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WORLD MARITIME UNIVERSITY

Dalian,China

STUDY ON THE SAFETY ANALYSIS OF NAVIGATION ENVIRONMENT IN CAOFEIDIAN PORT

By

YUEWANCHENG

The People's Republic of China

A research paper submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2017

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DECLARATION

I certify that all the materials in this dissertation that are not my own work have been identified, and that no materials are included for which a degree has previously been conferred on me.

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ABSTRACT

Title of research paper: **Study on the Safety Analysis of Navigation Environment in Caofeidian Port**

Degree: **MSc**

With the rapid development of China's economy and the continuous progress of the ship's scientific and technological quantity, the modern ship has gradually become larger and faster, and the chance of the ship's collision in the port is getting bigger and bigger. As the water areas of port are limited, the traffic in the harbor becomes more and more crowded. With the increase of the number of ships in and out Caofeidian Port, the factors that affect navigation safety are gradually increasing. In order to meet the rapid development of shipping demand, to ensure the safety of navigation of Caofeidian Port and improve the efficiency of ship navigation as well as avoid the occurrence of safety accidents, this paper took Caofeidian Port navigation environment as the object of research, and mastered the characteristics of its water areas through site visiting and questionnaires, and collected relevant information from the meteorological departments, maritime departments, waterway departments. On the basis of this, the Analytic Hierarchy Process (AHP) was used to establish the navigation safety assessment index system of Caofeidian Port, and then the corresponding index was calculated based on the improved Delphi method. Finally, the evaluation model of navigation safety of Caofeidian Port was established by using the comprehensive evaluation theory of set pair analysis, so as to evaluate the safety of navigation environment in the water areas, and eventually determined the safety level of Caofeidian navigation environment. The paper analyzed each index using the theory of set pair and potential connection number, at the same time, it gave the evaluation grade of the index, and then got the future trend of the safety level of the index.

According to the evaluation results of this paper, the overall situation of the traffic environment of Caofeidian Port and the influence of different factors on the navigation safety of the ship could be obtained. To analyze the evaluation results and

propose the targeted improvement measures for the evaluation, this can not only provide an effective scientific basis for the maritime sector in improving the Caofeidian Port navigation safety and navigation efficiency, but also have a certain practical significance for the enrichment of marine traffic engineering research system.

Key words: navigation environment, safety assessment, set pair analysis.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
MSA	Maritime Safety Administration
SOA	State Oceanic Administration
GC	General Cargo
LNG	Liquefied Natural Gas
AIS	Automatic Identification System
SRS	Ship Routing System
TSS	Traffic Separation Schemes
VTS	Vessel Traffic Service
SPA	Set Pair Analysis

Chapter Ⅰ Introduction

1.1 The Background and the significance of the research

1.1.1 The Background of the Research

With the rapid development of the world's economic integration, the quantity of the international trade was also increasing, and the main mode of transport in the international cargo transport was marine transport. Statistics suggested that 80% international cargo was transported by marine transport, and over three fourths of foreign trades were done by marine transport, from this, we could foresee that the quantity of the cargo by marine transport will increase with the development of the world's economy. (Wang & Chen, 2017) With the rapid increase of the marine transport's quantity, the handing capacity of most port would increase rapidly, among these, the handing capacity of the Caofeidian Port had exceeded five hundred million tons, it had caught up with the Jingtang Port and even had the tendency to surpass it while the number of the ships' entering and leaving the port was increasing and the size of the ships became larger. Because of the increasing number of the ships, the water area of the transport became more and more crowded, the chances of collision of ships in port channel was increasing， which led to the frequent marine traffic accidents, and it was not only a threat to the crew's life, but also caused huge economic losses or serious pollution to the marine environment. The frequent occurrence of traffic accidents had put forward higher requirements for the port navigation environment and marine traffic safety management, relevant research made progress unceasingly, but most of the research was to study the safety of navigation of the ship itself, while the research on port navigation environment safety still needed to be improved. (Zhang, 2014)

The navigation environment referred to the space and conditions of the ship, including navigable waters, natural conditions and traffic conditions. The port navigation environment safety analysis refers to the understanding of the factors of the danger of the ship which sailed in the port area and the degree of risk factors, and put forward the pertinent improvement measures to improve the safety of navigation and to prevent the accident. (Wang & Li, 2017) The navigation environment evaluation has been an important research topic in the field of maritime traffic safety, and it is also an important basis for the relevant maritime administration to make management decisions, and the theoretical basis to improve the port navigation environment.

1.1.2 The significance of the research

In recent years, port traffic accidents occurred frequently in China, although the annual number of accidents had decreased, the economic losses were increasing year by year, so the governance environment of port traffic became particularly important. (Li, 2009) How to improve the navigation conditions of the port, and ensure that the ship's sailing could be safe, orderly and smooth has become a key problem urgent. This research takes the typical traffic congestion area as Caofeidian Port and the nearby waters as the research port, , based on the filed investigation and the related information from the maritime sector 、 route sector 、 meteorological sector, to analyze and evaluate the navigation environment. This research discussed the method which is suited to evaluate the navigation environment of Caofeidian Port, and it also established the mathematical model of Caofeidian Port navigation, and it used this model to evaluate the navigation environment effectively.

Through the study of this paper, the factors that affect the safety of Caofeidian Port are determined, and the risk degree is qualitatively analyzed, and it got the evaluation results and the corresponding analysis conclusion, evaluation method and evaluation system to Caofeidian Port and the nearby waters traffic safety could be improved, which provided a theoretical basis for the further improvement of Caofeidian navigable waters and environmental governance, the maritime administrative department could grasp the detailed Caofeidian Port navigation environment risk level, so as to better ensure ship navigation safety.

1.2 The previous researches on navigation safety

The navigation safety of the ship in the port depends largely on port navigation environment, and safety evaluation of navigation environment plays an important role in the traffic management system of the port waters. (Zhang, 2006; Wu & Zhu, 2004) Many experts and scholars at home and abroad in recent years have carried out a large amount of researches on port navigation environment safety evaluation , and main methods include safety index method, factor analysis method, system simulation method, grey theory, fuzzy mathematics theory and other evaluation methods. Dalian Maritime University’s professor Wu Zhaolin (Ma & Wu, 1998; Wu, 1997) had introduced the safety index method in safety evaluation to measure the traffic safety situation with the ratio of traffic accidents and traffic volume, and provided a theoretical basis for the study of ship navigation safety; Zeng Hualan (Zeng & Shao,1999) once used the factor analysis method to analyze the factors which affect the navigation environment so that she could make a quantitative analysis of the factors affecting the control of ship and the evaluation of the navigation environment; Shao Zheping (Shao, 2002) used system simulation method to simulate the ship moving, so as to find the navigable waters total existence security problem; Professor Zheng Zhongyi (Zheng, 1998) used grey theory to select eight environmental factors affecting the safety of navigation, and evaluated safety of the port navigation environment in the coastal part ;Professor Zhao Renyu (Zhao, 1997) repeatedly applied fuzzy reasoning theory to evaluate the risk degree of marine traffic accident, collected the data of accident and established the evaluation model; Professor Zhang Xinggu (Zhang, 2002) improved fuzzy reasoning, analyzed the navigable environment of mud Bay, and determined the risk of the operation of the waters.

Study on the navigation safety abroad is mainly the specific operation and safety assessment of ship navigation safety in a given environment, in which Japan started earlier, the current research in the field is more mature. Japanese expert Kobayashi Hiroa (Kobayashi, 2001) proposed maritime navigation environment safety evaluation taking the ship handling difficulty as the evaluation index to evaluate the safety and efficiency of vessel navigation. Inoue Kinmi (Inoue, 1994) measured the navigation risk of this port through quantitatively processing the probability of the vessels to encounter others and the increase of its burden. Nii Yasuo's (Nii, 1994) research focused on the natural environment of the port, as the index to connect with the subjective feeling into the ship driver so that he could ensure the impact. In addition, fuzzy set theory and artificial neural network are combined to establish the risk prediction model by S.T.Ung; (Ung, 2006) Fuji Kaneko set probability theory into comprehensive evaluation, the evaluation would be applied in the port traffic safety; (Wang, 2000) A.K.C. Gardner has done some research in the development of the European port, and he pointed out that the effect of the natural environment of the port development.(Gardner, 2004)

1.3 Research Contents and Methods

This research is based on the Caofeidian Port navigable waters of natural environment to determine the navigation safety evaluation index, using pair analysis theory to establish the evaluation model, to analyze the possible problem in the navigation environment, to find out the weak link of navigable environment management, and to propose the solutions, and to strive for the largest safety security of the vessels which is sailing in the Caofeidian Port from the objective conditions. The specific research methods are:

(1) Discussed the characteristics of the navigable waters of Caofeidian Port environment, summarized the characteristics of the recent flowing port traffic, and analyzed the factors that affect the safety of Caofeidian Port on the basis of the survey data.

(2) According to the results of the survey data and the research of relevant literature, the AHP method is used to establish the evaluation index system of the navigation environment safety of Caofeidian Port, and the evaluation criteria are determined for each index to get the standard of the evaluation.

(3) Using the improved Delphy method to calculate the weight of each evaluation index, the influence of the evaluation index on the navigation safety was obtained.

(4) Using the set pair method to construct the mathematical model of the safety evaluation of the Caofeidian Port navigation environment, and use the model to determine the safety level of the evaluation index.

(5) According to the evaluation results, the theory of set pair potential and the theory of set pair coefficient were analyzed reasonably, and the rationalization proposals were put forward in view of the problems existing in the navigation environment of Caofeidian Port.

Chapter Ⅱ Navigation environment and traffic conditions in Caofeidian Port

2.1 Geographic location

Caofeidian is located in the southern coastal area of Tangshan City, Hebei province, the center of Bohai Bay. It was originally a sand island like a belt that stretches from northeast to southwest, and originated from the ancient Luanhe River which was alluvial into the sea. Caofeidian has the history of more than 5,000 years, whose name was from the Caofeimiao built on the island. (Wang, 2007) The distance from west of Caofeidian Port to Tianjin Port is 38n mile, northeast 33n mile away from Jing tang Port,92n mile away from Qinhuangdao. Its geographic coordinates are: Northern Latitude 38 °55 ′N, longitude 118 °30 ′E. 500 meters in front of the Port Island's depth are 25 meters, and then extends forward to 36 meters,-30 meters of contour waters of things up to 6 kilometers, the distance from north and south is about 5 kilometers wide; by the extending of Caofeidian waters to the Bohai Strait, a natural waterway with a depth of 27 meters is straight through the Yellow Sea. So advantageous geographic conditions make Caofeidian make an ideal site for building large deep-water port. The geographic location of Caofeidian Port is shown in Figure 1.

Figure 1 Geographic location of Caofeidian Port

Source: www.baidu.com

2.2 Meteorological conditions

2.2.1 Temperature

Caofeidian area belongs to Continental monsoon climate, with obvious warm and moist monsoon climate characteristics of temperate zone. (Wang & Liu, 2010) According to the measured data of the Tanghai weather station and the Nanpu weather station around the Caofeidian Port, the annual average temperature of Caofeidian Port is 11.4 ℃, the annual extreme highest temperature is 36.3 ℃, the annual extreme lowest temperature is-20.9 ℃, the temperature of January is the lowest and the temperature of August is the highest.

2.2.2 Precipitation

The precipitation of Caofeidian Port waters vary greatly from season to season, most rainfall is between June and August, and precipitation forms 70% of annual precipitation, however, December to the March is the drought season, the precipitation of these four months is only 3.5% of annual precipitation. According to the statistics of the data from the meteorological Department, the annual average number of daily precipitation exceeding 25.0mm in the region is 5.8 days, the average number of days of precipitation above 50.0mm is only 2 days, the annual average precipitation is 554.9mm, the annual maximum precipitation is 934.4mm, and the largest precipitation of a day is 186.9mm.

