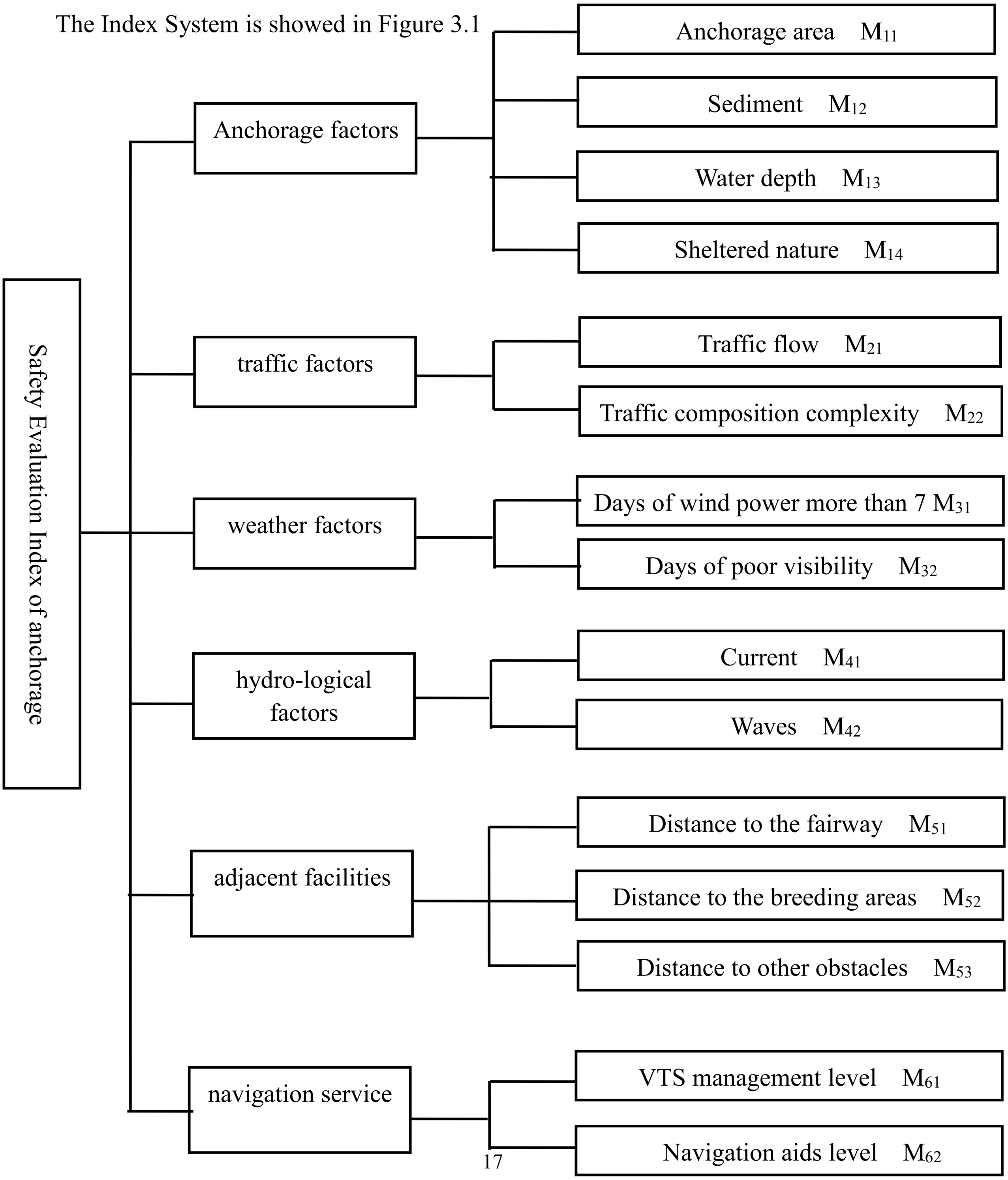

Figure 3.1 The safety evaluation index system

Source: Duan, 2007

3.3 Analysis Hierarchy Process and its improved model

3.3.1 Overview of Analytic Hierarchy Process

Analytic Hierarchy Process is a quantitative and qualitative weight determination method. When we use AHP to determine the weight of each index, we need to compare all the evaluation elements involved in the assessment, determine the importance of these indicators and the ratio of scale between each elements. Then construct judgment matrix contains elements of these indicators, use these comparison method to calculate the weight of each element more accurate.

However, when we determine index weights with AHP, the results must meet the conformance requirements. If the results of the analysis can not meet compliance requirements, it is necessary to constantly adjust relevant elements proportion of scale. The new results should consistency check until the result achieve consistency. In order to avoid such cumbersome and complex procedure, the authors of this paper make a simple improvement AHP model, and after that is no longer necessary to make consistency test with the outcome (Wu, 2007. pp.43-47).

3.3.2 Method to determining the weights of factors

In the evaluation system, different factors have different degree of importance in the realization of system functions and objective evaluation. The weight indicates the relative importance of different factors, or the scale factor represented when a benefit substituted for another benefit. Weight is very important information in comprehensive evaluation; it should be determined according to the factors contribution to overall evaluation. Based on the information basis, we can select precise quantitative data processing methods, the method of determining by the qualitative experience, and hybrid approach to determine the weights of different factors.

3.3.3 AHP judgment matrix

In AHP, after we establish the hierarchical structure, the upper element dominate the lower element $u_1, u_2, ..., u_n$ with guideline C . Therefore, decision-makers must given corresponding weight to $u_1, u_2, ..., u_n$ in accordance with the importance of the guideline C. Use "every two comparison method", under the Guideline C, which elements u_i or u_j is more important, how much it is important, at the same time assign proportion scale 1-9 to elements according extent of importance (see Table 3.1 and Table 3.2) (Zeng, 2004). For example, C is the anchorage element, u_i is the anchorage area dominated by C, u_j is anchorage sediment dominated by C. If anchorage sediment are more important than anchorage area, divide according to "the same， a little important, important, much more important, extremely important", belong to "important", then we can get:

$$\frac{\text{Importance of } u_i \text{ under C}}{\text{Importance of } u_{\text{j}} \text{ under C}} = a_{ij} = \frac{1}{5}, \qquad a_{ij} = \frac{1}{5}$$

As shown above, according to certain percentage of scaling defined a_{ij} satisfies:

$$a_{ij} > 0,\ \ a_{\text{ji}} = 1/a_{ij},\ \ a_{ii} = 1. \qquad \text{(formula 3.1)}$$

Based on the above formula (Formula 3.1) , judgment matrix consists of " a_{ij} ":

$$\text{A} = (a_{ij})_{n*n} \qquad \text{(formula3.2)}$$

Such a judgment matrix is called positive reciprocal matrix. If the positive reciprocal matrix (Formula 3.2) can satisfy:

$$a_{ij} \times a_{jk} = a_{ik} \qquad \text{(formula 3.3)}$$

Then it can be claimed that this judgment matrix A has consistency characteristics.

Table 3.1 Importance degree definition table of compared factors

Index	Importance degree
1	Comparison of two factors, one is the same importance as the other
3	Comparison of two factors, one is a little more important than the other
5	Comparison of two factors, one is important than the other
7	Comparison of two factors, one is much more important than the other
9	Comparison of two factors, one is extremely important than the other
2,4,6,8	Important degree between median of the adjacent two

Source : Zeng, 2004

Table 3.2 Secondary degree definition table of compared factors

Index	Secondary degree
1/3	Comparison of two factors, one is is a little less important than the other
1/5	Comparison of two factors, one is less important than the other
1/7	Comparison of two factors, one is much less important than the other
1/9	Comparison of two factors, one is extremely less important than the other
1/2,1/4,1/6,1/8	Secondary degree between median of the two adjacent

Source : Zeng, 2004

In the Analytic Hierarchy Process, whether the judgment matrix (a_{ij}) is consistent is very important. If the judgment matrix (a_{ij}) isn't consistent, then examine the consistence with the C.R. When C.R.<0.1, is generally considered consistency of matrix A is acceptable, if C.R.≥0.1, then should make the appropriate adjustments to judgment matrix (Shao, 1999, 51-56).

3.3.4 Measure judgment matrix

Suppose under the guideline C, relative measure between u_i and u_j can be expressed as

u_{ij} ($u_{ij} \in [0,1]$), relative measure between u_j and u_i can be expressed as u_{ji},there are:

$$0 \le u_{ij} \le 1, \quad 0 \le u_{ji} \le 1, \quad u_{ij} + u_{ji} = 1 \quad (i \ne j) \qquad \text{(formula 3.4)}$$

Then matrix satisfying formula 3.4, $M=(u_{ij})_{m \times n}$ is the measure of judgment matrix. Measure judgment matrix consistency should meet the basic conditions:

$$\text{If} \quad u_{ij} > u_{ji} \ \text{and} \ u_{jk} > u_{kj} \ \text{then} \ u_{ik} > u_{ki} \qquad \text{(formula 3.5)}$$

If the measure of judgment matrix (u_{ij}) satisfies the above conditions and the consistency, weight vector W of the elements $u_1, u_2, u_3, \ldots, u_n$ can be expressed as:

$$W = (w_1, w_2, \ldots, w_n)$$

$$w_i = \frac{2}{n(n-1)} \sum_{i=1}^{n} u_{ij} \qquad (i=1,2,\ldots,n) \qquad \text{(formula 3.6)}$$

above model is AHP measure model (Hu, 2014, pp114-116).

3.3.5 Improved AHP model

In AHP, the judgment matrix (a_{ij}) in many cases can not satisfy the principle of consistency, but if the judge matrix can satisfy:

$$\text{When} \ a_{ij} \ge 2, \ \text{and} \ a_{ik} \ge 2, \ \text{exists} \ a_{ik} \ge 2 \qquad \text{(formula 3.7)}$$

That is when $u_i > u_j$, $u_j > u_k$ if $u_i > u_k$. Then use the following conversion formula:

$$u_{ij} \begin{cases} \dfrac{\beta k}{\beta k + 1} & a_{ij} = k \\ 1/2 & a_{ij} = 1, \ i \ne j \\ \dfrac{\beta k}{\beta k + 1} & a_{ij} = \dfrac{1}{k} \\ 0 & a_{ij} = 1, \ i = j \end{cases} \qquad \text{(formula 3.8)}$$

At formula 3.8, $k > 1$ and $\beta \ge 1$, under normal circumstances take β as 2.

If the judgment matrix a_{ij} does not satisfy the principle of consistency, but satisfying the formula 3.7, we can use formula 3.8 transform the judgment matrix, then get measure of judgment matrix:

$$M=(u_{ij})_{m*n}$$

Measure of judgment matrix M satisfies the consistency. In AHP measure model, after multiplication the u_{ij} can get the corresponding elements of vector W, then an get corresponding weights of elements $u_1,u_2,u_3,...,u_n$ (Hu, 2014, pp114-116).

In summary, the steps determine index weight of factors with the improve AHP model are as follows:

First, analyze the relationship between different factors, establish the hierarchical structure of functions system;

Second, use the same layer factor inter to evaluate the importance of the upper layer, and construct pairwise comparison judgment matrix a_{ij};

Third, use the formula 3.8 transformed judgment matrix a_{ij}, get measures of the AHP judgment matrix u_{ij};

Fourth, calculate the weights of different factors.

