8-24-2014

Study on environmental risk assessment of oil spill accidents in Shanghai Port

Jingzhou Chang

WORLD MARITIME UNIVERSITY

Dalian, China

STUDY ON ENVIRONMENTAL RISK ASSESSMENT OF OIL SPILL ACCIDENTS IN SHANGHAI PORT

By

Chang Jingzhou

The People's Republic of China

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

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENT MANAGEMENT)

2014

DECLARATION

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

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

(Signature): Chang Jingzhou

(Date): July 10, 2014

Supervised by: Wu Wanqing
Professor of Dalian Maritime University

ACKNOWLEDGEMENT

I would like to express my gratitude to China Maritime Safety Administration and Shanghai Maritime Safety Administration for nominating me to attend this MSEM programme to expand the horizons of maritime knowledge.

The greatest gratitude goes to Mr. Xia Darong, my leader-the director of Shanghai Pudong Maritime Safety Administration. He recommended me to attend the project of MSEM 2014 and encouraged me in further study and career development. His advices and his help always gave me strong spiritual power during the whole MSEM programme.

My sincere thanks must also be given to my research paper supervisor, Professor Wu Wanqing, Dalian Maritime University. His scientific guidance and constructive advice urge me to overcome lots of the difficulties I encountered in this paper.

I am also willing to convey my special thanks to all of the professors in this MSEM programme, whose professional teaching has not only considerably improved my knowledge but also greatly benefited this dissertation.

Finally, I would like to express deepest gratitude to my wife and my daughter for enduring a long period in my absence and for providing unconditional support and inspiration.

Thank you all very much!

ABSTRACT

Title of Research Paper: **Study on Environmental Risk Assessment of Oil Spill Accidents in Shanghai Port**

Degree: **MSc**

With the development of marine transportation and Shanghai's economy in recent years, there exists high contamination risk of ship oil spill in Shanghai Port waters. However, ship oil spills accidents not only cause serious marine environment pollution and damage marine ecosystems, but also bring huge economic losses. Therefore, carrying out the study of ship oil spill risk assessment, identifying and analyzing the reasons of oil spills in Shanghai Port, discriminating accident pollution characteristics and the degree of harm, and putting forward corresponding precautions to reducing the pollution hazard have very important theoretical significance and practical value to promote the construction of Shanghai Port ship oil spill pollution emergency capacity and reduce the losses caused by the oil spill pollution as soon as possible.

This thesis first introduces the behavior of oil spill and the research status, and the environmental risk assessment research status quo of oil spill. According to the Shanghai Port transportation status and development planning, through statistical analysis of vessel traffic flow data and the oil spill history records, some important risk parameters are identified and determined. Collision and improper operation is respectively the main reason of accidental oil spills and operational oil spills in Shanghai Port. It can be seen that the probability of happening operational oil spills is higher than accidental oil spills. But, the harmful consequence of accidental oil spills is very serious.

Then based on Dr. Zheng wenbo's theory, the oil spill drift-diffusion model and the oil spill weathering model are established. On that basis, it uses the typical scenario simulation method and random scenario statistics method combined with hydrological and meteorological conditions to forecast oil spill hazards. Also it proposes new oil spill harmful consequences exponential model which can take into account oil spill quantity, sensitivity to environmental protection goals, and the probability of contamination at the same time.

At last, by adopting Analytic Hierarchy Process (AHP), combined with traffic management situation and oil spill response capability situation of Shanghai Port waters, this thesis analyzes the exiting main problems from two risk factors (reducing the happening frequency of oil spills and reducing the harmful consequences of the oil spill), and put forward the corresponding risk preventive measures.

Key Words: Ship oil spill; Risk assessment; Shanghai Port waters; Prediction model; Analytic Hierarchy Process (AHP); Emergency response capability; Prevention measures and suggestion.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
COD	Chemical Oxygen Demand
DNV	Det Norske Veritas
FSC	Flag State Control
IMO	International Maritime Organization
ISM	International Safety Management
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
MSA	Maritime Safety Administration
NOAA	National Oceanic and Atmospheric Administration
PSC	Port State Control
SOA	State Ocean Administration
SOPEP	Shipboard Oil Pollution Emergency Plan
VTS	Vessel Traffic Service

Chapter 1 INTRODUCTION

1.1 Background and significance

The sea is the cradle of life. Its area covers more than 70% of the earth, with human survival and development closely inseparable. It is not only a natural treasure-house providing abundant mineral resources and fishery resources for people, but also the most economic transportation environment. According to incomplete statistics, 70%-80% of global freight volumes are accomplished through ocean transportation. And economic globalization promotes the sustainable growth of seaborne trade. Prompting economic development, at the same time, ship causes pollution to the sea, accounting for 45% of the marine pollution. According to statistics, in 1960-2005, the world had 40 pieces of more than 10,000 gallons of ship oil spill accident, an average of about 250 gallons each accident (Shi, 2007, p. 225). It not only polluted the marine ecological environment, but also caused huge economic loss.

In recent years, there have been a few typical ship oil spill accidents in the world: in March 1989, the "Exxon Valdez" oil tanker, on the rocks near the Alaska spilt oil 36000 tons, direct economic losses as high as 10.5 million pounds; in November 2002, the "Prestige" ship encountered a strong storm in the process of sailing leading to fracture sinking, about 17,000 tons of fuel oil leaking, 400 km of the Spanish coastline severely contaminated (Xiao, 2010, p. 31).

The rapid development of economy makes china’s energy demand on the increase. With the increasing of ship traffic flow and the development of large-scale, ship oil spill accidents occur more and more. In November 1983, "the East Ambassador" ship in Qingdao port ran aground, 3,343 tons oil overflowing due to hull damage, polluting the Jiaozhou Bay, nearly 230 km of coastline, economic loss to tens of millions of yuan (Li, 1999, p. 4). On March 24, 1999, heavy oil tankers "Min Ran Gong 2" collided with the channel in the Pearl River, about 589.7 tons heavy oil spilled. On July 18 2010, oil tank pipeline fired, resulting in huge quantities of crude oil leakage in Dalian Xingang port, polluting approximately 100 km^2 port water, marine ecological environment severely disrupted. As shown in Figure 1-1.

Figure 1-1 The "7.16" major oil spill accident happened in Dalian Xingang port in 2010.

Source: Retrieved June 6, 2014 from the World Wide Web: http://image.baidu.com/i?ct=503316480&z=&tn=baiduimagedetail&ipn

Shanghai is one of the world's famous trade ports, also one of the largest port in China. 99% of Shanghai foreign trade goods are via port in and out. In recent years, with the development of petrochemical industry, Shanghai's demand for oil and chemicals volume is increasing by 10% year by year. More than 90% of the oil and chemicals are transported by ship (Yu, 2007, p. 225), thus making petroleum and chemical production more and more frequent in Shanghai.

In short, rapid development of port and waterway economic increase the risk of marine oil spill pollution in Shanghai Port waters. It is important to carry out ship oil spill accident risk assessment research in Shanghai Port waters, identify and analyze the possible locations, quantity, characteristics and harm degree of oil spill, and put forward corresponding preventive measures to reduce risk. It will help the Maritime Safety Administration (MSA) more effectively to deal with accidents and minimize harm and durability influence of oil spill. For the next step, it has important theoretical significance and practical value to prevent and control the pollution from the ship and its related activities.

1.2 The behavior of oil spill and the research status

1.2.1 The behavior of oil spill

Due to the effect of marine advection, drift, and its own gravity, the effect of shear flow and turbulent flow and spreading around, oil is constantly complex physical, chemical, and biological change after it spills into the ocean. In summary, after oil spills into the ocean, it has three different dynamic behaviors: drift, diffusion and weathering.