2.2.3 Wind

According to the statistics of the observation data from Nanpu Meteorological Station, the wind in Caofeidian Port area varies with seasons. The northwest wind prevails in winter, the occurrence frequency is 47%, the average wind speed is about 5m/s, the wind from south and southeast is more in the spring and summer , the frequency of its occurrences are 49% and 64%, the average wind speed is about 5m/s and 6.6m/s, the southwest wind prevails in autumn, the frequency of the occurrence is 34%, the average wind speed is about 4.9m/s. In addition, the usual wind direction in the port area is the SSW, whose frequency is 10%, the second usual wind direction towards the ENE and the SSE, whose frequency is 9%. Strong wind direction towards the ENE, the maximum wind speed is 25m/s, the second strong wind direction towards the NE, the maximum wind speed is 21 m/s, the annual average wind speed is about 5.3 m/s. The frequency of the wind speeds exceeding 6 level is 4.9%. The detail is in Table 1 and wind Rose Figure 2.

Table 1 Statistics on wind speed, direction and frequency of Caofeidian Port

wind speed	average wind speed（m/s）	maximum wind speed（m/s）	frequency（%）
N	3.9	10.0	3.0
NNE	4.4	13.0	4.9
NE	5.3	21.1	4.9
ENE	7.4	25.3	8.8
E	7.2	20.4	6.0
ESE	6.0	14.0	6.0
SE	4.7	11.9	3.9
SSE	5.1	13.0	8.8
S	4.7	10.9	7.0
SSW	4.7	11.9	9.8
SW	5.1	13.0	7.0
WSW	4.9	15.1	7.9
W	4.6	13.0	4.0
WNW	5.8	17.9	6.0
NW	5.3	16.8	6.0
NNW	5.1	14.0	5.1

Source: Tangshan MSA. Statistics of Nanpu Meteorological Station

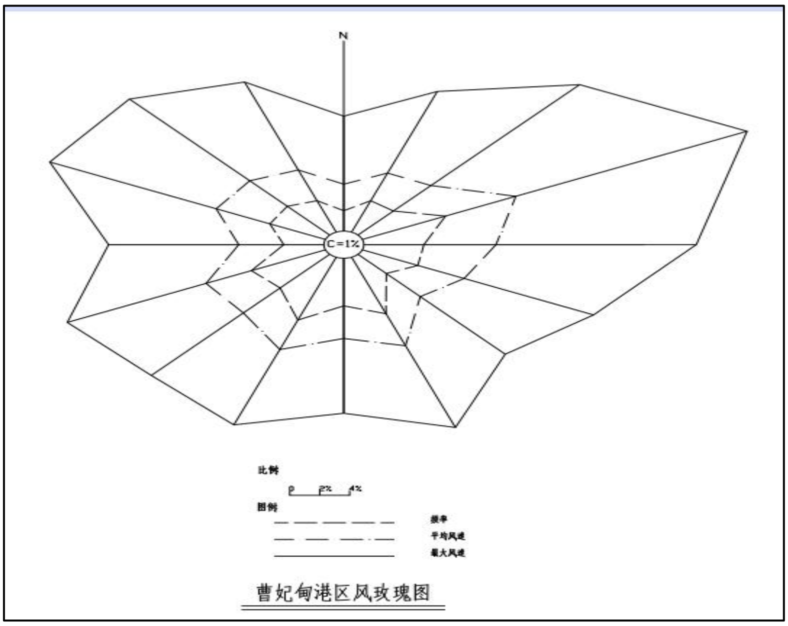

Figure 2 Wind rose of Caofeidian Port

Source: Tangshan MSA. Statistics of Nanpu Meteorological Station

2.2.4 Fog

The fog in Caofeidian Port area is heaviest annually in autumn and winter. The period between November and February in the second year is foggy, and each year there are about 29 foggy days, during which the visibility is less than 1km 9 days, and during this period, foggy days accounted for about 77% of the entire year, the longest consecutive foggy days lasted 3 days.

2.3 Hydrological conditions

2.3.1 Tides

The tidal nature of the Caofeidian waters belongs to the irregular half-day tide. (Chen, 2000) According to the tidal observation data from October 16, 2000 to October 15, 2001, the highest annual tidal level of the port is 3.38m, the lowest annual tidal level is 0.14m, the average annual high tidal level is 2.47m, the average annual low tidal level is 1.07m, the average sea level is 1.77m, and the annual average tidal range is 1.40m. The above tide values are calculated from the lowest ebb surface of local theory.

2.3.2 Waves

The North Sea branch of the State Oceanic Administration (SOA) had dropped the DS14-type telemetry buoy in the water which as deep as 26m on the south side of the

Caofeidian for a year to have wave observations from 1996 to 1997. The Qingdao Around Oceanic Survey and Research Institute used the SZF-Ⅱ digital wave meter, Seapac2100h and HAB-2-type landed optical wave meter to carry out the wave supplementary observations for nearly a year from 1999 March to December(The observation was stopped in winter because of ice). According to the above observation data, the Caofeidian Port area's constant wave direction is the S, the frequency of occurrence is 10.87%, the second frequent wave direction towards the SW, the frequency of occurrence is 7.48%, the strong wave direction towards the ENE, the maximum wave height can reach 4.9m, the second strong wave direction is NE, and the maximum wave height can reach 4.m. The details are shown in Table 2 and wave rose Figure 3.

Table 2 The statistics table of wave height and frequency in different directions of Caofeidian Port (Unit: m)

wave height / wave direction	0-0.5	0.6-0.8	0.9-1.0	1.1-1.2	1.3-1.5	1.6-2	>2.1	total
N	1.08	0.81	0.43	0.27	0.11	0.03	0.05	2.79
NNE	0.76	0.41	0.43	0.14	0.16	0.19	0.08	2.17
NE	2.11	1	0.35	0.38	0.24	0.35	0.62	5.07
ENE	1.27	0.87	0.46	0.43	0.65	0.84	0.79	5.31
E	2.55	1.25	0.7	0.65	0.79	0.41	0.14	6.48
ESE	1.95	0.79	0.46	0.24	0.24	0.16	0	3.85
SE	4.5	1.44	0.46	0.38	0.16	0.03	0	6.97
SSE	2.47	0.98	0.52	0.22	0.19	0.11	0	4.47
S	4.99	2.82	1.65	0.62	0.6	0.11	0.08	10.87
SSW	2.28	1.38	0.68	0.54	0.14	0.11	0.03	5.15
SW	4.74	1.41	0.52	0.27	0.14	0.24	0.16	7.48
WSW	1.87	1.11	0.52	0.43	0.3	0.19	0.16	4.58
W	2.25	0.84	0.41	0.33	0.16	0.22	0.03	4.23
WNW	1.71	0.81	0.24	0.24	0.14	0.19	0.03	3.36
NW	1.9	1.14	0.73	0.46	0.35	0.6	0.35	5.53
NNW	0.92	0.24	0.19	0.22	0.14	0.08	0.22	2.01
C	19.68							
total	57.03	17.3	8.75	5.82	4.51	3.86	2.74	100

Source: Tangshan MSA. Statistics of North Sea branch of SOA

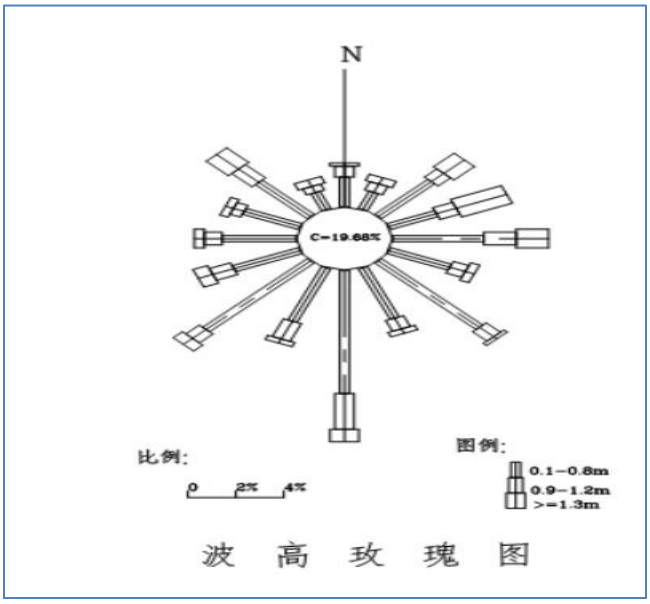

Figure 3 Wave rose of Caofeidian Port

Source: Tangshan MSA. Statistics of North Sea branch of SOA

2.3.3 Tide

According to the observational data, the tidal currents of Caofeidian waters have the following features:

(1)The tidal wave in Caofeidian waters is characterized by standing wave, the flow rate is the highest in the middle tide and the turning is in the high and low tide. As shown in Fig. 4, of the tide and flow chart of the 7# point in Caofeidian Port, the rate of flowing is the largest in the middle tide. On the whole, the flowing rate in the Caofeidian sea area is greater than the ebb-flow. The average rising rate of the spring tide is 0.40~0.60m/s, ebb-flow rate is 0.35~0.50m/s; the average flow rate of neap tide is 0.25~0.40m/s, ebb is 0.25~035m/s.

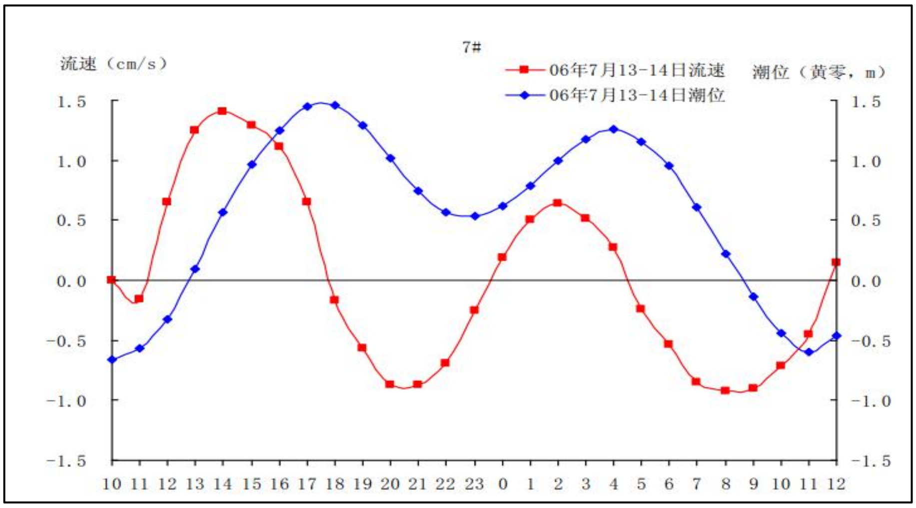

Figure 4 The location and speed of spring tide of the 7# point on 2006

Source: Tangshan MSA. Statistics of Nanpu Meteorological Station

(2)The tide of the sea is basically the form of movement of reciprocating flow, however, the change of seabed topography changed the direction of the flow, due to the beach surface water resistance and the impact of the deflecting flow from cape, the flow direction, which is in the head and shoals of the meadow in the offshore areas, has the trend of going along the shore .

2.3.4 Sea ice

The historical observation data of the National Oceanic Environmental Monitoring Center shows that the annual glacial glacier of Caofeidian waters appearing from the middle of January to the middle of February. The average ice thickness is 10cm and the maximum ice thickness is 40cm. During the winters from 2009 to 2010, affected by persistent cold weather, Bohai Sea and Yellow Sea suffered the most serious sea ice situation in nearly 30 years. But because of the deep harbor waterway ,the urgency of currents, the lighter ice sentiment compared to other ports, the Caofeidian waters also once showed the appearance of ice without fixed ice, and the snow is basically about 10 cm thickness.