3.4 Calculating weight of factors in anchorage safety evaluation

3.4.1 Establishing hierarchy structures

Establishing hierarchy structures is a very important process in AHP. Analysis based on full understanding of the system, finds the structure and linkages between different factors within the system, and divided this structure into several layers. The hierarchical structure of anchorage evaluation system is shown in Figure 3.2:

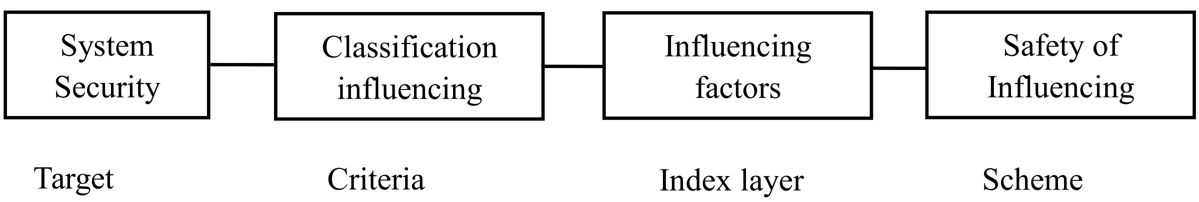

Figure 3.2 The hierarchical structure of anchorage evaluation system
Source: Author

3.4.2 Calculating weight of factors in criteria layer

In order to determine the weight of index of anchorage safety assessment, the authors have done a lot of research work, collect a lot of data, design rationality questionnaires,and determine an index system with different experts' advice. By questionnaires and using analytic hierarchy process model to calculate the weight of each layer index. Criteria layer hierarchy as shown in Figure 3.1, there are anchorage factors, traffic factors, weather factors, hydrology factor, adjacent facilities, navigation services total 6 elements, constitute the main assessment matrix A is shown as follows:

$$A=(a_{ij})=\begin{matrix} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \\ A_6 \end{matrix}\begin{matrix} \begin{matrix} A_1 & A_2 & A_3 & A_4 & A_5 & A_6 \end{matrix} \\ \begin{pmatrix} 1 & 2 & 2 & 1/2 & 1/3 & 1 \\ 1/2 & 1 & 1 & 1/4 & 1/6 & 1/2 \\ 1/2 & 1 & 1 & 1/4 & 1/6 & 1/2 \\ 2 & 4 & 4 & 1 & 2/3 & 2 \\ 3 & 6 & 6 & 3/2 & 1 & 3 \\ 1 & 2 & 2 & 1/2 & 1/3 & 1 \end{pmatrix} \end{matrix}$$

Constructing measure judgment matrix M, taking β=2, according with the formula 3.8, calculate u_{ij} by a_{ij} as follows:

$$M=(u_{ij})=\begin{pmatrix} 0 & 0.8 & 0.8 & 0.2 & 0.143 & 0.5 \\ 0.2 & 0 & 0.5 & 0.111 & 0.077 & 0.2 \\ 0.2 & 0.5 & 0 & 0.111 & 0.077 & 0.2 \\ 0.8 & 0.889 & 0.889 & 0 & 0.75 & 0.8 \\ 0.857 & 0.923 & 0.923 & 0.25 & 0 & 0.857 \\ 0.5 & 0.8 & 0.8 & 0.2 & 0.143 & 0 \end{pmatrix}$$

Calculate weight vector W with the formula 3.6 as follows:

$$W=(W_{A1},W_{A2},W_{A3},W_{A4},W_{A5},W_{A6})=(0.163,0.073,0.073,0.275,0.253,0.163)$$

The calculation results have been checked, summarized as shown in Table 3.3:

Table 3.3 Calculated weight of factors in criteria layer

Importance degree	A_1	A_2	A_3	A_4	A_5	A_6	W_A
A_1	1	2	2	1/2	1/3	1	0.163
A_2	1/2	1	1	1/4	1/6	1/2	0.073
A_3	1/2	1	1	1/4	1/6	1/2	0.073
A_4	2	4	4	1	2/3	2	0.275
A_5	3	6	6	3/2	1	3	0.253
A_6	1	2	2	1/2	1/3	1	0.163

Data source: expert questionnaires. Calculated by Author.

3.4.3 Calculating weight of factors in index layer

1. Calculating weights of anchorage factors

Figure 3.1 shows the hierarchy, anchorage factors contain four indicators: Area of anchorage M_{11}, sediment $M_{12,}$ depth M_{13}, sheltered nature M_{14}, establishing anchorage factors judgment matrix M_1, computational structure summarized in Table 3.4:

Table 3.4 Anchorage factors weight calculation (M_1)

Importance degree	A_1	A_2	A_3	A_4	W_A
A_1	1	2	2	1	0.35
A_2	1/2	1	1	1/2	0.15
A_3	1/2	1	1	1/2	0.15
A_4	1	2	2	1	0.35

Data source: expert questionnaires. Calculated by Author.

2. Calculating weights of traffic factors

Figure 3.1 shows the hierarchy, traffic factors contain two indicators: traffic flow M_{21}, traffic composition complexity M_{22}, establishing traffic factors judgment matrix M_2, computational structure summarized in Table 3.5:

Table 3.5 Traffic factors weight calculation (M_2)

Importance degree	A_1	A_2	W_A
A_1	1	2	0.80
A_2	1/2	1	0.20

Data source: expert questionnaires.   Calculated by Author.

3. Calculating weights of weather factors

Figure 3.1 shows the hierarchy, weather factors contain two indicators: wind M_{31}, visibility M_{32}, establishing weather factors judgment matrix M_3, computational structure summarized in Table 3.6:

Table 3.6 Weather factors weight calculation (M_3)

Importance degree	A_1	A_2	W_A
A_1	1	1/2	0.20
A_2	2	1	0.80

Data source: expert questionnaires.   Calculated by Author.

4. Calculating weights of hydro-logical factors

Figure 3.1 shows the hierarchy, hydro-logical factors contain two indicators: current M_{41}, waves M_{42}, establishing hydro-logical factors judgment matrix M_4, computational structure summarized in Table 3.7:

Table 3.7 Hydro-logical factors weight calculation (M_4)

Importance degree	A_1	A_2	W_A
A_1	1	1/2	0.20
A_2	2	1	0.80

Data source: expert questionnaires.   Calculated by Author.

5. Calculating weights of adjacent facilities factors

Figure 3.1 shows the hierarchy, adjacent facilities contain three indicators: distance to the fairway M_{51}, distance to breeding areas M_{52}, distance to other obstacles M_{53}, establishing adjacent facilities factors judgment matrix M_5, computational structure summarized in Table 3.8:

Table 3.8 Adjacent facilities factors weight calculation (M_5)

Importance degree	A_1	A_2	A_3	W_A
A_1	1	3	2	0.552
A_2	1/3	1	2/3	0.131
A_3	1/2	3/2	1	0.317

Data source: expert questionnaires. Calculated by Author.

6. Calculating weights of navigation service factors

Figure 3.1 shows the hierarchy, navigation service factors contain two indicators: VTS management level M_{61}, navigation aids level M_{62}, establishing navigation service factors judgment matrix M_6, computational structure summarized in Table 3.9:

Table 3.9 Navigation service factors weight calculation (M_6)

Importance degree	A_1	A_2	W_A
A_1	1	1	0.50
A_2	1	1	0.50

Data source: expert questionnaires. Calculated by Author.

3.5 Summary

This chapter introduces and analyze the principles of safety assessment anchorage, and uses analytic hierarchy process analyzed and compared anchorage safety assessment factors. Making simple improvements for different weights with AHP, constructing a new AHP measure model, and calculating the weight value index of the layers for safety assessment anchorage system. The improved AHP model avoids more complex, cumbersome consistency test, the weight of factor values of different indicators has obtained substantial mathematical theory as basis, it is reasonable. In the end, the evaluation index system of comprehensive evaluation of the safety of anchorage is established.

Chapter 4 Unascertained measure methods for safety evaluation of anchorage

Safety evaluation is made of the qualitative and quantitative security situation assessment and estimation of the system. Science security is usually reflected through danger, safety evaluation system is state of the hazards and dangers assessed and evaluated.

It is very complex to define the safety of the ship, at the same time it is more complicated and difficult to accurately calculate. That means the boundary between safety and danger of ship is "unascertained", so we can use unascertained measure theory to analyze safety of anchorage.

4.1 Unascertained Measure Model

The measurement methods can be divided into indirect measurements and direct measurement, unascertained measure are indirect measurement. Regardless of indirect measurement or direct measurement, the first thing is establishing a measurable space or a measure space, then define the measure rules (Hu, 2014, pp.140-150).

Set $x_1, x_2, ..., x_n$ are n objects, use X to represent the object space, then:

$$X = \{x_1, x_2, ..., x_n\}$$

To evaluate the object x_i need to be measured m indicators, $I_1, I_2, ..., I_m$, I represents index space, then:

$$I = \{I_1, I_2, ..., I_m\}$$

If x_{ij} represents i-th subject x_i measurement on the j-th indicator I_j, the x_i can be expressed as an m-dimensional vector:

$$X = \{x_{i1}, x_{i2}, ..., x_{in}\}$$

X_{ij} has p for evaluation level $c_1, c_2, ..., c_p$, evaluation level space referred to as U, then:

$$U = \{c_1, c_2, ..., c_p\}$$

And $c_i \cap c_j = \varnothing$ $(i \neq j,\ i, j = 1,2, ..., p)$. With c_k evaluation k-th level, if c_k "higher" than c_{k+1}, denoted by $c_k > c_{k+1}$, $(k = 1,2, ..., p-1)$, if $c_1 < c_2 < ... < c_p$ or the $c_1 > c_2 > ... > c_p$, then $\{c_1, c_2, ..., c_p\}$ is an orderly evaluation of space on the split U class.orderly evaluation of space in safety evaluation of anchorage means the safety of before grade is higher than the after-level. Obviously U can be expressed as:

$$U=\{ A \left| A = \bigcup_{i=1}^{k} a_i, a_j \in \{\phi, 1, c_1, c_2, ..., c_k\}, 1 \leq i \leq k \right. \}$$

4.1.1 Single index unascertained measure

Taking the general measurement space law into account, establish the existence of an ordered space $U=\{c_1, c=_2, ..., c_k\}$, use $u_{ijk}=u\ (x_{ij} \in c_k)$ to evaluate c_k with the measured values x_{ij} belonging to the k-th degree evaluation level, the requirements of U is:

$$u(x_{ij} \in U) = 1 \quad (i=1,2,...,m) \qquad \text{(formula 4.1)}$$

$$u(x_{ij} \in U) = 1 \quad (i=1,2,...,n,\ j=1,2,...,m) \qquad \text{(formula 4.2)}$$

$$u\left(\lambda x_{ij} \in \bigcup_{p=1}^{k} c_p\right) = \sum_{p=1}^{k} u(x_{ij} \in c_p) \quad (k=1,2,...,r) \qquad \text{(formula 4.3)}$$

$$0 \leq u(xij \in ck) \leq 1 \quad (i=1,2...,n \quad j=1,2,...,m \quad k=1,2,...,r) \qquad \text{(formula 4.4)}$$

Respectively, the formula (4.1) and (4.2) are u meet the "normalization" principle and the "additive" principle of the evaluation space U, while if u meets four equation (formula 4.1 to 4.4) is called measure or unascertained measure. The matrix:

$$(u_{ijk})_{m \times r} = \begin{bmatrix} u_{i11} & u_{i12} & \cdots & u_{i1r} \\ u_{i21} & u_{i22} & \cdots & u_{i2r} \\ \vdots & \vdots & & \vdots \\ u_{im1} & u_{im2} & & u_{imr} \end{bmatrix}$$

is a single index evaluation matrix (Hu, 2014, pp.140-150).

