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Research on optimal allocation of oil spill contingency resources base on oil spill risk assessment in Taizhou port

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REARCH ON OPTIMAL ALLOCATION OF OIL SPILL CONTINGENCY RESOURCES BASED ON OIL SPILL RISK ASSESSMENT IN TAIZHOU PORT

By

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DECLARATION

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

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

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ABSTRACT

Title of Dissertation: **Research on optimal allocation of oil spill contingency resources base on oil spill risk assessment in Taizhou port**

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With the continuous increase in maritime oil transportation and rapid development of construction for bunker terminal, the risks of oil spill caused by ships is increasing which threaten the marine environment severely. prevention of oil pollution from ships has attracted attention of the shipping industry.Currently,the prevail countermeasures is development of contingency response capacity after assessment of oil spill risk.

However, the establishment of oil contingency response capability for each individual terminals will cause waste of resources and could not effectively address the oil spill risk. It is necessary to introduce shard area to develop joint oil spill response capability and undertake proper allocation of oil spill contingency resources.

In this dissertation , after reviewing the countermeasures to oil spill such as risk assessment, the method of probability direct calculation is applied to study the risk of oil spill in Taizhou port based on adequate statistical data. Then, the divided sharing area has been presented through the method of Fuzzy clustering.

According to the calculated risk of oil spill in the sharing area, the joint contingency capability shall be established. And the solution of optimal allocation of oil spill contingency resources has addressed based on calculation of sharing proportion of each terminals.

KEY WORDS: oil spill, risk analysis, oil contingency response,Taizhou port, sharing area ,optimal allocation

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LIST OF ABBREVIATIONS

IMO	International Maritime Organization
SEPA	State Environmental Protection Administration of China
ITOPF	The International Tanker Owners Pollution Federation Limited
US	United States of America
UK	United Kingdom of Great Britain and Northern Ireland
MARPOL	International Convention for the Prevention of Pollution From. Ships, 1973 as modified by the Protocol of 1978
OPRC	International Convention on Oil Pollution Preparedness Response and Co-operation 1990
OSRA	Oil Spill Risk Assessments
OSCAR	Oil Spill Contingency And Response
SCNPC	Standing Committee of the National People's Congress
S	South
N	North
E	East
SSW	South-South-West
NE	North-East
GC	Gross Tonnage
DWT	Deadweight Tonnage
MATLAB	MATrix LABoratory
FCM	Fuzzy C-means

CHAPTER 1

INTRODUCTION

1.1 Background of research

With the sustained and rapid development of international economy, import and export trade and energy demand continues to increase, which promotes the continuous increase in maritime oil transportation and rapid development of construction for bunker terminal. In addition, the risks of pollution to the marine environment especially the risk of oil spill caused by ships is increasing due to the recent trends of bigger ship size of bunkers(Neves , et al. (2015).

In recent years, several severe oil spill accidents have occurred , such as oil pollution of Gulf of Mexico (AH.Walker, R.Pavia ,2015), collision of vessel of "Hebei spirit" (UH Yim, M Kim, SY Ha , S Kim 2012), and the major oil spill accident in Dalian on 16 ,July ,2010. The risk of marine pollution caused by oil spill shall not be ignored. Normally, the severe oil spill accidents occur in the area of busy coastal waters for oil extraction and transportation, as well as the areas with relatively fast development of economic and intensive large chemical industry, which leads to more demand of energy and dense transport ships (Stewart, T. R., & Leschine, T. M. ,2010).

Taizhou City is located in the central coastal areas of Zhejiang Province of China with close distance to Shanghai port and Ningbo port , and borders East China Sea and have the sea area of 6910 square kilometers (China SEPA,2007). Taizhou Port is an important port in coastal areas of Zhejiang Province , its geographical advantages are obvious, and the natural conditions of it are favorable. Due to the rapid development of economy, the Taizhou port is booming and its port throughput grow rapidly. However, With the rapid development economy of Taizhou and the continuous growth of energy demand, cargo transportation of sea goods, especially oil and bulk chemicals increases sharply,and shipbuilding industry also sees a rapid development. Because of the frequent entry and depart of Taizhou waters area of large scale ships, the ship traffic is surging in this area, and the relevant operational activities leads to increasing risk of pollution to marine environment especially in the circumstance of complex navigation conditions in Taizhou area.

In response to the oil spill, IMO and China's domestic legislature have adopted large number of corresponding laws, regulations and technical guidelines about oil spill environmental risk assessment and equipment of oil spill contingency resource(IMO ,1990). In accordance with them, the port and terminals are required to to carry out ship pollution risk identification and assessment , and develop ship pollution accident contingency response capacity according to the pollution risk.(Ding Wangping,2013) However, in Taizhou area, as the requirements of the technical specifications, each terminals shall to establish oil contingency response capability independently and respectively. Which will leads to equipment of huge amount of oil spill contingency resource and facilities such as oil absorption felt, oil dispersant,etc. In the event of oil spill accidents, Only the effective use of large scale of oil spill contingency equipment, response personnel, and oil spill contingency materials can actually form the oil spill contingency force(Łukasz Jankowski,et al,2011). Otherwise,on one hand,the equipment of large number of consumptive oil spill contingency facilities in area will results in a waste of resources ,on the other hand, which does not form an effective oil spill contingency capability.

A reasonable approach is to develop shard area, after ship pollution risk assessment for the shared area, it is recommended to unite the terminals and relevant companies within the shared area to establish oil spill contingency response capacity and share the cost of management. Through the implementation of the establishment of response capability in shared area , it is possible to avoid the repeated configuration of equipment and other supplies such as asphalt felt,and reduce the burden on terminals. Meanwhile, a more effective contingency response capability can be achieved.

1.2 Objectives of research

This dissertation is aim to enhance the capability of oil spill contingency response in shared area and conduct research on optimal allocation of oil spill contingency resources in Taizhou area after investigation of terminals and calculation of probability of oil spill risk in Taizhou port. Which will strengthen the establishment of ability of oil spill contingency response , improve the use efficiency of equipment and facilities, and prevent and control the bad impact of oil spill from ships on the marine environment

1.3 Methodology

In this dissertation, large number of relevant literature and research reports have been reviewed to understand the current condition of tanker transport and the latest research and achievements in the field of contingency response for oil spill pollution, including the appropriate IMO documents, International Conventions, and Chinese national legal requirements. Furthermore, investigation to water environment and tanker terminals of Taizhou port, relevant shipping companies, and contingency response units have been conducted as well as collection of secondary resources and necessary statistical data to conduct adequate research. In order to solve the main points of this dissertation, two aspects of researches have been carried out including risk of ship oil spill accident and optimal allocation of oil spill contingency resources. Through estimating the risk of oil spill and analyzing the existing problems in the allocation of oil spill contingency resources in Taizhou port, optimal allocation of oil spill contingency resources have been presented to enhance the oil spill contingency response capability of Taizhou port.

CHAPTER 2

HAZARDS OF MARINTIME OIL SPILL AND COUNTERMEASURES

With the increase of oil transportation by sea, the number of world tanker fleets entering and departing ports raise steady yearly, especially in China's port, which results in oil spill accidents occurring frequently. China is a major oil importer with transport Petroleum volume just lower than that of US and Japan, and its port oil throughput is growing at an annual rate of about 10 million Tons(Song Y X, 2015). It makes the marine environment face a great risk of oil spill because of high-density tanker terminals, oil pipelines, and transport vessels(Michel, J.et al,2013). Moreover, operation of loading and unloading on tanker terminals and storage of oil in coastal tank area may also produce oil spills. As the oil is toxic and the density is less than seawater, the spill of oil into sea will seriously contaminate marine environment and shoreline ,which cause huge losses to the marine ecological resources. In addition, marine industries such as fisheries, aquaculture, tourism will be seriously affected by oil spills (Henkel, et al. 2012).

2.1 The harm of oil spill to marine industry

2.1.1.Damages caused by oil spilling to the marine fishery

The fishes in the net cages of the fish farm cannot escape, and can become inedible after being polluted by the oil spilling(Lawrence, A., Hemingway, K. L 2003). The scallops and seaweeds will also meet the same fate. Moreover, the net cage for the culture can hardly be cleaned after being polluted, only by replacement can the problem be completely corrected, however the expenses are extremely high.

2.1.2.Damages caused by the oil spill to the terminals and industries

The terminals and the yacht harboring area are also quite sensitive to the oil spill and normally the water in the port areas must be thoroughly cleaned(Yu.Q.B,2011). Thus this definitely affects entering and departing of ship. The cleaning measures should be taken for the polluted terminals and the yacht harboring areas and those measures will cost much. If the shoreline is provided with the water intake for a factory, the spilled oil will enter into the factory equipment and system, and then it may damage the equipment and even cause a factory to disable. Both salt industry and sea water desalination industry will be directly harmed by the spilled oil pollution, and lead to catastrophic economic losses (Ketkar, K. W. 1995).

2.1.3.Damages caused by spilled oil to the marine transportation

If the oil spill accident occurs in a sea route or an anchorage space, it is necessary to clean the fouling timely; the use of large quantity of oil fences and other fouling cleaning devices on the high sea will occupy the original sea route or the area of the anchorage space and the vessels can only stay or make a detour at that time. Consequently, it will bring a certain level of influence to the marine transportation (Goerlandt, F., Montewka, J. 2015).

2.1.4 The influence caused by the oil spilling to the shallow water area and shoreline

The shallow water area is the area with the most concentrated habitats of sea creatures such as shells, fry, coral and the like which are active in this area. This area is also the place where the seaweed resides, the sea creatures are highly sensitive to the oil spilling in this water area (Lawrence, er al 2003). If the spilled oil dispersant is used in this area, more damages are inevitable. Besides, the oil spill pollution to the shoreline will directly affect the tourism industry(ITOPF,2010).

2.2 Analysis of marine oil spill accidents

The ship oil spill accident means that the ships or the operations related therewith encounter oil leakage or oily mixture leakage causing marine environmental pollution, which can be mainly categorized into the shipwreck oil spilling accidents and the operation oil spilling accidents(Jiao,J.C. 2011). There are many factors which can lead to the marine ship oil spilling accidents. Besides the oil spilling accidents caused by the operation mistakes made during the on-ship loading and unloading operation, illegal discharge of the water of the cabin bottom and the oil refueling, the factors such as ship collision, stranding, striking a reef and maritime climate change can all cause the accidents to happen (Li, X. F., Yang, Y. G. 2013).

Among them, the ship accidents, terminal oil tank area explosion and the fire hazards and explosions in the offshore drilling platform and submerged pipeline are the main accident categories which induce the major accidents. In general, the ship accident is highly likely to cause the occurrence of marine oil leakage, but as the ship building technology in recent years is improving all the time, and the techniques of the ship crew also enhance year after year (Goodman, R. 1994); the incidence of the ship accidents is decreasing year by year, and the incidence of the oil spilling accidents caused by ship accidents is also decreasing year by year.

2.3 Analysis on the risk factors of oil spill from ships

The factors contributing to the ship oil spilling risk mainly include the factors which might lead to the occurrence of shipwreck accidents, the sensitive level of the water area environmental resources and the contingency disposal capability. Wherein, the shipwreck accident factors comprise mainly: Natural environment, navigation environment, management environment and human factors, and the like (DS Etkin.2000).

2.3.1 Natural environmental factors

Weather and sea conditions are closely related to the ship's oil spill accident. On one hand, the heavy wind and waves will affect the safety of the ship's navigation and easily cause accident or sink; on the other hand , it will have great impact on removal and recovery of oil when the ship's oil spill occurred, in the harsh conditions, those operations even May even not be able to be carried out.

Meteorology

The wind has an obvious effect to the ships and it causes the ship to stall or accelerate, thus making the ship tilted, drift to deflect from the original route. Although there is no direct relationship between the wind and the ship oil spilling accidents, the wind can lead to the occurrence of the ship oil spilling accidents or worsen the damage consequences (Badri, M. A., Azimian, A. R. 2010).

The fog is the utmost factor which affects the visibility on the sea, and will have a direct important influence to the ship navigation, and there might be dangerous situations such as leeway, stranding, striking reef or colliding. In case of poor visibility, the ship is highly likely to collide.

Hydrology

The ship is influenced by the waves, ocean current and tide current on the sea. The higher the wave is, the ship navigation safety gets influenced to heavier extent (Boufadel,et al，2009). As the upgrade of the shipbuilding technology, the wind and wave resistance of the ships increases. However, the influence brought by the heavy wind and waves to the ships cannot be underrated. Same as the heavy wind, high wave will also influence the cleaning and recovery of the filthy oil. If the applicable wave height range of the oil fence and oil skimmer and the like is surpassed, the fouling cleaning and controlling capabilities will be substantially undermined. In the extremely bad conditions, these facilities can be even unusable. If the sea wave is higher than 1m, most oil fences cannot effectively prevent the filthy oil from drifting.

2.3.2 Navigation factors

The occurrence of the ship oil spilling accidents and the sea route conditions, and navigation and navigation assistant equipment and the like all have certain relationships(Zhu.S.L,2011). Surely, the excellent sea route condition, consummate navigation and assistive equipment and devices can reduce the incidence rate of the ship collision, and stranding and other accidents, therefore, can reduce the incidence of the ship oil spilling accidents. However, because the water area mentioned in this article is the littoral area, the oil spilling caused by the ship collision and stranding caused by navigation factors will not be considered as the major factors.

