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Navigation safety assessment in routeing system waters of Changjiang River estuary

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NAVIGATION SAFETY ASSESSMENT IN ROUTEING SYSTEM WATERS OF CHANGJIANG RIVER ESTUARY

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

Evaluation to navigation safety is very difficult due to the uncertainties and complexity of multiple related evaluation indexes. This research paper aimed at navigation safety assessment in Ship's Routeing Waters of Changjiang River Estuary by using multi-connection number of the set-pair analysis theory. Firstly, the author introduces the background of the research. Then it is the Characteristics in Routeing System Waters of Changjiang river Estuary. After the HAZID, the factors are confirmed. Based on the set-pair analysis theory and fuzzy mathematics, comprehensive safety assessment is conducted. Finally, after analysis, the author gives some suggestions to the administration, followed by a conclusion.

Key Words: Set-Pair Analysis ,Ship's Routeing Waters, FSA

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LIST OF ABBREVIATIONS

CJK	Chang Jiang Kou
FSA	Formal ship Safety Assessment
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
MRRA	Model based on Relative Risk Assessment
MSA	Maritime Safety Administration
MSC	Maritime Safety Committee
MSEP	Maritime Safety Evaluation Program
MSES	Maritime Safety Evaluation System
NE	Northeast
NW	Northwest
QRA	Quantitative Risk Assessment
SW	Southwest

Chapter-I Introduction

1.1 Background

With the development of world economy and trade, the relationship between countries is increasingly close and the role of maritime transport is becoming more and more important in international communication. In recent years, because of the large-scale and diversification in ship, as the link of the port, the fairway is increasingly busy and the traffic density is substantial increase. Along with the increasing complexity of navigation environment, navigational safety issues are outstanding. “Shipping is perhaps the most international of all the world's great industries and one of the most dangerous”. (IMO, 2002)

Ships routing system is widely used in key areas, narrow channel and special waters as traffic management measures by international community. It requires the ships to adhere to the principles of traffic separation and navigation on the starboard side, so as to specify the traffic flow, enhance the efficiency of the traffic and ensure the safety of navigation.

Since 1976 when the Dover strait between Britain and France implemented the traffic separation scheme, the safety of navigation has been greatly improved. Specifically, it has played a positive role in improving the navigation environment, reducing the number of traffic accidents, improving navigation efficiency, ensuring the safety of life at sea, strengthening marine environmental protection and promoting social and economic development. Also as is widely recognized in the international community, more and more traffic separation schemes are established in succession. In 1985, IMO (International Maritime Organization) adopted the "General provisions on ships' routeing", marking that the complete framework of ship’s routeing has been basically established. At present, all countries in the world continuously strengthen the study of this aspect, and almost every year, many proposals on the new ship’s routeing or the amendment to the existing one are submitted to IMO. Shipping routeing system has become recognized as effective means of regulating the navigation order in complex waters. By the year 2010, a total of 261 ship’s routeing proposals were adopted by IMO, of which 159 are traffic separation schemes.

The Changjiang River estuary located in China's central coastal waters is the intersection zone of the north and south China coastal waters and intensive route and extreme density are seen in this waters all year round. As China's north-south hub, it is one of the world famous navigable dense regions. Meanwhile, as the waters of bad weather, it is an accident-prone area. In order to reduce the risk of ship accidents, standardize the order of navigation and improve traffic efficiency, China Maritime Safety Administration approved the Changjiang River Estuary Ship's Routeing on September 1, 2002. After several amendments, the formation of the current " Changjiang River Estuary Ship's Routeing (2008)" is adopted. It mainly consists of two navigational warning area, including traffic lane, two-way routes, dividers, medians and anchorages, etc. The geographical scope of the following 4 points are the waters of Changjiang River Estuary Ship's Routeing:

1）31°13′10.4″N/122°40′00″E;
2）30°55′28″N/122°40′00″E;
3）30°55′28″N/122°28′00″E;
4）31°13′10. 4″N/122°28′00″E。

In order to regulate ship’s sailing behavior, improve water transport efficiency and increaase safety of level management, China Maritime Safety Administration (MSA) issued " Notice about Conducting the National Coastal Ships' Routeing Research Planning" which requires the implementation of the Chinese coastal route planning. Currently, China MSA is collaborating with several organizations to study China's coastal ships' routeing. With the increase of ship speed, size, draft and the further development of the shipping industry, especially the growing awareness of people’s safety and environmental protection, people are paying increasing attention improving the safety of navigation and protecting the marine environment from damage. As we know, Ships' Routeing is an effective measure in traffic management and plays a pivotal role in regulating vessel traffic flow, ensuring navigation safety, improving traffic efficiency, ensuring the safety of life at sea, enhancing marine protection and promoting social and economic development.

In this context, through the study of the objective law of Changjiang River Estuary navigable waters and the evaluation of the navigation safety, this research especially has a positive significance for China MSA to set Chinese coastal ships' routeing scientifically and reasonably.

1.2 The Objective and Scope of the Study

Transportation by sea has characteristics of high risk, especially in recent years, with the development of shipping industry, great changes have taken place in ship's quantity, type, tonnage. A lot of new ships are put into market, which has greatly increased the density of navigation leading to high frequency of traffic accidents. As is known to all, every accident at sea usually can cause significant economic losses and serious social consequences. Therefore, among the three factors of maritime traffic -safety, efficiency and benefit, safety is the top issue for people. As a result, we need to assess the situation of navigation safety.

Navigational environment, ship factors and human factors are major components in ocean transport, especially in traffic separation schemes waters; hence, it is highly essential to make an assessment of safety conditions of ship's routeing waters. Quantitative analysis of related factors influencing water safety facilitates will make the authorities examine the most influential factors so as to improve safety. Formal ship safety assessment (FSA) is a new approach that has attracted great attention in the marine industry over the last several years (J. Wang, 2001,p19). FSA of navigational safety helps those who are engaged in shipping understand the concept of ship's routeing, content, implementing methods and performances to make safer navigation, cleaner ocean and more convenient shipping.

> Having been approved by the IMO to primarily verify the effectiveness of proposed rules and regulations, the FSA technique applies its broad principles of quantitative risk assessment(QRA) in the five-step procedure. The availability of suitable data necessary for each step of the FSA process is very important. When data are not available, expert judgement, physical models, simulations and analytical models may be used to achieve valuable results.
>
> (Guedes S. C. & Teixeira A. P., 2001,p.305)

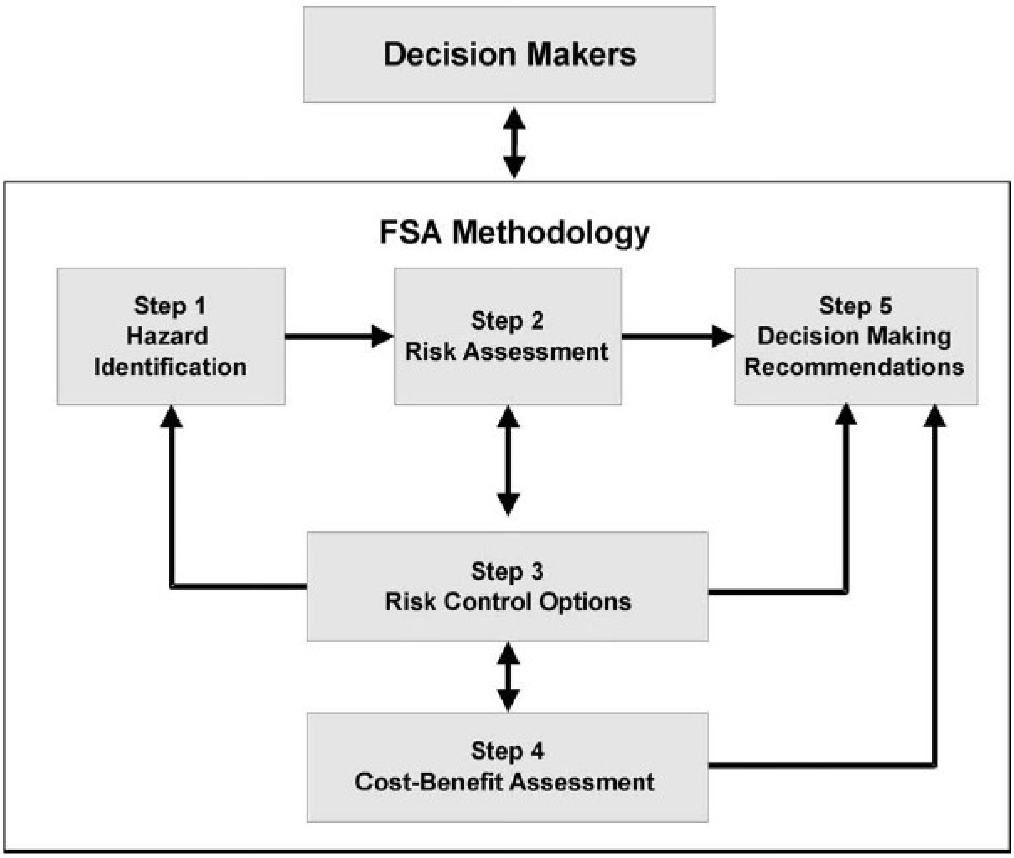

Figure 1: Flow Chart of the FSA Methodology

Source: IMO (2002) MSC/Circ.1023, MEPC/Circ.392, 2002

The purpose of this paper is to conduct navigational safety and quality in Changjiang River Estuary and analyze the current situation and trend based on the comprehensive results. Besides, constructive suggestions are provided for China MSA to improve navigational safety and efficiency aiming at the current shortages.