1.2.1.1 Marine oil spill drift

Drift refers to the surface of the oil film under the action of wind, current and wave moving from one location to another. Under the wind current, pressure gradient flow, density flow, dilute under the joint action of currents and tide, the synthetic vector field construction of oil film drift flow field (Shao, 1999, p. 2). When the oil spill accidents happen in offshore waters, two factors deciding the oil spill trajectories are tide and wind drift. Generally, we can use a numerical method to simulate the tide and wind drift field, as shown in Figure 1-2.

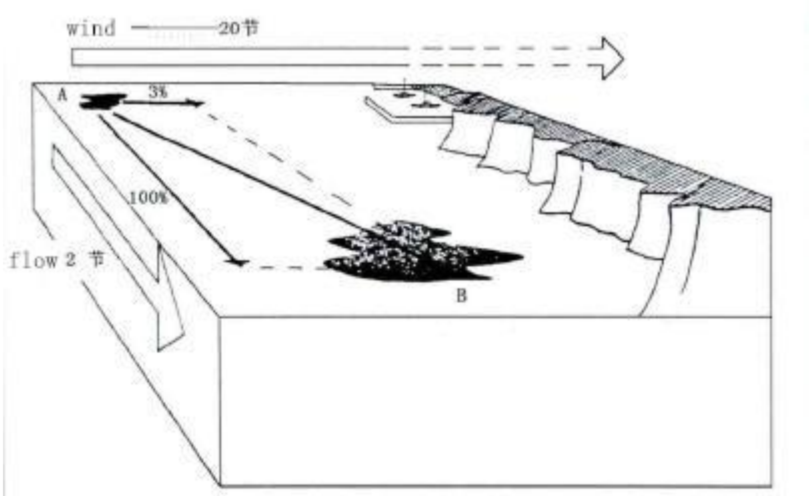


Figure 1-2 The schematic Figure of marine oil spill drift.

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

1.2.1.2 The spread of the oil spill at sea

Early into the marine environment, the oil film under its own gravity, the net surface tension, inertia force, viscous oil/water interface force, internal sticky, the action of force and so on expand itself around, but this process is very short. Turbulence and shear flow play a very important role in the spread of the oil spill in marine environment. Because of the average distribution of flow space, it leads to deformation of the oil film (i.e. distorted or spin). Ocean turbulence makes oil spill spread around, oil film covering and product change (Ma, 1998, p. 5).

1.2.1.3 The weathering process of oil spill at sea

The weathering process is also an important process of oil spill at sea. It mainly includes evaporation, emulsification, dissolve, disperse, light oxidation and biodegradation, etc. In the process of weathering, viscosity and density of the oil film also change accordingly.

1.2.2 The Research status

1.2.2.1 Oil spill drift forecasting model

The study of the diffusion model of oil spill began in the 1960s in the world. With free oil as an extension in the plane of the premise, from the conservation of mass of the oil film, Blocker established expanding diameter formula in 1964 (Chen, 1998, p. 6). In 1971, Fay proposed the theory of three phase oil film extension, namely the gravity-inertia force phase, the gravity-viscous force phase and surface tension-viscous force phase (Chen, 1998, p. 7). The theory got groundbreaking results in the application of extension of oil spill model. But these models cannot effectively simulate oil spill on a lee oval extension and broken up. Lehr modified oil film diffusion model based on the study of the Fay in 1984 (Chen, 1998, p. 9). In 1986, Elliot put forward and established a concept of "oil particle", which can effectively overcome the traditional numerical simulation methods of divergence, and successfully simulate oil film crushing process (Chen, 1998, p. 10).

Since then, a large number of oil spill drift forecasting models made use of oil particle model in the world, and gradually changed from the two-dimensional drift diffusion to vertical movement of oil spill (Zhao, 2006, p.40). Research progress on oil spill model of the 20th century, oil spill drift prediction mainly depends on the development of calculation. Over the past 10 years, with the large increase in computing capacity, super computer application has become more and more widely. Quick prediction of three-dimensional ocean environmental dynamics can provide support for the drift prediction of oil spill. In 2010, when the "Deepwater Horizon" drilling platform spilt oil into the Gulf of Mexico, National Oceanic and Atmospheric Administration (NOAA) used six gulf circulation real-time forecasting model to support the surface of the trajectory prediction of oil spill (Liu, 2010).

The research on oil spill model began in 1990s in China. In 1994, Zheng lianyuan set up a three-dimensional forecast model of oil spill, which used Lagrange method to forecast heart movement of oil spill (Zheng, 1996, p. 6). Zhang Cunzhi established a three-dimensional dynamic forecast model of oil spill and applied to Bohai Bay. The model simulation results coincide with satellite data (Zhang, 1998, p. 21). Based on GIS, Liu Yancheng set up marine oil spill drift diffusion model in 2002. In recent years, domestic scholars actively try to establish a more comprehensive sea drift diffusion model, and had reached the international advanced level (Liu, 2002, p. 216).

In conclusion, the study of the surface of the oil spill drift diffusion model, both at home and abroad, have achieved significant results. At present, oil particle track method is adopted internationally. The method adopts a certain number with characteristics of Lagrange "oil particles" representing oil spill, by the method of additional attributes for each particle’s quality, properties, volume, density of the letter interest rates, record its three-dimensional space coordinates, weight, change information such as the nature, finally through the statistics of all particles to determine the time and space distribution of oil spill in marine environment.

1.2.2.2 Oil spill weathering model

Spilled oil weathering model is mainly used for predicting oil spill properties changes (such as the rate of evaporation, degree, density) in marine environment. Thus it can provide important information for the action of the oil spill emergency decision makers. In general, spilled oil weathering model can calculate oil film extension, evaporation, emulsification, dispersion, sedimentation process, etc (Xiao, 2001). At present, the spilled oil weathering model mainly has two types: one is based on the experience of mathematical equation to calculate spilled oil properties change, the other is based on the experimental number to calculate spilled oil properties change.

Developed countries studied on mathematical model of the weathering process in earlier time. On the empirical model research, Stiver and Mackay (1984) established the mathematical model of the petroleum hydrocarbon and oil mixture evaporation rate in 1984 (Wang, 1990, p. 230). In 1987, Payne established the calculation of oil and suspended particle interaction model. Based on the experiment, Delvigne and Sweeney set up a model to calculate the dispersion process of oil spill (Jiang, 1993, p. 6). With the research and the actual need, Norway and the United States pay more attention to establish the model of weathering combined with a large number of experimental results. At present, Norway SINTEF institute developed OWM commercial oil spill weathering model (Zheng, 1994, p. 17), and the United States NOAA developed ADIOS1 and ADIOS2 weathering model for free use (Zheng, 1994, p. 19). After 20 years of development, the two models get more widely used around the world. Among them, the SINTEF weathering model has a large database. It includes more than 200 kinds of oil properties, distillation curve and laboratory weathering data; ADIOS2 weathering model adopts thousands of oil and oil products to get the result of the direct measurement (Zheng, 1994, p. 20).

Study on weathering process and model of oil spill began in the 1980s in China. Yang Qingxiao analyzed the oil weathering progress in 1984 (Yan, 2001, p. 225). In 1987, Xu Xueren studied photochemical oxidation of oil in marine environment. Wang Liansheng studied the biological process of oil in 1988(Yan, 2001, p. 226). Yang Qingxiao studied emulsification under the action of broken waves in 1997 (Yan, 2001, p. 227). On the basis of oil spill model and weathering experiment in the laboratory, using VB6.0 professional edition and ACCESS database software, Yan Zhiyu established the weathering forecast model of oil spill in 2001(Yan, 2001, p. 230). In 2006, on the basis of reference oil weathering model, Xu Yandong established the Dalian Bay waters weathering model for prediction of oil spill (Zhou, 2009).