2.3.3 Ship factors

The ship factors including mainly the ship types, ship tonnage, ship equipment technological conditions and ship age all have influences to some extent to the ship navigation. As to the ship type, the influence of the oil spilling accidents occurring on the oil tanker or other ships, and the consequences triggered therefrom are quite different(Song X H,2009).

The ship equipment technological condition reflects the navigability, automatic level and the operational performance and the like of the ship in a comprehensive manner. The operational performance of the ship refers to whether the ship has good course stability, tracing ability, turning ability and the ship parking performance, and whether it is possible to conduct the satisfactory control.

2.3.4 Human factors

The statistics of ship accidents in shipping industry show that human factors are the main reasons for the occurrence of the ship pollution accidents. The human factors are a complex concept which encompasses a plurality of domains and influences the marine safety, security and protection and environmental protection (Raphael Baumler.2017). It includes the crew health condition, crew training comprehensiveness, crew skills and experiences, crew occupational responsibility, crew overall level, operation procedure standard level, high level crew supervision level, and the familiarity level of the crew to the ship and the sea area, and the like(Zhang .Q,(2014). All the factors above might increase the possibility of the occurrence of the ship oil spilling accidents.

2.3.5 Sensitive Environmental Factors

In an ecological environment, the resources which are highly sensitive to the environmental changes, and are prone to be affected by the ship oil spilling and oil spilling contingency reaction due to its own fragility of anti-damage capability which causes the damages, are called the environment sensitive resources(Gao.L.Y,2015) (Ulusçu.et al,2009). The marine oil spilling sensitive resources are the seashore, creatures and resources used by mankind, which might be affected by the marine oil spilling, including the recreational areas; animal nature protection zone, marine cultivating area, resource development area, cultural heritage relics, military zones and the like.

2.4 Common approach to response to risk of oil spills

Because of long-term and tremendous destruction caused by oil spill pollution, prevention of oil pollution from ships has attracted more and more attention in the shipping industry. the US has held the biennial international oil spill conference since 1969 and research the the development and application of technology in the prevention of oil pollution(Chen.X,Geng H,2011). IMO has adopted a series of regulations such as MARPOL Convention and the OPRC Convention to develop a series of preparedness and response measures based on potential oil spill risks, As long as severe oil spill accidents have occurred, regional and international cooperation shall be carried out to reduce the damage caused by oil pollution through rapid and effective action. Hence, analyzing the potential oil spill impacts and taking quick response are the key activities to response the oil spill risk(Ventikos, N. P., Sotiropoulos, F. S. 2014). For the shipping industry, oil spill risk assessment and development of oil spill contingency plan are the common measures to address oil spill risk.

2.4.1 Oil Spill Risk Assessment

The contingency response action against oil spill plays a key role in reducing and eliminating oil pollution, it is essential to carry out oil spill prediction firstly. Because the oil spill is affected by complex factors, it is random and uncertain(Qiu.P.B,2011). Risk assessment of oil spill is a necessary means to prevent accidents, and which can figure out the maximum possibility of oil spill in the sea area (Price, J. M., et al. 2003). Before the pollution accident, the risk management and countermeasures could be taken in advance according to the evaluation results .which will play a major role in preventing or reducing the occurrence of oil spill accidents. Similarly, after the oil spill occurs, the high-risk area can be determined for the first time, and contingency measures should be taken to reduce pollution damage.

Since 1960s, researchers have engaged in a lot of research on oil spill accidents, many scholars have conducted simulate and forecast for the probability of oil spill from ships through the application of stochastic theory, fuzzy mathematics,and matter element analysis method (Ii, G. W. S.,et al,1987) (Psarros, G.,et al ,2011). Many oil spill assessment models have been developed, and numerical models for predicting and predicting oil spill and volume of oil spillage have been established. Among them, OSRA, OSCAR, and other numerical models are more advanced. The OSRA system can be used not only as simulation of oil spill but also can predict the most probable area for oil spill. It is a effective tool for the assessment of oil spill risk, after updated several times, it has been widely used in practice. (Smith,1982) (Price, J. M.,et al,2004) (Johnson, 2007).In addition, The OSCAR system can provide the distribution of contingency resources and lay out simple contingency strategies, (Reed, et al,1995).In 2010, New Zealand has adopt MOSRA10 project to carry out oil spill risk assessments (Bermingham, et al,2011).

2.4.2 Development of oil spill contingency plan

In order to prevent the oil spill, chemical leakage and fire accidents caused by the operations of ships, terminal and liquid chemical operation, it is necessary to provide corresponding contingency plans to protect the terminal and marine environment resources, safeguard the safety of mankind and the sound social system (Santoli, et al,2011). Once the oil spilling, chemical leakage or fire accidents occur in terminal, the factors such as geographical environment of the terminal and the loading and unloading equipment shall be fully considered, and the contingency equipment, apparatuses and contingency personnel shall be scientifically and reasonably allocated in order to implement the fastest, most effective disposal to the oil spill and chemical leakage, thus reducing the extent of the damages caused by the accidents. And activities for oil spill shall be guided by the oil spill contingency plan including equipment of oil spill contingency resources, establishment of response team.

The ship oil spilling risk management in the US is realized through the establishment of the US ship pollution contingency system (Konkel, R. S. 1987). The US not only enacts relatively complete laws and regulations and establishes a national anti-pollution response system, but also establishes a scientific and reasonable oil spilling prevention, control and contingency strategy system, information database system, oil spilling pollution differentiation system and oil spilling pollution damage compensation system command center, and the triple levels of oil spilling contingency response system built up by the state governments. Once there is any marine oil spilling accident, the national contingency response system and related functional departments can immediately take actions according to the oil spill contingency plan in time, and strive to control the oil pollution in the shortest time.

The ship oil spilling risk management in the UK is undertaken by the Marine Pollution Management Committee, which belongs to the Ministry of Transport of British Government, whose main responsibility is the disposal of marine pollution accidents and the beach cleaning work which is coordinated with the littoral regional governmental departments; the local government is responsible for the cleaning of local beaches at the cost of the regional governments(Bai,J.Y,2010). For the sake of carrying out the cleaning in an even better fashion, the regional government shall dispatch specialized professional cleaning teams, and conduct training regularly.

The ship oil spilling risk management in China is mainly undertaken by MSA, as well as the littoral provincial and municipal governments for concrete measures(Zhao.G.H,2010). Base on the related requirements in the OPRC Convention and domestic marine environment protection law, all the marine boards and all levels of local people's governments enact the ship oil spill contingency reaction plan of the jurisdiction area, based on the frame of five levels of contingency system comprising the state level, sea area level, provincial level, municipal and regional level and port and terminal level, the identification and assessment of the risks that the ship pollutes the sea, and build the ship pollution accident contingency disposal capability matching with the risks.

CHAPTER 3

OVERVIW OF TAIZHOU PORT AND ANALYSIS OF ALLOCATION OF OIL SPILL CONTINGENCY RESOURSES

3.1 General natural situation of Taizhou port

Taizhou port locates in Southeast of China and involving with international trade, and has a coastline of 745 kilometers. Its distance to Shanghai port is 160 nautical mile and the geographical coordinates is 121 ° 27'E, 28 ° 41'N((China SEPA,2007)). Taizhou port is made up of six ports, which are Da Maiyu port, Linhai port, Haimen port, Huangyan port, Wenling port and Jiantiao port. According to the statistics of Taizhou maritime Safety Administration, there are 234 productive berths in Taizhou port by September 2015(Taizhou MSA,2016) .

Figure 3.1 Water map of Taizhou administrative area

Source: http://image.baidu.com/search/detail?ct=503316480&z=0&ipn=d&word

3.1.1meteorologic condition

Taizhou area is located in subtropical monsoon climate zone, affected by marine climate with comfortable meteorologic condition including distinct seasons, warm climate and humid air.In addition,there are also Adequate light and long frost free period in this area.

Temperature condition

Table 3.1 Temperature statistics in Taizhou area

Statistical projects over the years	Temperature
Annual mean temperature	17.0℃
Extreme high temperature over the years	38.1℃
Extreme low temperature over the years	-6.8℃
The average temperature in the hottest month (August)	27.7℃
The average temperature in the coldest month (January)	6.6℃

Source: Taizhou MSA,2016

Precipitation condition

The precipitation in this area is mainly concentrated from March to September, accounting for about 75% of the whole year. In May, June and September, it was mainly controlled by the southeast air current and the influence of plum rains and typhoons, which resulted in the majority of rainfall. From October to January, the amount of precipitation was less, which accounted for only 20% of the total annual output. The annual average relative humidity was 73% to 82%, and the maximum relative humidity appeared during June.

Wind condition

This area is in a typical monsoon zone, and the change of wind direction is obvious, the northerly wind prevails in winter, whereas SSW wind is common in summer.In addition, NW wind is dominant in inland area while NNE wind is popular in islands area.

Typhoon (tropical cyclone)

Normally, in this area, the average duration of tropical cyclones and typhoons is around 1 ~ 3 days , even only a few hours in some circumstance. The rain usually lasts for a long time about 3 days, however it may continue 5 days when the typhoon directly land nearby.

Fog condition

Taizhou water area locates in brumous sea area in the East China Sea, within which the advection fog is prevalent, which usually occurs in the morning and lasts for a short time. Average foggy days over years (visibility is less than 1km) is approx 50 days .Fog mostly occurs in winter and spring , and foggy day mainly concentrates in March to June, accounting for 72% of total foggy days over the year.

3.1.2Hydrological conditions

Tide conditions

Tide type: a typical informal semi-diurnal tides prevails in most of the sea area .Datum of tidal level: According to the Jiaojiang river figure published by the Chinese Navy,Characteristic value of sea level:According to the master plan of Taizhou port, Characteristic value of sea level are shown in table 3.2 below

Table 3.2 :Characteristic value of sea level of Taizhou port

Measuring station / Item	Dachen	Haimen	Jiantiao	Kanmen	Hengmen
Highest tide level over years	5.03M	7.50M	7.45M	7.08M	6.38M
Lowest tide level over years	-1.17M	-0.72M	-1.77M	-1.78M	-1.40M
Annual mean high tide	3.76M	4.30M	4.31M	4.07M	3.91M
Annual mean low tide	0.30M	0.28M	0.16M	0.12M	0.23M
Mean tide level	2.02M	2.20M	2.19M	2.90M	2.14M
Maximum tide level	5.85M	6.87M	7.23M	6.85M	6.83M
Mean range of tide	3.39M	4.02M	4.15M	3.96M	3.56M
Mean duration of rise	6：17H	5:14H	6:17H	6:19H	6:13H
Mean duration of fall	6：07H	7:21H	6:08H	6:06H	6:13H
Representative port area	Linhai	Haimen	Jiantiao	Da Maiyu	Wenling

Soure: :Compiled by author to interpret statistics of Taizhou MSA

Tidal current conditions

Taizhou water area is located in a tidal bay, in which the tidal current is full of power with large tidal range and rapid velocity. The flood tide is greater than the ebb tide, while ebb flow lasts longer than the duration of flood current. In general, the flow rate is 2 to 3.5 knots and the maximum flow rate can reach more than 5 knots in the flood season or if affected by typhoon storm tide.

Wave conditions

Taizhou Bay sea area is an open bay, and mixed waves prevail in this area, of which mainly is the surge . The most common wave direction is from N to NE with the frequency of occurrence is 53.7% while that from S to SSW is less usual with frequency is 14.6%. The direction of wave varies with the seasons, the direction of S ~ SSW is dominant in Summer while that of N ~ NE is common in other seasons. In addition , the frequency of occurrence of surge-less id 21.7% .

The average annual height of wave is 1.2m, the maximum height is 14.4m and the direction of wave is east.The height of wave is relatively high from July to November with average volume 1.3m to 1.4m and with summit of 6m to 14.4m. The average period of wave is 5.6 seconds,and the maximum period is 18.1S, from July to October, the period is relatively long with monthly average period of 5.8 ~ 6.1s.

3.1.3 Distribution of Sensitive Environmental Resource

There are many important sensitive environmental resources in Taizhou port. Once a ship pollution accident occurs, it will cause immeasurable and irreversible damage to these sensitive resources

Tourist area

There are 6 main scenic tourist areas in near Taizhou port, including Sanmen Bay scenic area, Taozhu scenic area, Dachen Island Scenic Area, Wenling southeast coastal scenic area, Dalu Scenic Area and the Yueqing Bay Scenic Area.There are also 5 leisure tourist areas which are respectively Longwan leisure tourist area, Dongji Islands leisure tourist area, Huanglang leisure tourist area,Dacheng leisure tourist area and Kanmen leisure tourist area.

Aquaculture Areas

Taizhou area are rich in aquatic resources, which has several important aquaculture areas including prawn artificial rearing area, Dachen area as national fishing port and oysters artificial rearing area in Yueqing Bay.

Power plant

There are many power plants located in Taizhou Port,including nuclear power plants in Sanmen Bay; Taizhou power plant in Taizhou Bay; Yuhuan Huaneng power plant, Yueqing power plant Yueqing Bay area.