1.3 Current research on Navigation safety

On the subject of safety assessment in navigation, scholars in UK, USA and Japan have already done some thorough research. Vladimir M. (from UK) put forward navigational safety management system of fairway based on danger degrees by first assessing ship traffic safety and then presented some improvement schemes. The UK Marine Safety Agency sent a proposal to apply FSA to ship safety for approval in 66th session of the Maritime Safety Committee (MSC) of IMO and finally it got great support form IMO.

FSA caused some countries to do research on its systematic method. In USA, Maritime Safety Evaluation Program (MSEP) that is in line with the basic objective of FSA put forward by IMO, was formulated and replaced the passive, postmortem safety assessment and management system and developed a predictable safety criterion system. Japan put forward Maritime Safety Evaluation System (MSES) which aims to keep the safety standard above the social tolerance and the conclusion of this method is more in favor of quantitative analysis and evaluation and it focus on the extraction of potential dangerous factors, risk assessment and establishment of safety standard and has already made many accomplishments.

Hu S. (2007) proposed a model based on relative risk assessment (MRRA) with fuzzy functions. Their approach considered five factors including detailed information about accident characteristics in ship navigation.

Meanwhile, many Chinese scholars and experts have done substantial research on ship safety assessment and also have got great results. For example, Professor Wu Zhaolin carried out the research from the perspectives of human, ships and environment. Professor Chen Weijiong designed the system model of "Human – Machine – Environment – Control (management)" and applied it to navigation safety assessment and management successfully, and brought precautionary strategies and typical measures combining the formal safety science and managerial science. Professor Zheng Zhongyi utilized Grey System Theory Index Weight Cluster to analyze eight environmental factors influencing safety of port area and assessed the risk degree of navigation environment in ten coastal ports in China.

1.4 Methods Used in the Study

At present, experts and scholars from different organizations have done much research on navigational safety, especially on port areas and navigational environment. What's more common is argument about port areas and fairway, while research specialized on navigational safety assessment in ship's routeing waters is not so thorough. After reading vast literature and data, it is found out that most of the research focuses on planning ship routeing and pre-safety assessment. This paper tries to utilize Set-Pair Theory established by Zhao Keqin, a Chinese scholar, to analyze navigational safety on ship's routeing waters in Changjiang River Estuary to enrich the assessment method of navigational safety.

Chapter-II Characteristics in Ship's Routeing Waters of Changjiang river Estuary

2.1 Basic Information of Ship's Routeing Waters

As is shown in Fig 1, there are two precautionary areas in ship's routeing waters of Changjiang River Estuary, namely precautionary area A and precautionary area B. Specifically, CJK light vessel which at the east end of the North channel is the center of precautionary area A and the light vessel of South channel is the center of precautionary area B. Ship's routeing waters of Changjiang River Estuary are comprised of five traffic lane, namely A, B, C1, C2 and C3. The length of A, B, C1 and C3 are about 2.0 nm, which leads vessels into Precautionary area A and B in good order. Traffic lane C2, connecting Precautionary area A and B is 4 nm long. Each traffic lane is centered by its traffic separation zone by 0.75 nm into two directions. Among them, traffic lane A crosses through Precautionary area A and B in the east-west direction; By contrast, traffic lane C1, C2 and C3 cross Precautionary area A and B in the south-north direction.

As Changjiang River brings abundant silt into the sea, the substrate of waters in Changjiang River Estuary is silty. However, the water condition is good and the depth of the fairway is over 12.8 meters and deepens from the West to the East gradually.

2.2 Navigational Aids

(1) Position of CJK Light vessel: 31°06′10.1″N 122°31′58.6″E

(2) Position of South channel Light Vessel: 30°59′30.5″N   122°31′58.6″E

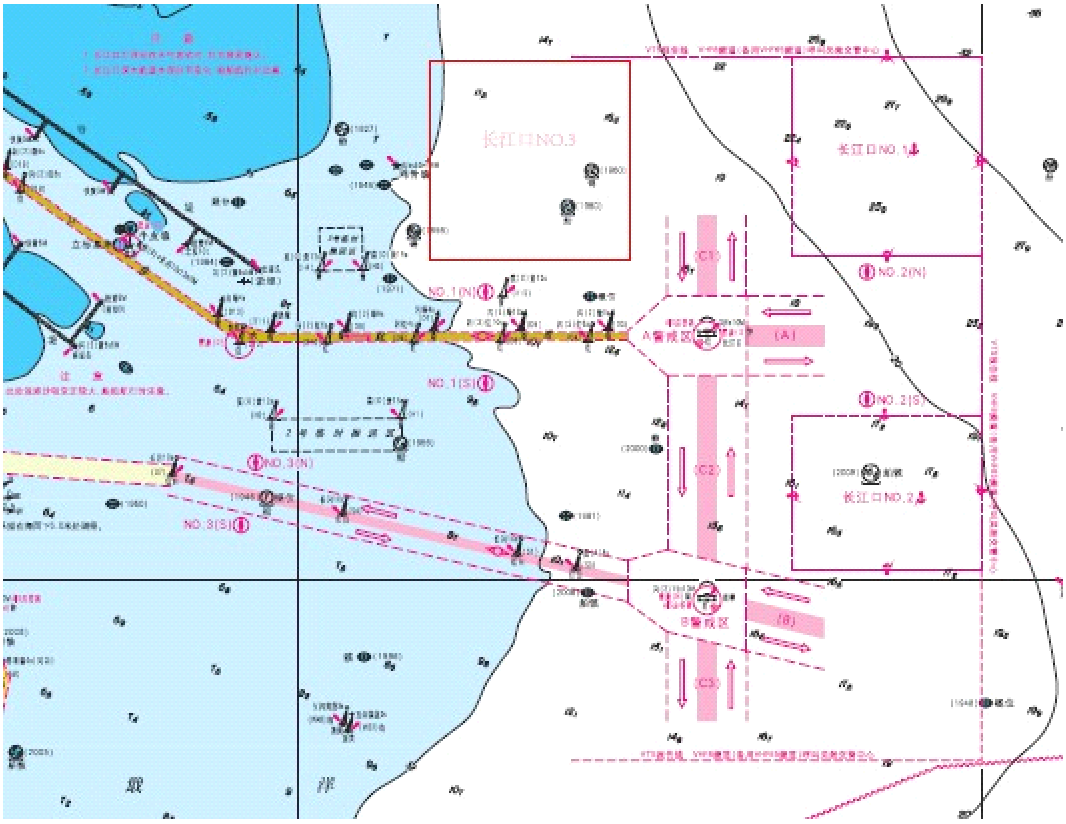

Figure 2: Changjiang River Estuary and its Vicinity

Source: Shanghai MSA (2010)

2.3 Anchorage

There are three anchorage berths in Changjiang River Estuary: Anchorage No.1 and Temporary Anchorage No.3 are mainly for large vessels and those that go into the North channel, and there are 6 specialized anchorages for Tanker or LNG etc; Anchorage No.2 is mainly used for medium-small ships and those that come into the South Channel.   The detailed position of the three anchorage berths are as follows:

Anchorage No.1 Water encircled by the following four points:

（1）31°08′10.3″N   122°34′29.0″E；

（2）31°13′10.4″N   122°34′29.0″E；

（3）31°13′10.4″N   122°40′00.0″E；

（4）31°08′10.3″N   122°40′00.0″E。

Anchorage No.2 Water encircled by the following four points:

（5）31°00′17.6″N　122°34′29.0″E；

（6）31°04′09.9″N　122°34′29.0″E；

（7）31°04′09.9″N　122°40′00.0″E；

（8）31°00′17.6″N　122°40′00.0″E。

Anchorage No.3 Water encircled by the following four points:

（1）31°16′00″N、122°25′00″E；

（2）31°16′00″N、122°30′00″E；

（3）31°11′00″N、122°30′00″E；

（4）31°11′00″N、122°25′00″E。

Chapter-III Identification of Hazards (HAZID)

3.1 Measures and Aim of HAZID

A lot of factors involving in ship's routeing waters are interconnected and the result will be one-sided if examining them insularly. As a result, systematic analysis must be carried out to detect various potential risk factors. In order to make certain the safety of the ship's routeing waters, all important factors must be taken into unified consideration to explore the relationship and laws among them.