Compared with the research abroad, China has carried out weathering experiment study and set up some empirical model, unable to establish a model like OWM and ADIOS based on a large number of experimental data. In recent years, the State Oceanic Administration and Yantai Oil Spill Response Technical Monitoring Center have gotten obvious progress in "oil fingerprint" identification which used in ships, offshore oil platform (Jiang, 2010, p. 21). Apparently, the course of weathering experiment can provide data support for the research of spilled oil weathering model.

1.3 Environmental risk assessment research status quo of oil spill

1.3.1 The content of the environmental risk assessment

Environmental risk refers to the sudden accident (not including natural disaster and contingency) doing harm to the environment (or health and economy) (Zheng, 2003, p. 35). We use R to represent risk value, define accident probability as P and environment (or health and economy) consequences as C, thus we can get:

R(Risk)＝P(Probability)×C(Consequence)

Environmental risk assessment generally includes risk identification, hazard analysis, consequence forecast, risk evaluation calculation and risk management. Similarly, the environmental risk assessment of ship oil spill pollution refers to the vessel occur sudden oil spill in the navigation and operation. Oil spill pollution risk R can be defined as the oil spill accident probability P multiplied by pollution hazard consequences C:

R (oil spill pollution risk) = P (oil spill probability) × C (pollution hazard consequences)

1.3.2 International oil spill environmental risk assessment research status

The earlier shipping transportation risk model was set up in 1990 by Det Norske Veritas (DNV) to study the port health and safety risk assessment. The model had great influence the later oil spill risk assessment. The model calculates different area risk index, combined with the accident frequency (frequency) of oil spill and the size of the oil spill (size) (Song, 1997). At the same time, it also considers the oil spill from a regional points to the possibility of diffusion (diffusion factors), and different oil in the environment performance (oil factors).

According to Russia's proposal, the International Maritime Organization (IMO) decided to develop the oil spill risk and preparedness level assessment guide in the 49th session of the Marine Environment Protection Committee (MEPC). At present, the guide preliminary studies suggest that different risk assessment method is suitable for different levels (regional, national or local), and the guide will provide two methods-quantitative and qualitative (Wang, 2003).

1.3.3 Domestic oil spill environmental risk assessment methods

At present, the research methods adopt oil spill pollution accident risk analysis, mainly including: based on ship traffic pollution accidents (or port throughput) to determine the risk area and probability of accident, based on quantity of oil spill to determine harmful consequences. Then they carry out a comprehensive risk analysis, find out the influence factors to prevent accidents, and seek solution to compensation.

1.4 Research contents of the thesis

In this thesis, on the basis of the above research, combined with the regional characteristics of Shanghai Port, the expansion of ship oil spill in the narrow waterway and pollution hazard assessment will be discussed. The harbor area (mainly the Huangpu River, the Yangtze River, etc.) will be discussed firstly, then Shanghai jurisdiction of other areas. The results will provide auxiliary to Shanghai Port ship oil spill emergency disposal, such as the scope of ship oil spill estimates, the determination of the ship oil spill emergency preplan start. At the same time, the author puts forward some countermeasures to Shanghai Port ship oil spill prevention and control, such as skimmers and equipment equipped, the selection of oil spill disposal methods, oil spill prevention and control means, etc.

Chapter 2 An overview of Shanghai Port

2.1 Traffic situation of Shanghai Port

2.1.1 Port condition

Shanghai Port is located in the middle of China's mainland coastline, with the Yangtze River and the East China Sea at 31° 14′ N 121° 29′ E31. Shanghai sits at main axis intersection along the Yangtze River and coastal development zone "T" type. The amphibious transportation is convenient, with internal and external two-way radiation location advantage, international routes associated with both domestic and global port. As the economic center of China, Shanghai and its nearby cities have formed a large scale, complete functions, wide radiation of the Yangtze River delta port group, in the eastern part of economic development, and important strategic significance. In 2013, Shanghai Port’s cargo throughput up to 776 million tons and the container throughput is up to 33.6 million TEU, both continue to keep the first position of the world (Wu, 2013, p. 21).

2.1.2 Wharf condition

Shanghai Port wharf is mainly distributed in the south bank of the Huangpu River, Yangtze River estuary, north of Hangzhou Bay and Yangshan deepwater port. By 2011, Shanghai’s coastal pier length is up to 119.7 km, and 1226 coastal berths. Among them, bulk oil berth 52, bulk chemical berth 25, mainly concentrated in the Huangpu River, Yangtze River estuary (Zhou, 2011, p. 5).

2.1.3 Wharf condition

Shanghai Port's main channel including: the main channel of Yangtze River -Shanghai sector, auxiliary channel, the Huangpu River, Yangshan deepwater port channel, small shipping channel, Jinshan harbour area channel and Caojing chemical industry zone channel. The length of channel is approximately up to 368 nm.

2.1.4 Anchorage condition

Shanghai Port currently has a total of 26 different types of anchorage, including 4 dangerous cargo anchorages, namely: Hengsha dangerous cargo anchorage, Jiangya temporary dangerous cargo anchorage, Jinshan dangerous cargo anchorage and Caojing chemical industry zone dangerous cargo anchorage.

2.2 Natural condition of Shanghai Port

2.2.1 Meteorological condition

The climate of Shanghai Port is subtropical maritime monsoon climate. Affected by alternating wind in winter and summer, Shanghai Port has obviously changed seasons. Warm and rainy in Shanghai Port all the year. Annual average temperature is around 16 ℃, annual rainfall is about 1148.8 mm. Southeast wind throughout the year round, strong wind is northeast wind. The typhoon happens in the summer and fall, above 10 level typhoon once every two years, on average. Fog day in Shanghai is on average 43.3 days throughout the year, the Yangtze River estuary 24.2 days. In most cases, the duration of the fog is 2 to 3 hours, there has a little influence on the shipping, loading and unloading. The channels have no freezing phenomenon in one hundred years (Xiao, 2001, p. 44).

2.2.2 Hydrological condition

The Huangpu River is a tidal River flow, informal semidiurnal tide, two tidal a day. The Yangtze River estuary is a regular semidiurnal week tide, two tidal a day. The average tidal range is 2 m to 2.5 m.

2.3 Sensitive resources situation

Shanghai Port has about 450 km of coastline, more than 900 km^2 of tidal flats, 13 islands and about 7200 km^2 offshore sea area. Because of the influence of the Yangtze River and the Qiantang River, coastal of Shanghai Port belongs to the typical River estuarine ecosystem. The environmental sensitive area in Shanghai Port refers to natural conservation area, source of drinking water, tourism resource and conservation of aquatic resources. The presence of these sensitive resources increases the effect of ship oil spill accidents.

2.3.1 Natural conservation area

Shanghai has built four natural conservation areas, including the Jinshan marine ecological reserve, Chongming Dongtan bird nature reserve, Jiuduansha shoals wetland nature reserve and the Yangtze estuary Chinese sturgeon larvae nature reserves.

2.3.2 Source of drinking water

At present, a total of more than 70 drinking water sources (including those under construction) have been built in Shanghai, including four key drinking water sources

(Huangpu River upstream, Chenhang reservoir, Qingcao sand and Chongming dongfeng). Shanghai municipal drinking water sources protection zone is divided into reserves and prospective reserves. In the Qingcao sand and Chongming dongfeng drinking water sources, the shipping traffic is banned. In the Huangpu River upstream water source, other drinking water reserves and prospective reserves, it is prohibited to transport highly toxic chemicals and hazardous waste except waste mineral oil passage of the ship.