3.2 Navigation Situation of Taizhou Port

The main inbound navigation route of the coastal area in Taizhou port are mainly comprise the entrance route of Da Maiyu port, Wenling port, Haimen and Huangyan port,Linhai port and Jiantiao port.

Da Maiyu port

Currently, the inbound navigation route of Da Maiyu port is composed of two routes located on East and West. The east one starts from the west route of the Southeast side of the Luxi Island and extends North through the water area between Luxi Island and Nanpan Island, then goes into Yueqing Bay through the water area between Yuhuan Island and Heng Cishan Island. The length of the route is about 31.5km, of which the minimum depth is 10.8m with length around 4.6km. The east route is in good navigation condition which can ensure ships of 30,000 GC access to the port all-weather while ships of 50,000 GC to 70000 GC access to the port with taking tide.The west route starts from Hutou Island and crosses the Huangda strait of the west side of Luxi Island,then goes into goes into Yueqing Bay through the water area of Hengzi mountain.The natural water depth of the route can basically meet the requirements of access to port by ships of 10,000 GC through taking tide.

Wenling port

The inbound navigation route of Wenling port Yong'an operating area connects the high sea with the Jinqing lock,and the water depth of it can meet the needs of access port of ship with 500 GC; Shitang, Longmen operating area directly connects with the high sea, and its natural water depth can meet the needs of access port of ship with 2000 GC with taking tide; The inbound navigation route of Shanshan operating area directly connects Yueqing Bay through the water area between Shashan and Hengzi Island.

Haimen,Huangyan port

The inbound navigation route of Haimen, Huangyan port is the outbound route of Jiaojiang River, which extends from Taizhou first pilot anchorage to the Niutou rock with a total length of about 30km. Among which, there is a shallow route about 18KM from Laoshu mountain to Baisha with water depth only about 2m (theoretical basis, the same below). Within the port, ships with 3,000 gross tons can navigate with taking the tide, while ships with 5,000 gross tons and shallow draft ships have limited chance to access to port subject to the tide.

Linhai port

Linhai port consists of Lingjiang River operating area and Toumen operating area, in which Toumen operating area operating area is composed of two routes located on North and South. The north one starts from west route near the You Caihua Island and extends to the southwest, then goes into the Toumen operating area through the water area between the Tianao Island and Dongji Island. The south one starts from the East rout of east side of Da Huacha Island and extents to the south side of Liangmao Island,then head Northwest to Toumen operating area. At present, the natural water depth of the both 2 routes can meet the requirements of access to port by ships of 10,000 GC through taking tide. As for the Lingjiang River operating areas, Its inbound navigation route mainly divides by Hongguang terminal, its downstream section meets the requirements of access to port by ships of 3,000 GC through taking tide while the upstream section allow the access to port by ships of 1,000 GC by tide.

Jiantiao port

The inbound navigation route of Jiantiao port is composed of two routes located on North and South.The south one starts from the east route of the east side of the Dongji Island and extends Northwest to the Southeast side of the Cao Xiepo island then heads to Northwest to Goutou gate passing south water area of Da Jiashan anchorage. The north one starts from the west route of the You Caihua Island and extends Southwest to the Southeast side of the Cao Xiepo Island then connects the south route.At present, the water depth of the south line and the northern line is basically between 8 and 10 m, which can meet the needs of access of ship with 10000 GC.

3.2.1 Ships entering and departing Taizhou port

According to the statistical data of Taizhou MSA, ships entering and departing Taizhou port classified by ship type from 2006 to 2014 is listed by table 3.3.

Table3.3: ships of entering and departing Taizhou port with classified by type of ship from 2006 to 2014

Year	Cargo ship							Tug	Barge	Non-transport Ship	Summary
	Bunker	Liquefied gas carrier	Chemical	Bulk Carrier	Container	RO-RO	Other				
2006	2649	97	861	2084	562	4468	37823	93	43	86	48766
2007	3064	82	818	3400	273	2124	35393	1301	149	148	46752

2008	2769	53	769	3962	488	1937	31422	1049	86	119	42654
2009	3034	53	782	4562	479	6007	25930	880	74	163	41964
2010	3557	29	715	5099	765	6794	21836	1013	169	642	40619
2011	3475	35	537	5486	702	6008	20919	1020	57	284	38523
2012	1535	40	547	5530	588	5496	19403	341	47	1168	34695
2013	3013	32	545	5686	829	3320	19106	1089	75	574	34269
2014	3249	2	644	6032	508	4400	19900	782	30	644	36191
Sum	26345	423	6218	41841	5194	40554	231732	7568	730	3828	364433

Soure: :Compiled by author to interpret statistics of Taizhou MSA

Statistical data for ships entering and departing Taizhou port classified by ship tonnage from 2006 to 2014 is listed by table 3.4. It can be seen that ships with gross tonnage less than 500 are dominant out of all ships entering and departing Taizhou port, of which 100 to 499 gross tonnage ships account for 55%. Hence, small and medium-sized ships are primary ships that enter and depart Taizhou port.

Table3.4:ships of entering and departing Taizhou port with classified by gross tonnage of ship from 2006 to 2014

	99 GT and below	100 ～ 499	500 ～ 999	1,000 ～ 2,999	3,000 ～ 9,999	10,000 ～ 49,999	50,000 and above
2006	12368	25010	1468	7900	1993	27	0
2007	8243	27192	849	8142	2177	146	4
2008	6448	25795	506	7195	2427	257	26
2009	8227	22756	486	7755	2395	296	49

2010	7474	21550	437	8426	2318	372	42
2011	6492	20399	358	8621	2252	275	126
2012	6492	18304	172	9351	2015	206	150
2013	3629	19449	220	8805	1824	238	104
2014	4660	20410	114	8749	1813	354	91
Summary	64033	200865	4610	74944	19214	2171	592

Source:Compiled by author to interpret statistics of Taizhou MSA

3.2.2 Statistics of oil spill accidents in Taizhou port

From 2006 to 2014, there were 5 oil spill accidents that happened in the Taizhou port, including 4 shipwrecked accidents and 1 operational accidents. Among them, the "Hua Chen 27" collision occurred in 2006 which leaded to187 tons oil spilled into sea,and there have been 2 accidents cause spilled oil more than 50 tons. It can be seen that with the trend of large-scale ships in Taizhou port, the risk of major oil spill accidents is increasing in this area,and the statistics of oil spill accidents in Taizhou port is shown in table 3.5.

Table 3.5: Statistics of oil spill accidents in Taizhou port from 2006 to 2014

	Date	Location	Attribution	Type of accident	Amount of spilled oil
1	21/3/2006	Diaobing of Taizhou port	Collision	shipwrecked	187 tons
2	8/4/2007	About 7 nautical miles southeast of the Taizhou Islands	Collision	shipwrecked	50 tons-100 tons
3	28/2/2008	About 45 nautical miles southeast of the Taizhou Islands	Collision	shipwrecked	10 tons
4	13/3/2008	About 15 nautical miles southeast of the Taizhou	Sink	shipwrecked	10tons desel 50tons heavy fuel

		Islands			oil
5	4/8/2008	About 24 nautical miles northeast of the Taizhou Islands	Human factor	operational	Few amount

Source: :Compiled by author to interpret statistics of Taizhou MSA

3.3 Analysis on Allocation of Oil Spill Contingency Resource in Taizhou Port

3.3.1 General requirements in Taizhou Port

At present, the oil spill contingency response force in the Taizhou port can effectively cope with the pollution incidents of ships within the coastal port area of Taizhou and offshore waters (12 nautical miles offshore). Oil spill contingency response force is distributed as follow: the capacity of oil spill comprehensive remove and control in one time shall reach 500 tons for the water area outside the port; the capacity of oil spill comprehensive remove and control shall reach 1500 tons for whole port area, in which, the capacity of Haimen port and Huangyan port shall reach 400 tons, and that of Linhai port,Wenling port, Da Maiyu port and Jiantiao port shall reach 300 tons , 300 tons, 300 tons,and 200 tons respectively. Under the circumstance of good sea or weather condition, the emergency response forces shall arrive at the pollution position in port area in 2-4 hours while they shall arrive at the pollution position outside port water area within 6 hours.

By 2020, an all-round coverage and rapid response marine environment contingency response system will be built, and the contingency response forces will cover all waters area in Taizhou port, Oil spill contingency response force is distributed as follow: the capacity of oil spill comprehensive remove and control in one time shall reach 1000 tons for the water area outside the port (Taizhou Municipal People's Government,2014); the capacity of oil spill comprehensive remove and control shall reach 2000 tons for whole port area, in which, the capacity of Haimen port and Huangyan port shall reach 400 tons, and that of Linhai port,Wenling port, Da Maiyu port and Jiantiao port shall reach 500 tons , 400 tons, 400 tons,and 300 tons respectively. Certain contingency reponse capacity for slove chemical leakage accidents shall be established. Under the circumstance of good sea or weather condition, the contingency response forces shall arrive the position in 2-4 hours no matter where the location of pollution.

3.3.2 Analysis on Oil Spill Contingency Resource in Taizhou Port

In order to cope with the ship oil spilling risks in a terminal, the terminal organization shall prepare certain oil spilling contingency facilities and equipment. Based on the requirements listed in the Ship Pollution of the Marine Environment Risk Assessment Technical Specification (trial) (also known as Specification below), the port and terminal shall be equipped with the oil fences, spilled oil dispersant and adsorption materials and other related contingency materials which matches with the risk level. The oil spilling contingency materials supplied are to timely and effectively remove the spilled oil during the occurrence of the oil spilling accidents, reducing the economic losses and environmental pollution brought by the oil spilling to the sea. However, based on the actual situations in Taizhou area, the oil product terminal and the bulk cargo terminal are small in tonnage. Although each terminal is equipped with corresponding oil spilling contingency materials to guarantee that the whole jurisdiction area possesses a certain number of oil spilling contingency materials, corresponding large oil spilling contingency equipment are lacked to utilize these materials, and the shipyards in the jurisdiction area is also unable to have these materials independently; hence, if a large oil spilling contingency accident happens here, it is not possible to apply the terminal oil spilling contingency resources in a highly effective manner due to lack of large ship oil spilling contingency equipment, and therefore the oil spilling contingency capability is not built up. Therefore, except for ship oil spilling contingency materials supplied, large ship oil spilling contingency equipment and facilities are also required in Taizhou to improve the contingency capability of oil spilling.

In accordance with requirements of oil contingency plan, the Taizhou should be equipped with one oil product terminal for the professional floating oil recovery ship (the professional oil terminal in Liushuikeng, Shitang, Wenling is 5,000 DWT and 8,000 DWT); there are 66 terminals for shipyards, which are distributed in Jiaojiang River, Sanmen, Lingjiang, Wenling, Yuhuan, etc. Through analysis, large oil spilling contingency equipment should be provided in Taizhou; it can be derived that:

Several terminals in Sanmen, Jiaojiang River, Linhai and Wenling should be equipped with professional floating oil recovery ship. If each terminal is equipped with the ship independently, on one hand, it is unfulfillable due to the unbearable financial burden on the enterprise; on the other hand, the incidence rate of the ship oil spilling accidents is quite low, thus the resources will be wasted. If the professional floating oil recovery ship equipped by certain enterprise is used, and agreements are signed with other terminals, there are no extremely competitive large enterprises in Taizhou, so the ultimate outcome will still be the question "who will pay the equipment?" So, one leading force is needed to guide the terminals in the jurisdictional area to equip the large oil spilling equipment and facilities in a sharing style, and the corresponding oil spilling contingency material.

The deployment of the professional floating oil recovery ship is based on the seriousness of the risks of ship oil spilling, and the ship oil spilling risk of one region is different from the ship oil spilling risk of a single terminal, the former is higher than the latter, but the former is not the simple combination of the all the ship oil spilling risk factors of all the terminals. By merely depending on the oil spilling contingency resources equipped in the area, it is very difficult to realize the targeted capability to clean the spilled oil in comprehensive mode and one-time fashion, it is necessary to calculate the ship oil spilling risks of the area, and combined with the requirement of the one-time oil spilling comprehensive cleaning the corresponding large oil spilling contingency facilities and equipment and oil spilling contingency material are equipped to attain the effect that the region and even the whole jurisdiction area can witness the buildup and improvement of oil spilling contingency disposal capability.

Therefore, several equipment sites for oil spill contingency, respectively invested by the government and the enterprises, could be set up in Taizhou port. The local government guides the establishment of the equipment sites, on the one hand, the government could make the contingency supplies for regional oil spilling be utilized reasonably through relying on and integrating enterprises' oil spilling contingency supplies, forming oil spilling contingency force to tackle the risk of ships' oil spilling in the whole area; on the other hand, enterprises can also tackle the risk of their own ships' oil spilling in the terminals through partially sharing the resources, thus alleviating enterprises' burden.

There are certain requirements for the construction of equipment sites for oil spilling contingency, and the details are as follows: 1.The capability of constructed equipment sites for oil spilling should cope with the risk of oil spilling for each and every terminals ship that shares such resource in the periphery of the equipment sites; 2. The capability of constructed equipment sites for oil spilling contingency should cope with the risk of ships' oil spilling in the whole shared area; 3. The capability of constructed equipment sites for oil spilling contingency shall meet the requirements over such area for reaching one-time cleaning capacity toward spilled oil.