The FSA is not to be applied to a ship in isolation but rather to a collection of systems including organizational, management, operational, human, and hardware, which fulfils specific functions. (Guedes S. C. & Teixeira A. P., 2001, p.305). Based on the results of previous research, a thorough after-accident review and analysis of potential dangers are conducted, utilizing the form of investigation and forum. The Environmental factors (meteorological hydrological factor and geography factors), ship factors, crew factors and navigation support factors are chosen as research objects so as to give a thorough assessment of ship's routeing waters of Changjiang River Estuary.

3.2 HAZID in Ship's Routeing Waters of Changjiang river Estuary

3.2.1 Environmental Factors

By analyzing environmental factors of ship's routeing waters of Changjiang River Estuary, visibility, wind, Maximum flow, width of the traffic lane, density of ships, traffic flow and so on are chosen to carry out further analysis.

3.2.1.1 Wind

Wind directions vary prominently at Changjiang River Estuary as seasons change, and

Southeast(SE) wind happens most often while Northeast(NE) wind follows, and the strong wind is NE wind. From October to February, the cold air heads down to the south to form strong wind. Each time cold air spills south, there usually arises strong wind, usually north wind or Northwest (NW) wind. During winter and spring, there is often north wind or NE wind that can be as strong as Beaufort scale 8. During summer, typhoon hits Chinese coastal area most frequently, especially from July to September. While Shanghai experiences Beaufort scale 6 to 7, it can have 8 to 10 wind scale in Changjiang River Estuary.

3.2.1.2 Tide

The tide in Changjiang River Estuary comes down to irregular semidiurnal tide, and the tidal range can be 0.5 to 1 metres; average tidal range for many years is 2.66 metres; maximum tidal range is 4.62 metres. The size of the tide in Shanghai is defined as below (Tidal range: the difference between the high tide and low tide in the same tide):

Table 1: Definition of the size of the tide in Shanghai

size of the tide	tidal range
Super Small	under 0.91 meters
Small	0.92 m - 1.83 m
Medium	1.84 m - 2.74 m
Maximum	2.75 m - 3.66 m
Super Maximum	3.67 m above

Source: Zhao R. H. (2011). *Tide of Shanghai Port.* Unpublished handout, Shanghai Pilot Station Shanghai, China

From the above definition, we can clearly see that the average tidal range in Changjiang River Estuary is Medium, but the data is more nearly Maximum.

Flow time of falling tide is 6.5 to 8.5 hours and it varies according to season and wind directions. Tide is much influenced by wind, as when north wind or NE wind is over 6 wind scale, the height of the tide increases by 40 to 50 centimetres whereas NW wind decreases by 20 to 30 centimetres. Tide of Changjiang River Estuary is usually rotating flow and changes clockwise. 4 hours before the high tide of Zhongjun, the water starts to rise, and the current changes from south to Southwest (SW) clockwise; it changes to west by north during soar and then changes from NW tide to South tide and Southeast (SE) tide after the high tide.

Owing to the relationship among tide, draft and usable water depth, large ships must come in and go out of the water by tide while small ships can move freely. In consequence, it becomes extremely densed and complicated in local area at certain time, which affects navigational efficiency and safety.

3.2.1.3 Waves and Swells

It is wave or swell or the combination of these two kinds that usually happen, and it's quite rare to observe the simple surge. Northerly is the major tide direction with the frequency of 20% to 31%; East by South (E/S) to South by East (S/E) is the second dominant tide direction with the frequency of 20% to 27%. According to the current actual measurement data, the maximum height of the wave is 6.1 metres, which occurred in August 1970, and the maximum cycle is 16.1 seconds, which occurred in September 1967. Maximum wave height and maximum cycle are damps from outside to inside Changjiang River Estuary.

3.2.1.4Visibility

The most important reason that affects visibility in Changjiang River Estuary is fog, mainly advection fog and frontal fog, which occur from February to June and from October to January; the heavy fog mainly clusters between February and April and usually come from the time after midnight to early morning. Abnormal weather occasionally causes traffic jam in ship's routeing area. It is widely known that

Changjiang River Estuary is the foggy area in China and affects navigation to a great extent. When fog suddenly happens, entry plan is cancelled temporarily, causing intense density, complicated navigational environment and inordinate orders, which is quite likely to cause collision or grounding.

3.2.1.5 Ships Traffic flow

According to incomplete statistics, ship volume in Changjiang River Estuary increases by 15% each year, among which 60% are large ships, with 280 and 330 ships per day in Precautionary area A and B respectively.

The current traffic flow in Ship's Routeing Waters of Changjiang River Estuary is as follows:

(1) Most ships crossing Shanghai Port and Changjiang river basin generally need to go with the tide. Five hours before Changxing high water, many ships proceed to the Pilot Station (PS) or Traffic Separation Lane and precautionary area from North channel and south Channel. Due to the different entry time and ship condition, takeover happens occasionally, which is likely to increase risks to a large extent. Within 1.5 hours before Changxing high tide, ships with draft of over 7.0 metres can enter North Channel in succession.

(2) Ships to enter the North Channel are required to come to the pilot Station during the time window that authorities approve in sequence. As a result, there are often large vessels that heave up anchor from Anchorage No.1 in queue, which causes great density in Precautionary area A and its adjacent waters, increasing the risk of crossing with the ships using traffic lane C.

(3) The traffic is regulated for ships entering into South Channel from Zhongjun low water to 2 hours after low water; so many ships are ready to enter South Channel drifting at the east of buoy S6 in order to wait for the entrance time, causing increasing ship density.

3.2.2 Ship Factors

Unexpected accident of the ships makes it more complicated to sail in ship's routeing waters and thus the navigational resources are more valuable. The major reason for the accident is bad machine conditions and poor ship maintenance. Especially for those old ships and low standard ships, faults are more likely to occur. As a result, ship's tonnage, ship's age, maneuvering system, guided system and telesystem are taken into consideration.

3.2.2.1 Ship Size

Tonnage and length of the ship are the first concerns when it comes to maritime activities. According to the data, the accident rate is directly proportional to 3/2 power of ship's length. Other things being equal, the greater the ship tonnage, the greater the momentum, the more clumsy and more dangerous to turn over and keep clear.

3.2.2.2 Ship Age

Ship age is a very important factor that influences ship safety as the longer the ship is used, the degrade of vessel constructure, increased ship accident and aged ship machines, the unreliability of the equipment happen more and more often. Especially for the vessels over 15 years old, when it comes to invalid period, the fault occurs more often each year. Various data show that the older the ship age, the greater the accident frequency. As a result, ship age is an important index.

3.2.2.3 Manoeuvring System

The manoeuvring is a crucial property and affects navigational safety. With the development waterborne transport, upsize of the ships, increasing speeds, mounting ship numbers and traffic density, it all poses a great challenge to manoeuvring skills. Stress is complicated during the voyage, and environmental factors, such as wind, tide, speed of the water and directions, all have a strong influence on the ship, which changes the manoeuvre system of the ship. If the ships are not operated well, it's likely that it has been influenced by some environmental factors that are hard to control the direction and the speed, which enhances the chance of ship accident. As is shown by statistics, technical defect in operational system takes up a large proportion.

3.2.2.4 Guided System

Navigation is the guided system of ship's safety. Good guide system helps avoid obstacles and protects ship safety. The completeness of Navigation is fundamental for safe navigation. Besides, the completeness of nautical chart, sailing direction, light list, notice to mariners and tidal tables are requirements for the effectiveness of the guided system, and fundamental guarantee of safe navigation. With the change of many factors such as hydrology, tides, port waters, construction, unupdated information of the guided system or wrong and ineffective guided information may also give rise to the ship grounding and striking.

3.2.3 Crew Factors

Human factors, such as incompetent crew, insufficient sense of responsibility and operational procedures not up to the required procedures, plus lack of routine maintenance, cause breakdowns. Harrald(1998) notes that human error is cited as the predominant cause of transportation accidents. Therefore we should not ignore the crew factors when doing the navigation safety assessment.