2.4 Port Navigation Environment

2.4.1 Waterway

There are many routes in the Caofeidian Port area, and the three main routes are the first port channel, the second port channel and the third port channel. The total length of outer waterway of the first port channel is 593m, the azimuth angle of the waterway is 35 ° ~215 °, the bottom elevation of the waterway depth is -18.3m, and the width is 210m. The first port channel can meet the 150,000 tons bulk cargo vessels' navigation water depth requirements. The base elevation of the second port channel designing is -13.8m, the outer waterway standard section width is 180m, the mouth gate section channel width is 280m, the inner waterway width is 160m, and the waterway slope was taken 1:5 ,the fairway azimuth angle is 330 ° ~150 ° and 000 ° ~180 °, the connecting section is 30 °curvature. The third port pool is the most complex one, the curvature is larger, the waterway azimuth angle is 000 ° ~180 °, 155 ° ~335 °, 105 ° ~285 °, 063 ° ~243 ° and 115 ° ~295 °. The schematic diagram of the third port pool waterway is shown in Fig. 5.

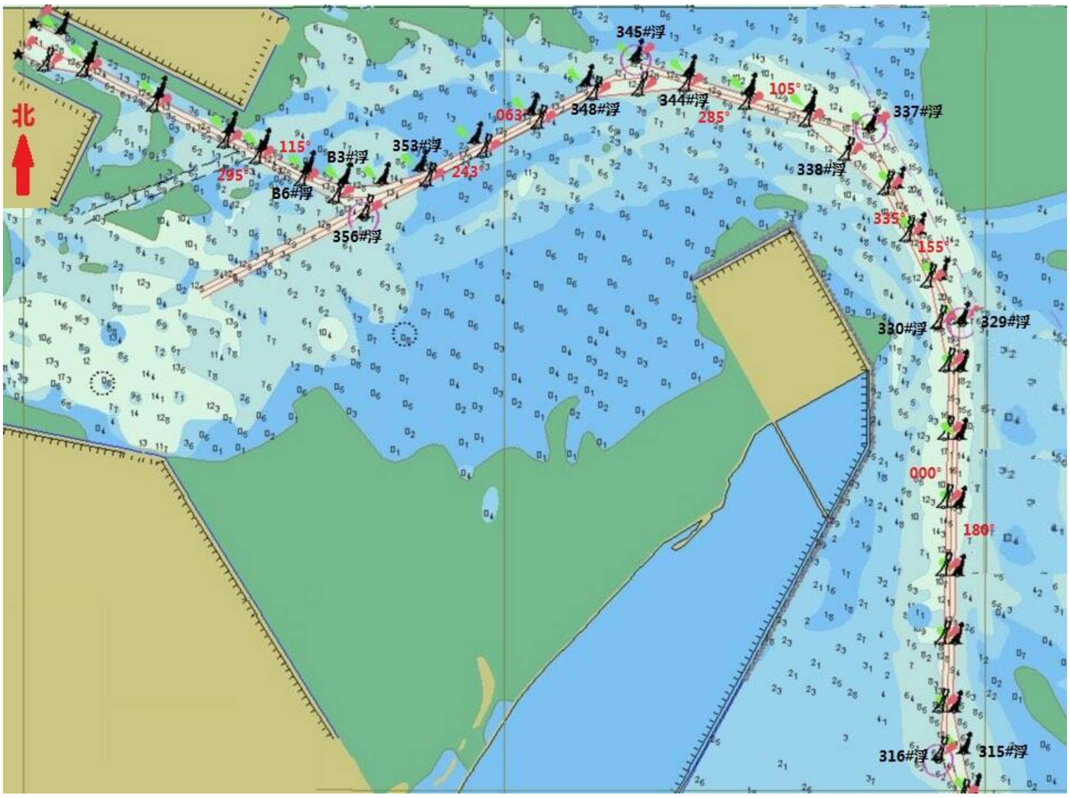

Figure 5 Diagram of the third harbor channel

Source: Pilotage manual of Tangshan port (2016)

2.4.2 Anchorage

Caofeidian Port area "sea area anchorage" is up to 200 square kilometers, and is divided into two outside anchorage of the port from east and west. The west harbor anchorage is a comprehensive anchorage, with the waters area 52km², mainly used for coal ship, General Cargo (GC) carrier, containers, Liquefied Natural Gas (LNG) carrier and other ships anchoring, natural water depth is 12m~29m. East harbor anchorage is for oil tanker, large bulk cargo vessels, the waters area is 148km², mainly used for oil tankers and large bulk cargo vessels, the natural depth of 21m~32m. The anchorage details are shown in Figure 6 and Table 3.

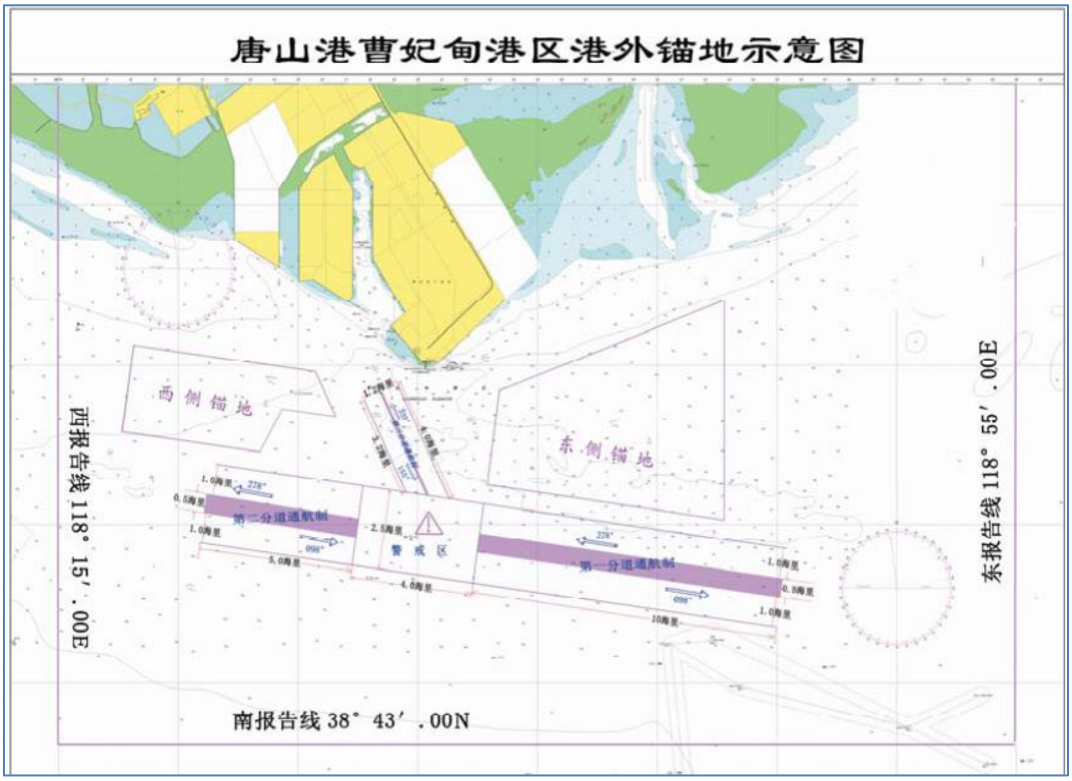

Figure 6 Anchorage diagram of Caofeidian Port area

Source: Pilotage manual of Tangshan port (2016)

Table 3 Anchorage location of Caofeidian Port area

name	control point	coordinate		natural water depth(m)	main use
		Latitude N	East longitude E		
west port external anchorage	1	38°55′37.02"	118°18′08.77"	13～28	coal, containers and grocery vessels anchorage
	2	38°54′47.79"	118°25′43.61"		
	3	38°53′25.80"	118°24′39.60"		
	4	38°53′37.20"	118°24′39.60"		
	5	38°52′21.60"	118°23′51.00"		
	6	38°52′53.69"	118°17′39.80"		
east port external anchorage	1	38°54′12.00"	118°33′24.00"	23～31	oil tankers and large bulk cargo vessels anchorage
	2	38°57′00.00"	118°42′48.00"		
	3	38°50′10.89"	118°42′47.98"		
	4	38°51′17.08"	118°32′53.83"		

Source: Pilotage manual of Tangshan port (2016)

2.4.3 Navigation Facilities

Caofeidian Port navigation facilities are fully equipped, the breakwater of the first harbor has eastern and western light beacons on the head and eastern and western warning lamp piles, and there are 12 light buoys in the inner harbor. The second harbor has planned to build 16 new light buoys since 2012, and set up one transponder. The third harbor has 14 light buoys that is used to instruct the course and guide the ship to sail, which can satisfy the existing voyage demands.

2.5 Port Traffic Flow

It can directly draw the vessel density in port waters by analyzing the characteristics and the regularity of traffic flow in the waters of Caofeidian, and to some extent, reflecting the movement regularity of ships in the waters and the busy degree of the waters. (Gu, 2016; Li & Fu, 2009) Figure 7 is the Automatic Identification System (AIS) contrail of the vessels in the Caofeidian waters.

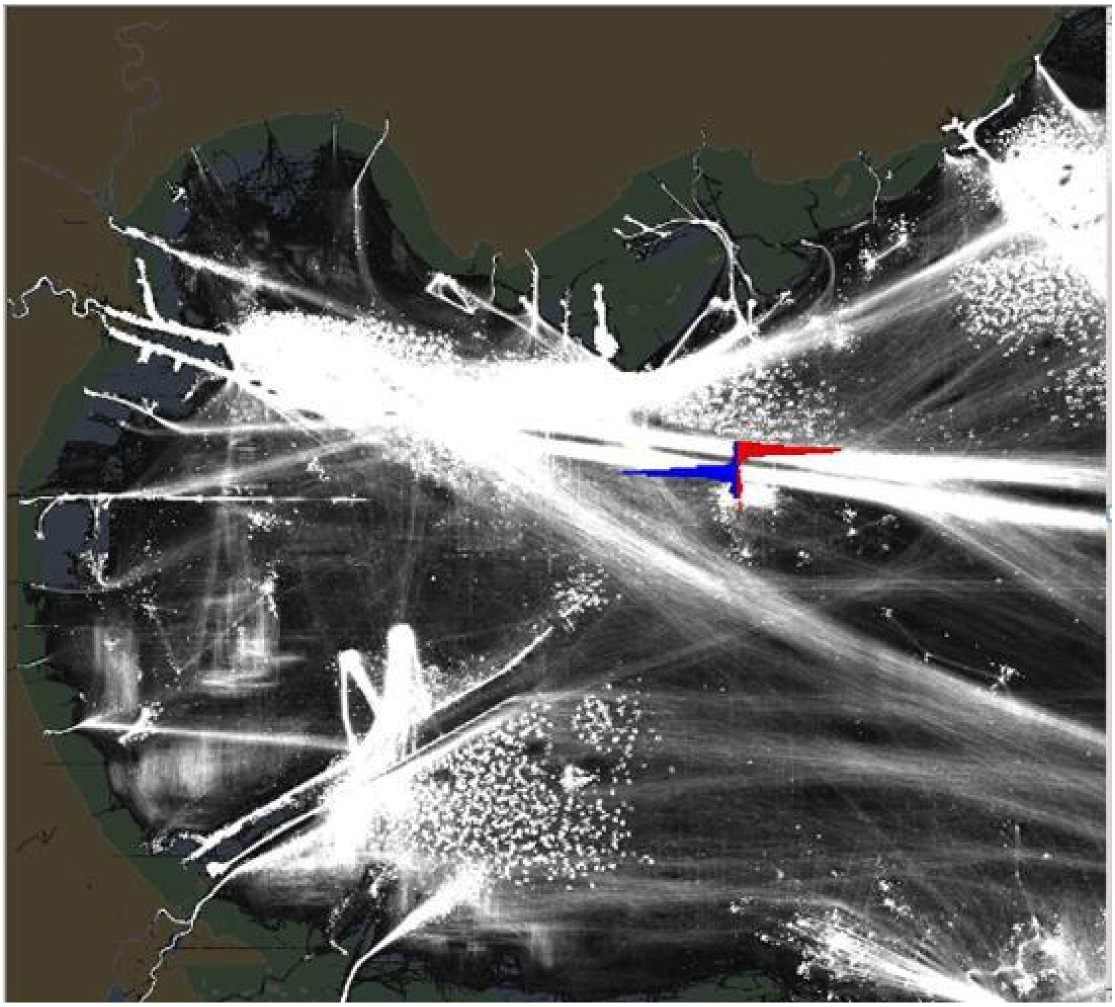

Fig.7 AIS contrail diagram of ships entering and leaving Caofeidian Port

Source: Tangshan MSA Vessel Traffic Service (VTS) Center

It can be seen from the graph that the ship routes near Caofeidian's north traffic flow accounted for about a half, and most of them are ships through the Laotieshan waterway to enter the Tianjin Port. A large part of the other is the traffic flow on the south. Ships are mainly between Tianjin and the northern port or waters of Shandong Peninsula. A small part of the traffic flow in the northeast direction and the track line distribution is wide. Owing to the recent construction of Caofeidian Port area, the traffic flow in the port of the coastal navigation is increasing. Generally speaking, the traffic flow in Caofeidian waters is large and the navigation waters are relatively narrow. The traffic flow from the north side is near the Caofeidian head, which mainly distributes in the planned anchorage area. The traffic flow will be concentrated on the Ship Routing System (SRS) waters, and the navigation waters are limited, and there are small ships which go across line waters.