2.3.3 Tourism resources

Shanghai is rich in tourism resources, which is one of the most important tourism cities in China. The major tourist attractions in Shanghai have: Sanjia port beach Lujiazui tourism area, Jinshan city beach, Riverside forest park, ocean islands, the EXPO tourist area, Nanhui mouth view sea park and the Fengxian Bay tourist area.

2.3.4 Conservation of aquatic resources

Advantaged natural conditions of the Yangtze River estuary make biodiversity abundance rich fishing industry resources. There are not only the Japanese eel, the rock crab, Songjiang envy famous fish, and other aquatic organisms, but also the Chinese sturgeon, the Baiji, shaggy fruited dittany finless porpoise and mullet.

2.4 Vessel traffic flow

The traffic flow has a direct impact on the ship oil spill risk. Shanghai Port's traffic flow is the most densest flow in China. There have Table 2-1 show the Shanghai Port traffic flow respectively from 2008 to 2013.

Table 2-1 Shanghai Port vessel traffic flow.

Year	River boats	Seagoing ships	Total
2008	1697650	136429	1834079
2009	1725965	132722	1858687
2010	1750630	118390	1869020
2011	1811690	139051	1950741
2012	1712404	154932	1867336
2013	1484558	179460	1664018

Figure 2-1 Shanghai Port vessel traffic flow and types from 2008 to 2013.

Source: compiled by the author Chang Jingzhou (June 6, 2014) from Shanghai MSA.

From the above data we can see: Firstly, in recent years in Shanghai Port, ship traffic flow stabilizes in more than 1.6 million a year. Secondly, the quantity of river boats still accounts for the vast majority of Shanghai shipping quantity. But, the overall number of river boats is declining. Thirdly, the number of seagoing ship has a significant growth since 2010.

2.5 The numbers and characteristics of ship oil spill in Shanghai Port

Due to the economic development of Shanghai, shipping has become a major source of environmental pollution. According to statistics, from 2004 to 2013, there are 76 ship oil spill accidents in Shanghai Port, with accumulative total of 1429.17 tons of oil spill. It means that 7.6 ship oil spill pollution happening in Shanghai Port per year, average 142.92 tons of oil spill per year. (See Table 2-2 and Appendix-1)

Table 2-2 The number and characteristics of ship oil spill in Shanghai Port from 2004 to 2013.

Items / Year	*Ordinary oil spill accident (tons)*	*Number*	*Major oil spill accident (tons)*	*Number*	*Extraordinary serious oil spill accident (tons)*	*Number*
2004	*0.158*	*6*	*30*	*1*	*0*	*0*
2005	*3.48*	*15*	*0*	*0*	*252.82*	*2*
2006	*11.885*	*9*	*18.11*	*1*	*0*	*0*
2007	*12.38*	*9*	*20.33*	*1*	*92.33*	*2*
2008	*1.63*	*4*	*16.3*	*1*	*0*	*0*
2009	*18.7*	*3*	*0*	*0*	*126.5*	*1*
2010	*5.962*	*5*	*14*	*1*	*0*	*0*
2011	*3.275*	*4*	*0*	*0*	*0*	*0*
2012	*1.41*	*3*	*10.185*	*1*	*161*	*1*
2013	*5.437*	*4*	*10*	*1*	*613.278*	*1*
Total	*64.317*	*62*	*118.925*	*7*	*1245.928*	*7*

Source: compiled by the author Chang Jingzhou (June 6, 2014) from Shanghai MSA.

In recent years in Shanghai Port waters, oil spill accidents can be summed up in the following features: (1) the number of ship oil spill accident in general is on the decline, but the scale of oil spill is increasing; (2) the number and quantity of ship oil spill accidents have contingency and unpredictability; (3) because of the development of small and medium-sized shipping companies in Shanghai port, a large number of poor technical conditions, long ship age, small tonnage of ships involve in water transportation industry, therefore, the ship become a major oil spill risk source; (4) collision and improper operation is respectively the main reason of accidental oil spills and operational oil spills.

2.6 Analysis on the probability of ship oil spill accident

Ship oil spill accident is divided to two types: operational oil spills and accidental oil spills. Analyzing the statistic of ship oil spill accidents, most of them belong to operational oil spill accident. And the quantity of oil spill is little, generally below 10 tons. Although the number of accidental oil spills is small, the oil spill quantity is big-mostly more than 50 tons, sometimes even up to thousands of tons. Thus it makes big damage to the marine environment. The reason of accidental ship oil spill accident mainly including: collision, sinking, stranding, etc. From Table 2-2 and Appendix-1, since 2004, 7 major oil spill accidents and 7 extraordinary serious oil spill accidents are all caused by collision in Shanghai Port.

From Table 2-2 and Appendix-1, Shanghai Port ship oil spill accident statistics shows: 76 oil spill accidents include 54 operational oil spills and 22 accidental oil spills. The frequency of operational oil spills is 5.4 per year, and the accidental oil spills is 2.2 per year. The average quantity of operational oil spills is only 1 ton, but the average quantity of accidental oil spills is about 62 tons. Apparently, the type of oil spill accident which spilling the largest number of oil is accidental oil spills.

In 2013, Shanghai Port cargo throughput is a total of 776 million tons, the frequency of ship oil spill accident is 0.23 per one million tons. In 2010, Shanghai Port vessel traffic flow is a total of 1664018, and the rate of accident is about 1.3‰(Wu, 2013, p. 5).

Chapter 3 Ship Oil Spill Risk Assessment in Shanghai Port

3.1 Overview

With the progress of science and technology and the improvement of management level, factors of ship oil spill accident have been obviously controlled, but oil spill accidents continue to happen. These accidents will affect the people's life that lives along the River and those people who benefit from marine resources. In most cases, the damage is temporary due to harmful physical properties of oil. But, sometimes it needs to take cleaning measures over the years. In rare cases, the damage can be irreversible. Depending on the toxicity and pollution of the oil’s chemical composition, it has a composite influence on the marine life and the diversity of ecosystems. However, if the measures are taken properly and timely, the damage to the environment will be reduced to a minimum degree (Li, 2000, p. 36).

Ship pollution prevention and control technology are the basis of ship pollution prevention and control engineering. Accurate evaluation for technical condition directly affects the rationality and scientific nature of ship pollution prevention plan. The influence factors for prevention and control of vessel pollution technology are usually limited to the qualitative description of the assessment, the fuzzy evaluation results, the analysis and comparison (Zhang, 1998). Therefore, it is necessary to use ship pollution prevention and control of quantitative techniques, and to make the result of the technology of prevention and control of marine pollution more quantity value and more explicit.

3.2 Prediction model of spreading of ship oil spill in Shanghai Port

Due to the changing of the tides, the instability of water flow velocity and the complicated changeable wind, it is difficult to make technical processing on sudden pollution accident. But, with the research and development of digital watershed technology and aid decision making system of sudden pollution accident, it provides advanced technology support to deal with the sudden accident. Once local pollution and local part of the monitoring project are up to the alert standard of system, it will immediately call internal prediction model to perform pollution impact prediction. According to the result of the impact prediction, it will use the system optimization model plan to choose optimization decision-making, when possible pollution accident happens.

Shanghai Port waters have three main types: narrow River waters, coastal waters and intersection waters. And the narrow River waters include the Huangpu River and the Yangtze River water. Coastal waters center in the outside of the adjacent waters of Yangtze estuary and the Hangzhou Bay. Intersection water refers to the Yangtze River estuary waters. The research emphasis of this thesis focuses on the ship oil spill diffusion model in narrow River waters.