3.2.3.1 Professional Capacity

Ship handling is a practical skill, which needs not only complete professional knowledge but also practical handling experience in order to perform safe navigation. The operational experience is gained through self-training and grasp and it grows with sailing time. According to relevant statistics, the older the seaman, the lower the accident rate. Of course, language communication competence is also another aspect of seaman's professional qualification. In Ship's Routeing Waters of Changjiang River Estuary, some coastal ships often cannot communicate with foreign vessels in fluent English and missed the best avoidance timing, causing close-quarters situations and/or risk of collision.

3.2.3.2 Awareness of Safety

For navigational safety, whether seaman holds strong sense of safety is more important. Without adequate sense of safety, it is quite likely to give rise to unsafe operation. Viewed from present accidental data, unqualified maneuvering is the major reason for accidents and potential accidents.

3.2.4 Management of VTS

VTS is the direct manager of risk managerment, which faces vessel motions directly and provides aid services for ships. Meanwhile, as a means of traffic separation scheme, forced pilotage, enhanced efficiency, guarantee of navigation and environmental safety, VTS also plays an essential role of safety. Wusong VTS, as the management of Ship's Routeing Waters in Changjiang River Estuary, the qualification of the watch officer and the managerial standard are an adjustment factor of the waters in some aspect.

3.2.5 Pilotage Services

In every navigable waterway of significance throughout the world, maritime pilots conduct ships between the oceans and berths at the land-sea interface during the part of each voyage that presents the greatest number of risks. (Darbraa R. M. & Crawford J.F.E., 2007, P.736)

The quality of pilotage affects safety of navigation. When the wind and tide is bigger, considering safety of boarding and disembarkation, the pilot usually boards the ship in Buoy D3 to D5 (North Channel) or S1 (South Channel); when there is gale and maximum tide, moves to Buoy D18 to D20 and Buoy S14. As the pilot disembarks in advance, the ships in Routeing Waters in Changjiang River Estuary sail in disorder, which harms the safety standard.

Furthermore, as there is a high density of ships sailing across Shanghai Port and along Changjiang River, the long distance and time leaves the pilot under great mental stress, which does harm to the pilotage quality.

Chapter-IV Hazard Assessment

4.1 set-pair analysis

The set pair analysis (SPA), proposed by Keqin Zhao in 1989, is a modified uncertainty theory considering both certainties and uncertainties as an integrated certain–uncertain system and depicting the certainty and uncertainty systematically from three aspects as identity, discrepancy and contrary (Zhao K. Q. & Xuan A. L. 1996, p18)

4.1.1 Number of Connections

A set-pair is a pair comprised of two sets linked to each other. It regards certainty and uncertainty as a certain-uncertain system and its characteristic is portrayed by connection number, which is depicted as:

$\mu=\frac{S}{N}+\frac{F}{N}i+\frac{P}{N}j$=a + bi + cj, and N=P+S+F

N, P, S and F represent the total number of characteristics, common characteristics, opposing characteristics and dissimilar characteristics. Regardless of weights of characteristics, a, b and c mean degree of identification, degree of opposition and degree of difference respectively.

According to the definition, a, b and c satisfy a + b + c = 1. i is the coefficient of degree of difference and ranges from -1 to 1. j is the coefficient of degree of opposition and is set as -1.

If there are n set-pairs, i can be decomposed into i_1, i_2,…, taking the form of $\mu = a + b_1 i_1 + \ldots + b_{n-2} i_{n-2} + cj$, under the name of n-ray connection number.

4.1.2 Set-pair Comprehensive Assessment Model

Suppose there are m indexes, which constitute assessment set I={ I1，I 2， …， I m }, the assessment standard has n grades, which is portrayed by C={C1，C2 ，…，Cn }, (Wu J. J & Xiao Y. J., 2011, p.31), so each assessment index comprise classified standard matrix, as is shown in Table 2. a_{22} represents the standard value of the second assessment grade of the second assessment index.

Table 2: Standard Assessment Classified Matrix of Assess Indexes

	C_1	C_2	…	C_n
I_1	a_{11}	a_{12}	…	a_{1n}
I_2	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…
I_m	a_{m1}	a_{m2}	…	a_{mn}

Source: complied by the author

The assessment set A = {a_{kl}}, and get the assessment matrix:

$$A=\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

Among which $1 \le k \le m$， $1 \le l \le n$， $a_{m1} < a_{m2} < \ldots < a_{ml} < a_{mn}$, or $a_{m1} > a_{m2} > \ldots > a_{ml} > a_{mn}$. According to the specific value t_k of each index, all true values and grades of indexes are determined for each assessment object.

4.1.2.1 Determining comprehensive n-ray connection number μ_k of each index

Connection number μ=a + bi + cj is called 3-ray connection number, which can be expanded to n-ray connection number. The assessment index of sum of I_k can be expressed as $\mu_k = r_{k1} + r_{k2} i_1 + \ldots + r_{kl} i_{l-1} + \ldots + r_{kn} j$, among which $r_{kl} \in [0,1]$ is the connection component of I_k to grade C_l.

$\sum_{l=1}^{n} r_{kl} = 1$; $1 \le k \le m$, $1 \le l \le n$.

Suppose the actual value of assessment index is $I_{k,}$. Set $a_{k1} < a_{k2} < \ldots < a_{kl} < a_{kn}$, and $1 \le l < n$, and calculate μ_k through the following method.

1)when $t_k \le a_{k1}$, $\mu k = 1 + 0i_1 + 0j$;

2) when $a_{k1} < t_k \le a_{k2}$, $\mu k = \frac{|t_k - a_{k2}|}{|a_{k1} - a_{k2}|} + \frac{|t_k - a_{k1}|}{|a_{k1} - a_{k2}|} i_1 + 0i_2 + \ldots + 0j$;

3)when $a_{kl} < t_k \le a_{k(l+1)}$, $\mu k = 0 + \ldots + \frac{|t_k - a_{k(l+1)}|}{|a_{kl} - a_{k(l+1)}|} i_{l-1} + \frac{|t_k - a_{kl}|}{|a_{kl} - a_{k(l+1)}|} i_l + \ldots + 0j$;

4)when $a_{k(n-1)} < t_k \le a_{kn}$, $\mu k = 0 + \ldots + 0i_{n-3} + \frac{|t_k - a_{kn}|}{|a_{k(n-1)} - a_{kn}|} i_{l-2} + \frac{|t_k - a_{k(n-1)}|}{|a_{k(n-1)} - a_{kn}|} j$;

5)when $t_k > a_{kn}$, $\mu k = 0 + 0i_1 + \ldots + 0i_{n-2} + 1j$;

4.1.2.2 Determining Comprehensive Assessment n-ray Connection μ of the total index

$$R_{kl} = \begin{pmatrix} r_{11} \\ r_{21} \\ \vdots \\ r_{nl} \end{pmatrix} = \begin{pmatrix} a_{11} & b'_{11} & b''_{11} & \cdots & c_{11} \\ a_{21} & b'_{21} & b''_{21} & \cdots & c_{21} \\ a_{31} & b'_{31} & b''_{31} & \cdots & c_{31} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{nl} & b'_{nl} & b''_{nl} & \cdots & c_{nl} \end{pmatrix}$$

Meanwhile, suppose w_k is the weight of I_k in the system, comprising the weight set of W, and W=（w_1 w_2 … w_n）, which satisfies $\sum_{k=1}^{m} w_k = 1$. As a result, $R = W \cdot R_{kl}$ =（w_1

$w_2 \ldots w_n) \cdot \begin{pmatrix} r_{11} \\ r_{21} \\ \vdots \\ r_{nl} \end{pmatrix}$, which means $r_l = \sum_{k=1}^{m} w_k \cdot r_{k.l}$.

In consequence, by μ =R. E, we get the n-ray connection number of the total index is

$\mu = r_1 + r_2 i_1 + \ldots + r_3 i_2 + \ldots + r_l i_{l-1} + \ldots + r_n j.$ (4-1)

4.1.2.3 Comprehensive Assessment

As μ is n-ray connection number, μ∈ [-1,1]. Divide [-1,1] into n-1 parts, and set i_{n-2}, i_{n-1}, … i_2 and i_1 as the equal division point from left to right, and j=-1.

$$-1 \leftarrow \frac{3-n}{n-1} \ldots \ldots \frac{n+1-2l}{n-1} \ldots \ldots \frac{n-3}{n-1} \rightarrow 1$$

So the main value of the n-ray connection number is obtained, and it is recorded as

$$\mu = r_1 + r_2 \frac{n-3}{n-1} + r_3 \frac{n-5}{n-1} + \ldots + r_l \frac{n+1-2l}{n-1} + \ldots + r_n(-1) \quad (4\text{-}2)$$

Divide the interval [-1,1] into n ranges and make them represent n grades of the assessment set, while the comment C_k for the connection number n is the comprehensive assessment result. By comparing various n-ray connection numbers of many assessment objects, the sequence of the objects is determined. The larger μ is preferred, and the maximum represent the optimal number.