ChapterⅢ The construction of the assessment index system of Caofeidian Port waters environment.

This paper makes a summary which analyze the navigation environment of Caofeidian Port. It uses the set pair comprehensive evolution theory to build up an evolution model of the safety of the navigation environment. But before setting the model, we should figure out the evaluating indicator and the proportion of it. A scientific and responsible method is necessary when choosing a proper indicator and building up a system. Choosing an evaluating indicator plays an important role in the overall evaluation. This paper makes a deeply study of the relevant documents at home and abroad, choosing a suitable evaluating indicator and carrying the improved Delphi Technique to calculate the proportion of the evaluating indicator to build up the index system of the evolution model of the navigation safety of Caofeidian. It is very operational and practical. (Olmsted, 1983; Zheng, 2005)

3.1 The selection of the assessment index

The natural environment of Caofeidian is an essential factor which affects the safety of the navigation traffic. But evaluating the safety of the navigation environment can't be limited to the natural environment. According to the analysis of the chapter Two, we can infer that the navigation also includes the infrastructure construction and the transportation condition and so on. So which indexes can affect the safety of the navigation environment and how much the effect will be must be concluded from a systematic analysis. Therefore, Tangshan MSA was entrusted to issue questionnaires to the relevant crews. There were 100 questionnaires, and 97 were collected in which 95 were valid. Questionnaire is shown in Appendix A. The statistical results are as follows:

Table 4 Indexes which affect the safety of the navigation environment of Caofeidian

The name of indexes	The number of people who agree	The number of people who don't agree
Wind	84	11
Flow	85	10
Visibility	82	13
Channel Width	78	17
Channel Depth	80	15
Channel Curvature	76	19
Channel Crossing	40	55
Obstruction Distribution	79	16
Navigation Density	90	5
Sand and Fishing ships	21	74
Navigation facilities	69	26

Source: Edited by author

According to the analysis of the statistical results and on-the-spot investigation, limited to the Traffic Separation Schemes (TSS), there are few channel crossings in Caofeidian. So the channel crossings won't have a big impact on the safety of the navigation environment in Caofeidian.

Due to the Caofeidian Port is a newly built port in recent years, there are few fishing and dredging ship operations and most of them are sailing in and out of the port. Although there is occasional failure to the rules, it doesn't affect the port navigation safety too much. So these two items are not used as the evaluation index of the environmental safety of Caofeidian Port waters.

3.2 Classification of risk assessment standards

In order to make sure the risk level of the ship navigation environment, we should make a clear standard of the corresponding evaluation. It means that for a certain evaluation index, what extent is safe or dangerous and how dangerous is the extent will be. (Trbojevic VM, 2000) The evaluation criteria are determined in this paper, according to the simulation results of the ship's operating parameters , such as the subjective evaluation value of the navigation risk degree and the pressure value of the ship operating environment from some foreign scholars and the results from some relevant experts in China. (Smith, 1989) The evaluation criteria are divided into five grades. They are low risk, lower risk, general risk, higher risk, and high risk.

3.3 The analysis of each index and the standard of risk assessment

In order to make that the evaluation index can better reflect the safety of navigation environment in Caofeidian Port waters, based on the Table 4, this paper combined with the actual situation of Caofeidian Port and some related literature and used the analytic hierarchy process to determine the evaluation index system. It is divided into two layers .One layer includes hydrology factors, channel condition factors and transportation factors. Another one includes visibility, wind, current, channel width, channel depth, channel curvature, obstruction distribution, traffic and navigation aids.

(1)Visibility. Fog, snow, rain, and hail, which cause poor visibility, have a greatest impact. According to statistics, caused by meteorological disasters in the sea, the accident caused by fog accounted for 31.4%, is two times as much as typhoon accident. The results show that the number of accidents and the visibility distance are exponential, and the regression equation is:

$$K = 90 \times D^{-0.8} \tag{3.1}$$

When the visibility distance is less than 4km, it has a little impact on the safety of ship navigation. When the visibility distance is less than 1km, the number of accidents increases significantly. (Sheng & Liang, 2011; Wen, 2003) Although the ship navigation technology is advanced, the ship will still appear yaw, collision and grounding and some other accidents. Therefore, this paper chooses the number of the days whose visibility distance are less than 2km as the evaluation index of visibility risk in the navigation environment of Caofeidian Port. And it also makes the following evaluation criteria:

Table 5 Assessment standard of the risk of visibility

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
Bad visibility days per year	15	25	35	45	50

Source: Edited by author

(2) Wind. The influence of wind on ships is related to many factors. The larger the wind is, the more ships will roll, the greater the deflection and drift is. In windy and typhonic days, the ship navigation safety and efficiency will be adversely affected. Strong wind makes the ship yaw, collision and anchor, in particular, in the restricted waters such as channel will lead to greater risks. Therefore, wind is an important factor in the assessment of the risk of navigation environment. In order to fully consider the influence of wind on the safety of the navigation, this paper considers the wind in the level 6 as a standard index and the wind stronger than level 6 into the standard wind. As well, this paper considers the average number of days as the evaluation index of value, so as to better reflect the navigation environment risk of the Caofeidian Port waters. The standard conversation algorithm is: the average annual number of days of standard wind = the number of days of level 6-7 per year +1.5 * 8 the number of days of level 8 per year. The assessment index of the risk level of the navigation environment in Caofeidian Port waters:

Table 6 Assessment standard of the risk of wind

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
Standard wind days per year	30	50	80	110	140

Source: Edited by author

(3) Current. The major effects of current on the ship motion are the ship speed, stroke, rudder, cycle and some other aspects of ship maneuverability. When the ship is sailing downstream, the actual speed will increase, the stroke to the ground will also increase

and the steerage will become bad. When the ship is sailing upstream, the actual speed will decrease and the steerage will be improved. The influences of current are flow velocity and flow direction. But the influences of the current are complicated and they are difficult to measure the direction with a single standard. Therefore, this paper uses the maximum current speed as the assessment index of the risk degree of the navigation environment in Caofeidian Port. (Li, 2006)

Table 7 Assessment standard of the risk of current

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
The speed of the current/kn	0.5	1.0	2.0	3.0	4.0

Source: Edited by author

(4) Channel width. When a ship is sailing in a narrow channel, it is easy to have some accidents such as the collision with the shore or grounding. Through the study of the influence of the variation of the channel width on the ship collision rate, with the channel width increasing, the collision rate will decrease. In the case of a certain amount of traffic, if the width is double, then the collision rate is almost reduced to half. They are almost in a linear change. Taking into account the size of the ship on the same channel width, the encounter rate and collision rate are also different. Therefore, the ratio of the width of the channel and the maximum width of the ship is used as the index to evaluate the risk of the width of the channel in the navigation waters. (Cheng, 2001)

Table 8 Assessment standard of the risk of channel width

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
Channel width/ship beam	0.5	1.0	2.0	3.0	4.0

Source: Edited by author

(5) Water depth of the channel. Whether the under keel clearance of ship is enough or not will directly affect the ship and the navigation safety. When the ship is

maneuvered in shallow water, the rudder effect will be reduced or even there is no rudder effect, while navigation resistance will increase. The ship will be trimmed by stern and the host power will come down, at that time the situation is very dangerous. (Xiong, 2008) The study shows that when the ratio of water depth and the draft of the ship are 2.5, the ship maneuverability will be affected; when the water depth and draft ratio are less than 1.5, the impact will be increased significantly. Therefore, the ship in the coastal shallow water navigation should pay special attention to manipulation changes to prevent accidents. Based on the analyses, combined with the relevant literature, this paper is to study water depth and ship draft ratio as Caofeidian Port waters. The evaluation index of the environmental risk level is shown in Table 9.

Table 9 Assessment standard of the risk of water depth of the channel

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
Channel water depth/ ship draft	4.5	3.5	2.5	1.5	1.2

Source: Edited by author

(6) The curvature of the channel. The difficulties the ships faced sailing in a curved waterway are much more than sailing in a straight channel navigation .When the ship is in a curved channel, it is not only limited by the size of the channel, but also by the wind at the turn. Ship handling performance will be decreased, coupled with the blocking of mariner’s sight at the corners of channel; it is prone to have collision accident. (Godlwell. TG, 1983)In this paper ,the maximum deflection angle of channel is used as the risk assessment index of channel curvature in the navigable waters of Caofeidian Port , and the specific criteria are shown in Table 10.

Table 10 Assessment standard of the risk of channel curvature

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
The maximum bending angle of the channel	15	25	35	50	60

Source: Edited by author

(7)Obstacle distribution .When a ship sails in the fairway, due to the width of the channel and so on, its own navigation space will be limited, coupled with the channel and its surrounding obstacles and navigation space will be further limited. The impact of the dangerous cargo on the safety of the ship's navigation depends mainly on the number of obstacles and the distance from the channel. The more obstacles there are ,the closer the distance from the channel ,the greater the impact is .Considering the comprehensive evaluation of environmental safety of navigable waters Caofeidian Port operation , we should select between navigation and channel distance as the indicator of risk evaluation because of air distribution in the waters of Caofeidian Port navigation environment which is shown in Table 11.

Table 11 Assessment standard of the risk of obstacle distribution

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
The reciprocal of the distance between the object and the channel	1/200	1/150	1/80	1/30	1/20

Source: Edited by author

(8)Traffic volume .How many the ships sailing in the space control the ship's actions in space and in the psychological shadow is. The behavior of the carousel poses a sense of danger to the ship operator. (Lv & Fang, 1996) Therefore, the traffic volume is an important factor in the evaluation of the environmental risk .The amount of the traffic refers to the number of ships passing through a certain point in a certain period of time, which can fully reflect the busy degree of the water area, and to a certain extent, reflecting the traffic congestion and dangerous degree. (Zhang & Xiao, 2015) In general ,the more traffic in the water area ,the greater the traffic density and congestion are ,the worse the degree of safety is ,the higher the degree of management requirements are .According to the above analyses ,this paper uses the traffic volume in one day as the evaluation index of the degree of navigation environment risk in Caofeidian Port ,as shown in Table 12.

Table 12 Assessment standard of the risk of traffic volume

Risk rank	Low risk	Lower risk	General risk	Higher risk	High risk
Amount of traffic per day	10	15	25	50	60

Source: Edited by author

(9)Navigation facilities. Navigation facilities generally have four functions, namely, navigation positioning function. Dangerous warning function and confirmation function, such as simple lights floating. If there is a problem with navigational aids, it will result that the ship cannot receive information from navigational facilities, which will cause a great impact on the safety of ship navigation. The completion rate of navigational aids is used as Caofeidian Port navigation environment risk evaluation standard. Completion rate of navigational aids is the ratio that channel which equipped with perfect navigational facilities accounting for the total number of the channel. Specific standards are shown in Table 13.