4.1.2 Index weight

Use w_j represents l_j measure compared to the relative importance of other indicators, require w_j met:

$$0 \le w_j \le 1, \sum_{j=1}^{m} w_j = 1$$

w_j is the weight for I_j, the vector

$$w = (w1, w2, ..., wn)$$

is index weights vector.

4.1.3 Multi-index comprehensive measure

If u_{ik} meets:

$$0 \le u_{jk} \le 1, \quad u_{ik} = \sum_{j=1}^{m} w_j u_{ijk}$$

Then u_{ik} is unascertained measure; it is called matrix:

$$(u_{ik})_{n\times r} = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1r} \\ u_{21} & u_{22} & \cdots & u_{2r} \\ \vdots & \vdots & & \vdots \\ u_{n1} & u_{n2} & & u_{nr} \end{bmatrix}$$

is a multi-index comprehensive measure evaluation matrix, the matrix i-th row (u_{i1}, u_{i2}, ..., u_{ir}) is x_i multi-index comprehensive evaluation vector (Liu, 2006).

4.2 Synthesis of uncertainty measurement evaluation conclusions

4.2.1 Experts trust degree

In the safety assessment, the general method of determining the value of the safety evaluation of qualitative indicators is the expert scoring method. Expert scoring method is simple, convenient, but the result of experts scoring is influence by the the level of knowledge and experience. Therefore, in order to ensure more accurate results, usually average value is calculated as the final index value. Because of experience, knowledge of experts involved in the evaluation scores and other differences, the average calculation method is often difficult to fully reflect expert scoring, resulting in reduction of credibility of the index value.

The credibility of the experts, or authoritative of experts, using a ($0 \leqslant a \leqslant 1$) indicates, a=0 indicates that a specialist best not to be believed, a=1 indicates an expert the most trustworthy (He, 1997, pp.36-41). Safety assessment of anchorage, can be based on expert professional direction, education, job title, length of service to determine the credibility of the experts. Evaluation of the operations is shown table 4.1 and table 4.2.

Table 4.1 Expert assessment trust table

Item	Professional direction	Education	Job title	Length of service	Score	Credibility
Expert						

Source: Author.

Table 4.2 Expert evaluation trust standard scoring table

Item	Professional direction			Education		
Category	Navigation	Maritime management	other	Master degree	Undergraduate degree	Specialist qualifications
Score range	[5,10]	[6,10]	[2,8]	[7,10]	[6,9]	[3,7]
Item	Job title			Length of service		
Category	Senior Engineer	Intermediate Engineer	Junior engineer	≥20 years	10~20 years	＜10 years
Score range	[8,10]	[4,7]	[1,3]	[7,10]	[4,7]	[1,4]

Source: He, 1997.

Respectively use g_i (i=1,2,3,4) represented as the assessment score of professional direction, education, job title, length of service, the credibility of the experts cloud use the formula 4.5 representing:

$$a = \frac{\sum_{i=1}^{4} g_i}{40} \qquad \text{(formula 4.5)}$$

As we can from the above formula, the value is between 0 and 1, the value is more smaller, represents the lower the trustworthiness of the experts; the greater indicating the trust degree of experts is higher.

Because experts' cognitive behavior also has unascertained characteristics, we can use unascertained rational indicates experts assessment information, this method is called uncertainty quantification of expert opinion (Wu, 2004).

In the pre-evaluation of the safety of anchorage, Let A be one of evaluated, and m indicators are represented by A_1, A_2, ..., A_m. N experts B_1, B_2, ..., B_n evaluated m indicators of A, were according 100 score system to evaluation of these indicators, the scoring table form is shown in Table 4.3:

Table 4.3 Expert assessment score table

Factors	Score			
	B_1	B_2	⋯	B_n
A_1	C_{11}	C_{12}	⋯	C_{1n}
A_2	C_{21}	C_{22}	⋯	C_{2n}
⋮	⋮	⋮	⋮	⋮
A_n	C_{m1}	C_{m2}	⋯	C_{mn}

Source: Wu, 2004

The $C_{ij} \in G(i=1,2,...,m; j=1,2,...,n)$. If C_{i1}, C_{i2}, ..., C_{in} is scored by a group of experts for factor A_i, comprehensive trust degree of experts are a_1, a_2, ..., a_n, then in the set (C_{i1}, C_{i2}, ..., C_{in}), use the same number representation the relatively rational fuzzy (Hu, 2014, pp140-150). At the end this all rational numbers can arranged as: C_{ij1}, C_{ij2}, ..., C_{ijn}, then you can get the number of blind f_i (x):

$$f_i(x)=\begin{cases} a_{ij1} & x=C_{ij1} \\ a_{ij2} & x=C_{ij2} \\ \vdots & \vdots \\ a_{ijk} & x=C_{ijk} \\ 0 & x\notin\{C_{ij1},C_{ij2},...,C_{ijk}\}\cap x\in G \end{cases}$$

Set w_i is the weight factor of A_i, then the uncertainty quantification value of A can be expressed as:

$$C = \sum_{i=1}^{m} w_i f_i(x)$$

The C is called uncertainty quantification of the evaluation value of object A. From the above can know, C is the blind number, and its mean E (c) is unascertained rational number the comprehensive quantitative value of expert opinion. In this case, only when $x=x_0$, the independent variable X's credibility $a \neq 0$, and when x is other value, the credibility is 0, E(c) is comprehensive quantitative value of expert opinion. We call the above-identified target A quantitative evaluation of the value of C and comprehensive quantitative value E(c) is the blind model of multi-agent base modeling, referred to as MABM (Hu, 2014, pp.140-150).

The conclusion of the synthesis method uncertainty agent system is established on the blind number, unascertained rational number concepts and computation basis. The results of operations of the synthesis of the conclusions is that the desires of the data after a given that the process will not effect by human factors, because the process is realized by a computer, the results obtained are objective.

Determination of risk assessment index value anchorage of the multi-agent system synthesis method, compared with the average method and other synthetic function method are totally different, because it represents the views of different experts or to ascertain the number of blind rational, expert advice conversion to synthesis corresponding blind number or unascertained operations. Due to the blind number, unascertained rational calculation has the theoretical basis, thus obtaining synthetic conclusions contain credibility.

4.3 Safety assessment unascertained measure model of anchorage

4.3.1 Single index measurement model for safety assessment of anchorage

Anchorage is complete and complex system, accordance with the requirements of the safety evaluation of the system, according to different functions refined it to six parts the six elements of anchorage safety assessment. Each small part is an independent entity, so we put each element of anchorage safety assessment as a separate object for specialized research. The anchorage safety assessment unascertained measure model object space X:

$$X=\{X_1, X_2, X_3, X_4, X_5, X_6\}$$

X_1, X_2, X_3, X_4, X_5, X_6, represent anchorage factors, traffic factors, weather conditions, hydro-logical factors, adjacent facilities and navigation service.

Establish evaluation space U. According to "Harbor total graphic design specifications" and refer to other relevant documents, the safety of the anchorage points can divide into five grades, class I, class II, class III, class IV, class V, represent low risk, general low risk, medium risk, high risk, very high risk. Evaluation of space U written as:

U = {class I, class II, class III, class IV, class V} = {c1,c2, c3, c4, c5}

In anchorage safety assessment system weather factors, hydro-logical factors and depth of anchorage factors, area and other factors are objective quantitation indicators. In addressing these factors including secondary layers, we first need to construct the unascertained measure model, then the relevant sub-index measuring values are substituted into the evaluation criteria to calculate the index factor for each sub-index single measure vector, and then combined with the secondary corresponding weights indexes. Finally, the unknown factor is calculated multiple index comprehensive measure vector (Zeng, 2004).

Anchorage sediment, sheltered nature, traffic, navigation assistance facilities management degree and VTS factors basically belong to qualitative factors, the qualitative indicators commonly used expert scoring method and then synthesis to uncertainty conclusion (Zeng, 2004). Expert score is based on the use of uncertainty after the expert opinion concluding synthesis process, then get the expert comprehensive evaluation value, and with the grading standards-based construction single index unascertained measure functions can be calculated and get a different index factor single index measure vector.

4.3.2 Determining the safety evaluation grade with single index measure function of anchorage

Anchorage area and depth can be quantified processing, classification of area and depth safety factors can be shown in Table 4.4 (He, 1997, pp.36-41).

Table 4.4 Anchorage area, depth safety classification table

safety / Evaluation index	c1	c2	c3	c4	c5
Anchorage Area (Anchor positions/berth)	≥2	1~2	1/2~1	1/2~1/4	≤1/4
Depth (Depth/loaded draft)	≥4.0	2.0~4.0	1.2~2.0	1.2~1	≤1

Source: Expert questionnaires.

Establish index of unascertained measure function u ($x_i \in c_p$), in order to obtain all measure value u_{ik}, then obtain evaluated factors of anchorage unit N measure space $(u_{ik})_{2x5}$, i = 1 or 2, 1≤k≤5 (Hu, 2014, pp.140-150).

According to the division classification indicators Table 4.4, c_1 level values take the lower limit value as c_1 grade standards; c_5 take the high limit value as the c_5 grade standard; c_2, c_3, c_4 level then take the median interval number as grading criteria.

The unascertained measure function of anchorage area M_{11} can be expressed as:

$$u(M_{11} \in c_1) = \begin{cases} \dfrac{u-1.5}{0.5} & 1.5 \le u < 2 \\ 1 & u \ge 2 \\ 0 & u < 1.5 \end{cases}$$

$$u(M_{11} \in c_2) = \begin{cases} \dfrac{u-0.75}{0.75} & 0.75 \le u < 1.5 \\ \dfrac{u-1.5}{0.5} & 1.5 \le u < 2 \\ 0 & u \ge 2 or 0.75 > u \end{cases}$$

$$u(M_{11} \in c_3) = \begin{cases} \dfrac{u-0.375}{0.375} & 0.375 \le u < 0.75 \\ \dfrac{u-0.75}{0.25} & 0.75 \le u < 1 \\ 0 & u \ge 1 or 0.375 > u \end{cases}$$

$$u(M_{11} \in c_4) = \begin{cases} \dfrac{u-0.125}{0.25} & 0.125 \le u < 0.375 \\ \dfrac{u-0.375}{0.375} & 0.375 \le u < 0.75 \\ 0 & u \ge 0.75 or 0.125 > u \end{cases}$$

$$u(M_{11} \in c_5) = \begin{cases} 1 & u < 0.125 \\ \dfrac{u-0.375}{0.25} & 0.125 \le u < 0.375 \\ 0 & u > 0.375 \end{cases}$$

It can be seen that measure function $u(u_{ij} \in c_k)$, $0 \le u_{ijk} \le 1$, $\sum_{k=1}^{5} u_{ijk} = 1$, so it is a unascertained measure function (Yue, 2001, pp.58-67).