4.2 Safety Assessment Model of Ship Routeing Navigational Waters

4.2.1 Establishment of Comprehensive Safety Assessment Model

Through analysis of hazard in Chapter III, it is found out that there are many factors that influence navigational safety of ship routeing waters (Zheng Z. Y. & Chen X. &

Huang G. Z., 2012, p.743). Through qualitative analysis of relevant data and consultation of experts, the factor sequence is obtained, which means visibility(I_{11}: less than 1 km in average during recent five years in navigational waters, unit: days per annum), strong wind(I_{12}: the days with force 6 and over wind in average during recent five years in navigational waters and the days from typhoon starts till its end, unit: day per annum), Maximum flow(I_{13}: the Maximum flow velocity appraised the navigational waters) , length of Traffic lane (I_{21}, the length of the main channel, unit: n mile/h), Crossing traffic flow(I_{22}, the intersection the number of intersections over 25°with the depth of over 1 m), breadth/the width of course(I_{23}, the average breadth of sailing vessels that are allowed to pass in specific navigational water , and the breadth of the course is set as the narrowest width, unit: n mile), ship traffic density(I_{24}: number of ships per square miles during unit time, unit: ship/ n mile^2.h), management of VTS(I_{31}, expert rate), quality of pilotage(I_{32}: expert rate) and the normality rate of navigational aid marks(I_{33}: normality rate of navigational aid marks), size of ships(I_{41}), ship age(I_{42}), maneuvering and guided system(I_{43}), professional capacity of crew(I_{51}) and sense of safety of crew(I_{52}). The index system is shown in Figure 1.

Based on the above comprehensive index system, the assessment index set is U= {I_1,I_2,I_3,I_4,I_5} .

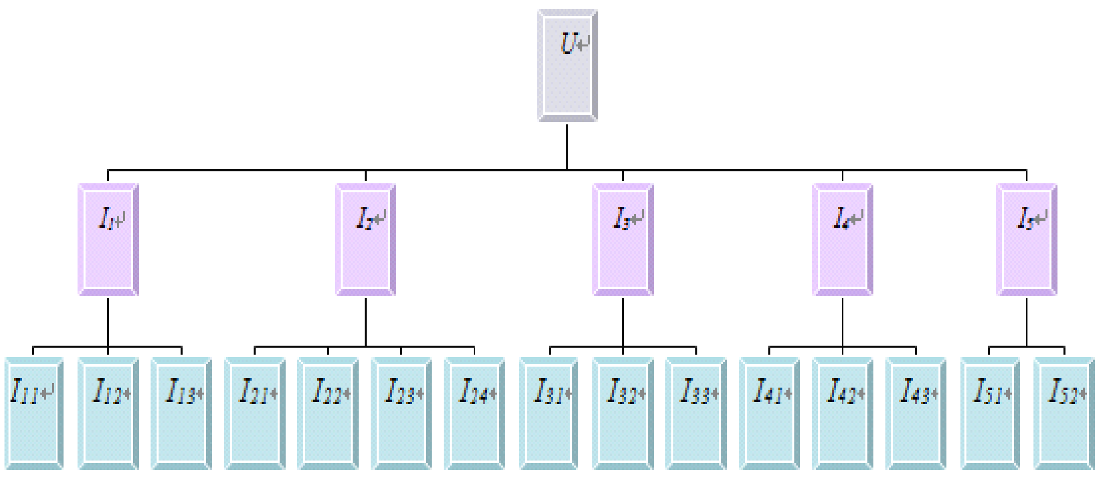

Figure 3: The assessment index set

Source: complied by the author

4.2.2 Method of Determining Weight of Comprehensive Assessment Index

After establishment of comprehensive assessment indexes, there is a need to determine the weights of all indexes. The degree of contribution of each index to the overall goal in the multi-goal assessment decision reflects the coefficients of the assessment objects. The paper uses consistent matrix to determine the weights of all indexes in routeing system water assessment system. The basic steps are :(1) formulating hierarchy model; (2) establishing judge matrix; (3) calculating weight with consistent matrix analysis (Li H.X. & Zheng Z.Y. & Li M. ,2011, p132)

4.2.2.1 Formulating Hierarchy Model

In order to determine the weight of indexes, hierarchy model is established first by hierarchical analysis structure of analytic hierarchy process (AHP). The AHP (Saaty, 2000) is a technique used in decision making. Based on the contribution of different experts, it aims at the creation of a unique priority index for each possible decision, which summarizes all experts' judgments, minimizing their inconsistency (M. Fera, R. Macchiaroli, 2010, p1362).

In general, AHP decomposes the system into different factors and classify them into different grades by analyzing the factors contained in the system and relations among them; Multi-grade analytical structural model is formulated objectively. By comparing and judging factors on a certain level and the factors on its adjacent above level in pairs, comparative degree of its relative importance is obtained, which can be used to establish judgement matrix. By calculating the maximum characteristic root and its corresponding characteristic vector, important sequence of each level to its adjacent above level is gained and so is the relative weight vector. Finally, use the combination weights of the adjacent above grade from top to bottom to get the weighted sum of this grade and calculate the combination weight of all factors for each level about the total systematic goal, in order to work out the sequence of the final weight which provides guidance for the optimal project.

4.2.2.2 Establishment of Judgement Matrix

Method of establishing judgement matrix in AHP is taken in this case. A judgement matrix shows the importance of a certain factor to the factors on its above grade, so the quantitative relative importance of each index is obtained. Suppose B_k in grade B has some connections with A_1, A_2, …, A_n in grade A, the established judgement matrix is tabulated below:

Table 3: The n-stage judgement matrix

B_k	A_1	A_2	…	A_n
A_1	a_{11}	a_{12}	…	a_{1n}
A_2	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…
A_n	a_{n1}	a_{n2}	…	a_{nn}

Source: Derived from reference (Shi, 1997)

A_1, A_2, …, A_n shown in the n-stage judgement matrix is the factor of its upper stage B_k , and element a_{ij} (i= 1,2, ...,n;j= 1, 2, ..., n) shows the importance of A_i to A_j.

By introducing judgement matrix to measure relative importance of factors, the meaning of each scale is shown below:

Table 4: Judgement matrix

Judgment Scale	Definition
1	Factor B_k, B_k are same important to A_i and A_j
3	Factor B_k, B_k are slightly important to A_i and A_j
5	Factor B_k, B_k are obviously important to A_i and A_j
7	Factor B_k, B_k are strongly important to A_i and A_j
9	Factor B_k, B_k are extremely important to A_i and A_j
2,4,6,8	Importance is between the adjacent two numbers
Reciprocal of the above	If importance of i to j is $a_{ij,}$ so importance of j to i is $a_{ji=}$ I/a_{ij}

Source: complied by the author

4.2.3 Calculation of Weights in the Comprehensive Assessment Index

4.2.3.1 Advantages of Consistent Matrix Analysis

After consistency check of weights in judgement matrix with the method of AHP, the judgement matrix may not live up to the standard and needs repetition. Consistent matrix not only reduces workload caused by repeated establishment, but also guarantees consistency of judgement matrixes, simplifying the process of determining the indexes.

Suppose to carry out iteration of any judgement matrix.

When m=1,2,…, $a_{ij}^{(m)}>0$, $a_{ij}^{(m)}=1$, $a_{ij}^{(m)}=1$, $a_{ij}^{(m)}=1/\ a_{ij}^{(m)}$ are always true.