Table 13 Assessment standard of the risk of navigation facilities

Danger degree	Low risk	Lower risk	General risk	Higher risk	High risk
Completion rate of navigational aids	100	90	80	70	60

Source: Edited by author

3.4 Determination of the weight of each assessment index

Using a set of comprehensive evaluation method to analyze the navigable environment of Caofeidian Port waters must consider the relative importance of each index, namely each index weight or weight coefficient and the weight of this study refers to the important degree of every influence factors. There are many methods to affect the weight of each index, which can be divided into subjective weight, objective weight and combination weight method. (Jiao & Yang, 2006) The AHP (Deng, 2012) belongs to the subjective weight method that weights based on subjective judgment ,which is the most commonly used method but there may be too much emphasis inconsistent with the actual one .In this paper, it adopts an improved

Delphy method to ensure index weight .

In order to make the data and the weight of index more convincing and scientific, as shown in appendix A, this article issued a total of 50 questionnaires. And 49 copies were recovered, of which there were 47 valid questionnaires. The grades that every expert thought were obtained, and then according to the evaluation results of each expert, each grade is assigned, and the original weight of the index is obtained. Assignment table is shown in Table 14.

Tab.14 Assignment standard of each grade

Influence level	Rank assignment
less	1
little	2
general	3
big	4
bigger	5

Source: Edited by author

It is supposed that a total of m enterprises experts and n evaluation indexes , a_{ij} is number i expert's index weight in the sight of index of number j (i =1,2,3… m ; j =1,2,3… n). And the same experts' sum on the weight of different indicators is 1, which is also known as $\sum_{j=1}^{n} a_{ij} = 1$ .Then, according to the original weight value of each index, to calculate the average weight of each index, the calculating method is:

$$a_j = \frac{\sum_{i=1}^{m} a_{ij}}{m} \tag{3.2}$$

After then, according to the weighted average value of each expert, to calculate each index of the original weight difference a_{ij}^* , is also shown as :

$$a_{ij}^* = \left| a_{ij} - a_j \right| \tag{3.3}$$

Finally you can calculate the ultimate value of each index:

$$b_j = \frac{b_j^-}{\sum_{j=1}^{n} b_j^-} \qquad (3.4)$$

b_j^- is a transition value without a unified treatment in the formula above ,the calculating formula is:

$$b_j^- = \frac{\sum_{i=1}^{m} (a_{ij} \times a_{ij}^-)}{\sum_{i=1}^{m} a_{ij}^-} \qquad (3.5)$$

$$a_{ij}^- = \frac{\max a_{ij}^* - a_{ij}^*}{\max a_{ij}^* - \min a_{ij}^*} \qquad (3.6)$$

The $\max a_{ij}^*$ in the formula is the maximum volume of original weight that every experts deal with the each index, while $\min a_{ij}^*$ is the minimum volume.

According to the above formula, we can calculate the weight value of the first and second layers, as shown in the following table.

Table 15 Weight of the first layer assessment index

First layer index	Hydrological and meteorological factors	Channel condition factor	Traffic factor
Weight value	0.379	0.302	0.319

Source: Edited by author

The weight of each index in the second level of hydrological and meteorological factor is:

Table 16 Weight of each index in the second layer of hydrological and meteorological factor

Second layer index	Visibility factor	Wind factor	Current factor
Weight value	0.375	0.327	0.298

Source: Edited by author

The weight of each index in the second level of channel condition factor is:

Table 17 Weight of each index in second layer of channel condition

Second layer index	Channel width	Channel water depth	Channel curvature	Obstacle distribution
Weight value	0.228	0.249	0.257	0.266

Source: Edited by author

The weight of each index in the second level of traffic factor is:

Table 18 Weight of each index in second layer of traffic factor

Second layer index	Traffic factor	Navigational aids factor
Weight value	0.543	0.457

Source: Edited by author

If the first layer of each index weight value is I_1, and the second is I_2, the ultimate value as to the comprehensive evaluation of navigation environment safety of each index is :

$$\omega_j = I_1 \times I_2 \tag{3.7}$$

The result by calculating is

$$\begin{aligned} W &= (\omega_1\ \omega_2\ \omega_3\ \omega_4\ \omega_5\ \omega_6\ \omega_7\ \omega_8\ \omega_9) \\ &= (0.142\ \ 0.124\ \ 0.113\ \ 0.069\ \ 0.075\ \ 0.078\ \ 0.080\ \ 0.173\ \ 0.146) \end{aligned}$$

ChapterⅣ Establishment and analysis of set pair comprehensive evaluation model for the safety of navigation environment

4.1 Set pair comprehensive evaluation model

In recent years, with many scholars paying more and more attention to the navigation safety, there are more methods of safety assessment for people to use, and choosing a proper safety evaluation method is the foundation of navigation safety assessment. At present, the safety evaluation theory of our country is developing and improving continuously. After studying a large number of references, this paper analyzed the various evaluation methods based on the actual navigation environment of Caofeidian Port, and compared to many ways of asses the object and finally selected the comprehensive evaluation method of set pair analysis to the Caofeidian Port navigation environment for a comprehensive evaluation of safety. The comprehensive evaluation method of set pair analysis is carried out by means which is the combination of quantitative and qualitative. (Tian, 2013) These analyses use the identical and different judgments and also analyze objects from different categories. And it also uses mathematical operation to analyze objects. The quantitative analysis is carried out to conduct a comprehensive evaluation. This evaluation is comprehensive and applicable to different problems in different contexts.

4.1.1 Introduction of Set Pair Analysis

Set Pair Analysis (SPA) is an analytic theory founded by Chinese scholar Zhao Keqin in 1989. The main mathematical tools are the number of connections. (Zhao, 1994) Over the years, set pair analysis theory has been widely used in science, technology, engineering and other fields.

(1) The number of connections. Assuming that there is set A and set B, the set of two sets is H = (A, B), and the problem W needs to be analyzed by pair set of two sets.

There are N features between the two sets, one of which is common. There are features in the two sets of mutual opposition, the remaining $F = N - S - P$ features are neither the same nor the opposite. We denote S / N as the same degree of the set pair under the problem W, and is abbreviated as a ; for the set of differences under the problem W we define it as F / N , is abbreviated as b ; for the set of the degree of opposition in question W, we define it as P / N and abbreviated as c . The same degree of difference, the degree of alignment in different aspects of the description of the degree of connection of the two sets, according to which we said the two sets of questions in the number of connections under the problem of W is:

$$\mu(W) = \frac{S}{N} + \frac{F}{N} i + \frac{P}{N} j = a + bi + cj \tag{4.1}$$

Where i is the different coefficient, in the interval [-1,1] value, j stands for the alignment coefficient, with the value of -1, and the formula $a + b + c = 1$, several parameters affect each other. This kind of calculation method of connection number is from the opposite of three aspects of things reflecting the uncertainty.

(2) The number of multiple connections. Sometimes the evaluation of the object level needs to be more detailed, and there may be multiple equivalents, and then you can break down the different factor in the formula 4.1 into multiple, such as the formula 4.2.

$$\mu = a + b_1 i_1 + b_2 i_2 + \ldots + b_{n-2} i_{n-2} + cj \tag{4.2}$$

In the formula a b_1 b_2 b_{n-2} c all belong to (0, 1), and $a + b_1 + b_2 + \ldots + b_{n-2} + c = 1$; i_1 i_2 i_{n-2} is the difference coefficient, in the interval [-1,1] value; for the alignment coefficient j , where the value is still -1. We refer to the number of connections of type 4.2 as meta-associative numbers.

(3) Contact potential. The ratio of the same degree is defined as the linkage potential of the two sets under the problem, and the degree of alignment in the number of connections is not zero. Know as:

$$SHI = \frac{a}{c} \tag{4.3}$$

We name $\frac{a}{c}>1$ as the same trend , $\frac{a}{c}=1$ as the equal trend, and $\frac{a}{c}<1$ as the anti trend. The contact potential reflects the possible trend of the two sets in the context of the problem, and indicates the degree of contact with the opposite.

(4) The number of partial connections. Refering to the literature, we can see that the number of co variance is the ad-joint function of the number of connections. This function reflects the development trend of the two sets in the background of the problem. The partial co variance can be divided into positive partial coefficient and general partial coefficient and negative partial coefficient. (Zhao, 1996) Generally, the safety trend of the evaluation object is analyzed by the combination of the partial connections and the linkage potential.

Suppose there is a multiple connections number μ :

$\mu = a + b_1 i_1 + b_2 i_2 + \ldots + b_{n-2} i_{n-2} + cj$, where, a , b_1 , b_2 … b_{n-2} , $c \in [0,1]$, $a + b_1 + b_2 + \ldots + b_{n-2} + c = 1$, i_1 , i_2 … $i_{n-2} \in [-1,1]$, $j = -1$ .The first-order partial positive connection number is:

$$\partial\mu = \partial a + \partial b_1 i_1 + \partial b_2 i_2 + \ldots + \partial b_{n-2} i_{n-2} \tag{4.4}$$

In the formula, $\partial a = \frac{a}{a+b_1}$, $\partial b_1 = \frac{b_1}{b_1+b_2}$, $\partial b_2 = \frac{b_2}{b_2+b_3}$, …, $\partial b_{n-2} = \frac{b_{n-2}}{b_{n-2}+c}$.

The positive connection coefficient reflects the positive trend of the number of connections.

The first-order negative partial coefficient is:

$$\partial\mu = \partial b_1 + \partial b_2 i_1 + \partial b_3 i_2 + \ldots + \partial c i_{n-2} \tag{4.5}$$

In the formula, $\partial b_1 = \frac{b_1}{a+b_1}$, $\partial b_2 = \frac{b_2}{b_1+b_2}$, $\partial b_3 = \frac{b_3}{b_2+b_3}$, …, $\partial c = \frac{c}{b_{n-2}+c}$ 。

The negative partial coefficient reflects the negative trend of the number of links.

The first-order general partial coefficient is:

$$\partial\mu = \partial a + \partial b_1 i_1 + \ldots + \partial b_{n-2} i_{n-2} + \partial cj \tag{4.6}$$

Where, $\partial a = \dfrac{a}{a+b_1}$, $\partial b_1 = \dfrac{b_1}{b_1+b_2}$, …, $\partial b_{n-2} = \dfrac{b_{n-2}}{b_{n-2}+c}$, $\partial c = \dfrac{c}{a+c}$.

The general partial coefficient reflects the trend of the same variation of the number of links.

4.1.2 Establishment of set pair evaluation model

Assuming that there are a total of m, the indicators of the evaluation object, these indicators constitute the set of indicators: $Q = \{Q_1, Q_2, ..., Q_m\}$; for the evaluation of indicators having a rating level, the evaluation of the composition of the rating set is $V = \{V_1, V_2, ..., V_n\}$. The evaluation criteria for each indicator is known, so the following criteria can be written to evaluate the standard matrix: (Wu, 2010)

$$\begin{array}{c} \\ Q_1 \\ \vdots \\ Q_l \\ \vdots \\ Q_m \end{array} \begin{array}{c} \begin{array}{cccc} V_1 & V_2 & \cdots & V_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{l1} & a_{l2} & \cdots & a_{\ln} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \end{array} \tag{4.7}$$

Either in the formula $a_{l1} < a_{l2} < \cdots < a_{\ln}$ or $a_{l1} > a_{l2} > \cdots > a_{\ln}$.