CHAPTER 4

RISK ANALYSIS OF SHIP OIL SPILL IN TAIZHOU PORT

The establishment of certain quantity of preserve position for oil spill emergency equipment is not only to address the risk of oil spill from ships near the oil terminal, but also to deal with that in any region. Therefore, it is necessary to calculate and analyze the risk of oil spill from ships.

4.1Probability estimation of oil spill from ships

The probability of oil spill accident in an area means Possibility of the possibility of oil spill accident in the region. The probability of oil spill accidents in different types of ships is various, similarly,every operation will cause different probability of oil spill accidents. Hence, it is necessary to research the probability of oil spill accident in an area to develop well-directed capability of oil spill contingency response and protect the area with high probability of oil spill.

4.1.1Mathematical Model of Probability Prediction of Ship Oil Spill Accident

The probability of occurrence of oil spills in an area is very small, and the occurrence of oil spill between each vessel is an independent event. There are only two cases for each individual ship in the case of oil spill accident name occurrence and nonoccurrence, the occurrence of oil spill accident from any individual ship in a area means the occurrence of oil spill accident in the whole place. In mathematics, dispersed binomial distribution is introduced to calculate the number of occurrences of an event in several independent trials, hence, in this dissertation, the dispersed binomial distribution is used to calculate the probability of occurrence of oil spills in an area.

Assuming that k times accidents occurred in the ships entering and departing the area, the probability of occurrence of the k times accidents is as follow:

$$P(x = k) = c_n^k p^k q^{n-k} \tag{4.1}$$

Where: P is the probability base value for each ship's oil spill accident (assuming that the calculated value of the ship's oil spill probability is consistent);

$q = 1 - p$ indicates the probability of nonoccurrence of oil spill from every ships

C_n^k is the combined formula.

According to formula 4.1, the following two conclusions can be obtained:

K = 0 indicates that 0 ship out of n ships entering and departing the area were involved in an oil spill,which means there is no oil spill that occurred in the area.

K ≠ 0 indicates that 1 or more ships out of n ships entering and departing the area were involved in an oil spill,which means there is oil spill that occurred in the area.

The process of calculating the probability of occurrence of oil spills in an area is how to calculate the probability if K ≠ 0 in the second conclusions based on formula 4.1.In this formula, the basic value p of the probability of oil spill accident in each ship is fundamental conditions, however, the calculation of P value is complicated, Poisson distribution will be introduced. In mathematics, Poisson distribution is suitable for describing the number of random events occurring per unit time. There is only one parameter λ, which is the mean of the Poisson distribution and the variance of the Poisson distribution.

The probability function of Poisson distribution is

$$P(X = k) = \frac{e^{-\lambda}\lambda^k}{k!} \quad (k = 0,1,2,..) \qquad (4.2)$$

Where: λ is the average incidence of random events per unit time or unit area.

The relationship between the Poisson distribution and the binomial distribution is that when n is large and p is very small (usually when $n \geq 10$, $p \leq 0.1$), the binomial distribution can be approximated by the Poisson distribution and there relationship can be described as .

$$\lambda = np \qquad (4.3)$$

Where: λ is the average incidence of random events per unit time or unit area, n is the ships entering and departing the area in binomial distribution and P is the probability base value for each ship's oil spill accident in binomial distribution.

For the calculation of the probability of oil spill accident in area, the ship oil spill accident is usually a small probability event due to the large number of ships entering and departing the area. Therefore, the Poisson distribution can be used to approximate the value of the oil spill probability , The probability of ship oil spill accident is calculated when k is 0, 1, ..., n, that is, the probability of occurrence of ship oil spill accident in the area from 0,1 ..., n.

Furthermore, this method of the calculation is flexible, besides of probability of oil spill accident in area, many kinds of probability of oil spill can be calculated such as probability of oil spill occurred in a certain type of ship and the probability of a certain kind of oil spill accident as long as calculation of number for relevant ships with the unit time(normally one year). For instance, according to the cause of the accidents, the ship oil spill accidents are divided into two categories: operational oil spill accident and shipwrecked oil spill accident. The probability of oil spill for each kind of accidents can be calculated separately by this method.

The average incidence of random events per unit time or unit area(λ) is a vital data required for the calculation. However, if there is no ship oil spill in the area to be calculated, the calculation can not be carried out directly, but an expand for certain range of area is necessary (Assuming that the basic value of probability for oil spill in the area is the same), until there is oil spill accident data in the expansion area and then the indirect estimate can be conducted.

The calculation process of oil spill accident probability through the method of regional expansion is as follows: Assuming ships entering and departing of study area is n1while the ships in expanded area is n2, and the probability of oil spill from ships within 1 year is λ2,then the probability of oil accident value in expanded area p2 shall be calculate firstly.

$$p_2 = \frac{\lambda_2}{n_2}$$

（4.4）

The P2 is used as the basic value of the ship's oil spill probability in the study area

$$p_1 = p_2 = \frac{\lambda_2}{n_2}$$

（4.5）

According to formula 4.3, the frequency of ship's oil spill occurring in a year in the study area is calculated as λ 1.

$$\lambda_1 = n_1 p_1$$

（4.6）

Then, the probability of oil spill from ships in the area can be calculate as

$$P(X = k) = \frac{e^{-\lambda_1} \lambda_1^{\ k}}{k!} \qquad (k = 0,1,2,...)$$

（4.7）

4.1.2 Probability Prediction of Ship Oil Spill Accidents in Taizhou Port

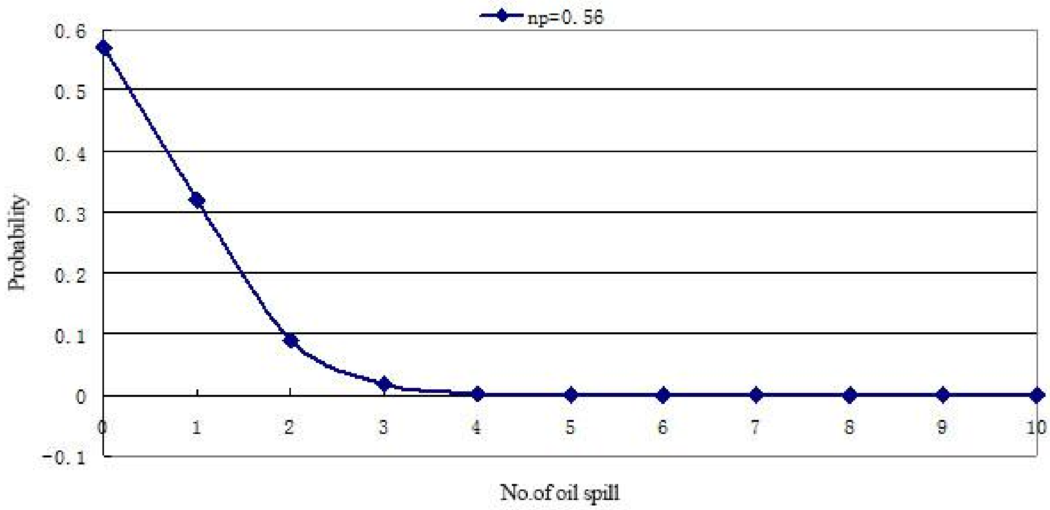
According to the above-mentioned mathematical model of regional ship oil spill accident probability,through investigating the relevant oil spill accidents data of the area,the probability of oil spill from ship in area can be calculated as well as the probability classified by the type of accident and the type of ship. The probability of ship oil spill accident could be calculated as follows:

According to statistics of Taizhou MSA, from 2006 to 2014 there are 5 oil spill accidents occurred Taizhou water area (Taizhou MSA, 2016) ,the number of ship spill incidents in each year could be calculated :

$$\lambda = \frac{5}{9} = 0.56$$

When λ is 0.56, according to the Poisson distribution map , the relationship between the number of annual ship oil spill accidents and its probability could be calculated and shown in in Figure 4.1

Figure4-1 relationship between the number of annual ship oil spill accidents and its probability in Taizhou Port.



Source: Compiled by author

According to Figure 4-1, the probability of oil spill in Taizhou area is about 0.57 per year, and the probability of 1 oil spill accidents is 0.32, and the probability of 2 oil spill accidents is 0.09. The most likely oil spill accident occurred every year is 1, and the most probable ship oil spill probability is 3 year.

4.2 Estimation of volume of oil spillage in Taizhou port

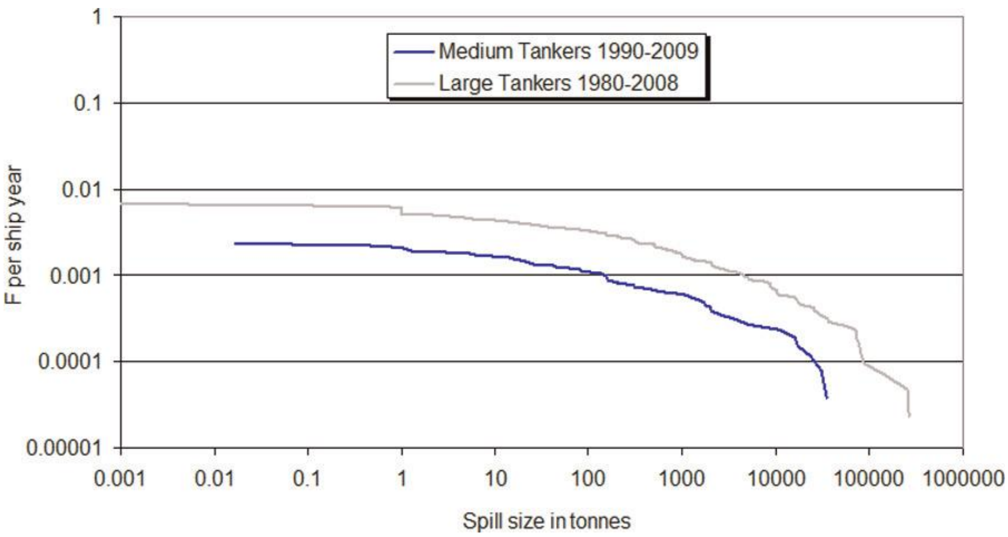
4.2.1 Probability Distribution of Volume of oil spillage

When the oil spill occurs, the volume of oil spilled is related to the type of ship and the tonnage of a ship. For a certain ship, the amount of oil spilled is uncertain and random. However, as shown by historical data of ship oil spill, it is generally that the proportion of accidents with small amount of oil spills is big while that with large amount of oil spill is small.

Generally speaking, when large bulk carrier or tanker hold cargo leaks, the amout of oil spilled are large while that is small in the event of operating oil spill accidents and some shipwrecked accidents. However, with the development of double hull bunker, the probability of oil spills in large tankers and the amount of oil spills in the event of accidents are greatly reduced.

Some statistical analysis by experts have been carried out ,they are about oil spill accident of medium tankers from 1990 to 2009 and large tankers from 1980 to 2008(ITOPF,2009). Function distribution law about amount of spilled oil and the probability of occurrence of oil spill with that volume was introduced.

Figure4.2 The function distribution of oil spill volume and its occurrence probability



Source: complied by author

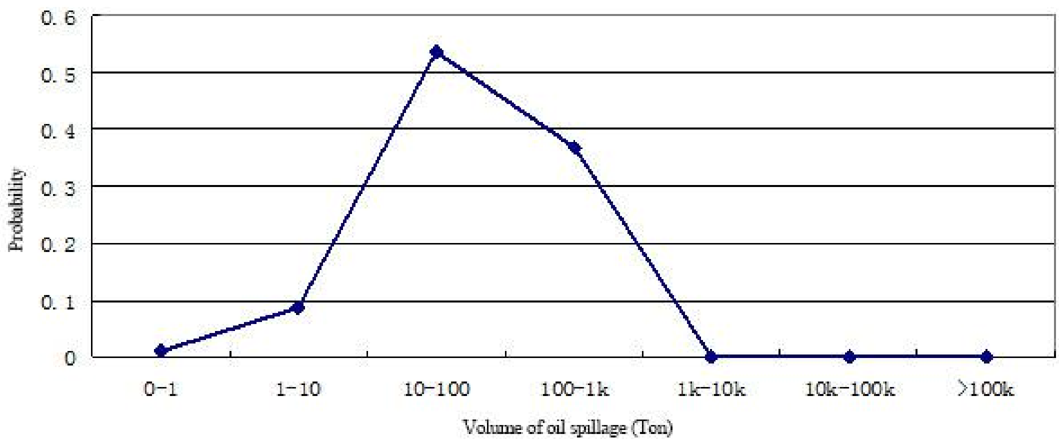
It can be seen from Figure 4.2 that the probability of small oil is larger when the oil spill is oil spill, and the probability of occurrence of large oil spill is small, and the distribution of exponential distribution is the whole. Therefore, the method of exponential distribution was introduced to research the probability distribution of amount of spilled oil in an area when an oil spill occurs .