So:

$$a_{ij}^{(m+1)} = \sqrt[n]{\prod_{k=1}^{n} a_{ik}^{(m)} a_{kj}^{(m)}} = \sqrt[n]{\prod_{k=1}^{n} \sqrt[n]{\prod_{l=1}^{n} a_{il}^{(m-1)} a_{lk}^{(m-1)}} \bullet \sqrt[n]{\prod_{i=1}^{n} a_{kl}^{(m-1)} a_{ij}^{(m-1)}}}$$

$$= \sqrt[n]{\sqrt[n]{(\prod_{l=1}^{n} a_{il}^{(m-1)} a_{lk}^{(m-1)})^n}} = a_{ij}^{(m)} \qquad (4\text{-}3)$$

In analogy, there is

$$a_{ij}^{(m)} = a_{ij}^{(1)} = \sqrt[n]{\prod_{k=1}^{n} a_{il}^{(m-1)} a_{kj}^{(m-1)}} \left(m = 1,2,\cdots\right) \qquad (4\text{-}4)$$

, so iteration limit exists.

$$b_{ij} = \lim_{m \to \infty} a^{(m)} = a_{ij}^{(l)} = \sqrt[n]{\prod_{k=1}^{n} a_{ik}^{(0)} a_{kj}^{(0)}} \qquad (4\text{-}5)$$

$$b_{ik} b_{kj} = \sqrt[n]{\prod_{k=1}^{n}\prod_{l=1}^{n} a_{il}^{(0)} a_{ik}^{(0)} a_{kj}^{(0)} a_{ij}^{(0)}} = \sqrt[n]{\prod_{k=1}^{n} a_{ik}^{(0)} a_{lk}^{(0)}} = b_{ij} \qquad (4\text{-}6)$$

Likewise, $b_{ii}=1$, $b_{ji}=\frac{1}{b_{ij}}$.

Any matrix A=（a_{ij}） can be transformed into consistent matrix B=（b_{ij}） after one iteration, which satisfies the condition of $b_{ij} = b_{ik} \cdot b_{kj}$.

4.2.3.2 Calculation Procedures of Consistent Matrix Analysis

The basic thought of consistent matrix is to revise element aij in judgement matrix A=（aij）, in order to satisfy the consistent conditions. The calculation procedures are as follows:

Firstly, establish judgement matrix

A=（a_{ij}）n×n， $a_{ii}=1$,

$a_{ji}=\frac{1}{a_{ij}}$;

Secondly, set

$$\text{bij}=\sqrt[n]{\prod_{k=1}^{n} a_{ik} a_{kj}}$$

to get consistent

matrix B=（b_{ij}）n×n, and b_{ii}=1,

$$b_{ji}=\frac{1}{b_{ij}};$$

Thirdly, the weight of the index

$$\omega_j=\frac{c_j}{\sum_{k=1}^{n} c_k}(j=1,2,\cdots,n) \tag{4-7}$$

It also satisfies

$$c_j=\sqrt[n]{\prod_{k=1}^{n} b_{jk}}(j=1,2\cdots,n)$$

4.2.3.3 Calculation of index weight

Take the final assessment matrix of meteorological hydrological factors as an example. Meteorological hydrological factor I_1= {Visibility I_{11}, Strong Wind I_{12}, Maximum Flow I_{13}} , the eventual assessment matrix is

$$A=\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}=\begin{pmatrix} 1 & 2 & 3 \\ \frac{1}{2} & 1 & 2 \\ \frac{1}{3} & \frac{1}{2} & 1 \end{pmatrix}$$

b_{12} is calculated according to the equation(4-6),

$$b_{12}=\sqrt[3]{a_{11}\cdot a_{12}\cdot a_{12}\cdot a_{22}\cdot a_{13}\cdot a_{32}}=\sqrt[3]{1\times 2\times 2\times 1\times 3\times \frac{1}{2}}=\sqrt[3]{6}$$

Other b_{ij} can be gained through the same means, so the transformed consistent matrix is

$$B=\begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}=\begin{pmatrix} 1 & \sqrt[3]{6} & \sqrt[3]{36} \\ \sqrt[3]{\frac{1}{6}} & 1 & \sqrt[3]{6} \\ \sqrt[3]{\frac{1}{36}} & \sqrt[3]{\frac{1}{6}} & 1 \end{pmatrix}$$

According to the equation (4-7), we can calculate the index weight w_1 of Visibility $I_{11:}$

$$c_1=\sqrt[3]{b_{11}\cdot b_{12}\cdot b_{13}}=\sqrt[3]{1\times\sqrt[3]{6}\times\sqrt[3]{36}}=\sqrt[3]{6}$$

$$c_2=\sqrt[3]{b_{21}\cdot b_{22}\cdot b_{23}}=\sqrt[3]{\sqrt[3]{\frac{1}{6}}\times 1\times\sqrt[3]{6}}=1$$

$$c_3=\sqrt[3]{b_{32}\cdot b_{32}\cdot b_{33}}=\sqrt[3]{\sqrt[3]{\frac{1}{36}}\times\sqrt[3]{\frac{1}{6}}\times 1}=\sqrt[3]{\frac{1}{6}}$$

$$w_1=\frac{c_1}{c_1+c_2+c_3}=\frac{\sqrt[3]{6}}{\sqrt[3]{6+1+\sqrt[3]{\frac{1}{6}}}}=0.5396$$

In a similar way, the index weights of Strong Wind $I_{12,}$ Maximum Tide I_{13} can be obtained, so the weight vector of meteorological hydrological factor is w = $\{w_1,w_2,w_3\}$ = $\{0.5396,0.1634,0.2970\}$.

Similarly, other combination weights can be calculated, which is shown in the table 5 below:

Table 5: Combination weights

Meteorological hydrological factor I_1	0.208	Visibility I_{11}	0.5396
		Strong Wind I_{12}	0.1634
		Maximum flow I_{13}	0.297
Geography Factor I_2	0.285	Length of traffic lane I_{21}	0.235
		Crossing Traffic Flow I_{22}	0.091

		Breadth/Width of Course I_{23}	0.21
		Ship Traffic Density I_{24}	0.464
Navigational Support Factor I_3	0.237	VTS Management I_{31}	0.623
		Pilotage Services I_{32}	0.23
		Normality Rate of Navigational Aids I_{33}	0.147
Ship Factor I_4	0.114	Size of Ship I_{41}	0.308
		Ship Age I_{42}	0.35
		Maneuvering and Guided System I_{43}	0.342
Crew Factor I_5	0.156	Professional Capacity I_{51}	0.522
		Sense of Safety I_{52}	0.478

Source: complied by the author

4.2.4 Classification Standard in the Comprehensive Assessment System

We can analyze safety from two aspects; one is by degree of safety, the other by degree of risk. Some literature classifies the navigational risk grades in reference of Statistics of Waterborne Traffic Accidents. Some classify it into 5 grades, which are very safe, relatively safe, ordinary, relatively dangerous and very dangerous. Some other literature also classify assessment grades into: low degree of danger, rather low degree of danger, medium degree of danger, rather high degree of danger and high degree of danger.

The paper chooses to appraise safety of navigational environment in routeing waters from the perspective of danger degrees, which enhances the awareness of ships and the authorities and improves navigational safety and efficiency. Assessment grades are classified into five grades: very safe, relatively safe, ordinary, relatively dangerous and very dangerous, which reflects safety condition of the assessment objects from one side. As a result, comment set of danger degree in the comprehensive assessment system determined by degree of danger is : C = {C1,C2，C3，C4，C5} ={low degree of danger, rather low degree of danger, medium degree of danger, rather high degree of danger, high degree of danger}

4.2.5 Establishment of Set-pair Comprehensive Assessment Model

Based on the results of the expert inquiry of Chinese scholars and the subjective assessment value of navigational safety danger of foreign scholars, navigational safety grade standard is obtained, which include five degrees of danger: low, rather low, medium, rather high and high(shown in the table):

Table 6: Navigational safety grade standard

First Level Indexes	Second Level Indexes	Low Degree of Danger C1	Rather Low Degree of Danger C2	Medium Degree of Danger C3	Rather High Degree of Danger C4	High Degree of Danger C5
Meteorological Hydrological Factor I_2	Visibility I_{11}	10	25	40	55	70
	Strong Wind I_{12}	30	60	90	120	150
	Maximum Tide I_{13}	1.0	2.0	3.0	4.0	5.0
Separation Geography Factor I_2	Length of Course I_{21}	30	45	60	75	90
	Intersection Curve Degree of Traffic Flow I_{22}	15	30	40	50	60
	Breadth/Width of Course I_{23}	13	9	5.5	3.5	2
	Ship Traffic Density I_{24}	5	17.5	30	42.5	55

Navigational Support Factor I_3	VTS Management I_{31}	≥4.5	4.5-3.5	3.5-2.5	1.5-2.5	≤1.5
	Pilotage Services I_{32}	≥4.5	4.5-3.5	3.5-2.5	1.5-2.5	≤1.5
	Normality Rate of Navigational Aids I_{33}	95	90	85	80	75
Ship Factor I_4	Size of Ship I_{41}	≤500	≤3000	≤20000	≤100000	≥100000
	Ship Age I_{42}	5	10	15	20	25
	Operational and Guided System I_{43}	90	80	70	60	50
Crew Factor I_5	Professional CapacityI_{51}	90	80	70	60	50
	Sense of Safety I_{52}	90	80	70	60	50