The true evaluation value of the evaluation index is the meta-coefficient of the index:

$$\mu_l = t_{l1} + t_{l2} i_1 + \cdots + t_{lk} i_{k-1} + \cdots + t_{\ln} j \tag{4.8}$$

Where $1 \le l \le m$, $1 \le k \le n$, $t_{lk} \in [0,1]$, i_1 , i_2 , …, $i_{k-1} \in (0,1)$, $j = -1$ and there are:

$$t_{l1} + t_{l2} + \cdots + t_{lk} + \cdots + t_{\ln} = 1 \tag{4.9}$$

The true value of the evaluation index Q_l is q, that the number of multiple connections of the index n is calculated as follows:

(1) When $q \le a_{l1}$ or when $q \ge a_{l1}$:

$$\mu_l = 1 + 0i_1 + 0i_2 + \cdots + 0j \tag{4.10}$$

(2) When $a_{l1} < q \le a_{l2}$ or when $a_{l2} \le q < a_{l1}$:

$$\mu_l = \frac{|q - a_{l2}|}{|a_{l1} - a_{l2}|} + \frac{|q - a_{l1}|}{|a_{l1} - a_{l2}|} i_1 + 0i_2 + \cdots + 0j \tag{4.11}$$

(3) When the time $a_{l2} < q \le a_{lk} (3 \le k \le n-1)$ or $a_{lk} \le q < a_{l2} (3 \le k \le n-1)$:

$$\mu_l = 0 + \cdots + \frac{|q - a_{lk}|}{|a_{lk-1} - a_{lk}|} i_{k-2} + \frac{|q - a_{lk-1}|}{|a_{lk-1} - a_{lk}|} i_{k-1} + \cdots + 0j \tag{4.12}$$

(4) When the time $a_{\ln-1} < q \le a_{\ln}$ or $a_{\ln} \le q < a_{\ln-1}$:

$$\mu_l = 0 + \cdots + 0i_{n-3} + \frac{|q - a_{\ln}|}{|a_{\ln-1} - a_{\ln}|} i_{n-2} + \frac{|q - a_{\ln-1}|}{|a_{\ln-1} - a_{ln}|} j \tag{4.13}$$

(5) When $q > a_{\ln}$ or when $q < a_{\ln}$:

$$\mu_l = 0 + 0i_1 + 0i_2 + \cdots + 0i_{n-2} + 1j \tag{4.14}$$

According to the above method, we can calculate the meta-coefficient of all the evaluation indexes, and then make the multi-index connection number form matrix.

$$T = \begin{bmatrix} t_{11} & t_{12} & t_{13} & \cdots & t_{1n} \\ t_{21} & t_{22} & t_{23} & \cdots & t_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ t_{m1} & t_{m2} & t_{m3} & \cdots & t_{mn} \end{bmatrix} \tag{4.15}$$

Assume that the weights of all the indicators in the corresponding evaluation system are set as $W = (\omega_1, \omega_2, \cdots, \omega_m)$, and the sum of all weights is 1, that is to say, $\omega_1 + \omega_2 + \cdots + \omega_m = 1$. So the total number of meta-indices for all indicators is:

$$\mu = W * T * E = (\omega_1, \omega_2, \cdots, \omega_m) * \begin{bmatrix} t_{11} & t_{12} & t_{13} & \cdots & t_{1n} \\ t_{21} & t_{22} & t_{23} & \cdots & t_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ t_{m1} & t_{m2} & t_{m3} & \cdots & t_{mn} \end{bmatrix} * E \tag{4.16}$$

And E is the coefficient matrix $E = (1, i_1, i_2, \cdots, j)$. Because of $i \in [-1,1]$ and $j = -1$, we use the principle of equalization, and $[-1,1]$ divide into $n-1$ parts, and then the coefficient E including $i_1, i_2, \cdots, i_{n-2}$ in accordance with the order from right to left, respectively, to take an equal part of the value. For example, when $n = 5$, the interval is divided equally into 4 parts, from right to left three liquors of the value of 0.5,0, -0.5, so the coefficient matrix $i_1, i_2, \cdots, i_{n-2}$ values are 0.5,0, -0.5.

In order to obtain the interval corresponding to the evaluation level, we divide $[-1,1]$ into n parts, and n ranks of the evaluation grade is corresponding to the range of right to left, so that the total element n relation number μ of all the indexes is calculated according to equation (4.16) .The size of which belongs to the range, then the range of the corresponding evaluation level is the final evaluation results.

4.2 Analysis of the results of the evaluation

4.2.1 Set pair analysis of comprehensive evaluation model

In this article, we take the 5 element connection number as an example to discuss the evaluation results of the set of potential analysis. Assuming the existing 5 element connection number is $\mu = a + bi_1 + bi_2 + bi_3 + cj$, this article is to comment on the concentration of "low risk" level as a reference standard, according to the previous section of the theory of set pair, contact potential a/c.

When $a/c > 1$, it was shown that the safety of the navigation environment of the objects we evaluated was the same as the reference standard, that is, the set had the same trend in the context of the problem, that is to say, the navigation environment risk of the evaluation object tends to be "low risk".

When $a/c < 1$, it was shown that the safety of navigation environment and the reference standard of the object we were evaluated were in the opposite tendency, that is, the set trend of the set against the background of the problem, that is, the navigation environment risk of the evaluation object tends to be "high risk".

When $a/c=1$, it was shown that the safety and reference standards of the navigation environment of the objects we evaluated were in a different trend, that is, the concentration of the navigation environment in the context of the problem was that "the general risk" of the evaluation object was "generally dangerous".

4.2.2 Partial connections analysis of comprehensive evaluation model

On the analysis of partial coefficients, this paper is based on 5 element connection number as an example to discuss the problem. Because the above set of potential analysis is based on the "low risk" , this paper only needs to discuss the partial connection coefficient and the full offset coefficient analysis method of 5 element connection number.

We know that the set-pair analysis is to analyze the trend of the navigation environment risk of the evaluation object, and the positive connection coefficient analysis is to analyze the dynamic change rate of the trend on the basis of the change trend. In this paper, we use the method of partial coupling coefficient analysis and set pair potential analysis. From the definition of the positive connection coefficient, we can see that when $n=5$, 5 element connection number is $\mu=a+bi_1+bi_2+bi_3+cj$ and there is a first-order partial positive connection number:

$$\partial\mu=\partial a+\partial b_1 i_1+\partial b_2 i_2+\partial b_3 i_3 \tag{4.17}$$

Which $\partial a=\dfrac{a}{a+b_1}$, $\partial b_1=\dfrac{b_1}{b_1+b_2}$, $\partial b_2=\dfrac{b_2}{b_2+b_3}$, $\partial b_3=\dfrac{b_3}{b_3+c}$ and $a+b_1$, b_1+b_2 , b_2+b_3 , b_3+c are not equal to 0. For the positive connection number of equation (4.17), the contact potential is calculated.

If the case $\dfrac{\partial a}{\partial b_3}>1$, then the first-order partial positive coherence in the context of the problem has the same trend, that is to say, the evaluation of the target navigation environment risk decline in the first-class trend, and slow down; if $\dfrac{\partial a}{\partial b_3}<1$, then the first- number of links has a tendency to oppose in the context of the problem, that is to say, there is an overall first-order upward trend in the navigation environment of the evaluation object, and the rising speed is faster; if $\frac{\partial a}{\partial b_3}=1$, the first-order positive coherence is described in the context of the problem. In the balance of power, that is to say, the evaluation of the overall navigation environment risk changes in the overall change, and the speed of change is in general.

According to the above analysis method, if the evaluation object is in the counter-potential in the set-pair potential analysis, and the first-order positive coherence coefficient also has the opposite tendency, it indicates that the navigation environment risk of the evaluation object tends to "high risk". This trend is changing fast, so that the evaluation of the object or evaluation index is that we need to focus on. (Wang, 2009)

The positive connection coefficient is the dynamic change rate of the navigation environment risk of the evaluation object, and the full degree of contact is the risk condition of the navigation object. In this paper, the analysis coefficient model is full of 5 element connection number as an example.

When $n=5$, 5 element connection number is $\mu=a+bi_1+bi_2+bi_3+cj$, there is a first-order general partial coefficient:

$$\partial\mu = \partial a + \partial b_1 i_1 + \partial b_2 i_2 + \partial b_3 i_3 + \partial cj \tag{4.18}$$

Which $\partial a=\frac{a}{a+b_1}$ ， $\partial b_1=\frac{b_1}{b_1+b_2}$ ， $\partial b_2=\frac{b_2}{b_2+b_3}$ ， $\partial b_3=\frac{b_3}{b_3+c}$ ， $\partial c=\frac{c}{a+c}$ and $a+b_1$ ， b_1+b_2 ， b_2+b_3 ， b_3+c ， $a+c$ are not equal to 0. In the first-order general partial coefficient $\partial c=\frac{c}{a+c}$, from the above set of potential theory, we can see that the contact potential is equal to a/c , so $\partial c=\frac{1}{1+SHI}$ when the contact potential is bigger, the ∂c is smaller, the better the navigation environment of the evaluation object is, the safer the navigation is. When $\partial c<0.5$, the evaluation of the navigable environment in general is good, and the ship can sail safely. When $\partial c>0.5$, the evaluation of the navigable environment is relatively bad and is not safe enough to sail, so it's necessary to take protective measures. When $\partial c = 0.5$ the evaluation of the navigable environment is ordinary. It is OK to navigate but you have to be cautious.

Chapter Ⅴ Set pair comprehensive evaluation for the safety of navigation environment in Caofeidian Port

5.1 Determination of the evaluation index value of the navigation environment in Caofeidian Port areas

In order to be able to determine the suitable value of the evaluation index of Caofeidian Port waters, this thesis studies the relevant information which provided by the meteorological department, hydrological departments and maritime sector, combining with the observation data in the past. In the navigation environment , on the basis of comprehensive evaluation standard ， this paper determines the specific value of each evaluation index.

5.1.1 The standard set of evaluation index for navigation environment of Caofeidian Port

According to the analysis of the third chapter, the author collected the total standard value of each evaluation index to get the standard set of evaluation index for navigation environment of Caofeidian Port which is shown in Table 19.

Table 19 Standard set of evaluation index for navigation environment of Caofeidian Port

First level index	Second level index	Low risk	Lower risk	General risk	Higher risk	High risk
Hydrological Factor	visibility	15	25	35	45	50
	wind	30	50	80	110	140
	current	0.5	1.0	2.0	3.0	4.0
Channel condition	channel width	8.0	6.0	4.0	2.5	1.5
	channel depth	4.5	3.5	2.5	1.5	1.2
	channel curvature	15	25	35	50	60
	barrier distribution	1/200	1/150	1/80	1/30	1/20
Traffic factor	traffic	10	15	25	50	60
	aids to navigation	100	90	80	70	60

Source: Edited by author

5.1.2 Determination of the index value of the navigation environment safety evaluation of Caofeidian Port

According to the above analyses, we know that there are a total of 9 indicators for the assessment of the environmental safety of Caofeidian Port, namely visibility, wind, flow, channel width, channel depth, channel curvature, obstacle distribution, traffic volume and navigation aids. In the aspect of hydrological and meteorological factors, according to the latest information of the Tanghai Meteorological Station and South Fort Weather Station around the Caofeidian Port site, the evaluation index of visibility was 21.The evaluation index of wind was 35. According to the statistics of hydrological department, the evaluation index of current was 2.3.This paper is based on the data of the Caofeidian Port channel, which was described in the latest *Tangshan port pilotage manual* in 2016 and the provisions of *The general layout design code of the harbor* and *The standards for the hydrology code of waterway and* *port*. Inner channel width was 160m.The width of the tow towing fleet was about 22 m .Therefore, the channel width evaluation index value was 7.3.The channel depth was 13.2 m. So the evaluation index of channel depth was1.6.The evaluation index of the maximum bending angle of channel curvature was 60.The evaluation index of obstacle distribution was 1/150.

In the aspect of traffic factor， according to the field survey records and previous observations from the maritime sector ， the evaluation index of traffic volume was 18. Through the second chapter of Caofeidian Port waters navigation facilities introduction , it can be seen that the region is relatively perfect navigation facilities. It can meet the requirement of ship navigation safety. Therefore, the evaluation index of the navigation aids is 100% .To sum up, the evaluation index of the Caofeidian Port navigation environment safety evaluation is shown in Table 20.