3.2.1 Technology quantitative model of ship oil spill accident

In order to make the system achieve the above aims, sudden pollution accident simulation model must have the following features:

Firstly, it must have a faster convergence speed, thus we can make a quick prediction after the pollution accident happens.

Secondly, it must have a good stability, thus we can calculate the reasonable result in a variety of geographical conditions and hydrologic conditions.

Thirdly, it must be a simple and feasible operation process, thus we can provide a scientific and feasible solution to the pollution after the accident happens. According to characteristics of these requirements, Dr. Zheng Wenbo put forward a simulation model in which sudden pollution accident happened in a River (Chen, 2001, p. 225). The basic idea is that pollutant flows continuously into the direction of low concentration, due to the concentration difference. When reaching a steady state, the quantity of pollutants in the damage zone gets balance with the quantity of pollutants in low concentration zone which gets resources from the damage zone. In a word, it means pollutants were no longer expanded.

3.2.2 Principle of simulation model

Suppose u and v, respectively represents x axis and y axis vertical mean velocity, t means the time required for pollution diffuse to a certain range, h as a benchmark of the water (benchmark surface on the basis of the Yellow Sea in China) to the surface of the vertical distance, H as the benchmark vertical distance to the bottom of the River water, $\boldsymbol{\varepsilon}$ is the diffusion coefficient of oil pollution, $\boldsymbol{\varepsilon_x}$, $\boldsymbol{\varepsilon_y}$ respectively represent x axis and y axis direction sewage diffusion coefficient, C is the pollutants concentration, D_x and D_y represent pollutants turbulent diffusion coefficient, s is the source of pollutants, R is pollutants variation in the process of diffusion concentration, g is the gravitational acceleration, $\boldsymbol{s_c}$ is pollution load, f_x , $\boldsymbol{f_y}$ mean the bottom frictional resistance and C_f is experience friction coefficient (Yang, 2004, p. 2).

So, the pollutant diffusion equation is:

$$\begin{cases} \frac{\partial h}{\partial t}+\frac{\partial uH}{\partial x}+\frac{\partial vH}{\partial y}=0 \\ \frac{\partial uH}{\partial t}+\frac{\partial u\cdot uH}{\partial x}-\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial uH}{\partial x}\right)+\frac{\partial u\cdot vh}{\partial y}-\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial uH}{\partial y}\right)= \\ -f_x-H\cdot g\cdot\frac{\partial h}{\partial x}+\frac{\partial}{\partial x}\left(\varepsilon H\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon H\frac{\partial v}{\partial x}\right) \\ \frac{\partial uH}{\partial t}+\frac{\partial u\cdot uH}{\partial x}-\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial vH}{\partial x}\right)+\frac{\partial v\cdot vH}{\partial y}-\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial vh}{\partial y}\right)= \\ -f_y-H\cdot g\cdot\frac{\partial h}{\partial y}+\frac{\partial}{\partial x}\left(\varepsilon H\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial x}\left(\varepsilon H\frac{\partial v}{\partial y}\right) \\ \frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=D_x\frac{\partial^2 c}{\partial x^2}+D_y\frac{\partial^2 c}{\partial y^2}+s+R \end{cases} \quad (3\text{-}1)$$

The bottom frictional resistance of two directions as follows:

$$f_x=\rho C_f u\sqrt{u^2+v^2}$$

$$f_y=\rho C_f v\sqrt{u^2+v^2}$$

Through induction, formula (3-1) can be represented by formula (3-2) :

$$\frac{\partial(\rho\phi u-\Gamma\frac{\partial\phi}{\partial x})}{\partial x}+\frac{\partial(\rho\phi v-\Gamma\frac{\partial\phi}{\partial y})}{\partial y}=s \quad (3\text{-}2)$$

In the formula, $\emptyset$ represents the spatial distribution function of the pollutant.

3.2.3 Simulation model in the application of correction

This model puts the oil pollution as a strict rectangle, but it does not exist in real life.

The shape of oil pollution is highly irregular, so the model needs to be improved. According to the water conservancy expert Baumann's method and through model transformation, the formula (3-2) can be rewritten as (Yang, 2004, p. 3):

$$\left[\frac{\partial(Hu\phi)}{\partial\zeta}+\frac{\partial(Hv\phi)}{\partial\eta}\right]=$$

$$\frac{\partial}{\partial\eta}\left(\frac{\varepsilon.H}{J}\alpha\phi_{\zeta}\right)+\frac{\partial}{\partial\eta}\left(\frac{\varepsilon.H}{J}\gamma\phi_{\eta}\right)-\frac{\partial}{\partial\zeta}\left(\frac{\varepsilon.H}{J}\beta\phi_{\eta}\right)+\frac{\partial}{\partial\eta}\left(\frac{\varepsilon.H}{J}\beta\phi_{\zeta}\right)+J.S(\zeta,.\eta) \quad (3\text{-}3)$$

If:

$$J.S.R(\zeta,\eta)=-\left[\frac{\partial}{\partial\zeta}\left(\frac{\Gamma}{J}\beta\phi_{\eta}\right)+\frac{\partial}{\partial\eta}\left(\frac{\Gamma}{J}\beta\phi_{\zeta}\right)\right]+J.S(\zeta,\eta) \quad (3\text{-}4)$$

Thus, the (3-3) can be rewritten as:

$$\left[\frac{\partial(Hu\phi)}{\partial\zeta}-\frac{\partial}{\partial\zeta}\left(\frac{\varepsilon.H}{J}\alpha\phi_{\zeta}\right)\right]+\left[\frac{\partial(Hv\phi}{\partial\eta}-\frac{\partial}{\partial\eta}\left(\frac{\varepsilon.H}{J}\gamma\phi_{\eta}\right)\right]=J.SR(\zeta,\eta) \quad (3\text{-}5)$$

3.2.4 Numerical computing method of the simulation model

The above discrete transformed formula can be operated by using SIMPLEC method. In order to achieve the effect of convergence and fast calculation, operation process uses finite difference method for numerical solution, finally we can get the following iterations formula (Yang, 2004, p. 4):

$$(\zeta)_p=(\zeta)_p^{sr}+RLX\cdot(\zeta)_P^{*} \quad (3\text{-}6)$$

$$u_p = u_p^{st} + \left(B^u h_\zeta^{\cdot} + C^u h_\eta^{\cdot}\right) \qquad (3\text{-}7)$$

$$v_p = v_p^{st} + \left(B^v h_\zeta^{\cdot} + C^v h_\eta^{\cdot}\right) \qquad (3\text{-}8)$$

$$U_p = U_p^{st} + B \cdot h_\eta^{\cdot} \qquad (3\text{-}9)$$

$$V_p = V_p^{st} + B \cdot h_\eta^{\cdot} \qquad (3\text{-}10)$$

The concrete operation process is as follows:

Firstly, we can get the initial pollutant concentration from the initial conditions. Through the initial pollutant concentration, we can get prediction speed u_p and v_p

Secondly, we can calculate the revised pollutant concentration by the pollutant concentration correction term. Then, through the speed correction term, we can get the revised speed value U、 V.

Thirdly, considering the influence of boundary factors, the revised pollutant concentration is seen as a new initial density back to formula (3-2) to calculate again. Thus, the whole calculation process can be done through computer operation (Yang, 2004, p. 5).