With the graphic can visually describe single index unascertained measure function of anchorage area, as in Figure 4.1

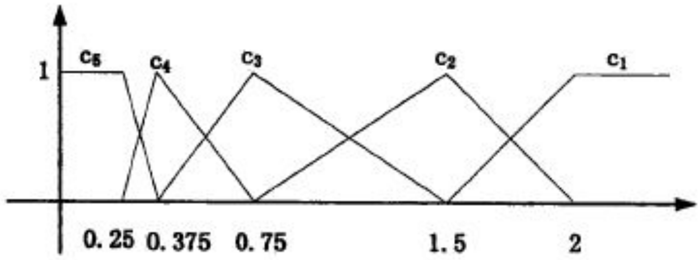

Figure 4.1 Single index unascertained measure function of anchorage area

Data source: expert questionnaires. Calculated and drawn by Author.

Similarly, according to Table 4.4, single index unascertained measure function of depth can be drawn as in Figure 4.2

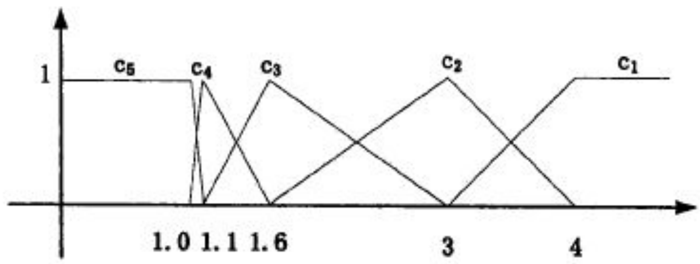

Figure 4.2 Single index unascertained measure function of depth

Data source: expert questionnaires. Calculated and drawn by Author.

Based on expert scoring tables and various statistics, the security level tables of other factors are shown as Table 4.5

Table 4.5 Other factors safety classification table

Evaluation index \ safety	c1	c2	c3	c4	c5
Wind power >7 (days/year)	<30	30~60	60~90	90~120	>120
Poor visibility (days/year)	<15	15~30	30~45	45~60	>60
Ocean current (m/s)	<0.5	0.5~1.0	1.0~1.5	1.5~2.0	>2.0
Wave height (m)	<0.5	0.5~1.5	1.5~3.0	3.0~5.0	>5.0
Distance to fairway (S/L)	>8	5~8	3~5	1~3	<1
Distance to obstruction (m)	>2000	1500~2000	1000~2000	500~1000	<500

Data source: expert questionnaires.

According to table 4.5, calculated and plotted single index unascertained measure function of strong wind as shown in Figure 4.3, single index unascertained measure function of poor visibility as shown in Figure 4.4, single index unascertained measure function of ocean current as shown in Figure 4.5, single index unascertained measure function of wave high as shown in Figure 4.6, single index unascertained measure function of distance to fairway as shown in Figure 4.7, single index unascertained measure function of distance to obstruction as shown in Figure 4.8.

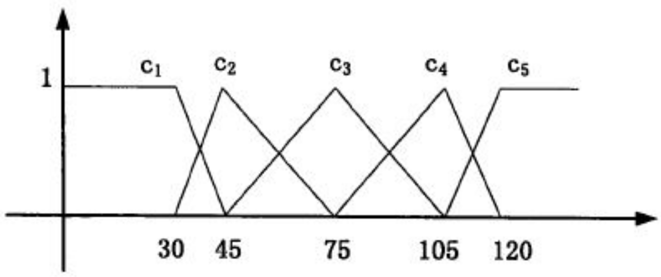

Figure 4.3 Single index unascertained measure function of strong wind

Data source: expert questionnaires. Calculated and drawn by Author.

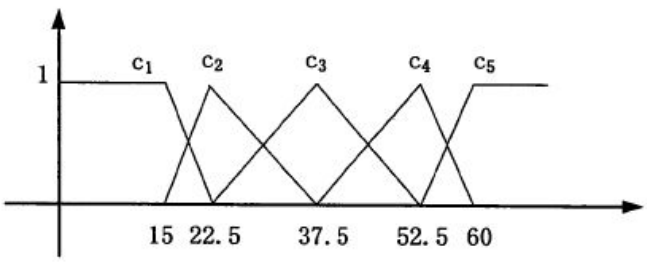

Figure 4.4 Single index unascertained measure function of poor visibility

Data source: expert questionnaires. Calculated and drawn by Author.

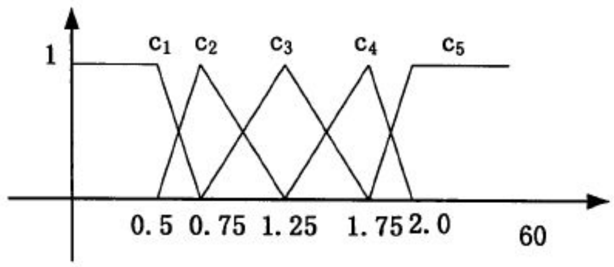

Figure 4.5 Single index unascertained measure function of ocean current

Data source: expert questionnaires. Calculated and drawn by Author.

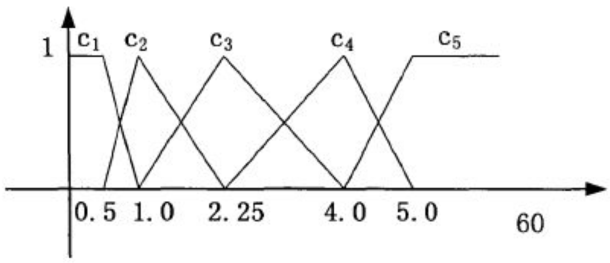

Figure 4.6 Single index unascertained measure function of wave high

Data source: expert questionnaires. Calculated and drawn by Author.

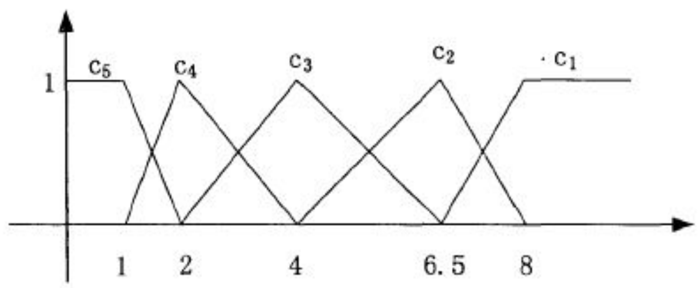

Figure 4.7 Single index unascertained measure function of distance to fairway

Data source: expert questionnaires. Calculated and drawn by Author.

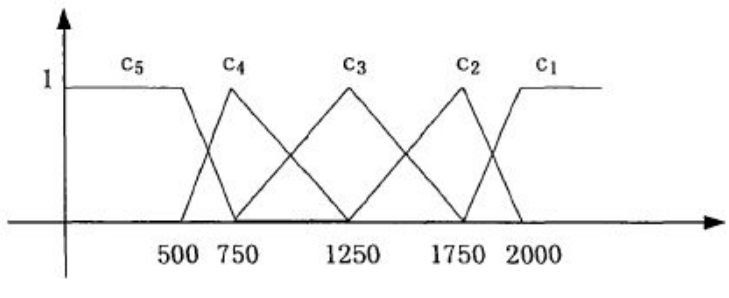

Figure 4.8 Single index unascertained measure function of distance to obstruction

Data source: expert questionnaires. Calculated and drawn by Author.

Above evaluation elements can be quantitative handled, and other indicators are mostly qualitative indicators, it is difficult to quantify process (Zhu, 1995, pp.17-22). Approach to qualitative indicators, in order to accurately determine the safety status of each evaluation factor, using multiple expert comprehensive scoring method or safety checklists to determine the safety value of each qualitative indicators. The general practice is to make expert index scoring interval [0, 100], professionals expert evaluation the security situation index by the scoring values, the higher the score, the higher the safety level, the lower score the lower safety level (Hu, 2014, pp140-150). Inserting within four points in setting the interval [0, 100], so the scores divided by the interval become a five intervals, that five security risk rating respectively, low risk, general low risk, medium risk, high risk, very high risk, classification as shown in Table 4.6.

Table 4.6 Qualitative index factors safety classification table

safety / Evaluation index	c1	c2	c3	c4	c5
Index score	>95	95~85	85~75	75~65	<65

Source: Hu, 2014.

According to table 4.6, calculated and plotted single index unascertained measure function of qualitative index factors as shown in Figure 4.9,

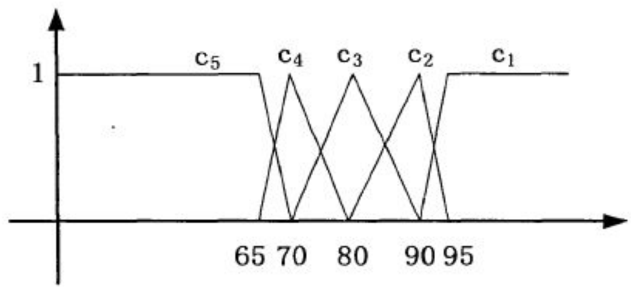

Figure 4.9 Single index unascertained measure function of qualitative index factors

Data source: Hu, 2014. Calculated and drawn by Author.

4.3.3 The rules of confidence level identification of safety evaluation

In the safety evaluation of anchorage, the evaluation space of unascertained measure evaluation model is {c_1, c_2, c_3, c_4, c_5}, c_1={low risk}, c_2={general low risk}, C_3={medium risk) , C_4={high risk), C_5={very high risk}.

Let λ is confidence level, ($\lambda > 0.5$, normally $\lambda = 0.6$ or 0.7), so that:

$$k_0 = \min \left| k : \sum_{l=1}^{k} u_l > \lambda, k = 1,2,\cdots,p \right|$$

The safety evaluation of anchorage c_{k0} belongs to k_0 grade (Shao, 1999, pp.51-55).

4.4 Summary

The safety assessment of anchorage involves uncertain information, due to objective conditions and subjective reasons, which results in safety evaluation object recognition with lot of unascertained. In Chapter Four, based on unascertained theory, combined with blind number theory and latest developments of unascertained measure, established the suitable safety comprehensive assessment of anchorage is established.

Analyze the different evaluation factors of anchorage assessment, establish single index and multi-index measure model of unascertained comprehensive assessment measure, and according to different characteristics of evaluation elements, establish single index function of unascertained comprehensive assessment measure.

The confidence level of unascertained comprehensive assessment measure of anchorage is described, it can objective determination safety situation. The confidence level is an effective method of safety assessment; it is the advantage of unascertained safety assessment measure method over others.

Chapter 5 Safety Assessment of Qinhuangdao Anchorage

This chapter uses unascertained mathematics to establish unascertained measure model for assessment of Qinhuangdao anchorage for an example, to obtain security level of anchorage which is closer to the actual situation.

5.1 Overview of Qinhuangdao Anchorage

There are four anchorages in Qinhuangdao Port, including East Anchorage, West Anchorage, Hundred thousand-ton ship Anchorage, Tanker Anchorage, the total area of four anchorages is 218.1 square kilometers (Zhang, 2014, pp.6-11).

West Anchorage: surrounded by the lighthouse of south hills as the center and basis points, radius of the arc respectively 3 nautical miles and 12 nautical miles as well as azimuth line of 165° and 190°. The sediment is a mixture of mud and sand, the area of anchorage is 100.6 square kilometers, the depth is 10.3 to 12.3 meters (Zhang, 2014, pp.6-11).

Tanker Anchorage: surrounded by the lighthouse of south hills as the center and basis points, radius of the arc12 nautical miles, azimuth line of 100 ° and 108 ° and parallel line of 3000 m distance from the eastern side of hundred thousand tons fairway. The sediment is a mixture of mud and sand, the area of anchorage is 30.7 square kilometers, the depth is 10.3 to 14 meters (Zhang, 2014, pp.6-11).