Assuming that the most likely amount of spilled oil from oil spill accident is λ, which means the expected value of the spilled oil amount is λ, in addition , the amount of spilled oil and the probability distribution of occurrence of oil spill meet the exponential function distribution. Therefore, the probability of occurrence of oil spill with spilled oil amount x is described as:

$$p = 1 - e^{-\frac{1}{\lambda x}} \quad (3.8)$$

Specifically, it is assumed that the expected value of amount of oil spilled by one certain ship in a year is 100, which means λ is 100. The probability distribution of the oil spill accident with x amount of spilled oil is shown in figure 4.3. As the amount of spilled oil is continuous and is a random number between 0 and the maximum when oil spill accident occurs, the probability distribution of amount of spilled oil in a area can be calculated.

Figure 4.3: Interval for amount of spilled oil from ship and its oil spill probability distribution



Source: complied by author

4.2.2 Probability Distribution of Volume of oil spillage in Divided Area

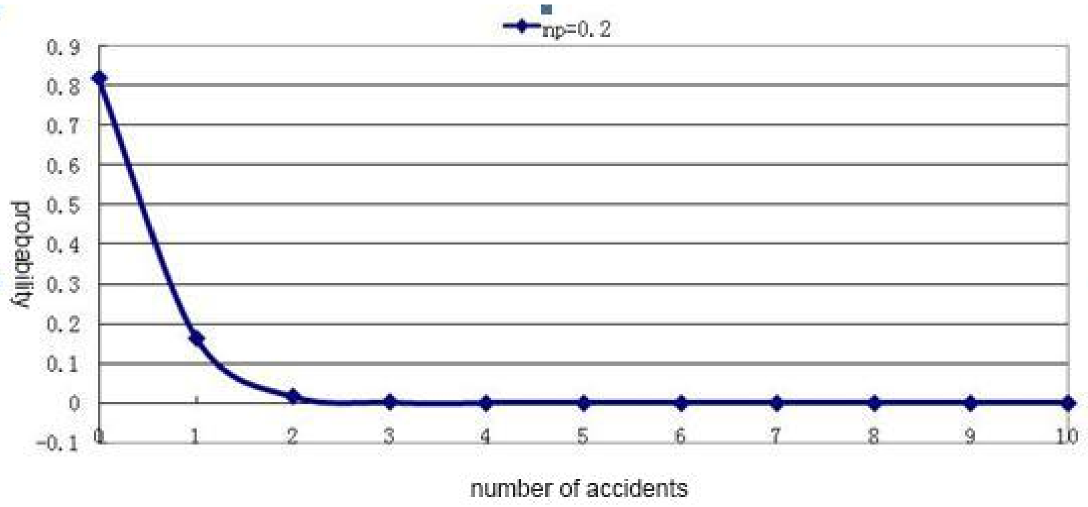
Oil spilling volume of the ships within such area mainly refers to the oil spilling volume occurs with a maximum probability within this area, identifying the relationship between oil spilling volume and its probability of occurring oil spilling accident within the area through calculating the probability distribution of the ships' oil spilling volume within the area, which can provide scientific reference for ships' oil spilling within the area in terms of the development of contingency capacity, the supply of facility and equipment for oil spilling accidents.

There is a certain probability distribution of oil spilling volume when oil spilling occurs to ships within such area, utilizing the probability distribution function when the accident of oil spilling is happened to ships within such area, then the probability distribution of oil spilling volume within such area can be finalized. Suppose that an accident of ship's oil spilling is happened in some area in every 5 years, namely, λ is 0.2. Therefore, it is concluded that:

$$np=\lambda=0.2 \qquad (4.9)$$

The distribution function between the No. of accident of ships' oil spilling occurred annually within such area can be drawn out according to the calculation of chapter 4, the details are shown in figure 4.4.

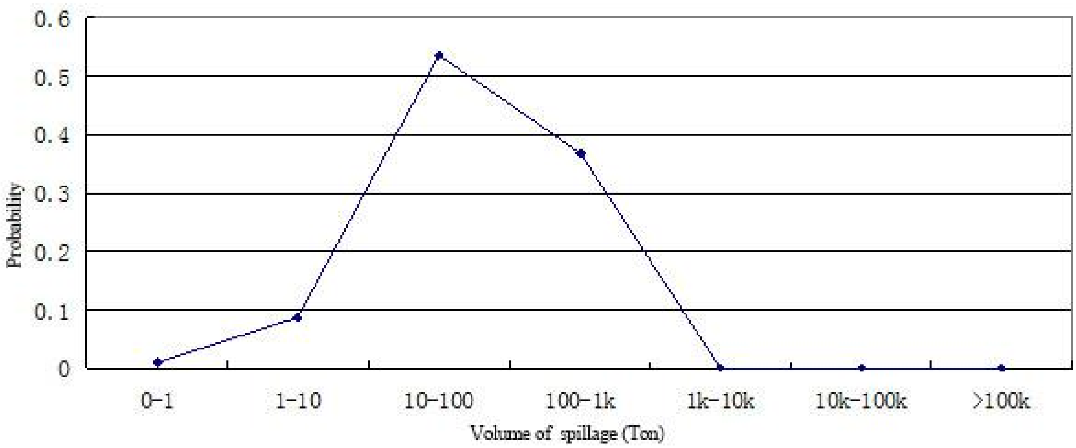
Figure4.4:The relationship figure between the number of ships' annual oil spilling accidents and probability within divided area



Source: complied by author

It is concluded from figure 4.4 that, when the No. of accident is 0, then the probability is 0.82, namely, the probability of not occurring the accident of ships' oil spilling is 0.82. Suppose that the expectation value of oil spilling volume for occurring ships' oil spilling within such area is 100, then the function relationship of probability distribution of oil spilling volume in oil spilling accident occurrence within such area is shown in figure 4. 5

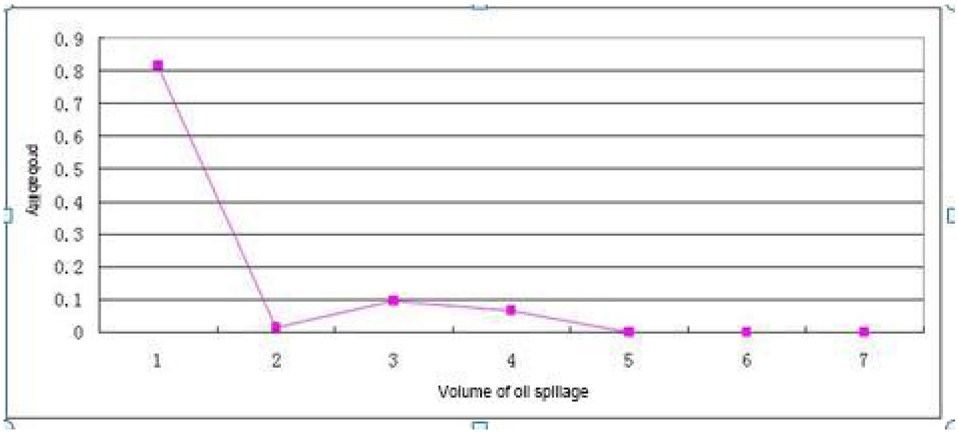
Figure 4.5 The probability distribution figure of oil spilling volume within divided area



Source: complied by author

The conclusion could be drawn by combining figure 4.4 and 4.5 that the probability distribution figure of regional oil spilling volume is shown in figure4.6.

Figure 4.6:The probability distribution figure of oil spilling volume within divided area



Source: complied by author

According to figure 4.6, the probability of oil spilling volume ranging between 0 and 1 ton is 0.82 within this area, yet the probability of oil spilling volume in other areas is very small. Therefore, spills oil occurring in such area is mainly with small volume. It can be taken as a preventive aim for oil spilling contingency within such area, so that corresponding contingency resources for oil spilling should be supplied.

Such calculation method is quite flexible, which can not only calculate the ships' oil spilling volume within some area and its corresponding probability distribution, but also purposely selects target ships, such as calculating respectively the probability distribution of oil spilling volume of oil ships, bulk carriers and general cargo ships within such area, and the probability distribution for oil spilling volume in accidents that occurred due to operational and shipwrecked reasons, etc. Providing proposals to administrations in charge and terminals for carrying out the establishment of contingency capacity to oil spill is based on demand to calculate its probability distribution of oil spilling volume.

CHAPTER 5

OPTIMAL ALLOCATION OF OIL SPILL CONTINGENCY RESOURSES IN TAIZHOU PORT

In order to develop effective capacity for divided regional oil spill contingency response, and reduce the pressure that local government and enterprises faced, certain quantity of preserve position for oil spill contingency equipment should be established in Taizhou Port, then, the terminals nearby should share the resources to achieve optimal allocation of oil spill contingency resources. The whole optimal process should comprise selecting location of preserve position for oil spill contingency equipment, the determination of the shared terminals and the calculation of the risk of oil spill in the shared area.

5.1method of optimal allocation

The reasonable area division of all oil spill contingency equipment supply points within Taizhou port shall be conducted in order to select the suitable location of the site and finalize its neighboring shared terminals. There are many methods of division, However, a relatively mature method of vague clustering have been introduced given that current data of Taizhou port at hand is relatively complete.

Clustering analysis is a kind of multiple analysis method in mathematical statistics, which quantitatively finalizes the sample's relationship of closeness or alienation with mathematical method, therefore objectively divides their types. Some of the boundaries among objects are definite, yet some are vague. When the clustering involves the vague boundary among objects, then the analytic method of vague clustering shall be applied.

FCM algorithm is one of the widest applied methods in vague clustering, which is based on the method of Ruspini's vague c-partition, whose idea is to make the maximum similarity of the targets divided into the same cluster, and minimum similarity of the targets in different cluster. The algorithm of vague average value C is an improvement to the algorithm of ordinary average value C, and the algorithm of ordinary average value C is rigid in terms of data partition, while FCM is a kind of flexible vague partition. The category of clustering in FCM can be set in advance, and it can also be automatically clustered according to the characteristics of the data. And the value function of FCM (or target function) is as followed:

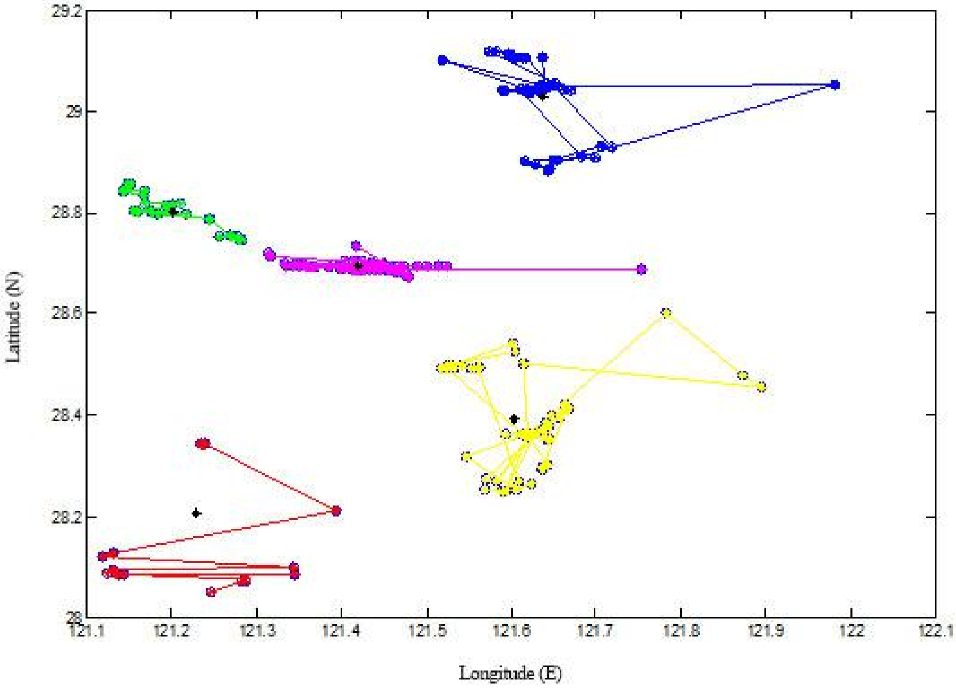
$$J(U, c_1, ..., c_c) = \sum_{i=1}^{c} J_i = \sum_{i=1}^{c} \sum_{j}^{n} u_{ij}^m d_{ij}^2 \quad (5.2)$$

In this dissertation, the author adopts the method of dividing data into categories toward vague average value C, combining the information of terminals geographic location within Taizhou port to carry out the division over similar areas, finalizing the shared area's scope of oil spilling contingency resources .

5.2 The division of sharing area

According to the distribution of terminals in Taizhou area and the the development plan for Taizhou Port, the Taizhou port will be divided into 5 areas through fuzzy clustering method and the implementation of MATLAB software,and the result is shown in Figure 5.1.