Source: complied by the author

According to the determination method of connection number, the 5-ray connection numberμ11 is worked out by the following way:

1） when $t_1 \le 10$, μ11=1；

2） when $10 < t_1 \le 25$, μ11=$\frac{|t_1-25|}{|10-25|}+\frac{|t_1-10|}{|10-25|}i_1=\frac{25-t_1}{15}+\frac{t_1-10}{15}i_1$;

3) when $25 < t_1 \le 40$, μ11=$\frac{|t_1-40|}{|25-40|}i_1+\frac{|t_1-25|}{|25-40|}i_2=\frac{40-t_1}{15}i_1+\frac{t_1-25}{15}i_2$

4)when $40 < t_1 \le 55$, μ11=$\frac{|t_1-55|}{|40-55|}i_2+\frac{|t_1-40|}{|40-55|}i_3=\frac{55-t_1}{15}i_2+\frac{t_1-40}{15}i_3$

5） when $55 < t_1 \le 70$, μ11=$\frac{|t_1-70|}{|55-70|}i_1+\frac{|t_1-55|}{|55-70|}i_2=\frac{70-t_1}{15}i_3+\frac{t_1-55}{15}j$

6)when $t_1 > 70$，μ11=1j；

Similarly, big degree of risk μ_{12}, Maximum flow degree of danger tide μ_{13} and other 5-ray connection numbers of other factors can be obtained.

Table 7: Connection number and degree of danger

Value of μ	[-1,-0.6]	[-0.6,-0.2]	[-0.2,0.2]	[0.2,0.6]	[0.6,1]
Degree of Danger	Highly dangerous	Rather Highly dangerous	Medium dangerous	Lower dangerous	Low dangerous

Source: complied by the author

When 5-ray connection numbers of comprehensive assessment are worked out, comprehensive set-pair assessment can be figured out with the corresponding relationship of the above connection number and degree of danger. For example, based on the statistics, bad weather days are 45 days. So 5-ray connection number of visibility in Routeing System Waters in Changjiang River Estuary can be calculated with the following equation:

$$\mu 11=\frac{55-t_1}{15}i_2+\frac{t_1-40}{15}i_3=\frac{55-45}{15}i_2+\frac{45-40}{15}i_3=0.667i_2+0.333i_3$$

Based on the "Equal Division Principle", i_1, i_2 and i_3 should lie in the quarterly interval [-1,1], so set i_1=0.5， i_2=0,i_3=-0.5,j=-1, and the main value of the connection number of visibility is 0.3335, and it lies in the interval of [0.2, 0.6], so the value of index $I_{11,}$ visibility, is in the rather low degree of danger. Likewise, main values of other connection numbers can be worked out. Certainly, only when the comprehensive 5-ray connection numbers are calculated, can the safety analysis of the assessment object be carried out.

Chapter-V Set-pair Comprehensive Assessment of Ship's Routeing Waters in Changjiang River Estuary

5.1 Values of Assessment Indexes

Based on the determining process in Section 4.2.5, 5-ray connection numbers are worked out. As for quantitative indexes, the values are determined by the method described in Section 4.2.2. As for qualitative indexes, experts filled out the expert assessment table designed to assess the safety of Ship's Routeing Waters in Changjiang River Estuary, and each expert grades the water based on their own understanding. After summarizing the results given by 50 experts, the frequency of each grade of each index is obtained, and the adaptation proportion of each index for each grade is its fuzzy degree of membership. The results of the expert opinions are as follows:

Table 8: Sub Connection Number of Degree of Danger

Assessment Index		Sub Connection Number of Degree of Danger				
		Highly dangerous	Rather Highly dangerous	Medium dangerous	Lowerdangerous	Low dangerous
Meteorological Hydrological Factor I_2	Visibility I_{11}	0	0.2	0.3	0.5	0
	Strong Wind I_{12}	0	0.2	0.6	0.2	0
	Maximum Tide I_{13}	0	0.3	0.4	0.3	0
Separation Geography Factor I_2	Length of Course I_{21}	0	0.6	0.3	0.1	0
	Intersection Curve Degree of Traffic Flow	0	0.3	0.6	0.1	0

	I_{22}					
	Breadth/Width of Course I_{23}	0	0.8	0.2	0.1	0
	Ship Traffic Density I_{24}	0	0.2	0.2	0.6	0
Navigational Support Factor I_3	VTS Management I_{31}	0.7	0.2	0.1	0	0
	Pilotage ServicesI_{32}	0.6	0.3	0.1	0	0
	Normality Rate of Navigational AidsI_{33}	0.8	0.2	0	0	0
Ship FactorI_4	Size of Ship I_{41}	0.1	0.2	0.3	0.4	0
	Ship Age I_{42}	0	0.2	0.5	0.2	0.1
	Operational and Guided System I_{43}	0.2	0.35	0.35	0.1	0
Crew FactorI_5	Professional CapacityI_{51}	0.3	0.4	0.3	0	0
	Sense of SafetyI_{52}	0.35	0.45	0.2	0	0

Source: Derived from the expert opinions (2013)

5.2 5-ray Connection Number of Assessment Indexes

Based on weights of each secondary index in the assessment index system in section 4.1.2, 5-ray Connection Numbers of secondary indexes are determined. In reference of Equation 4-1, 5-ray Connection Numbers of primary indexes. With the value of i , the corresponding relation of connection number and adaptation degree, adaptation degrees of the primary assessment indexes are obtained.

Take 5-ray connection number $\mu = r_1+r_2i_1+r_3i_2+r_4i_3+r_5j$ of Meteorological Hydrological Factor I_1 as an example, according to the values of Visibility I_{11} , Strong Wind I_{12} , and Maximum Flow I_{13}, the connection degree of I_{11}， I_{12} and I_{13} are r_{11} = (0, 0.5,0.3， 0.2,0), r_{12} = (0,0.2,0.6,0.2,0), r_{13} = (0, 0.3,0.4,0.3,0) respectively. The weight vector of meteorological hydrological factor I_1 is $W_1 =(\omega_{11,}\omega_{12,}\omega_{13,})$ = (0.5396,0.2970,0.1634), so the connection degree sub vector r_1 of Meteorological Hydrological Factor I_1 is

$$r_1 = W_1 \cdot \begin{pmatrix} r_{11} \\ r_{12} \\ r_{13} \end{pmatrix}$$

$$= (\omega_{11,}\omega_{12,}\omega_{13,}) \cdot \begin{pmatrix} r_{11} \\ r_{12} \\ r_{13} \end{pmatrix}$$

$$= (0.5396,0.2970,0.1634) \cdot \begin{pmatrix} 0 & 0.5 & 0.3 & 0.2 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \\ 0 & 0.3 & 0.4 & 0.3 & 0 \end{pmatrix}$$

$$= （0\ 0.39158\ 0.3787\ 0.2297\ 0）$$

So the 5-ray connection number of meteorological hydrological Factor I_1 is

μ_1 = 0+0.39158 i_1+0.3787 i_2+0.2297 i_3+0j .

According to the "equal division principle", i_1， i_2 and i_3, among 5-ray connection number, are at the quarterly division points of the interval [-1, 1], so set i_1=0.5, i_2=0,i_3=-0.5, j=-1. Calculate and determine the main values of connection numbers of each assessment indexes and that of the overall indexes.

Therefore, the main value of the connection number of Meteorological Hydrological Factor I_1 is $\overline{\mu}_1$=0.08094, which lies between the interval of [-0.2, 0.2] and graded as medium dangerous.

Similarly, 5-ray connection number of Geography Factor I_2 is

μ_2=0.021+0.4912 i_1+0.4298 i_2+0.079 i_3+0j.

The main value of the connection number of Geography Factor I_2 is $\overline{\mu}_2$=0.2271, which lies between the interval of [0.2, 0.6] and graded as rather low dangerous. 5-ray connection number of Navigation Support I_3 is

μ_3= 0.6917+0.2230 i_1+0.0853 i_2+0 i_3+0j;

The main value of the connection number of Navigation Support Factor I_3 is $\overline{\mu}_3$=0.8032 which lies between the interval of [0.6,1] and graded as low degree of danger. 5-ray connection number of Ship Factor I_4 is

μ_4= 0.0992+0.2513 i_1+0.3871 i_2+0.2274 i_3+0.035j;

The main value of the connection number of Ship Factor I_4 is $\bar{\mu}_4$=0.07615 which lies between the interval of [-0.2, 0.2] and graded as medium degree of danger. 5-ray connection number of Crew Factor I_5 is

μ_5=0.3239+0.4239 i_1+0.2522 i_2+0 i_3+0j .