East Anchorage: surrounded by the lighthouse of south hills as the center and basis points, radius of the arc12 nautical miles, azimuth line of 108 ° and parallel line of 1000 m distance from the eastern side of hundred thousand tons fairway. The sediment is a mixture of mud and sand, the area of anchorage is 79.9 square kilometers, the depth is 11 to 14.3 meters (Zhang, 2014, pp.6-11).

Hundred thousand-ton ship Anchorage: surrounded by the lighthouse of south hills as the center and basis points, radius of the arc 15.4 nautical miles and 16 nautical miles, azimuth line of 128° and parallel line of 1000 m distance from the eastern side of hundred thousand tons fairway. The sediment is a mixture of mud and sand, the area of anchorage is 6.5 square kilometers, the depth is 18.2 to 19.7 meters (Zhang, 2014, pp.6-11).

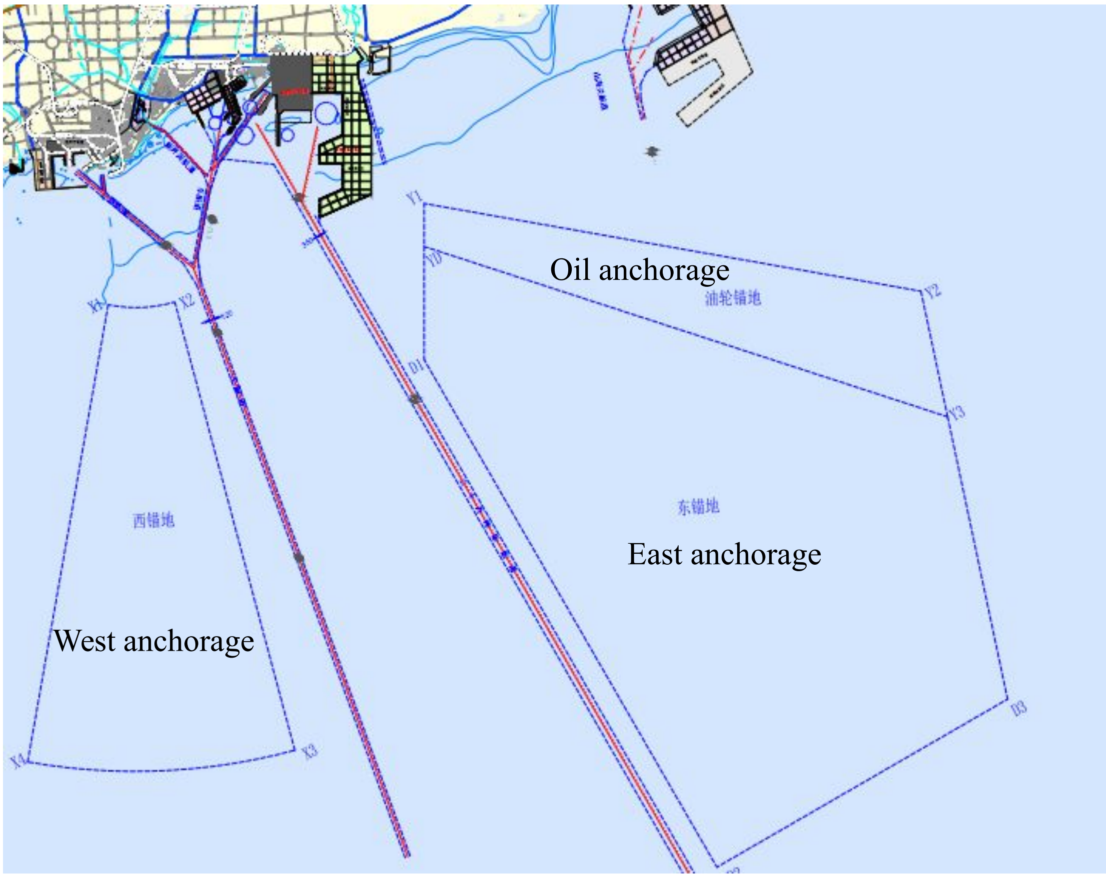

Figure 5.1 The overview diagram of Qinhuangdao Port Anchorage

Source: Transport Planning and Research Institute, Ministry of Transport.

5.2 Safety analysis of Qinhuangdao anchorage

5.2.1 Safety analysis of anchorage elements

1. The anchorage area and depth

West Anchorage: 1000 m from the fairway, the anchorage area is 100.6 square kilometers, the depth is 10.3 to 12.3 m. Tanker anchorage: 3000 m from the fairway, the anchorage area is 30.7 square kilometers, the depth is 10.3 to 14 meters. East anchorage: 1000 m from the fairway, the anchorage area is 79.9 square kilometers, the depth is 11 to 14.3 meters. Hundred thousand-ton ship Anchorage: 1000 meters from the fairway, the anchorage area is 6.5 square kilometers, the depth is 18.2 to 19.7 meters (Zhang, 2014, pp.6-11).

2. The Sediment of anchorage

The sediment of Qinhuangdao anchorage is a mixture of mud and sand (Zhang, 2014, pp.6-11).

3. Sheltered nature

There is no shelter for blocking wind in anchorage, so the anchorage can not be used as sheltered anchorage. But annual average wind speed is small, so it is suitable for general ship. Since the windy weather has greater impact on the ship's anchor, the captains of the ships should arouse enough attention, so when the wind is greater than 8, the ship should select a suitable site for shelter or standing by the main engine (Zhang, 2014, pp.6-11).

5.2.2 Safety Analysis of traffic factors

1. The traffic flow

The ships in and out of Qinhuangdao Port mainly are the coal carriers, including container ships, ores, grain and other bulk cargo. 90% of them are 10,000 DWT ship, half of them are Panamax bulk carrier. The traffic flow of Qinhuangdao in 2008-2013 is shown in Figure 5.2. The ships in and out of Qinhuangdao Port are about 46 per day in 2013 (QHD MSA, 2013).

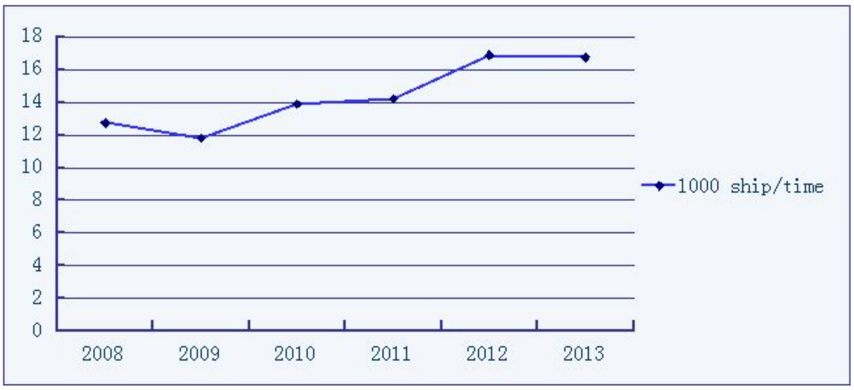

Figure 5.2 The chart of ship/time in and out of Qinhuangdao Port from 2008 to 2013
Source: Qinhuangdao MSA, 2013

2. Complex of traffic

In 2012 there were 16952 cargo ships into Qinhuangdao port and total DWT is 283.43 million, compared with 2005, total ships increased by 46.4%, with a total DWT increased by 61%, it is shown in Table 5.1:

Table 5.1 The ship-to-port divided by types and tons table

	2005			2012		
	Ship/time	Gross tonnage（10,000 tons）	DWT（10,000 tons)	Ship/time	Gross tonnage（10,000 tons）	DWT（10,000 tons)
Total	8243	11577	18120	16952	18637	28343
Oil tanker	679	440	576	1907	866	1183
Liquefied gas carrier	5	8		1	1	1
Bulk chemical tanker	97	36	60	43	38	62
Bulk carrier	4667	9553	15400	8007	16396	25339
Container ship	320	203	213	288	403	318
Ro-ro ship	2	6	3			
Other	2473	1330	1869	6706	932	1441

Source: Qinhuangdao MSA, 2013

5.2.3 Safety Analysis of Meteorological factors

1. The wind conditions

Qinhuangdao port sea wind changes with the season, in winter and spring prevalence northeasterly, in summer prevalence southwest wind (Zhang, 2014, pp.6-11).

The average wind speed is 4.1m/s. The maximum monthly average wind speed is 4.7m/s in April, the smallest is 3.3m/s in January. The wind speed is larger in April mainly because of cyclones. The maximum annual average wind is 5.2m/s with ESE and SSE , NW wind is minimum with an average of 2.9m/s (Zhang, 2014, pp.6-11).

2. The fog conditions

According to a detailed statistical analysis of the past decade, the annual average fog days in Qinhuangdao Port is 33.6 days, the largest is 72 days in 2004.

The annual days of port visibility≤1000m is 26.5 days (QHD MSA, 2013).

5.2.4 Safety Analysis of Hydro-graphic factors

1. Current

Qinhuangdao coast belongs to weak tide, tidal nature is the regular diurnal tide pattern. Statistics of tidal conditions of the sea areas in accordance with Qinhuangdao Marine Station and Anchor Bay Marine Station is showed in Table 5.2.

Table 5.2 Qinhuangdao each stations eigenvalues tide tables (unit: m)

	Qinhuangdao Marine Station	Anchor Bay Marine Station
Highest tide of past years	2.55 (1976.7.28)	2.32
Lowest tide of past years	-1.43 (1973.12.24)	-0.55
Mean high tide	1.24	1.47
Mean low water	0.51	0.69
Mean tide	0.89	1.05
Extreme tide range	2.63	2.56
Minimum tide range	0.01	0.03
Mean tide range	0.73	0.78
Statistics years	1960~1993	1992

Source: Zhang, 2014

2. Wave

According to nine years' waves statistics by Qinhuangdao Marine Station, most of this sea area waves are S and the frequency is 18.68%, then the wave is SSW direction, the frequency is 11.86%. Strong waves is the ENE direction, the direction, the frequency of $H_{1/10} \geq 1.5$m is 0.26%; second strongest wave is the S direction, the frequency of $H_{1/10} \geq 1.5$m is 0.16 %. Annual average wave in all directions, the frequency of $H_{1/10} \geq 1.2$m is 4.10%, the frequency of $H_{1/10} \geq 1.5$m is 1.06%, the frequency of $H_{1/10} \geq 2.0$m is 0.13%. The maximum wave height was 3. 3m, SE, occurs during the July 27, 1972 typhoon. The sea waves are mostly based mixed waves and storm waves which frequency is 75%, the frequency of the surge and swell-based mixed wave are about 22%. These waves are mostly remnants of the the storm or the wind speed decreases, the peak surface of wave is more smooth (Zhang, 2014, pp.6-11).

5.2.5 Safety Analysis of navigation aids

1. VTS management level

Qinhuangdao VTS system consists of Nanshan Radar Station (39° 54' 35 "N, 119° 36' 44" E) and Qinhuangdao VTS center (39° 55' 00 "N, 119° 35' 11. 56" E) .

The area under jurisdiction of Qinhuangdao VTS is the Nanshan lighthouse (39° 54' 38.8 "N, 119° 36' 57.6" E) as the center, the sector waters of 18 sea miles radius, as Figure 5.3. Within the VTS area includes the following fairways: the main fairway, east fairway, west fairway, thousand-ton fairway, Xinkaihe fairway, Shanhaiguan Shipyard fairway. These fairway are all one-way fairway, when the ship uses the fairway in or out of the port, they must be approved by VTS Center (QHD MSA, 2013).