Table 20 Value of evaluation index of Caofeidian port navigation environment

First level index	Second level index	Index value
Hydrometeor Factor	visibility	21
	wind	35
	current	2.3
Channel condition Factor	channel width	7.3
	channel depth	1.6
	channel curvature	60
	barrier distribution	1/150
Traffic factor	traffic	18
	aids to navigation	100

Source: Edited by author

5.2 Set pair comprehensive evaluation for the safety of navigation environment in Caofeidian Port

5.2.1 Evaluation of the first layer index for the safety of navigation environment in Caofeidian Port

Through the introduction of the fourth chapter，first，calculate the number of 5 links of each index of Caofeidian Port navigation environment safety evaluation ， according to the formula 4.10 to 4.14. According to the calculation of the 5 element connection number constitute multi index comprehensive evaluation matrix. The following is the specific calculation process：

$$\mu_1 = \frac{25-21}{25-15} + \frac{21-15}{25-15} i_1 + 0i_2 + 0i_3 + 0j$$

$$\mu_2 = \frac{50-35}{50-30} + \frac{35-30}{50-30} i_1 + 0i_2 + 0i_3 + 0j$$

$$\mu_3 = 0 + 0i_1 + \frac{3-2.3}{3-2} i_2 + \frac{2.3-2}{3-2} i_3 + 0j$$

$$\mu_4 = \frac{7.3-6}{8-6} + \frac{8-7.3}{8-6} i_1 + 0i_2 + 0i_3 + 0j$$

$$\mu_5 = 0 + 0i_1 + \frac{1.6-1.5}{2.5-1.5} i_2 + \frac{2.5-1.6}{2.5-1.5} i_3 + 0j$$

$$\mu_6 = 0 + 0i_1 + 0i_2 + \frac{60-60}{60-50} i_3 + \frac{60-50}{60-50} j$$

$$\mu_7 = \frac{1/150 - 1/150}{1/150 - 1/200} + \frac{1/150 - 1/200}{1/150 - 1/200} i_1 + 0i_2 + 0i_3 + 0j$$

$$\mu_8 = 0 + \frac{25-18}{25-15} i_1 + \frac{18-15}{25-15} i_2 + 0i_3 + 0j$$

$$\mu_9 = 1 + 0i_1 + 0i_2 + 0i_3 + 0j$$

We can divide (-1, 1) into 4 equal parts and take 3 points from right to left. So $i_1 = 0.5$, $i_2 = 0$, $i_3 = -0.5$. So we can find the 5 element connection number of each index to determine the comprehensive evaluation matrix of multi index connection number.

$$\begin{bmatrix} 0.4 & 0.6 & 0 & 0 & 0 \\ 0.75 & 0.25 & 0 & 0 & 0 \\ 0 & 0 & 0.7 & 0.3 & 0 \\ 0.65 & 0.35 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & 0.9 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0.7 & 0.3 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Through the introduction of the third chapter, we have obtained the weight of each evaluation index of Caofeidian Port navigation safety. Among them， the weights of the second layer indexes of hydrological and meteorological factors are：

$$W_{sw} = (\omega_1\ \omega_2\ \omega_3) = (0.375\ \ 0.327\ \ 0.298)$$

The weights of the second layer indexes of channel condition factors are：

$$W_{hd} = (\omega_4\ \omega_5\ \omega_6\ \omega_7) = (0.228\ \ 0.249\ \ 0.257\ \ 0.226)$$

The weights of the second layer indexes of traffic factors are：

$$W_{jt} = (\omega_8\ \omega_9\ ) = (0.543\ \ 0.457)$$

In summary ， we can get 5 element connection number of the first layer evaluation indexes of navigation environment safety in Caofeidian Port, connection number of hydrological and meteorological factor, channel condition factor and traffic factor are :

$$\mu_{sw} = (0.375\ \ 0.327\ \ 0.298) * \begin{bmatrix} 0.4 & 0.6 & 0 & 0 & 0 \\ 0.75 & 0.25 & 0 & 0 & 0 \\ 0 & 0 & 0.7 & 0.3 & 0 \end{bmatrix} * \begin{bmatrix} 1 \\ 0.5 \\ 0 \\ -0.5 \\ -1 \end{bmatrix} = 0.5039$$

$$\mu_{hd} = (0.228\ \ 0.249\ \ 0.257\ \ 0.226) * \begin{bmatrix} 0.65 & 0.35 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & 0.9 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} 1 \\ 0.5 \\ 0 \\ -0.5 \\ -1 \end{bmatrix} = -0.0679$$

$$\mu_{jt} = (0.543\ \ 0.457) * \begin{bmatrix} 0 & 0.7 & 0.3 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} 1 \\ 0.5 \\ 0 \\ -0.5 \\ -1 \end{bmatrix} = 0.6471$$

We divide the interval (-1,1) into 5 equal parts and five small section are obtained.

From the right to the left, 5 evaluation levels are corresponding, as shown in Table21.

Table 21 Mapping table of connection number and evaluation level

Evaluation level	Low risk	Lower risk	General risk	Higher risk	High risk
Connection number interval	[0.6,1]	[0.2,0.6]	[-0.2,0.2]	[-0.6,-0.2]	[-1,-0.6]

Source: Edited by author

After calculating, we get $\mu_{sw} = 0.5039$. It belongs to interval [0.2, 0.6], so the first layer evaluation index of meteorological and hydrological factors belong to lower risk level; $\mu_{hd} = -0.0679$, it belongs to interval [-0.2, 0.2]. Therefore, the first layer evaluation indicators of the channel condition is generally risk; $\mu_{jt} = 0.6471$, it belongs to interval [0.6, 1]. Therefore, the first layer evaluation index of traffic factor is at low risk level.

5.2.2 Evaluation of the second layer index for the safety of navigation environment in Caofeidian port

According to the above calculation method， similarly， we can figure out all 5 element connection numbers of evaluation indexes and determine the evaluation level according it.，

$\mu_1 = 0.4 + 0.6 \times 0.5 + 0 \times 0 + 0 \times (-0.5) + 0 \times (-1) = 0.7$ ， It is the connection number of Caofeidian Port visibility index which belongs to interval [0.6, 1]. So visibility belongs to the low risk level.

$\mu_2 = 0.75 + 0.25 \times 0.5 + 0 \times 0 + 0 \times (-0.5) + 0 \times (-1) = 0.875$ ， It is the connection number of indicators of wind in Caofeidian Port , belonging to the interval [0.6,1], so the wind belongs to the low risk level.

$\mu_3 = 0 + 0 \times 0.5 + 0.7 \times 0 + 0.3 \times (-0.5) + 0 \times (-1) = -0.15$ ， It is the connection number of indicators of current in Caofeidian Port , belonging to the interval [-0.2，0.2] .So the current belongs to the general risk level.

$\mu_4 = 0.65 + 0.35 \times 0.5 + 0 \times 0 + 0 \times (-0.5) + 0 \times (-1) = 0.825$ ， It is the connection number of indicators of channel width in Caofeidian Port , belonging to the interval [0.6,1].Therefore, the width of the channel belongs to the low risk level.

$\mu_5 = 0 + 0 \times 0.5 + 0.1 \times 0 + 0.9 \times (-0.5) + 0 \times (-1) = -0.45$， It is the connection number of indicators of channel water depth in Caofeidian Port , belonging to the interval [-0.6, -0.2].So the water depth of the channel belongs to the higher risk level.

$\mu_6 = 0 + 0 \times 0.5 + 0 \times 0 + 0 \times (-0.5) + 1 \times (-1) = -1$， It is the connection number of indicators of channel curvature in Caofeidian Port , belonging to the interval [-1,-0.6]. Therefore, the curvature of the channel belongs to high risk level.

$\mu_7 = 0 + 1 \times 0.5 + 0 \times 0 + 0 \times (-0.5) + 0 \times (-1) = 0.5$ ， It is the connection number of indicators of obstacle distribution in Caofeidian Port , belonging to the interval[0.2,0.6]. Therefore, the distribution of obstacles belongs to lower risk level.

$\mu_8 = 0 + 0.7 \times 0.5 + 0.3 \times 0 + 0 \times (-0.5) + 0 \times (-1) = 0.35$, It is the connection number of indicators of traffic in Caofeidian Port , belonging to the interval [0.2,0.6]. So traffic condition belongs to lower risk level.

$\mu_9 = 1 + 0 \times 0.5 + 0 \times 0 + 0 \times (-0.5) + 0 \times (-1) = 1$, It is the connection number of indicators of aids to navigation in Caofeidian Port , belonging to the interval[0.6,1]. Therefore, navigational aids belong to low risk level.

5.2.3 Comprehensive assessment of environmental safety in Caofeidian Port

The weights of all evaluation indexes of navigation environment safety in Caofeidian Port are:

$$
\begin{aligned}
W &= (\omega_1\ \omega_2\ \omega_3\ \omega_4\ \omega_5\ \omega_6\ \omega_7\ \omega_8\ \omega_9) \\
&= (0.142\ \ 0.124\ \ 0.113\ \ 0.069\ \ 0.075\ \ 0.078\ \ 0.080\ \ 0.173\ \ 0.146)
\end{aligned}
$$

Therefore, the total connection number of index of comprehensive evaluation of environmental safety in Caofeidian Port μ is

$$
\mu = (0.142\ \ 0.124\ \ 0.113\ \ 0.069\ \ 0.075\ \ 0.078\ \ 0.080\ \ 0.173\ \ 0.146) \times \begin{bmatrix} 0.4 & 0.6 & 0 & 0 & 0 \\ 0.75 & 0.25 & 0 & 0 & 0 \\ 0 & 0 & 0.7 & 0.3 & 0 \\ 0.65 & 0.35 & 0 & 0 & 0 \\ 0 & 0 & 0.1 & 0.9 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0.7 & 0.3 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 1 \\ 0.5 \\ 0 \\ -0.5 \\ -1 \end{bmatrix} = 0.3827
$$

$\mu = 0.3827$ is belonging to interval [0.2, 0.6]. So according to the analysis and calculation， the environmental safety of Caofeidian Port belongs to the lower risk level.

5.3 Analysis of safety assessment of navigation environment in Caofeidian Port

5.3.1 The set pair analysis of navigation environment safety evaluation in Caofeidian Port

According to the fourth chapter of this paper, the theory of set pair analysis is introduced.

Now the set pair power of evaluation of Caofeidian Port navigation environment safety results were to be analyzed.

Because $\mu = 0.3407 + 0.3414 \times 0.5 + 0.1385 \times 0 + 0.1014 \times (-0.5) + 0.078 \times (-1)$, so among them $a = 0.3407$, $c = 0.078$. Because $c \neq 0$, the connection trend of navigation environment safety evaluation in Caofeidian Port is $a / c = 4.368$ .Obviously, $a / c = 4.368$,it is bigger than one, which shows that the whole Caofeidian Port navigation environment safety and reference standards have the same trend. In other words, the overall risk of Caofeidian Port navigation environment tends to be low risk.

5.3.2 The analysis of partial connection number for environmental safety assessment of Caofeidian port

According to the introduction of the theory of the analysis of partial connect number in the fourth chapter, in order to get the analysis of the coefficient of partial connect number of environmental safety assessment of Caofeidian Port, it is necessary to calculate the number of positive partial connection number and total partial connection number. $a = 0.3407$, $b_1 = 0.3414$, $b_2 = 0.1385$, $b_3 = 0.1014$, $c = 0.078$, So the positive partial connection number is $\partial\mu = \partial a + \partial b_1 i_1 + \partial b_2 i_2 + \partial b_3 i_3$, among them :

$$\partial a = \frac{a}{a + b_1} = \frac{0.3407}{0.3407 + 0.3414} = 0.4994$$

$$\partial b_1 = \frac{b_1}{b_1 + b_2} = \frac{0.3414}{0.3414 + 0.1385} = 0.7114$$

$$\partial b_2 = \frac{b_2}{b_2 + b_3} = \frac{0.1385}{0.1385 + 0.1014} = 0.5773$$

$$\partial b_3 = \frac{b_3}{b_3 + c} = \frac{0.1014}{0.1014 + 0.078} = 0.5652$$

So $\partial\mu = 0.4994 + 0.7114 i_1 + 0.5773 i_2 + 0.5652 i_3$, and then we calculate the contact potential, $\partial a/\partial b_3$. It can be obtained by calculation $\partial a/\partial b_3 = 0.8836$. Obviously, this value is less than 1.That partial positive connect number has the opposite tendency .There is a general upward trend of the navigation environment risk of Caofeidian port. The speed of rising is faster.