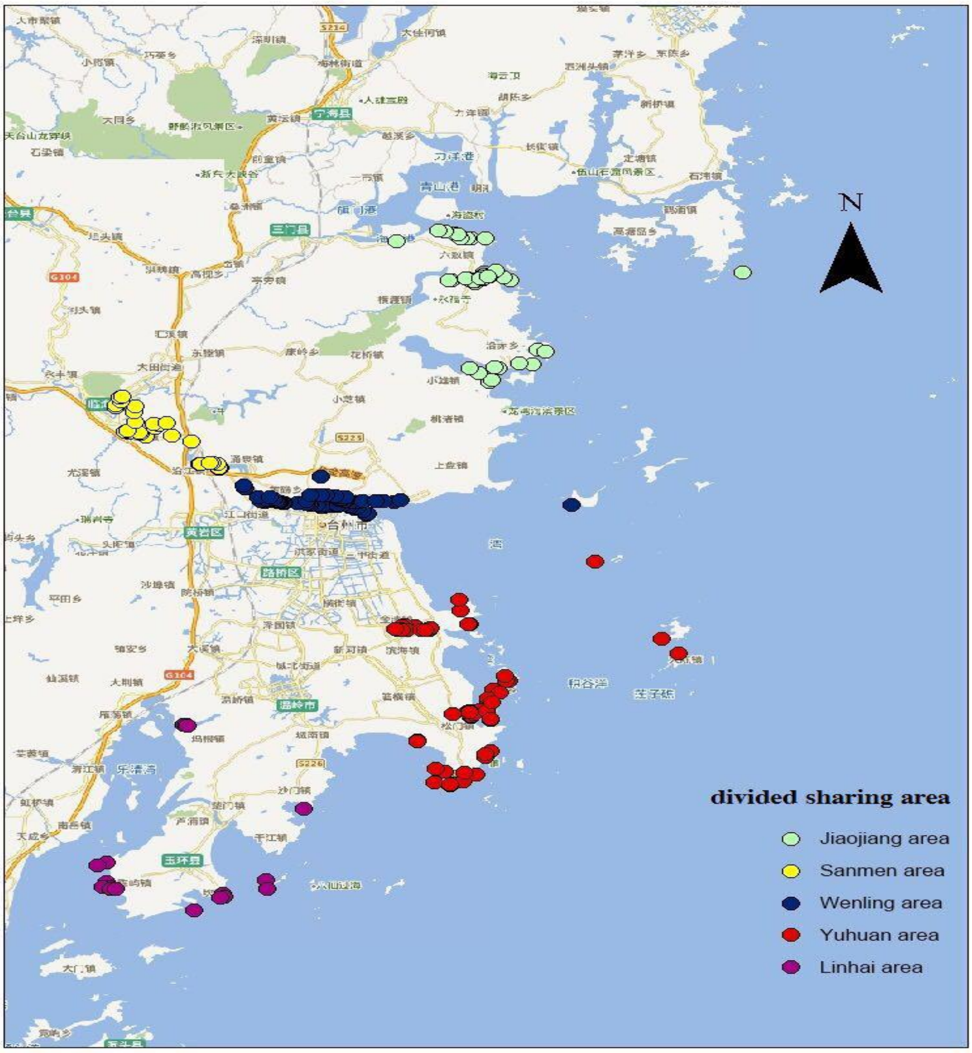
Figure5.1:Cluster analysis of terminals in Taizhou port



Source: complied by author

It can be seen from the above results, fuzzy clustering method can be used to find the optimal zoning based on the geographical characteristics of the terminal. The regional division is reasonable, in general, the terminals with close geographical location are classified in one area, otherwise, they are in different areas. Then, The MATLAB results map should be combined with actual map, the result will show in Figure 5.2.

Figure 5.2:Distribution map of terminals in Taizhou area



Source: complied by author

It can be seen from the chart that the five area of Taizhou port is divided according to the terminal location and the center point position. Obviously, there are certain differences with the administrative division, although the terminals belonging to the same administrative district are divided in the same area. As the center point is taken into consideration, the terminals in different administrative region may also be included with one shared area .

5.3 Calculation of oil spill risk from ships in shared area

The establishment of regional oil contingency response site is aiming to address the risk of oil spill in shared area. Therefore , it is necessary to calculate risk of oil spill in shared area and equip corresponding oil spill emergency facilities to form the emergency force in the shared area. However, there is a large number of terminals located in the shared area and each of them face the risk of oil spill. The risk of oil spill in shared area is not the summary of risk of every terminals, and the convolution calculation method is introduced to calculate it by taking the risk of oil spill of every terminals.Because there are more regional terminal and each terminal has a ship oil spill risk, regional oil spill risk is not the sum of every terminal ship oil spill risk, but the ship oil spill area risk is calculated according to each pier oil spill risk by means of convolution.

The process of convolution calculation is assuming that X (x=0,1,2,...) represents the volume of oil spillage of terminal No. 1, Y (y=0,1,2,...) indicates the volume of oil spillage of terminal No.2, and X and Y are discrete random variables, and they are independent of each other. Z=X+Y indicates the sum of the two terminals. Then the distribution function of Z is as:

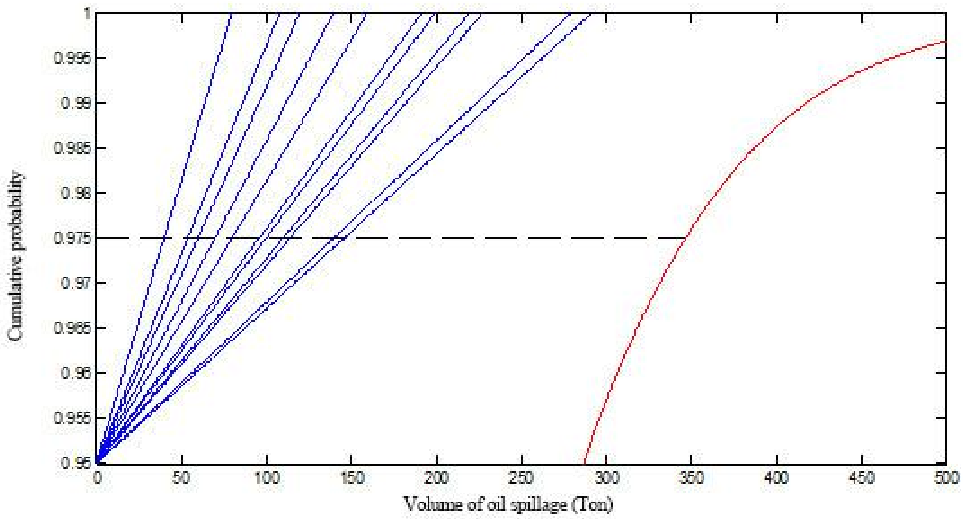
$$P(Z=n)=\sum_{k=0}^{n}P(X=k)P(Y=n-k)(n=0,1,2..;k=0,1,2,,,n) \quad (5.3)$$

According to the above calculation methods, it can separately calculate the oil spill risk of Sanmen area, Linhai area, Jiaojiang area, Wenling area and Yuhuan area in Taizhou port.

The process of calculation method is as followed. Firstly, the most likely volume of spilled oil of the terminal shall be calculated according to its type and tonnage. Secondly, the probability of oil spill of each terminal need to be calculated. (Because the regional division and port area division are different, the statistics of the ships entering and departing port is hard to conduct. In addition, since the probability of the ship oil spill accident is small , the probability of oil spill is 0.05 in this dissertation). Finally, the risk of oil spill from ships in sharing area shall be calculated by the method of convolution calculation in accordance with probability of oil spill and most likely volume of spilled oil of each terminals.

According to statistics, there are 46 terminals in Sanmen area, and the most likely volume of spilled oil in area is 347 tons while the most likely volume of spilled oil of each terminal is shown in appendix(take the probability as 0.975).The results is shown in figure 5.3.

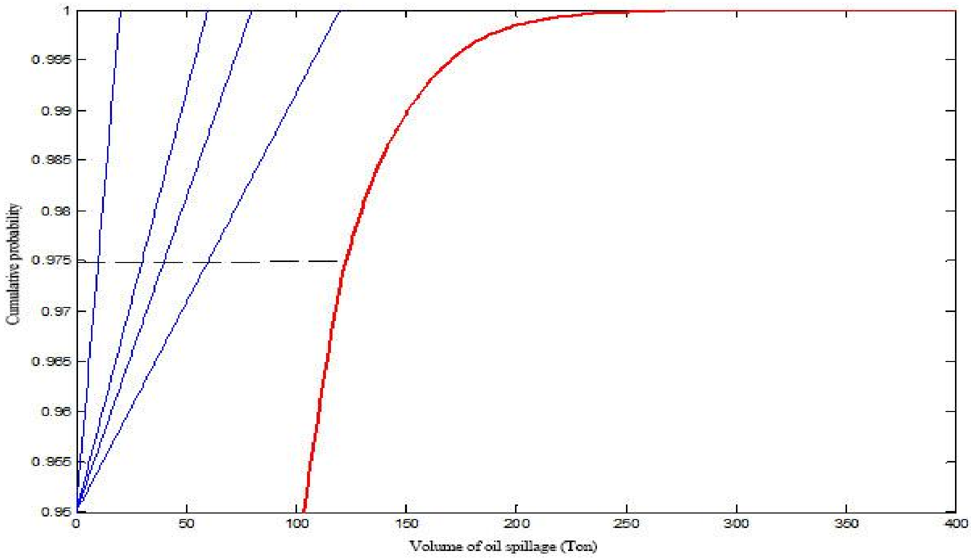
Figure 5-3:The most likely volume of spilled oil in whole area and at terminal in Sanmen area



Source: complied by author

There are 33 terminals in Linhai area, and the most likely volume of spilled oil in area is 129 tons while the most likely volume of spilled oil of each terminal is shown in appendix(take the probability as 0.975).The results is shown in figure5.4

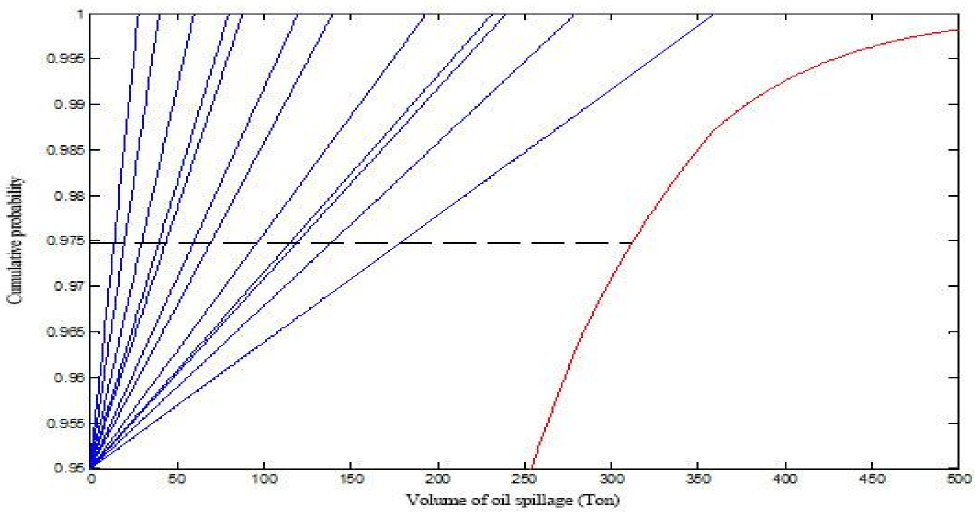
Figure 5.4: The most likely volume of spilled oil in whole area and at terminal in Linhai area



Source: complied by author

There are 84 terminals in Jiaojiang area, and the most likely volume of spilled oil in area is 129 tons while the most likely volume of spilled oil of each terminal is shown in appendix(take the probability as 0.975).The results is shown in figure 5.5.

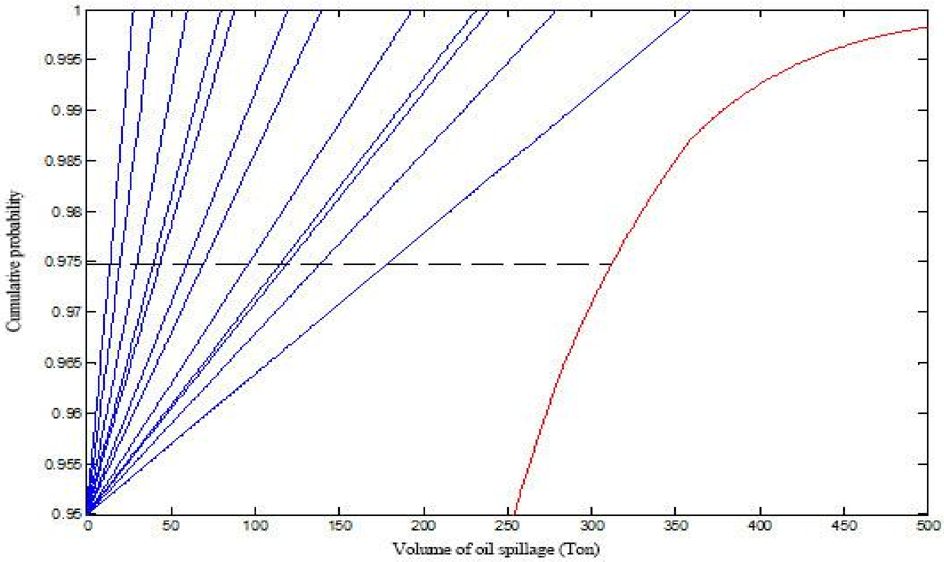
Figure 5.5: the most likely volume of spilled oil in whole area and at terminal in Jiaojiang area



Source: complied by author

There are 69 terminals in Wenling area, and the most likely volume of spilled oil in area is 313 tons while the most likely volume of spilled oil of each terminal is shown in appendix(take the probability as 0.975).The results is shown in figure 5.6.