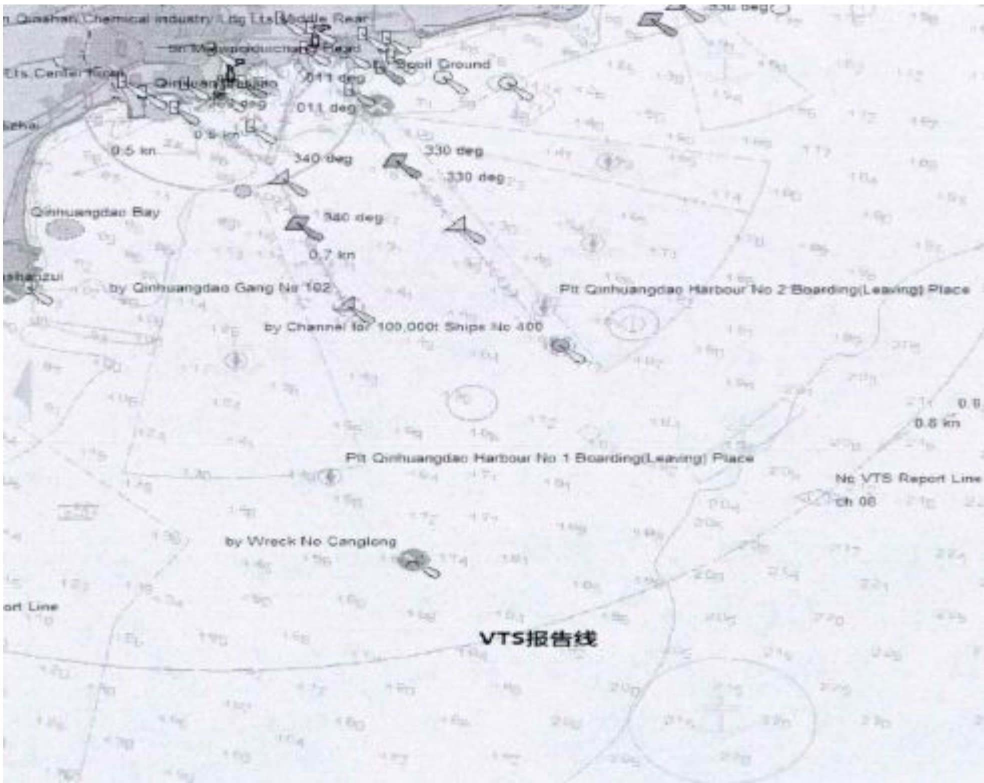

Figure 5.3 Qinhuangdao VTS jurisdiction schematic diagram

Source: QHD MSA, 2013

2. Navigation aids

Currently, there are 171 public buoys in the Qinhuangdao Port, wherein one lighthouse, 44 beacons, 32 lamp piles, 13 articulated lighthouses, 70 light buoys, one current mark, 8 radar transponders, one DGPS station, one AIS base station. At the same time, the Qinhuangdao Port has 5 dedicated beacons, wherein 4 lighthouse and one light buoy (QHD Lighthouse Bureau, 2014).

5.3 Representative types of ships

In order to make sure the assessment for the index is reasonable, it is necessary for some proper ships be standard ships. Taking into account the situation of the Qinhuangdao Port, and domestic and international shipping industry, this paper selected some ship types and their scale are shown in Table 5.3 .

Table 5.3 Representative ship types and their scale table

Ship type	Tonnage	Length	Breadth	Molded depth	Loaded draft
Bulk carrier	50000	223	32.3	17.9	12.8
	100000	250	43	20.3	14.5
	150000	289	45.0	24.3	17.9
Oil tanker	50000	229	32.2	19.1	12.8
	100000	246	43	21.4	14.8

Source: Qinhuangdao MSA, 2013

5.4 Safety assessment of Qinhuangdao anchorage

5.4.1 Single index unascertained measure safety assessment of anchorage

Security factors of Qinhuangdao anchorage can be divided into U_1 anchorage factors, U_2 traffic factors, U_3 weather conditions, U_4 hydro-logical factors, U_5 adjacent facilities and U_6 navigation service total six factors. Each of these factors is a relatively complete subsystem, therefore each factor of anchorage safety evaluation can be treated as an object to assess and construct measurement function, then measuring its safety content (Hu, 2014, pp.140-150). Unascertained measure safety assessment model of anchorage object space is X, then

$$X = \{u_1, u_2, u_3, u_4, u_5, u_6\}$$

From the above description we may know, many of these factors include secondary indicators.We take a different approach to quantization various indicators, but at the end we will establish measurement function and measurement vector. Anchorage area, depth, weather conditions, hydro-logical conditions and nearby facilities are objective type index, can get from the measured or estimated, after determinate the level of safety indicators, then constructed the indicators to unascertained measure function and the corresponding single index measure vector, then based on respective weight of secondary indicators obtain the multi-index measure vector of level indicators.

1. Safety measure of anchorage factors

Through detailed analysis of the Qinhuangdao anchorage, we obtain measuring indicators value of anchorage area and depth is shown in the following table 5.4:

Table 5.4 Qinhuangdao Anchorage factors index measured values

Index	Anchorage area	Depth
values	1.2	1.5

Data Source: Zhang, 2014. Calculate by Author.

Constructing single index measurement function of anchorage area, as shown in Figure 5.4:

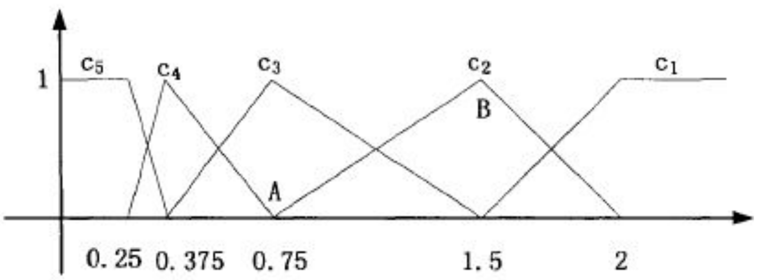

Figure 5.4 Single index measurement function of anchorage area

Data Source: Zhang, 2014. Calculated and drawn by Author.

From Figure 5.4 obtaining AB linear equation :

$$y = \frac{x - 0.75}{0.75} = \frac{1.2 - 0.75}{0.75} = 0.6$$

It means safety membership degree belong to anchorage area c_2 is 0.6, due to the normalized quality, the membership degree belongs to c_3 is 0.4, so the single index measure vector of anchorage area is:

(0, 0.6, 0.4, 0, 0)

Constructing single index measurement function of depth, as shown in Figure 5.5:

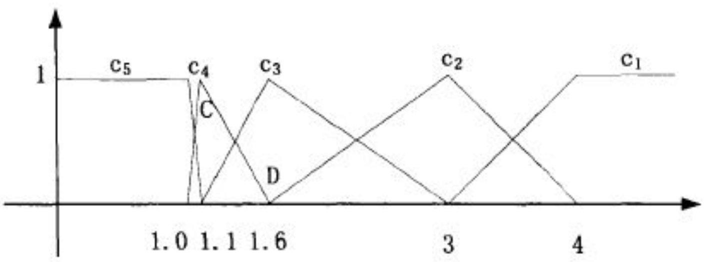

Figure 5.5 Single index measurement function of depth

Data Source: Zhang, 2014.   Calculated and drawn by Author.

From Figure 5.5 obtaining CD linear equation :

$$y = \frac{x-1.1}{0.5} = \frac{1.5-1.1}{0.5} = 0.8$$

It means safety membership degree belongs to depth c_3 is 0.8, due to the normalized quality, the membership degree belongs to c_4 is 0.2, so the single index measure vector of depth is:

$$(0, 0, 0.8, 0.2, 0)$$

There are four experts who had evaluated the safety of anchorage sediment of Qinhuangdao anchorage. The trust assessment of four experts for safety evaluation of sediment anchorage is shown in Table 5.5:

Table 5.5 The trust assessment of experts for safety evaluation of anchorage sediment

No.	Major	Educational background	Post	Length of service	Score	Trust
1	Navigation	Undergraduate	Chief officer	13	36	0.26
2	Navigation	Undergraduate	Captain	20	32	0.23
3	Maritime management	Master	Associate Professor	15	35	0.26
4	Other	Undergraduate	Senior Engineer	16	34	0.25

Data source: expert questionnaires.   Calculated by Author.

Based on formula 4.5 of Chapter IV, sorting the Table 5.5, calculating the trust assessment of four experts for safety evaluation of sediment anchorage, a is:

$$a= (a_1, a_2, a_3, a_4)= (0.26, 0.23, 0.26, 0.25)$$

Experts evaluation results of anchorage sediment is shown in Table 5.6:

Table 5.6 Experts evaluation results of anchorage sediment

Anchorage sediment	Expert No.			
	1	2	3	4
Expert evaluation results	83	79	85	80

Data source: expert questionnaires. Calculated by Author.

Based on chapter IV, sorting the Table 5.6, calculating the blind value of anchorage sediment c_m=82

The single index measurement function of anchorage sediment, as shown in Figure 5.6:

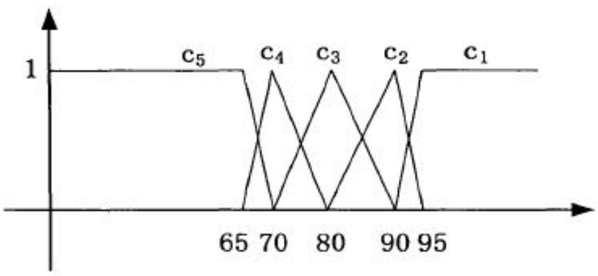

Figure 5.6 The single index measurement function of anchorage sediment

Data source: expert questionnaires. Calculated and drawn by Author.

Put blind value of anchorage sediment into the equation:

$$y = \frac{x-80}{10} = \frac{82-80}{10} = 0.2$$

So the single index measure vector of anchorage sediment is

(0, 0.2, 0.8, 0, 0)

There are two experts who had evaluated the safety of sheltered nature of Qinhuangdao anchorage. The trust assessment of two experts for safety evaluation of sheltered nature is shown in Table 5.7:

Table 5.7 The trust assessment of experts for safety evaluation of sheltered nature

No.	Major	Educational background	Post	Length of service	Score	Trust
1	Navigation	Undergraduate	Chief officer	18	30	0.52
2	Navigation	Undergraduate	Captain	14	28	0.48

Data source: expert questionnaires. Calculated by Author.

Based on formula 4.5 of Chapter IV, sorting the Table 5.7, calculating the trust assessment of two experts for safety evaluation of sheltered nature, a is:

$$a = (a_1, a_2) = (0.52, 0.48)$$

Experts evaluation results of sheltered nature is shown in Table 5.8:

Table 5.8 Experts evaluation results of sheltered nature

Sheltered nature	Expert No.	
	1	2
Expert evaluation results	75	72

Data source: expert questionnaires. Calculated by Author.