3.2.5 Ship oil spill accident technical quantitative models applied in Shanghai Port

Dr. Zheng Wenbo’s simulation model has a great practical value in the prevention and control of ship oil spill accident in Shanghai Port. Take the oil spill accident of "Changyang" ship (which happened on August 15, 2003) for example:

Assuming the average flow velocity of water is 1. 8 m/s, there is a COD 40 g/s pollution sources distance from the shore. In the process of calculation, we take $\triangle x = 100\text{-}150m$, $\triangle y = 100\text{-}150m$, $\triangle t = 60$, then we carry out iterative calculation. After 1 minute, the damage zone is up to 2400 m. Then, 4100 m after 2 minutes, 7500 m after 3 minutes..., 25 minutes up to 9700 m (Yang, 2004, p. 4). When reaching a steady state, the quantity of pollutants in the damage zone gets balance with the quantity of pollutants in low concentration zone which gets resources from the damage zone. In a word, it means pollutants are no longer expanded. Through continuously iterative calculation, the whole calculation process was basically stable after approximately 4 hours. That is to say, pollutants were no longer diffused after 4 hours. Computational simulation is shown in Figure 3-1-3-4.

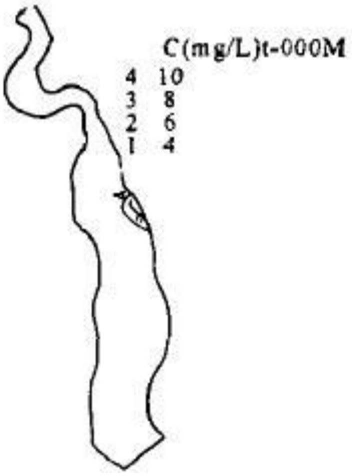


Figure 3-1 Damage zone (0 minute)

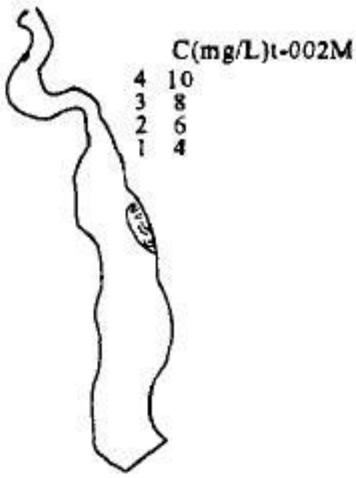
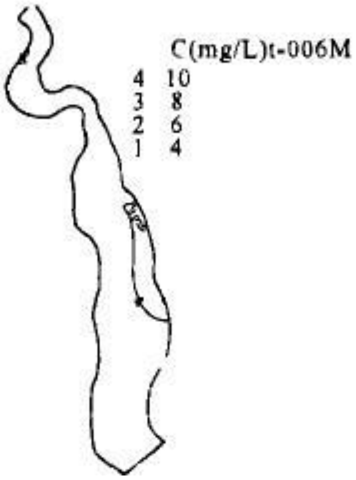


Figure 3-2 Damage zone (2 minute)



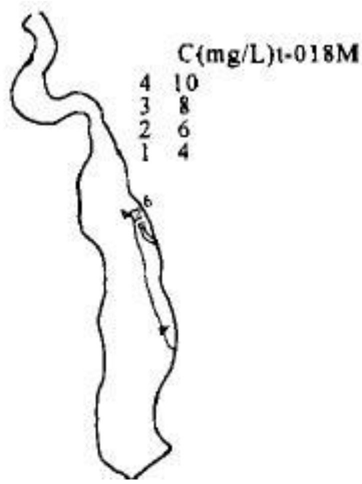


Figure 3-3 Damage zone (6 minute) Figure 3-4 Damage zone (18 minute)

Figure 3-1 to 3-4 Damage zone

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

According to the results of calculation, we can take action right away, rushing to the scene to control the situation. Thus, it will greatly reduce the unpredictability and blindness of oil spill accident.

3.3 Shanghai Port ship oil spill risk assessment model

The damage caused by ship oil spill pollution is very big, involving multiple subsystems and multiple environments, cultural elements. Ship oil spill pollution hazard assessment is a multilevel evaluation process, based on environmental and humanistic quality evaluation. According to the actual situation of Shanghai Port, combined with "IMO oil pollution manual Part IV" and the Shanghai maritime ship pollution emergency plan, this thesis uses the theory and model of Analytic Hierarchy Process (AHP) to establish Shanghai Port ship oil spill pollution multistage evaluation pattern and grasp the risk assessment of ship oil spill pollution quickly and effectively (Chen, 2001, p. 14).

3.3.1 The theory of Analytic Hierarchy Process (AHP)

AHP (Analytical Hierarchy Process) was put forward firstly by the operational research expert T. L. Saaty in the 1970 s. It is a decision-making method of qualitative and quantitative analysis, which divides related elements into the objective, criteria and solution, etc. The characteristic of this method is to perform deeper analysis on the essence of the problem, affecting factors and internal relations by using less quantitative information (Yan, 2000, p. 232). It makes decision thinking process model mathematically, thus providing simple and convenient decision-making method for multiple objectives, criterion, and no structural characteristics of complicated decision-making problem. It is especially suitable for the occasion in which it is difficult to accurate measurement directly.

The whole process of the Analytic Hierarchy Process (AHP) embodies the people's basic characteristics of the decision-making, namely decomposition, judgement and synthesis. Combining quantitative and qualitative analysis, it facilitates the communication between the decision makers. It is also a very efficient system analysis method, widely used in the economic management planning, exploitation and utilization of energy and resource analysis, industry planning, manpower forecasting, transportation, analysis of water resources utilization, etc (Li, 2002).

The Analytic Hierarchy Process (AHP) model is mainly divided into the following four steps:

Step 1: set up class hierarchy model;

Step 2: construct the judgment matrix in various levels;

Step 3: hierarchical single sorting and consistency check;

Step 4: hierarchy total sorting and consistency check.

3.3.1.1 Setting up class hierarchy model

According to the theory of Analytic Hierarchy Process (AHP), the evaluation index will be divided into few groups according to the property. Each group constitutes a hierarchical structure, forming a multi-level evaluation index system. Generally, analytic hierarchy structure can be divided into three layers: the objective layer G, criterion layer and solution layer. The elements of criterion layer reign the elements of solution layer, at the same time, it is at the mercy of the objective layer G (Zhang, 2000, p. 4). Its structural hierarchy chart is shown in Figure 3-5:

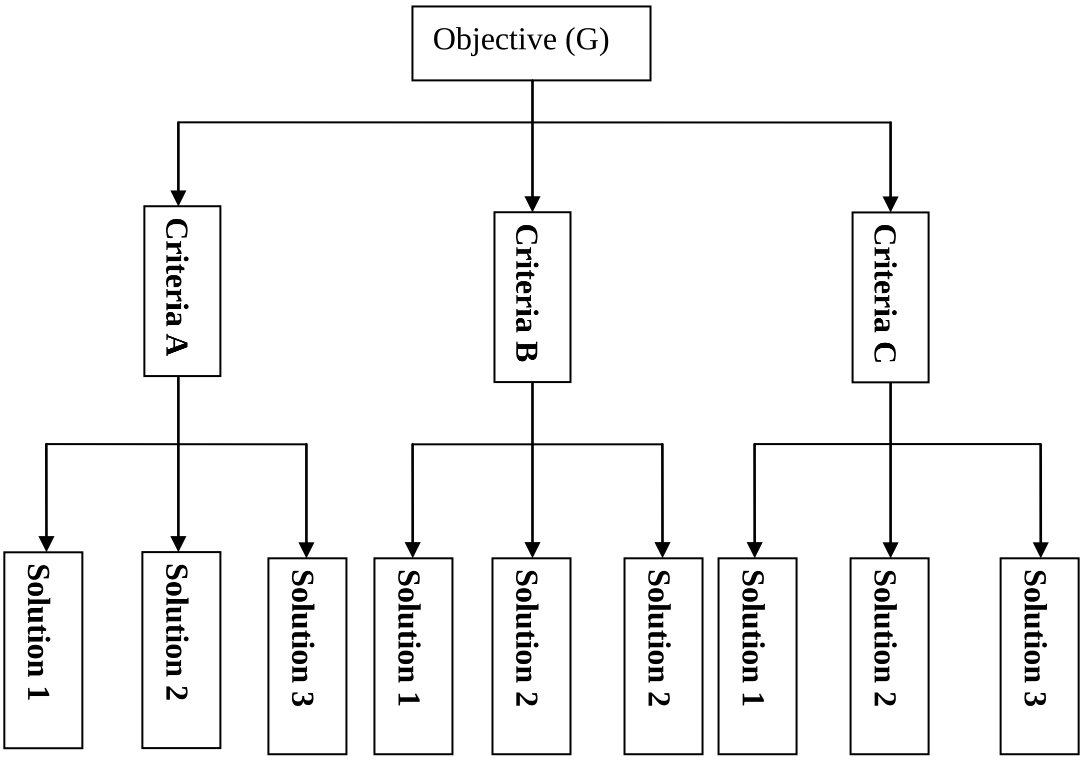


Figure 3-5 Analytic hierarchy structure chart

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

3.3.1.2 Construct comparative judgment matrix

According to the database, we can construct comparative judgment matrix by the method of pairwise comparison. To reduce the influence of subjective factors, first of all, we will make a relative importance comparison that belongs to the same index, forming the judgment matrix. Generally, index B_j (j=1, 2, ... , m) affiliated to the index A_i, its judgment matrix is a m dimensional matrix. See Table 3-1.

Table 3-1 The general form of the judgment matrix

A	B1	B2	…	Bm
B_1	B_{11}	B_{12}	…	B_{1m}
B_2	B_{21}	B_{22}	…	B_{2m}
…	…	…	…	…
B_m	B_{m1}	B_{m2}	…	B_{mm}

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

In the Table, B_{ij} affiliated to the A_i, it represents the importance of the index i relative to index j. It commonly uses ratio 1-9 scaling method proposed by Saaty (see Table 3-2).

Table 3-2 Judgment matrix scale and its meaning

Scale	Meaning
1	B_i is the same as B_j
3	B_i is a little important than B_j

5	B_i is obviously important than B_j
7	B_i is very important than B_j
9	B_i is extremely important than B_j
reciprocal	$B_{ij}=1/B_{ji}$
2, 4, 6, 8	B_i is the same as B_j

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

3.3.1.3 Hierarchical single sorting and consistency check

Sorting calculation method includes the power method, product method and root method. This paper uses the root method.

Step 1: calculate each line product M of judgment matrix:

$M_i=B_{i1} \cdot B_{i2} \cdot \ldots\ldots B_{ij}$ (i, j=1, 2, …, n)

Step 2: calculate $\overline{W_i}$

$$\overline{W_i} = \sqrt[n]{M_i}$$

$$\overline{W}=\overline{W_i}/\sum_{i=1}^{n} W_i \qquad W=(W_1,\ W_2,\ \ldots\ ,W_n)$$

Step 3: calculate the largest eigenvalues of judgement matrix $\boldsymbol{\lambda_{max}}$

$$\boldsymbol{\lambda_{max}}=\sum_{i=0}^{n}(AW)_i\,/nW_i$$

In order to get reasonable value and ensure to get the weight of rationality, it usually takes consistency check on every judgment matrix to see whether it satisfies the consistency. Otherwise, it modifies the judgment matrix, until it meets the consistency requirements. Computation formula is as follows:

$$CR=\frac{\boldsymbol{\lambda_{max}-n}}{(n-1)RI}<0.1$$

In the formula, RI represents the mean random consistency index. From 1 to 11, the RI is as follows:

Table 3-3 Random consistency index

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

3.3.1.4 Hierarchy total sorting and consistency check

Computing unified level for the sort of top (total goal) relative importance weights is referred to as level total sorts. This process means from the highest level to the lowest level, if higher level contains factors A_1、A_2, ... A_m, the next level B contains factors B_1、B_2, ... B_m, the level of the factors for A_j single sorting weight, respectively are b_{1j}, b_{2j}, … b_{nj} (when B_k has nothing to do with A_j, thus $b_{kj} = 0$). The level B of total sorts of weights are given in the Table below:

Table 3-4 The level B of total sorts of weights

B \ A	A_1	A_2	……	A_m	B total order value
	a_1	a_2	……	a_{ij}	
B_1	b_{11}	b_{12}	……	b_{1m}	$\sum_{j=0}^{m} a_i b_{1j}$
B_2	b_{21}	b_{22}	……	b_{2m}	$\sum_{j=0}^{m} a_i b_{2j}$

……	……	……	……	……	……
B_n	b_{n1}	b_{n2}	……	B	$\sum_{j=0}^{m} a_i b_{nj}$

Source: Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

If factors of B to A_j single sort of consistency refers to CI_j, the corresponding mean random consistency index is RI_j. Thus, the consistency ratio is:

$$CR = \frac{\sum_{j=0}^{m} a_j CI_j}{\sum_{j=0}^{m} a_j RI_j}$$

Similarly, when CR≤0.1, it means the judgment matrix satisfies the characteristic of consistency. Otherwise, it needs to adjust the judgment matrix element values, satisfying the consistency. By sorting and check, we can get the overall goal of the program and the hierarchical structure from the overall consistency index, and make decisions accordingly.

3.3.2 AHP apply in ship oil spill risk assessment in Shanghai Port

By analyzing oil spill accident, querying data and consulting, ignoring the minor factors, the author chooses four factors as evaluation indexes, including quantity of oil spill, varieties of oil spill, impacting area and movement trend of the oil spill. Due to many factors, the paired comparison analysis of Analytic Hierarchy Process (AHP) will produce a lot of matrix. Therefore, it makes the model simplified by the combined use of actual value and the judgment matrix, at the same time, complying with needs of practical application.

3.3.2.1 Comprehensive evaluation system

Due to the complexity and uncertainty of the environment and cultural factors, this thesis adopts the method that integrates the use of the judgment matrix and other factors in the practical application. Through the analysis of ship oil spill pollution hazard, we can see that the ship oil spill damage is generally divided into two categories: safety hazards and environmental hazards. Safety hazards include hazard to people and public safety. Environmental hazards contain: hazard to natural conservation, sources of drinking water, tourism resources, conservation of aquatic resources, various types of coastline, endangered plants and animals and habitats, intertidal creatures, farmland, swamps, and water-based facilities, etc.

The hazard of an oil spill accident depends on several factors, including: the quantity of oil spill, the characteristic of oil spill, the morphology of oil spill, weather conditions, sensitive area and so on. Through the analysis, this thesis combines with the characteristics of Shanghai Port and selected person, public safety as the hazards assessment items. Also the thesis selects natural conservation, sources of drinking water, tourism resources and conservation of aquatic resources as environmental assessment items.

In terms of influencing factors, this paper selects the quantity of oil spill, security features of oil spill, oil spill pollution characteristics, the impacting area, trend of movement and shoreline types as the main factors. As the main content of the analysis, this paper takes the meteorological conditions and seasons as secondary factors, reflecting in practical application through different values. This paper establishes the ship oil spill hazard assessment index class hierarchy shown in Table 3-5:

Table 3-5: Ship oil spill hazard assessment index class hierarchy

<table>
<tr><th>Objective layer</th><th colspan="2">Criterion layer</th><th>Solution layer</th></tr>
<tr><td rowspan="6">Ship oil spill hazards A</td><td rowspan="2">Safety hazards B1</td><td>Hazard to people B11</td><td rowspan="6">Quantity of oil spill C1
Safety characteristic of oil spill C2
Pollution characteristic of oil spill C3
The position and movement trend of oil spill C4</td></tr>
<tr><td>Hazard to public safety B12</td></tr>
<tr><td rowspan="4">Environmental hazards B2</td><td>Hazard to natural conservation area B21</td></tr>
<tr><td>Hazard to sources of drinking water B22</td></tr>
<tr><td>Hazard to tourism resources B23</td></tr>
<tr><td>Hazard to conservation of aquatic resources B24</td></tr>
</table>

Source: compiled by the author Chang Jingzhou (June 6, 2014) from Shanghai MSA.