The main value of the connection number of Crew Factor I_5 is $\bar{\mu}_5$=0.53585 which lies between the interval of [0.2, 0.6] and graded as rather low degree of danger.

5.3 Comprehensive Set-pair Assessment of Ship's Routeing Waters in Changjiang River Estuary.

From the above analysis, weight vector of the assessment indexes in Ship's Routeing Water in Changjiang River Estuary is

ω=(ω_1, ω_2, ω_3, ω_4, ω_5)=(0.208, 0.2850, 0.237, 0.114, 0.156),

Meteorological Hydrological Factor I_1 , Geography Factor I_2 , Navigation Support I_3 , Ship Factor I_4 , Crew Factor I_5 and connection vector r :

$$
r = \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{pmatrix} = \begin{pmatrix} 0 & 0.2297 & 0.37872 & 0.39158 & 0 \\ 0.021 & 0.4912 & 0.4298 & 0.079 & 0 \\ 0.6917 & 0.223 & 0.0853 & 0 & 0 \\ 0.0992 & 0.2513 & 0.3871 & 0.2274 & 0.35 \\ 0.3239 & 0.4239 & 0.2522 & 0 & 0 \end{pmatrix}
$$

So the connection vector of Ship's Routeing Waters in Changjiang River Estuary is

R = $\omega \cdot$ r

$$= (0.208, 0.2850, 0.237, 0.114, 0.156) \cdot \begin{pmatrix} 0 & 0.2297 & 0.37872 & 0.39158 & 0 \\ 0.021 & 0.4912 & 0.4298 & 0.079 & 0 \\ 0.6917 & 0.223 & 0.0853 & 0 & 0 \\ 0.0992 & 0.2513 & 0.3871 & 0.2274 & 0.35 \\ 0.3239 & 0.4239 & 0.2522 & 0 & 0 \end{pmatrix}$$

$$= (0.23176, 0.335397, 0.304955, 0.129887, 0.00399).$$

Hence, 5-ray connection number μ_{CJK} is formulated as

$$\mu_{CJK} = 0.23176+0.335397\, i_1+0.304955 i_2+0.129887\, i_3+0.00399j\ .$$

Likewise, set

i_1=0.5， i_2=0,i_3=-0.5,j=-1, and $\overline{\mu}_{CJK}$=0.33052.

The number is in the interval [0.2, 0.6], so the Routeing Waters in Changjiang River Estuary is appraised as lower degree of danger.

Chapter-VI Analysis and Suggestions

6.1 Analysis

According to the analysis of the previous chapter, we obtain the result that Routeing System Waters in Changjiang River Estuary is appraised as rather low degree of danger, but it is close to medium degree of danger. Meteorological Hydrological Factor I_1 is graded into medium degree of danger; Separation Geography Factor I_2 and Crew Factor I_5 are graded as rather low degree of danger, but Separation Geography Factor I_2 is between medium danger degree and rather low danger degree; Navigation Support Factor I_4 is graded as low danger degree. The conclusion generally accords with the actual condition of the water.

As there are many complicated factors influencing Routeing System Water in Changjiang River Estuary, the factors concerned are only the major ones. While determining the weights of all factors influences ship navigational safety, there is some subjectivity.

With the perfection of separation optimization in Changjiang River Estuary and optimization of courses of Shanghai, safety degree will further increase. Additionally, the assessment method and model mainly apply to safety assessment in coastal routeing system waters. If it is applied to safety assessment of routeing system waters in narrow waters, some optimization and perfection are necessary.

6.2 Suggestions

For ships in the routeing Changjiang River Estuary, continually improving navigational environment enhances safety degrees. But when it comes to the present situation, waterborne accidents happen each year and it is far from optimistic(Wusong

MSA, 2012). Based on the conditions, several suggestions are given below to provide some reference for the maritime authorities.

As for ships, while keeping ships in good maintenance and crewing, “The International Regulations for Preventing Collisions at Sea 1972”(COLREGS) must be utilized to its full potential. There are many cases of ship A meeting ship B in the precautionary area in an intersected way. So it is essential to enhance the interconnections between them and perform the prevention responsibility and obligations to avoid collision accidents. If other vessels’ motion is vague and cannot be communicated through high frequency telephones or fluent verbal communication, ships should decelerate and keep clear actively. Meanwhile, the ship must contact Wusong VTS to obtain more avoidance information and support from people on duty in VTS Center.

AS for maritime authorities, Wusong VTS must keep an eye on the ship traffic density constantly in Routeing System Waters in Changjiang River Estuary and desludge ships in the water in good timing and keep navigation in order by sending large patrol ships on spot. Especially when weather is bad, such as typhoon, cold air and some other adverse weather conditions, Wusong VTS should strengthen their service of organization by broadcasting warning information and implementing effective traffic organization (Yang X. D., 2010, p67).

Secondly, supervision of crossing and overtaking must be enhanced, and ships must be reminded to drive in and out of the water effectively and timely. Thirdly, ship databases must be perfected. Old ships and low standard ships must be given more attention and greater supervision. Fourth, from the perspective of crewing, it is crucial to improve safety supervision ability and comprehensive quality of people on duty in VTS Center.

Chapter-VII Conclusion

Through an in-depth survey and analysis of routeing system water in Changjiang River Estuary, select navigational safety is selected as the assessment object in the water and the comprehensive assessment system is established, under the guidance of the rules, standards of "General Regulations on Routeing System Waters" of IMO. Using multi-ray connection number in the set-pair theory, comprehensive assessment classification standard is determined. By combining AHP and Consistent Matrixes, the values of the indexes are determined. After introduction of quantitative analysis of all assessment indexes and assessment standards, sorted analysis mainly solves the comprehensive assessment problem of navigational safety in Routeing System Waters Changjiang River Estuary.

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Appendices

APPENDIX A- Navigational safety grade standard

First Level Indexes	Second Level Indexes	Low Degree of Danger C1	Rather Low Degree of Danger C2	Medium Degree of Danger C3	Rather High Degree of Danger C4	High Degree of Danger C5
Meteorological Hydrological Factor I_2	Visibility I_{11}	10	25	40	55	70
	Strong Wind I_{12}	30	60	90	120	150
	Maximum Tide I_{13}	1.0	2.0	3.0	4.0	5.0
Separation Geography Factor I_2	Length of Course I_{21}	30	45	60	75	90
	Intersection Curve Degree of Traffic Flow I_{22}	15	30	40	50	60
	Breadth/Width of Course I_{23}	13	9	5.5	3.5	2
	Ship Traffic Density I_{24}	5	17.5	30	42.5	55
Navigational Support Factor I_3	VTS Management I_{31}	≥4.5	4.5-3.5	3.5-2.5	1.5-2.5	≤1.5
	Pilotage ServicesI_{32}	≥4.5	4.5-3.5	3.5-2.5	1.5-2.5	≤1.5
	Normality Rate of Navigational	95	90	85	80	75

	AidsI_{33}					
Ship FactorI_4	Size of Ship I_{41}	≤500	≤3000	≤20000	≤100000	≥100000
	Ship Age I_{42}	5	10	15	20	25
	Operational and Guided System I_{43}	90	80	70	60	50
Crew FactorI_5	Professional CapacityI_{51}	90	80	70	60	50
	Sense of SafetyI_{52}	90	80	70	60	50

APPENDIX B- Sub Connection Number of Degree of Danger

Assessment Index		Sub Connection Number of Degree of Danger				
		Highly dangerous	Rather Highly dangerous	Medium dangerous	Lower dangerous	Low dangerous
Meteorological Hydrological Factor I_2	Visibility I_{11}					
	Strong Wind I_{12}					
	Maximum Tide I_{13}					
Separation Geography Factor I_2	Length of Course I_{21}					
	Intersection Curve Degree of Traffic Flow I_{22}					
	Breadth/Width of Course I_{23}					
	Ship Traffic Density I_{24}					
Navigational Support Factor I_3	VTS Management I_{31}					
	Pilotage ServicesI_{32}					

	Normality Rate of Navigational AidsI_{33}					
Ship FactorI_4	Size of Ship I_{41}					
	Ship Age I_{42}					
	Operational and Guided System I_{43}					
Crew FactorI_5	Professional CapacityI_{51}					
	Sense of SafetyI_{52}					