Based on chapter IV, sorting the Table 5.8, calculating the blind value of sheltered nature c_m=73

So the single index measure vector of anchorage sediment is

$$(0, 0, 0.3, 0.7, 0)$$

Using u_1' expresses the single index measure vector of anchorage factors, then:

$$u_1' = \begin{pmatrix} 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 0 & 0.8 & 0.2 & 0 \\ 0 & 0.2 & 0.8 & 0 & 0 \\ 0 & 0 & 0.3 & 0.7 & 0 \end{pmatrix}$$

Based on formula 3.6 of Chapter III, the weight vector of the anchorage factors, w_1 is:

$$w_1 = (0.35, 0.15, 0.15, 0.35)$$

$$u_1 = w_1 \bullet u_1' = (0, 0.24, 0.485, 0.275, 0)$$

2. Safety measure of traffic factors

There are five experts who had evaluated the safety of traffic factors of Qinhuangdao anchorage. The trust assessment of five experts for safety evaluation of traffic factors is shown in Table 5.9:

Table 5.9 The trust assessment of experts for safety evaluation of traffic factors

No.	Major	Educational background	Post	Length of service	Score	Trust
1	Navigation	Undergraduate	Chief officer	9	34	0.20
2	Navigation	College	Third officer	7	31	0.18
3	Maritime management	Master	Associate Professor	16	34	0.20
4	Maritime management	Master	Lecturer	6	32	0.19
5	Other	Master	Professor	19	36	0.23

Data source: expert questionnaires.   Calculated by Author.

Based on formula 4.5 of Chapter IV, sorting the Table 5.9, calculating the trust assessment of five experts for safety evaluation of traffic factors, a is:

$$a = (a_1, a_2, a_3, a_4, a_5) = (0.20, 0.18, 0.20, 0.19, 0.23)$$

Experts evaluation results of traffic factors sediment are shown in Table 5.10:

Table 5.10 Experts evaluation results of anchorage traffic factors

traffic factors	Expert No.				
	1	2	3	4	5
Expert evaluation results on traffic flow	82	79	80	83	77

Expert evaluation results on traffic composition complexity	79	77	75	81	74

Data source: expert questionnaires. Calculated by Author.

Based on Chapter IV, sorting the Table 5.10, calculating the blind value of traffic flow c_m=80, the blind value of traffic composition complexity c_m=77,

So the single index measure vector of traffic flow and traffic composition complexity are

$$(0, 0, 1, 0, 0) \text{ and } (0, 0, 0.7, 0.3, 0)$$

Using u_2' expresses the single index measure vector of traffic factors, then:

$$u_2' = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0.7 & 0.3 & 0 \end{pmatrix}$$

Based on formula 3.6 of Chapter III, the weight vector of the traffic factors, w_2 is:

$$w_2 = (0.8, 0.2)$$

$$u_2 = w_2 \bullet u_2' = (0, 0, 0.94, 0.06, 0)$$

3. Safety measure of weather factors

Through detailed analysis of the Qinhuangdao anchorage, we obtain measuring indicators value of weather factors is shown in the following table 5.11:

Table 5.11 Qinhuangdao weather factors index measured values

Index	Wind power more than 7 (days/year)	Poor visibility (days/year)
values	45	26.5

Data source: expert questionnaires. Calculated by Author.

The single index measurement function of wind, as shown in Figure 5.7:

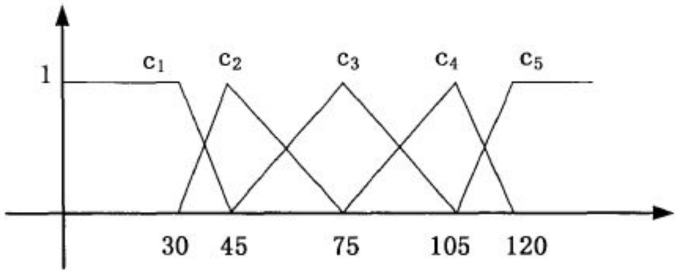

Figure 5.7 The single index measurement function of wind

Data source: expert questionnaires. Calculated and drawn by Author.

The single index of wind membership degree, c_2 is 1, so the single index measure vector of wind is:

$$(0, 1, 0, 0, 0)$$

The single index measurement function of poor visibility, as shown in Figure 5.8:

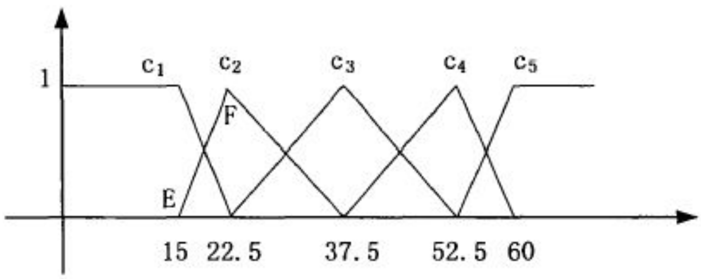

Figure 5.8 The single index measurement function of poor visibility

Data source: expert questionnaires. Calculated and draw by Author.

From Figure 5.8 obtaining EF linear equation :

$$y = \frac{x - 22.5}{15} = \frac{26.5 - 22.5}{15} = 0.27$$

It means safety membership degree belongs to poor visibility c_3 is 0.27, due to the normalized quality, the membership degree belongs to c_2 is 0.73, so the single index measure vector of poor visibility is:

$$(0, 0.73, 0.23, 0, 0)$$

Using u_3' expresses the single index measure vector of weather factors, then:

$$u_3' = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0.73 & 0.27 & 0 & 0 \end{pmatrix}$$

Based on formula 3.6 of Chapter III, the weight vector of the weather factors, w_3 is:

$$w_3 = (0.2, 0.8)$$

$$u_3 = w_3 \bullet u_3' = (0, 0.784, 0.216, 0, 0)$$

4. Safety measure of hydro-logical factors

Through detailed analysis of the Qinhuangdao anchorage, we obtain measuring indicators value of hydro-logical factors which are shown in the following table 5.12:

Table 5.12 Qinhuangdao hydro-logical factors index measured values

Index	Current (m/s)	Wave (m)
values	0.5	1.0

Data source: Zhang, 2014. Calculated by Author.

Constructing the single index measurement function of current, as shown in Figure 5.9:

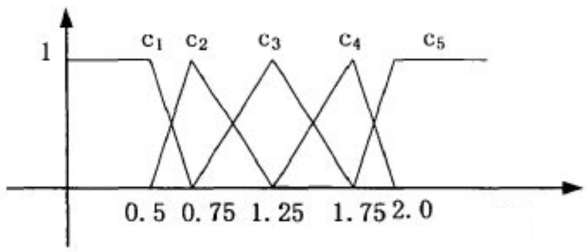

Figure 5.9 The single index measurement function of current

Data source: Zhang, 2014. Calculated and drawn by Author.

The single index of current membership degree, c_1 is 1, so the single index measure vector of current is:

$$(1, 0, 0, 0, 0)$$

Constructing the single index measurement function of wave, as shown in Figure

5.10:

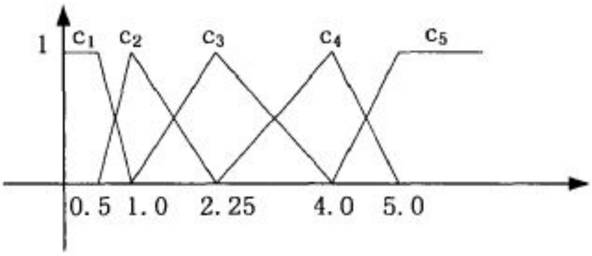

Figure 5.10 The single index measurement function of wave

Data source: Zhang, 2014. Calculated and drawn by Author.

The single index of wave membership degree, c_2 is 1, so the single index measure vector of wave is:

$$(0, 1, 0, 0, 0)$$

Using u_4' expresses the single index measure vector of hydro-logical factors, then:

$$u_4' = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{pmatrix}$$

Based on formula 3.6 of Chapter III, the weight vector of the hydro-logical factors, w_4 is:

$$w_4 = (0.2, 0.8)$$

$$u_4 = w_4 \bullet u_4' = (0.2, 0.8, 0, 0, 0)$$

5. Safety measure of adjacent facilities

Through detailed analysis of the Qinhuangdao anchorage, we obtain measuring indicators value of adjacent facilities which are shown in the following table 5.13:

Table 5.13 Qinhuangdao anchorage adjacent facilities index measured values

Index	Distance to fairway (S/L)	Distance to breeding area (m)	Distance to obstacles (m)
values	4.5	1300	>2000

Data source: Zhang, 2014. Calculated by Author.

Constructing the single index measurement function of distance to fairway, as shown in Figure 5.11:

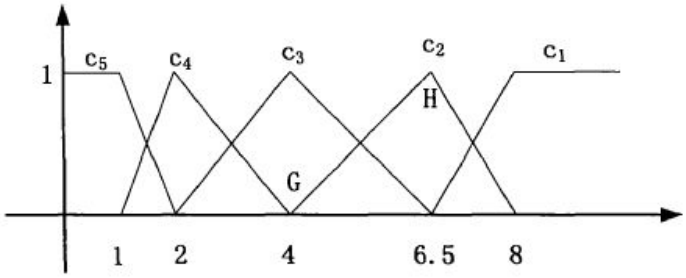

Figure 5.11 The single index measurement function of distance to fairway

Data source: Zhang, 2014. Calculated and drawn by Author.

From Figure 5.11 obtaining GH linear equation :

$$y = \frac{x-4}{2.5} = \frac{4.5\text{-}4}{2.5} = 0.2$$

It means safety membership degree belongs to distance to fairway c_2 is 0.2, due to the normalized quality, the membership degree belongs to c_3 is 0.8, so the single index measure vector of distance to fairway is:

(0, 0.2, 0.8, 0, 0)

Constructing the single index measurement function of distance to breeding area, as shown in Figure 5.12:

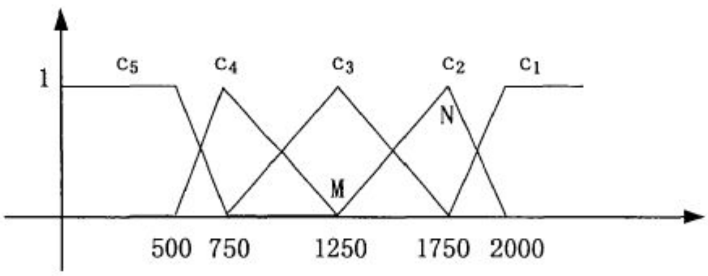

Figure 5.12 The single index measurement function of distance to breeding area

Data source: Zhang, 2014. Calculated and drawn by Author.

From Figure 5.12 obtaining MN linear equation :

$$y = -\frac{x-1750}{500} = -\frac{1300\text{-}1750}{500} = 0.9$$

It means safety membership degree belongs to distance to breeding area c_3 is 0.9, due to the normalized quality, the membership degree belongs to c_2 is 0.1, so the single index measure vector of distance to breeding area is:

$$(0, 0.1, 0.9, 0, 0)$$

Constructing the single index measurement function of distance to obstacles, as shown in Figure 5.13:

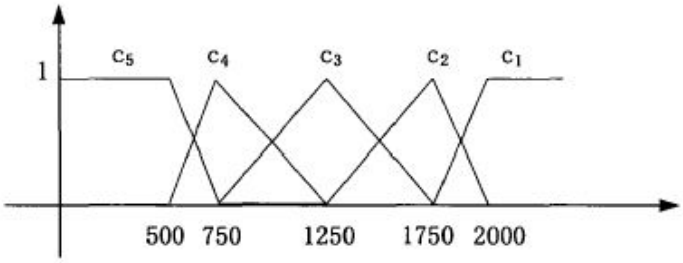

Figure 5.13 The single index measurement function of distance to obstacles

Data source: Zhang, 2014. Calculated and drawn by Author.