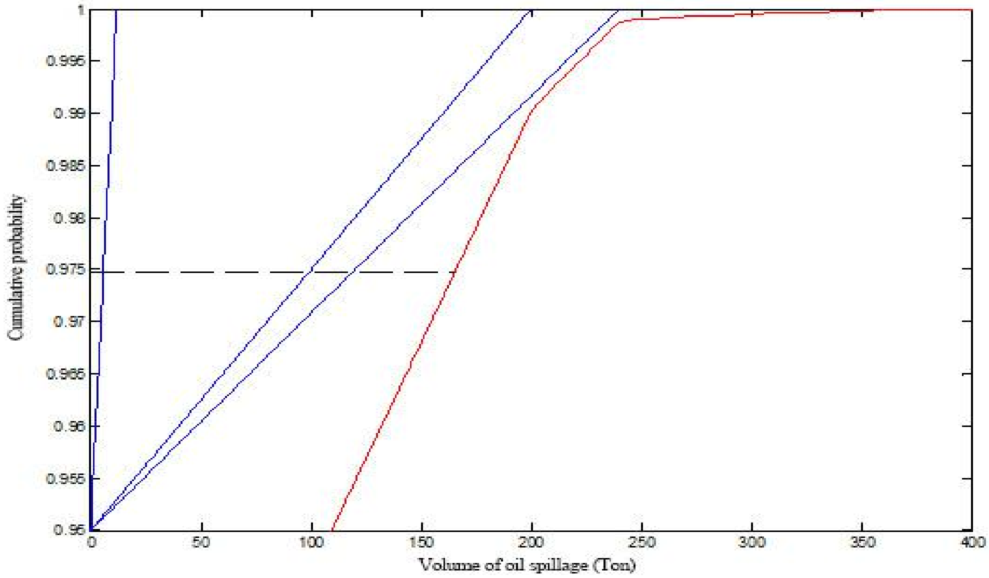
Figure 5.6: the most likely volume of spilled oil in whole area and at terminal in Wenling area



Source: complied by author

There are 25 terminals in Yuhuan area, and the most likely volume of spilled oil in area is 129 tons while the most likely volume of spilled oil of each terminal is shown in appendix(take the probability as 0.975).The results is shown in figure 5.7.

Figure 5.7:the most likely volume of spilled oil in whole area and at terminal in Yuhuan area



Source: complied by author

Table5.1: the most likely volume of spilled oil in whole area of 5 areas in Taizhou port

area	The summary of most likely volume of spilled oil at terminals(tons)	the most likely volume of spilled oil in whole area(tons)
Sanmen area	3460	347
Linhai area	1040	129
Jiaojiang Area	4119	400
Wenling Area	3960	313
Yuhuan Area	2017	166
Whole Taizhou area	14596	709

Source: complied by author

According to the the most likely volume of spilled oil in whole area, the the resources for oil spill contingency response shall be equipped.The cost of purchase and management those equipment shall be paid by terminals in area in accordance with the proportion of the risk of terminal of that in whole area.Taking Sanmen area as example, the most probable volume of oil spillage of each terminals and their sharing cost is shown in table 5.2

Table 5.2: the most probable volume of oil spillage of each terminals and their sharing cost in Sanmen area

Terminals	**Location**	**Tonnage**	**Most probable oil spillage(ton)**	**Cost sharing**
Sanmen Qianghui Shipping Co.	Sanmen area	40000	160	4.62%
Taixin shipping Co.	Sanmen area	35000	140	4.05%
Zhejiang Qinfeng Shipping Co.	Sanmen area	50000	200	5.78%
Zhejiang Chaoyu shipbuilding Co.	Sanmen area	40000	160	4.62%
Taizhou Zhongzhou shipbuilding Co.	Sanmen area	30000	120	3.47%
Zhejiang Kaihang shipping Co.	Sanmen area	73000	292	8.44%
Zhejiang Zhongbo shipping Co.	Sanmen area	100000	200	5.78%
Zhejiang Fengyuan shipping Co.	Sanmen area	48000	192	5.55%
Zhejiang Jiuzhou shipping Co.	Sanmen area	50000	200	5.78%

Zhejiang Chengzhou shipping Co.	Sanmen area	57000	228	6.59%
Taizhou Jinmao shipbuilding Co.	Sanmen area	70000	280	8.09%
Binhai shipbuilding Co.	Sanmen area	20000	80	2.31%
Zhejiang Taida shipbuilding Co.	Sanmen area	30000	120	3.47%
Zhejiang Haihang shipbuilding Co.	Sanmen area	30000	120	3.47%
Zhejiang Youhao shipbuilding Co.	Sanmen area	70000	280	8.09%
Zhejiang Taihang shipbuilding Co.	Sanmen area	40000	160	4.62%
Zhejiang Jiantiao shipbuilding Co.	Sanmen area	55000	220	6.36%
Sanmen Jiantiao shipyard Co.	Sanmen area	27000	108	3.12%
Sanmen multipurpose terminal	Sanmen area	5000	50	1.45%
Jinmao shipyard No.1 terminal	Sanmen area	10000	40	1.16%
Jinmao shipyard No.2 terminal	Sanmen area	5000	20	0.58%
Jiaotiao shipyard No.1 terminal	Sanmen area	10000	40	1.16%
Nuclear power plant	Sanmen area	5000	50	1.45%

Source: complied by author

It can be seen that the sum of the most probable volume of spilled oil of all the terminals in the Sanmen area and the most likely volume of spilled oil in whole area is 347 tons. The cost of establishment of oil spill contingency site can be calculated by the following formula:

$$x = \frac{q_T}{Q_{sum}}$$

Where: X takes the proportion of the investment management cost of the regional oil spill contingency supply site for a single terminal, the qt is the most likely volume of spilled oil of the terminal; Qsum is the sum of the most probable volume of spilled oil of all the terminals in the area.

In this way, it can calculate the proportion of the investment management cost of other terminals and finally calculate the proportion of the cost of each terminals in the whole area . (see Appendix).

5.4 Model of oil spill contingency resources allocation and management in Taizhou port

5.4.1The Provision and Management Mode of Oil Spill Contingency Resources

The allocation methods of oil spill contingency resources in Taizhou port may be adopted as centralized equipment by some resources and distributed equipment by others.The centralized oil spill contingency resources should include contingency unloading equipment, oil fence laying boats, contingency oil fence, professional oil recovery ship, oil recovery machine, part of oil spill dispersant and adsorption material (taking into account the terminal unit shall be equipped with a certain oil spill dispersant and adsorption material to deal with accident with small amount of oil spillage , 1/3 dispersant and adsorption materials of all shall be distributed to each terminal while the other 2/3 dispersion method and adsorption are centralized),and large oil spill dispersant spraying device.

The distributed oil spill contingency resources should include the permanent type of oil fence (for oil terminal),part of oil spill dispersant and adsorption material (1/3 dispersant and adsorption materials of all to deal with accident with small amount of oil spillage) ,and proper oil spill dispersant spraying device.The centralized oil spill contingency resources shall be available on oil spill position in 2 to 4 hours due to the limit time for response of oil spill accident.

The frequency of use of oil spill contingency resource is is generally low due to them only used in the event of oil pollution accident,Hence,better management and maintenance of the resources is an important part to ensure the capability of oil spill contingency response in good condition. The oil spill contingency resources are distributed to deal with the possible risk of oil spill in the daily production of the terminal. Therefore, each terminal should be equipped independently and maintenance the allocated oil spill contingency resources to ensure the oil spill contingency supplies valid and the oil spill contingency facilities are available at any time.However, the centralized oil spill contingency resources is in high quantity and is shared by all the terminals in the region, they shall be maintained and managed professionally.

Therefore, the dissertation mainly focuses on the allocation, maintenance and management of centralized oil spill contingency resources. The manager of the resource shall be selected in accordance with the following standard:

All the terminals in divided area are in small scale and there is no unit that can undertake the allocation, management and maintenance of the centralized oil spill contingency resources. In this case, it is suggested that qualified oil pollution cleaning company perform the duty of allocation, management and maintenance, and they charges a certain amount of management fee to the terminals in the region every year.

There is large scale terminal in divided area which has purchased some large oil spill contingency facilities and equipment (such as spilled oil cleaning boat etc.), and have the capable ability to allocate, mange and maintain the centralized oil spill contingency resources.Then it should be considered as shared supply point and manager.

5.4.2Establishment and management mode of oil spill contingency response team

The equipment of oil spill contingency facilities and equipment is aiming to solve oil spill risk from ships in shared area, and only the reasonable and efficient use of oil spill contingency facilities and equipment is the formation of ability of oil spill contingency response in area. The oil spill contingency response team will quickly and orderly use oil spill contingency facilities and take active and effective measures to deal with the oil spill pollution through professional training. Hence , it is necessary to establish a regional oil spill contingency response team, and its ability is highly related to the regional oil spill response efficiency. In Taizhou port, beside the equipment of related oil spill facilities which match the risk of oil spill, capable oil spill contingency response team shall be established.

The establishment of a professional and capable oil spill response team will require substantial manpower, material resources and financial resource, including recruitment of quality of personnel with the basic skills for oil spills, professional oil spill contingency training, and constant oil spill contingency drills. However, the frequency of oil spill accidents is not high, and it is a waste to establish professional oil spill response team in each divided area. Actually the oil spill response team can arrive at the oil spill site by any means of transportation. Therefore, in the Taizhou port, as long as the oil spill contingency equipment is adequate in pollution area, the response team can quickly reach the scene of oil spill to participate in contingency activities in any area.

Oil spill response team need oil spill contingency resource and facilities to carry out daily training. But the terminals in Taizhou port are in different circumstances, and any qualified oil pollution cleaning company or certain terminal could be considered as manager of the contingency resource. In theory, the establishment of a professional team in Taizhou port can meet the requirements of contingency response, However, for the sake of convenient operation, it is recommended that the oil spill contingency team should be established in the manner of centralized oil spill contingency resources.

The management contingency team should also be carried out by the manager of centralized oil spill contingency resources which should develop a corresponding oil spill contingency plan to and participate in spill training courses in the maritime administration or other specialized companies. Similar with the distribution of costs of oil spill contingency resource,the cost of establishment and management of the oil spill contingent team can be calculated by the manager, and it should be paid by terminals in the area according to their respective ship oil spill risk. As for the contingency personnel scattered in the various terminals, they should be recruited and managed according to oil spill contingency plans of every terminals.

5.4.3 Development of oil spill contingency plan

In the event of an oil spill accident, the reasonable contingency plan for oil spills can effectively guide oil spill contingency activities carried out properly, including how to report to the relevant departments quickly after receiving the accident report and how to adopt a positive and effective response procedure (Jaime Lima ,Flávio Diniz 2015). Therefore, all divided region should lay out detailed contingency plan for oil spills and report to the local maritime authorities. A reasonable contingency plan shall be clearly defined as follows:

Clearly division of organization and related responsibilities, Clarify clear leadership at contingency , command agencies, composition of the staff and the division of responsibilities of personnel in the organization of daily management , and the lists of the contact details of internal contingency personnel .

Internal and external reporting procedure. The plan shall stipulate procedures and contents of the internal reporting process, specify the requirements and procedures of the external reports, and list the contact ways of the external reporting units such as maritime administration.

Contingency response procedures. The plan shall define the contingency response actions of each contingency department in different levels of oil spill accidents.

List of the existing oil spill contingency equipment and attach the location map of contingency storage room at terminal.

List the detailed contact ways of the other contingency departments so as to timely call the external contingency resources for assistance and mitigate the consequences after the accident

List the detailed contact ways of the sensitive resource managers nearby, and build effective and daily contact mechanism, so as to notify the affected sensitive resource manager to take effective countermeasures in time in the event of oil spill pollution accident .

The purpose of Optimal allocation of oil spill contingency resources in Taizhou port is to effectively use the regional oil spill contingency resources to improve oil spill contingency response force to deal with the possible risk of oil spills in the area.There are numerous terminals in Taizhou port but with small size overall. Equipment of oil spill contingency resources for every individual terminal will cause waste of resources ,for instance,some vulnerable contingency resource as spilled oil dispersant will be equipped repetitively. Furthermore,due to large oil spill contingency equipment is insufficient, it is difficult to use them effectively and rapidly in the event of oil spills to built high-performance contingency forces.

CHAPTER 6

CONCLUSIONS AND PROPOSALS

In this dissertation, actual situation of terminals in Taizhou Port and the risk of ship oil spill in area have been analyzed, and environmental condition of Taizhou area of the terminal characteristics are fully considered. Reasonable divided area have been presented based on the the principle of efficient use of resources and the funds saving. Taizhou port will be divide into 5 areas, and Oil spill contingency equipment supply point will be established in each areas,then the oil spill contingency resources will be shared by terminals in the divided area. On one hand, The relevant companies can save allocation cost by sharing the oil spill contingency resources.On the other hand,The local government can deliver joint invest with relevant companies to built oil spill contingency equipment supply points to make reasonable use of the oil spill contingency resources. In this way, the oil spill response resources in a whole area will be used to address the probable risk of oil spill by ships in area and improve contingency response capability of oil spilling by ships.

proposals:

According to the regional oil spill risk, the local government should guide relevant enterprises to supply regional oil spill contingency equipment, provide corresponding oil spill contingency facilities and establish contingency response teams, and adopt oil spill contingency plan.The regional oil spill contingency equipment supply point can not only cope with the risk of oil spill at terminals, but also deal with the risk of oil spill from ships in whole area.