The total partial connection number is then calculated.

$\partial\mu = \partial a + \partial b_1 i_1 + \partial b_2 i_2 + \partial b_3 i_3 + \partial cj$, among them $\partial a = 0.4994$, $\partial b_1 = 0.7114$, $\partial b_2 = 0.5773$, $\partial b_3 = 0.5652$, $\partial c = \frac{c}{a+c} = \frac{0.078}{0.3407+0.078} = 0.1863$ .Because $\partial c = 0.1863$, less than 0.5. Therefore, the overall Caofeidian port navigation environment is in good condition. The ship navigation is safe.

We analyze the partial connection number of the first layer evaluation index of Caofeidian Port through the above analyses,

$\mu_{sw} = 0.3953 + 0.3067\times0.5 + 0.2086\times0 + 0.0894\times(-0.5) + 0\times(-1)$, among them $a = 0.3953$, $b_1 = 0.3067$, $b_2 = 0.2086$, $b_3 = 0.0894$, $c = 0$ .The partial positive connection number of hydrological and meteorological factors is: $\partial\mu_{sw} = \partial a + \partial b_1 i_1 + \partial b_2 i_2 + \partial b_3 i_3$, among them $\partial a = 0.5631$, $\partial b_3 = 0.0894$, so $\partial a/\partial b_3 = 6.3$. The result is more than 1. The results show that the first order partial positive connection number of hydrological and meteorological factors has the same trend , that is to say, there is a declining trend of first order of the risk of hydrological and meteorological factors. The speed of the declining is slow.

Because $\mu_{hd} = 0.1482 + 0.3058\times0.5 + 0.0249\times0 + 0.2241\times(-0.5) + 0.2570\times(-1)$, So

$a = 0.1482$, $b_1 = 0.3058$, $b_2 = 0.0249$, $b_3 = 0.2241$, $c = 0.2570$, So the partial positive connection number of channel condition factor is: $\partial\mu_{hd} = \partial a + \partial b_1 i_1 + \partial b_2 i_2 + \partial b_3 i_3$, among them, $\partial a = 0.3264$, $\partial b_3 = 0.4658$, So $\partial a/\partial b_3 = 0.7007$, .The result is less than 1 which shows that the first order partial positive connection number of the first layer evaluation index has opposite trend. The risk factors of channel conditions exist first order upward trend. The speed of changing is fast.

Similarly, $\mu_{jt} = 0.4570 + 0.3801 \times 0.5 + 0.1629 \times 0 + 0 \times (-0.5) + 0 \times (-1)$, $a = 0.4570$, $b_1 = 0.3801$, $b_2 = 0.1629$, $b_3 = 0$, $c = 0$ .Because $b_3 = 0$, so $\partial b_3 = 0$ .The connect number of first order of traffic condition factors of does not exist .According to the relation of the traffic conditions of 5 element connect number of connection component size , we analyze the set pair situation (Wu, 2010) $a > c$,and $a > b_1$, $b_1 > b_2$, $b_2 > b_3$, $b_3 = c$, Therefore, the risk factor of traffic condition has the same trend as the reference standard . It tends to "low risk" level.

Chapter Ⅵ Measures to improve the safety of navigation environment in Caofeidian Port

Through the above evaluation and analyses of the safety of Caofeidian navigation environment, it is possible to know that the safety of navigation in Caofeidian is generally low, which tends to the general danger level . Some individual indicators are at high risk and high risk level. So we have to strengthen the navigation environment management and improve navigation safety.

6.1 Measures for hydrological and meteorological factors

Because of hydrological and meteorological factors such as the visibility, wind, current these indicators, we cannot control its changes, but we can take some necessary management measures to improve navigation safety.

In terms of visibility, the Caofeidian Port area has more plain fog. When the visibility is bad, the traffic control department must strengthen the management. It should always pay attention to the entry and exit of the ship navigation dynamics to prevent the occurrence of an urgent situation. Ships have to notice the relevant channels to drive carefully.

Because of the wind factor, during the time that the wind would affect ships sailing, maritime traffic control department should be issued and the ship should be informed as soon as possible to take preventive measures to adjust the course in order to reduce the damage of winds.

Because of the impact of the flow, the risk rating is generally dangerous,and it is higher than the visibility. In the areas where the impact of the flow is more obvious, the ship should always pay attention to its own position to ensure that the navigation is on its own route, and you can operate rudder to control the role of water flow.

6.2 Measures for channel conditions factors

At present, Caofeidian Port will set up the precautionary area at the end of the traffic arteries, and the ship will enter the channel through the warning area. It's very important to ensure that the ship sails along the middle of the channel, instead of deviating from or even leaving the channel. In addition, before the ship sails into the channel, the narrowest width of the channel must be considered as a limited factor. For large ships, they need to sail in deep water channel and pay attention to speed restrictions. They should try to avoid the chase situation.

On the obstacle, the Caofeidian Port's obstacles mostly are the shoals and dangerous wrecks. These obstacles should be showed on the chart accurately. If there are any changes in a timely manner with the new vessels in the vicinity of obstacles in the past position, ships should be ensured to avoid the occurrence of collision accidents.

Maritime management departments should also be based on the situation of the channel to do maintenance work to protect the depth of the deep water channel requirements. Especially the water depth of the channel and the curvature of the channel, the evaluation level is at higher risk . Therefore, it is essential to strengthen the dredging work and ensure the navigation route width on the basis of increasing the water depth of the channel.

6.3 Measures for traffic condition factors

Nowaday , more and more ships enter Caofeidian Port every day, so it requires the traffic control departments to strengthen management. For the navigation vessels in the navigation , they should keep the safe speed sailing to maintain the safe distance and to avoid chasing. Some large-scale ship handling performance is poor, so we should arrange escort tugs, and all should give way to the principle of safety. We can improve navigation efficiency on condition of the safety.

The risk rating of the navigation facilities is at the low risk level, which indicates that Caofeidian Port 's naval facilities are relatively perfect. If there are some perfect facilities, there must be some complete maintenance. The relevant navigation departments need to do the maintenance of these navigation facilities management work and find the problem to repair in time. Be sure not to give ships which are in and out the port the wrong information, and then cause the security incident. At the same time, the location of these navigation signs must be definite.If there are some deviations, we must correct them on time to ensure to provide the accurate navigation information.

ChapterⅦ Conclusion

The safety of port navigation environment has an influence on the development of port economy. In recent years, the frequent occurrence of traffic accidents in port waters has caused the economic losses year by year. Therefore, actions should be taken to improve the navigation environment of ports and to ensure the safety of ship navigation.

Now the navigation environment of port mainly includes nature condition and traffic condition. The factors affect the safety of ship navigation and the influence will be analyzed through the investigation and research, which is called evaluation of port navigation environment. The reasonable improvement measures are put forward according to the factors which affect the navigation environment.

Because Caofeidian Port is a new developing port in China, there is not a complete set of methods to study the navigation environment safety of Caofeidian Port.

If we want to have a general understanding of the navigation environment of Caofeidian Port, we should refer to the field investigation and questionnaire survey of Caofeidian Port water areas. And other relevant information is further collected from some departments such as meteorological department, maritime department and route department. The evaluation index system of Caofeidian navigation safety is established and the evaluation criteria of each index are determined respectively through the use of the analytic hierarchy process on the basis of these studies and the research of relevant papers. Then, the weight of the index is calculated based on the improved Delphi method. The calculation of the original offset is improved to obtain the final index weight based on the expert scoring. Finally, the evaluation model of navigation safety of Caofeidian Port is established by using the set pair analysis and comprehensive evaluation theory. Final evaluation results and analyses conclusion are consistent with the actual traffic situation of Caofeidian Port.Through the analysis and evaluation of each index, it indicates that the model is reasonable and practical for Caofeidian Port.

The analysis method of the combination of the set potential and partial connection coefficient is innovatively applied to the comprehensive evaluation model of navigation safety in Caofeidian Port in this paper. It can not only evaluate the safety level of each index, but also give the dynamic trend of the safety level.

Some conclusions are proposed as follows according to the research of this paper:

• The navigation environment safety of Caofeidian Port is at the lower risk level.

• The risk of channel water depth and curvature is higher than other indexes, so it is necessary to pay more attention to improve the navigation environment of the harbor. Channel management department can strengthen dredging work to ensure the channel depth.

• Current is another index which affects the navigation environment safety of Caofeidian Port. Port VTS needs to strengthen management of ships to ensure navigation safety in the area where current effect is more serious. Moreover, a breakwater can be constructed to reduce the impact of current.

This method has made a relatively objective and complete evaluation of the safety coefficient and influencing factors of the shipping environment of Caofeidian Port in order to provide a scientific basis for the improvement of the navigation environment of Caofeidian Port and the management of port traffic and port development planning, which is more conducive to improve the navigation safety of Caofeidian Port.

Due to the complexity of the safety of Caofeidian Port, it is inevitable that there will be omissions and deficiencies in the safety evaluation. Caofeidian Port is a port which has developed rapidly in recent years, so there may be omissions in terms of port navigation environment information, which will have some impact on the evaluation results. In addition, when the evaluation index system is established, due to the limited data of the survey, the selection of the indexes may be less objective and there will be some restrictions. A further study will be completed for these shortcomings; we believe that we will have the ability to collect more comprehensive data to establish a more scientific evaluation method for the improvement of Caofeidian navigation environment.

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Appendix A: Questionnaire of evaluation index for navigation environment

Survey purpose: A complete evaluation index system needs to be built in order to strengthen management of the safety of navigation environment of Caofeidian Port and get a scientific evaluation method. Your answer is the important base for us to select the index. Thanks for your support.

Survey content: the indexes listed have an influence on navigation environment of Caofeidian Port.

Filling method: Draw a tick (√) after the option which you think is right according to your professional knowledge and navigation experience.

Indexes for selecting	Draw √ after the right option you think of
Wind	①Have influence ② have no influence
Current	①Have influence ② have noinfluence
Visibility	①Have influence ② have no influence
Channel width	①Have influence ② have no influence
Water depth of the channel	①Have influence ②have no influence
The curvature of the channel	①Have influence ②have no influence
Crossing of the channel	①Have influence ②have no influence

Obstacle distribution	①Have influence ②have no influence
Traffic density	①Have influence ②have no influence
Sand ship and fishing ship	①Have influence ②have no influence
Navigation facilities	①Have influence ②have no influence

Appendix B: Questionnaire of influence coefficient for evaluation index

Influence coefficient of the first layer index	Draw √ after the right option you think of
Hydrological and meteorological factors	① Very small ②Small ③Moderate ④ Big ⑤Very big
Channel condition factor	① Very small ②Small ③Moderate ④ Big ⑤Very big
Traffic factor	① Very small ②Small ③Moderate ④ Big ⑤Very big
Influence coefficient of the second layer index	
Visibility	① Very small ②Small ③Moderate ④ Big ⑤Very big
Wind	① Very small ②Small ③Moderate ④ Big ⑤Very big
Current	① Very small ②Small ③Moderate ④ Big ⑤Very big
Channel width	① Very small ②Small ③Moderate ④ Big ⑤Very big
Water depth of the channel	① Very small ②Small ③Moderate ④ Big ⑤Very big
The curvature of the channel	① Very small ②Small ③Moderate ④ Big ⑤Very big
Obstacle distribution	① Very small ②Small ③Moderate ④ Big ⑤Very big
Traffic volume	① Very small ②Small ③Moderate ④ Big ⑤Very big
Navigation facilities	① Very small ②Small ③Moderate ④ Big ⑤Very big