The single index of distance to obstacles membership degree, c_1 is 1, so the single index measure vector of distance to obstacles is:

$$(1, 0, 0, 0, 0)$$

Using u_5' expresses the single index measure vector of adjacent facilities, then:

$$u_5' = \begin{pmatrix} 0 & 0.2 & 0.8 & 0 & 0 \\ 0 & 0.1 & 0.9 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Based on formula 3.6 of Chapter III, the weight vector of adjacent facilities, w_5 is:

$$w_5 = (0.552, 0.131, 0.317)$$

$$u_5 = w_5 \bullet u_5' = (0.317, 0.1235, 0.5595, 0, 0)$$

6. Safety measure of navigation service

There are six experts who had evaluated the safety of navigation service of Qinhuangdao anchorage. The trust assessment of six experts for safety evaluation of navigation service is shown in Table 5.14:

Table 5.14 The trust assessment of experts for safety evaluation of navigation service

No.	Major	Educational background	Post	Length of service	Score	Trust
1	Navigation	College	Third officer	5	31	0.15
2	Navigation	Undergraduate	Captain	18	37	0.18
3	Navigation	Undergraduate	Chief officer	10	34	0.17
4	Maritime management	Master	Lecturer	7	32	0.16
5	Maritime management	Master	Associate Professor	15	34	0.17
6	Other	Master	Professor	20	36	0.17

Data source: expert questionnaires. Calculated by Author.

Experts evaluation results of navigation service are shown in Table 5.15:

Table 5.15 Experts evaluation results of navigation service

Navigation service	Expert No.					
	1	2	3	4	5	6
Expert evaluation results on VTS management level	88	87	92	90	92	85
Expert evaluation results on navigation aids level	85	80	79	87	83	84

Data source: expert questionnaires. Calculated by Author.

Based on chapter IV, sorting the Table 5.15, calculating the blind value of VTS management level c_m=89, the blind value of navigation aids level c_m=83,

So the single index measure vector of VTS management level and navigation aids level are

$$(0, 0.9, 0.1, 0, 0) \text{ and } (0, 0.3, 0.7, 0, 0)$$

Using u_6' expresses the single index measure vector of navigation service, then:

$$u_6' = \begin{pmatrix} 0 & 0.9 & 0.1 & 0 & 0 \\ 0 & 0.3 & 0.7 & 0 & 0 \end{pmatrix}$$

Based on formula 3.6 of Chapter III, the weight vector of the navigation service, w_6 is:

$$w_6 = (0.5, 0.5)$$

$$u_6 = w_6 \bullet u_6' = (0, 0.6, 0.4, 0, 0)$$

5.4.2 Multiple safety unascertained measure evaluation indicator of Qinhuangdao anchorage

The multiple safety unascertained measure evaluation indicator of Qinhuangdao anchorage can be calculated as:

$$U = W \bullet A$$

Wherein, W is weight vector of six safety assessment elements of anchorage, A is unascertained measure matrix of the six single index elements.

$$U = W \bullet A = (W_1, W_2, W_3, W_4, W_5, W_6) \bullet (u_1, u_2, u_3, u_4, u_5, u_6)$$

$$= (0.163, 0.073, 0.073, 0.275, 0.253, 0.163) \bullet$$

$$\begin{pmatrix} 0 & 0.24 & 0.485 & 0.275 & 0 \\ 0 & 0 & 0.94 & 0.06 & 0 \\ 0 & 0.784 & 0.216 & 0 & 0 \\ 0.2 & 0.8 & 0 & 0 & 0 \\ 0.317 & 0.1235 & 0.5595 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \end{pmatrix}$$

$$= (0.135, 0.446, 0.370, 0.049, 0)$$

The multiple safety unascertained measure evaluation indicator of Qinhuangdao anchorage is (0.135, 0.446, 0.370, 0.049, 0).

5.4.3 The confidence level of safety evaluation

Evaluation space of Qinhuangdao anchorage belongs to ordered space, according to confidence level identification rule, take confidence level λ = 0.6, so

$$k_0 = \min\left| k : \sum_{l=1}^{k} u_l \geq \lambda, k = 1,2,3,4,5 \right|$$

Based on the multiple safety unascertained measure evaluation indicator of Qinhuangdao anchorage, then is calculated according to the upper formula, k_0=2.3, so the safety assessment of Qinhuangdao anchorage belongs to the second level and the third level, overall the safety assessment of Qinhuangdao anchorage is general low risk.

5.5 Safety evaluation conclusion of Qinhuangdao anchorage

The Qinhuangdao anchorage is with the suitable depth, good sediment and can provide high anchors holding power, better wind and current conditions, anchorage location and features correspond to the planning of Qinhuangdao port, the anchorage scale also meet the recently operational requirements of Qinhuangdao Port. Anchorage is located near the harbor channel which means the ships are at ease in and out of port, it also keeps a certain distance to nearby fairways, it will not affect the surrounding traffic waters and habits along the coastal route.

There is no better shelter for ship blocking wind in anchorage, so the anchorage is not as sheltered. But the annual average wind speed is low, so it is suitable for general anchoring. Overall the selected anchorage of Qinhuangdao is suitable for use as the anchorage.

Chapter 6 Conclusion

6.1 Conclusion

In recent years, with the rapid development of China's economy and the shipping industry, ship traffic industry increased substantially, the demand for anchorage has seen a sharp increase with the growth fleet. Anchorage is an important part of the port operation and development, which is directly related to port security and economic benefits, therefore, safety analysis and research are particularly important for anchorage.

This thesis introduces the concept of unascertained information to the safety research for anchorage, by analysis of factors influencing the safety of anchorage, then initial establishment of the safety assessment model for anchorage. By determining the evaluation factors weight and improved Analytic Hierarchy Process with unascertained qualitative and quantitative mathematics indicators in safety evaluation process. After the systematic study of unascertained measure model and its application to the safety assessment of anchorage, we get the following conclusions:

1. The risk of accidents occurring in anchorage have burst, uncertainty, variability and uneasy control characteristics. The evaluation index system is built according to the advice of experienced pilots, captains, maritime management experts and classified under the professional guidance. However, in classification of the security level of factors, it is difficult to determine the level of ownership of some factors and the same level or hierarchy of factors sometimes is not exactly the same, so the deficiencies are still need to discuss in the safety evaluation system (Zhuo, 2009, pp.11-14).

2. In the safety assessment process of anchorage, there are some factors that can't be

easily evaluated by quantity. Due to unascertained measure, comprehensive evaluation method can be qualitative issues with a number of forms of expression. In a sense the evaluation results with this method is more accurate which is less affected by human factors. Therefore the unascertained measure comprehensive evaluation method is necessary.

3. The weighting is part of important information for a comprehensive evaluation. Empowering used AHP method can not handle uncertainty information, so we use a combination of qualitative and quantitative improved AHP to make the weight assignment, which is more scientific and reasonable, to fulfill the compliance requirements, and better reflects the impact of the weighting of various factors impact on anchorage.

4. By the Qinhuangdao anchorage safety assessment, we obtained safety level of Qinhuangdao anchorage. It shows the unascertained measure comprehensive evaluation can be widely used in safety evaluations of the general anchorage. But anchorage itself is a very complex system, closely linked to the construction of anchorage, harbor development, the proficiency of the navigator, maritime control services, so it is difficult to make quantitative or qualitative evaluation by one objective evaluation method (Ding, 2000, pp.63-67).

6.2 The deficiencies

In this paper there are some simple explorations for using unascertained mathematics in the field of safety assessment anchorage, the anchorage safety assessment is a complicated systematic project involving many factors and extensive. Because of limited time, space and the breadth and depth of knowledge, there are some problems and deficiencies need to be discussed, these issues are:

1. The safety assessment index of anchorage. Establishing a multi-level evaluation system is the core of safety unascertained comprehensive evaluation model of

anchorage, due to lack of experience, so it is necessary for further research in this regard, choose different levels of safety factor influence anchorage which is easy to apply, easy to quantify the evaluation.

2. The paper uses the expert questionnaire method to determine the weight of each layer index, due to the limited number of experts and the limitations of subjectivity of experts and data processing methods, it is difficult to eliminate subjective of evaluation index. So, how to further reduce subjectivity of safety evaluation still needs to solve in the future (Han, 2006).

3. In this paper, by using unascertained comprehensive evaluation we carried out safety assessment, obtained safety level of Qinhuangdao anchorage. However, due to the development speed of port is fast, while this research mainly focuses on the safety assessment for the Qinhuangdao anchorage until 2015, so it is inadequate consideration in some research filed for the development of the Qinhuangdao port in the future.

4. The offshore aquaculture industry of the Qinhuangdao port is developed. Due to incomplete statistics of fishing vessels, the paper considers less safety impact by fishing. Therefore, it is still necessary to continue research the safety impact by navigation and operation of vessels.

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APPENDIX: A Questionnaire of Safety Influencing Factors of Qinhuangdao Anchorage

Dear Expert:

First of all, thank you for completing this survey. In order to fully investigate and understand the security situation of Qinhuangdao anchorage, please combine your sailing experience or research experience in Qinhuangdao Port, completing the form below in accordance with the relevant requirements.

Please scoring the factors affecting the anchorage safety. Rate the range is 0 to 100, the higher scores means more safety.

Table 1 Expert scoring table

Factor	Score	Factor	Score
Anchorage area		Sediment	
Water depth		Sheltered nature	
Traffic flow		Traffic composition complexity	
Big wind		Poor visibility	
Current		Waves	
Distance to the fairway		Distance to the breeding areas	
Distance to other obstacles		VTS management level	
Navigation aids			
Additional recommendations:			

Table 2 Expert personal information table

Item	Professional direction	Education	Job title	Length of service
Expert				

APPENDIX: B Questionnaire of Safety Evaluation Index Weight of Qinhuangdao Anchorage

Dear Expert:

First of all, thank you for completing this survey. In order to fully investigate and understand the security situation of Qinhuangdao anchorage, please combine your sailing experience or research experience in Qinhuangdao Port, completing the form below in accordance with the relevant requirements.

Please refer to Table 3, evaluating the respective weight of following factors:

Table 3 Importance degree definition table of compared factors

Index	Importance degree
1	Comparison of two factors, one is the same importance as other
3	Comparison of two factors, one is a little more important than other
5	Comparison of two factors, one is important than other
7	Comparison of two factors, one is much more important than other
9	Comparison of two factors, one is extremely important than other
2,4,6,8	Important degree between median of the two adjacent

Table 4 Anchorage factors weight

Importance degree	Anchorage area	Sediment	Water depth	Sheltered nature
Anchorage area				
Sediment				
Water depth				
Sheltered nature				

Table 5 Traffic factors weight

Importance degree	Traffic flow	Traffic composition complexity
Traffic flow		
Traffic composition complexity		

Table 6 Weather factors weight

Importance degree	Big wind	Poor visibility
Big wind		
Poor visibility		

Table 7 Hydro-logical factors weight

Importance degree	Current	Wave
Current		
Wave		

Table 8 Adjacent facilities factors weight

Importance degree	Distance to the fairway	Distance to the breeding areas	Distance to other obstacles
Distance to the fairway			
Distance to the breeding areas			
Distance to other obstacles			

Table 9　Navigation service factors weight

Importance degree	VTS management level	Navigation aids
VTS management level		
Navigation aids		