The costs of establishment and management of regional oil spill contingency equipment supply point should be shared.Part of it should be allowance by local government and the rest should be provided by relevant companies in accordance with the percentage of their own risk of oil spill from ships accounted for the sum of risk of oil spill from ships of all terminals in whole area.Correspondingly,The income arising from participation of supply points in oil spill contingency response activities shall be allocated according to the distribution proportion.

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Appendix :

the risk of oil spill of each terminals and their sharing cost in Taizhou area

The risk of oil spill of each terminals and their sharing cost in Sanmen area

Terminal	Port belonging	Tonnage	Most probable oil spillage(ton)	Probability of oil spill	area	Proportion of sharing cost
Sanmen Qianghui Shipping Co.	Sanmen area	40000	160	0.05	Sanmen area	4.62%
Taixin shipping Co.	Sanmen area	35000	140	0.05	Sanmen area	4.05%
Zhejiang Qinfeng Shipping Co.	Sanmen area	50000	200	0.05	Sanmen area	5.78%
Zhejiang Chaoyu shipbuilding Co.	Sanmen area	40000	160	0.05	Sanmen area	4.62%
Taizhou Zhongzhou shipbuilding Co.	Sanmen area	30000	120	0.05	Sanmen area	3.47%
Zhejiang Kaihang shipping Co.	Sanmen area	73000	292	0.05	Sanmen area	8.44%
Zhejiang Zhongbo shipping Co.	Sanmen area	100000	200	0.05	Sanmen area	5.78%
Zhejiang Fengyuan shipping Co.	Sanmen area	48000	192	0.05	Sanmen area	5.55%
Zhejiang Jiuzhou shipping Co.	Sanmen area	50000	200	0.05	Sanmen area	5.78%

Zhejiang Chengzhou shipping Co.	Sanmen area	57000	228	0.05	Sanmen area	6.59%
Taizhou Jinmao shipbuilding Co.	Sanmen area	70000	280	0.05	Sanmen area	8.09%
Binhai shipbuilding Co.	Sanmen area	20000	80	0.05	Sanmen area	2.31%
Zhejiang Taida shipbuilding Co.	Sanmen area	30000	120	0.05	Sanmen area	3.47%
Zhejiang Haihang shipbuilding Co.	Sanmen area	30000	120	0.05	Sanmen area	3.47%
Zhejiang Youhao shipbuilding Co.	Sanmen area	70000	280	0.05	Sanmen area	8.09%
Zhejiang Taihang shipbuilding Co.	Sanmen area	40000	160	0.05	Sanmen area	4.62%
Zhejiang Jiantiao shipbuilding Co.	Sanmen area	55000	220	0.05	Sanmen area	6.36%
Sanmen Jiantiao shipyard Co.	Sanmen area	27000	108	0.05	Sanmen area	3.12%
Sanmen multipurpose terminal	Sanmen area	5000	50	0.05	Sanmen area	1.45%
Jinmao shipyard No.1 terminal	Sanmen area	10000	40	0.05	Sanmen area	1.16%
Jinmao shipyard No.2 terminal	Sanmen area	5000	20	0.05	Sanmen area	0.58%
Jiaotiao shipyard No.1 terminal	Sanmen area	10000	40	0.05	Sanmen area	1.16%
Nuclear power plant	Sanmen area	5000	50	0.05	Sanmen area	1.45%

The risk of oil spill of each terminals and their sharing cost in Jiaojiang area

Terminal	Port belonging	Tonnage	Most probable oil spillage(ton)	Probab ility of oil spill	area	Proportion of sharing cost
Haidong Shipyard	Jiaojiang port	5000	2500	0.05	Jiaojiang area	0.49%
Yuanshan Shipyard	Jiaojiang port	10000	5000	0.05	Jiaojiang area	0.97%
No.1 terminal of Haimen port	Jiaojiang port	5000	2500	0.05	Jiaojiang area	1.21%
Waisha Container terminal	Jiaojiang port	5000	2500	0.05	Jiaojiang area	1.21%
Conch Cement terminal	Jiaojiang port	3000-5000	2500	0.05	Jiaojiang area	1.21%
Forth terminal of Taizhou Plant	Jiaojiang port	5000	2500	0.05	Jiaojiang area	1.21%
Linhai Falong Shipyard	Linhai port	above15000	7250	0.05	Jiaojiang area	1.41%
Taizhou Ocean Shipyard	Jiaojiang port	15000	7500	0.05	Jiaojiang area	1.46%
Qiansuo Oil terminal	Jiaojiang port	1000	500	0.05	Jiaojiang area	1.82%
Qiansuo Wuzhou Shipyard	Jiaojiang port	20000	10000	0.05	Jiaojiang area	1.94%
terminal of Taizhou Plant(10000)	Jiaojiang port	10000	5000	0.05	Jiaojiang area	2.43%
Taizhou Wuzhou Shipping Co.	Jiaojiang port	27000	13500	0.05	Jiaojiang area	2.62%

Wenling Shenghai Shipyard	Wenling port	27000	13500	0.05	Jiaojiang area	2.62%
Jiaojiang refrigeratory	Jiaojiang port	1000-2000	1000	0.05	Jiaojiang area	2.73%
Taizhou Yichang Shipping Co.	Jiaojiang port	30000	15000	0.05	Jiaojiang area	2.91%
Taizhou Oil Company	Jiaojiang port	3000	1500	0.05	Jiaojiang area	4.10%
Hongguang Chemical terminal	Linhai port	3000	1500	0.05	Jiaojiang area	4.10%
Haidong Shipyard	Jiaojiang port	50000	25000	0.05	Jiaojiang area	4.86%
Taizhou Qiansuo Shipyard	Jiaojiang port	50000	25000	0.05	Jiaojiang area	4.86%
7816 Factory	Jiaojiang port	50000	25000	0.05	Jiaojiang area	4.86%
Zhejiang Mingfa Shipyard	Jiaojiang port	50000	25000	0.05	Jiaojiang area	4.86%
Taizhou Wanchang Shipyard	Jiaojiang port	100000	50000	0.05	Jiaojiang area	4.86%
Zhejiang Hongxin Shipping Co.	Jiaojiang port	120000	60000	0.05	Jiaojiang area	5.83%
Wanlong Shipping Co.	Jiaojiang port	150000	75000	0.05	Jiaojiang area	7.28%
Huaji Shipping Co.	Jiaojiang port	80000	40000	0.05	Jiaojiang area	7.77%
Taizhou Yanhai Shipyard	Jiaojiang port	310000	155000	0.05	Jiaojiang area	10.03%
Hongchang Shipyard	Jiaojiang port	320000	160000	0.05	Jiaojiang area	10.36%

The risk of oil spill of each terminals and their sharing cost in Linhai area

Terminal	Port belonging	Tonnage	Most probable oil spillage(ton)	Probability of oil spill	area	Proportion of sharing cost
Zhejiang Fangyuan Shipyard	Linhai port	5000	20	0.05	Linhai area	1.92%
Linhai Huajie Shipping Co.	Linhai port	Below 5000	20	0.05	Linhai area	1.92%
Taizhou Maple Shipping Co.	Linhai port	20000	80	0.05	Linhai area	7.69%
Linhai Huipu Shipyard	Linhai port	20000	80	0.05	Linhai area	7.69%
Taizhou Shipping Shipyard	Linhai port	20000	80	0.05	Linhai area	7.69%
Linhai Changshun Shipyard	Linhai port	20000	80	0.05	Linhai area	7.69%
Taizhou Hongda Shipping Co.	Linhai port	Below 20000	80	0.05	Linhai area	7.69%
Zhejiang Hongguan Shipyard	Linhai port	15000	60	0.05	Linhai area	5.77%
Linhai Hongzhou Shipyard	Linhai port	15000	60	0.05	Linhai area	5.77%
Linhai Haifeng Shipyard	Linhai port	15000	60	0.05	Linhai area	5.77%
Linhai Jianghai Shipyard	Linhai port	15000	60	0.05	Linhai area	5.77%

Linhai Hangchang Shipyard	Linhai port	15000	60	0.05	Linhai area	5.77%
Linhai Hongsheng Shipyard	Linhai port	15000	60	0.05	Linhai area	5.77%
Taizhou Yuehang Shipping Co.	Linhai port	Above 30000	120	0.05	Linhai area	11.54%
Linhai Xundong Shipping Co.	Linhai port	Above 30000	120	0.05	Linhai area	11.54%

The risk of oil spill of each terminals and their sharing cost in Wenling area

Terminal	Port belonging	Tonnage	Most probable oil spillage(ton)	Probability of oil spill	area	Proportion of sharing cost
Wenling Xianghui shipyard	Wenling port	5000	20	0.05	Wenling Area	0.51%
Wenling Longmen shipping Co.	Wenling port	7000	28	0.05	Wenling Area	0.71%
Wenling Kaili shipyard	Wenling port	10000	40	0.05	Wenling Area	1.01%
Wenling Yongli shipyard	Wenling port	10000	40	0.05	Wenling Area	1.01%
Wenling Xianfeng shipyard	Wenling port	15000	60	0.05	Wenling Area	1.52%
Jinqing Huaxuan terminal	jiaojiang port	1000	75	0.05	Wenling Area	1.89%
Yangfu Bay terminal	Wenling port	1000	75	0.05	Wenling Area	1.89%
Nangang terminal	Wenling port	1000	75	0.05	Wenling Area	1.89%
Wenling Century Shipyard	Wenling port	20000	80	0.05	Wenling Area	2.02%
Wenling Niluo Shiping Co.	Wenling port	22000	88	0.05	Wenling Area	2.22%
Wenling Ruoli Shipyard	Wenling port	22000	88	0.05	Wenling Area	2.22%

Taizhou Yuansheng Shipyard	Jiaojiang port	30000	120	0.05	Wenling Area	3.03%
Taizhou Golden Bay Shipyard	Jiaojiang port	30000	120	0.05	Wenling Area	3.03%
Zhejiang Jiaoshan Shipyard	Wenling port	30000	120	0.05	Wenling Area	3.03%
Wenling Xingyuan Shipyard	Wenling port	30000	120	0.05	Wenling Area	3.03%
Wenling Shipping Shipyard	Wenling port	30000	120	0.05	Wenling Area	3.03%
Wenling Changhong Shipyard	Wenling port	30000	120	0.05	Wenling Area	3.03%
Zhejiang Tenglong Shipyard	Wenling port	35000	140	0.05	Wenling Area	3.54%
Jinqing Huayuan terminal	Jiaojiang port	3000	168.75	0.05	Wenling Area	4.26%
Luoxing Island terminal	Wenling port	3000	168.75	0.05	Wenling Area	4.26%
Zhejiang Zhenxing Shipyard	Wenling port	48500	194	0.05	Wenling Area	4.90%
Hualuo Island terminal	Wenling port	3500	196.875	0.05	Wenling Area	4.97%
Shatou Oil terminal	Wenling port	3500	196.875	0.05	Wenling Area	4.97%
Hongyan Oil terminal	Wenling port	3500	196.875	0.05	Wenling Area	4.97%

Gangzhou Oil terminal	Wenling port	3500	196.875	0.05	Wenling Area	4.97%
Zhejiang Hexing Shipyard	Wenling port	58000	232	0.05	Wenling Area	5.86%
Zhejiang Jingang Shipping Co.	Wenling port	60000	240	0.05	Wenling Area	6.06%
Zhejiang Tianshi Shipyard	Wenling port	70000	280	0.05	Wenling Area	7.07%
Shitang Oil terminal	Wenling port	5000	360	0.05	Wenling Area	9.09%

The risk of oil spill of each terminals and their sharing cost in Yuhuan area

Terminal	Port belonging	Tonnage	Most probable oil spillage(ton)	Probability of oil spill	area	Proportion of sharing cost
Yingdong bunker	Yuhuan port	1000	75	0.05	Yuhuan area	3.72%
Shengli chemical	Yuhuan port	1000	75	0.05	Yuhuan area	3.72%
Zhejiang Haicheng shipbuilding Co.	Yuhuan port	50000	200	0.05	Yuhuan area	9.92%
YuhuanHai hang shipbuilding Co.	Yuhuan port	60000	240	0.05	Yuhuan area	11.90%
Da Maiyu multipurpos e terminal(20 000-30000)	Yuhuan port	20000- 30000	300	0.05	Yuhuan area	14.88%
Da Maiyu multipurpos e terminal(30 000)	Yuhuan port	30000	300	0.05	Yuhuan area	14.88%
Da Maiyu multipurpos e terminal(50 000)	Yuhuan port	50000	333.33	0.05	Yuhuan area	16.53%
Huaneng Yuhuan power plant coal terminal	Yuhuan port	50000/7400 0	493.33	0.05	Yuhuan area	24.46%