3.3.2.2 Establishing comparative judgment matrix, sorting and consistency check

According to the above class hierarchy structure and the importance of each factor, we can get judgment matrix Table 3-4 to 3-12:

Table 3-6 Shanghai Port ship oil spill risk assessment judgment matrix

A	B1	B2	Weight
B1	1	1/2	0.67
B2	2	1	0.33

λ_{max}=2, CR=0

Table 3-7 Shanghai Port ship oil spill safety hazard judgment matrix

B1	B11	B12	Weight
B11	1	1/2	0.67
B12	2	1	0.33

λ_{max}=2, CR=0

Table 3-8 Shanghai Port ship oil spill pollution hazard assessment judgment matrix

B2	B21	B22	B23	B24	Weight
B21	1	1	3	5	0.40
B22	1	1	2	5	0.36
B23	1/3	1/2	1	3	0.17
B24	1/5	1/5	1/3	1	0.07

$\lambda_{max}=4.03, \quad CR=\frac{\lambda_{max}-n}{(n-1)RI}=0.013\leqslant 0.1$

The above result is effective.

Table 3-9 Shanghai Port ship oil spill risk assessment judgment matrix (hazard to people)

B11	C1	C2	C3	Weight
C1	1	1/3	1	0.20
C2	3	1	3	0.60
C3	1	1/3	1	0.20

λ_{max}=3.00, $CR=\frac{\lambda_{max}-n}{(n-1)RI}$=0.00004≤0.1

The above result is effective.

Table 3-10 Shanghai Port ship oil spill risk assessment judgment matrix (hazard to public safety)

B12	C1	C2	C3	Weight
C1	1	1/3	1	0.14
C2	3	1	1/2	0.53
C3	1	2	1	0.33

λ_{max}=3.05, $CR=\frac{\lambda_{max}-n}{(n-1)RI}$=0.003≤0.1

The above result is effective.

Table 3-11 Shanghai Port ship oil spill risk assessment judgment matrix (hazard to natural conservation)

B21	C1	C2	C3	Weight
C1	1	3	1/3	0.26
C2	1/3	1	1/5	0.11
C3	3	5	1	0.63

λ_{max}=3.04, $CR=\frac{\lambda_{max}-n}{(n-1)RI}$=0.02≤0.1

The above result is effective.

Table 3-12 Shanghai Port ship oil spill risk assessment judgment matrix (hazard to sources of drinking water)

B22	C1	C2	C3	Weight
C1	1	2	1/3	0.25
C2	1/2	1	1/3	0.16
C3	3	3	1	0.59

λ_{max}=3.05, $CR=\frac{\lambda_{max}-n}{(n-1)RI}=0.03\leqslant 0.1$

The above result is effective.

Table 3-13 Shanghai Port ship oil spill risk assessment judgment matrix (hazard to tourism resources)

B23	C1	C2	C3	Weight
C1	1	1	1/3	0.20
C2	1/2	1	1/3	0.20
C3	3	3	1	0.60

λ_{max}=3.00, $CR=\frac{\lambda_{max}-n}{(n-1)RI}=0.00004\leqslant 0.1$

The above result is effective.

Table 3-14 Shanghai Port ship oil spill risk assessment judgment matrix (hazard to conservation of aquatic resources)

B24	C1	C2	C3	Weight
C1	1	3	1/3	0.26
C2	1/3	1	1/5	0.11
C3	3	5	1	0.63

λ_{max}=3.04, $CR=\frac{\lambda_{max}-n}{(n-1)RI}=0.02\leqslant 0.1$

The above result is effective.

3.3.2.3 Total sorting and consistency check

According to the calculation results, we can get the total results as Table 3-13:

Table 3-15: Total sorting and consistency check

B_{ij}	Safety hazard		Environmental hazard				
	0.67		0.33				Total sorting
B_{ij}	0.67	0.33	0.40	0.36	0.17	0.07	
	0.44	0.22	0.13	0.12	0.06	0.02	
C1	0.20	0.25	0.26	0.25	0.20	0.26	0.22
C2	0.60	0.59	0	0	0	0	0.44
C3	0	0	0.11	0.16	0.20	0.11	0.05
C4	0.20	0.16	0.63	0.59	0.60	0.63	0.33

$$CR = \frac{\sum_{j=0}^{m} a_j CI_j}{\sum_{j=0}^{m} a_j RI_j} = \frac{0.103}{2.32} = 0.044 \leq 0.1$$

The above result is effective.

From Table 3-13 and comprehensive consideration of the safety and the environment pollution hazard, the main factors of ship oil spill pollution in Shanghai Port include: the nature of the oil spill, oil spill location, movement trend and the quantity of oil spill.

3.4 Revise ship oil spill pollution hazard assessment model

Because of many factors, it produces a lot of matrix and has great inconvenience to the rapid judgment of oil spill pollution, if using paired comparison analysis method of the

Analytic Hierarchy Process (AHP). Therefore, in the practice, it no longer adopts paired comparison analysis method to analyze the main factors of ship oil spill pollution. According to the actual value of the factors, it is divided into several scales of magnitude. The method is as follows:

Firstly, quantify the main factors of ship spill pollution according to the actual value of exploration;

Secondly, calculate the product of the actual value of exploration and weights;

Thirdly, determine the pollution levels by the value of product.

Because this product is a key link, the corresponding ship oil spill pollution levels need practical examples for reference. For example, if we assume "Changyang" ship oil spill accident (happened on August 5, 2003) as an serious pollution accident, then the calculation result of the accident can be considered as a reference value of the serious pollution accident. We discuss several main factors of Shanghai Port ship oil spill pollution hazard in the following:

(1) Ship oil quantity is one of the important indicators of measuring ship oil spill pollution, and it has a positive correlation with the oil spill pollution hazard. According to the description of the "Shanghai Port ship pollution emergency plans", in this paper, the values are as follows:

Table3-16: Oil spill quantity (Quantity-value)

Oil spill quantity	Value	Remarks

Quantity <10 tons	10	If the source of oil spill has not been effective control, values need to add 5-10
Quantity between 10 and 50 tons	20	
Quantity >50 tons	30	

(2) The characteristic of the oil spill is one of the important determinants of ship oil spill pollution. According to narrative of IMO "oil manual part IV - against oil pollution ", oil can be roughly divided into two types: persistent oil and non-persistent oil. In this paper, the values of spilled oil safety hazard are as follows:

Table3-17: The characteristic of oil spill (Flash point-value)

The characteristic of oil spill	Value	Remarks
Flash point <28 ℃	20	Wind power <5, then +5; Wind power between 5 and 7, then +0; Wind power >5, then -5
Flash point between 28 and 60 ℃	15	
Flash point >60 ℃	10	

Table3-18: The characteristic of oil spill (Viscosity-value)

The characteristic of oil spill	Value	Remarks
Low viscosity (25 ℃, 5cSt)	10	According to the temperature change, add or subtract scores
Medium viscosity (25 ℃, 5-3000cSt)	20	
High viscosity (25 ℃,	30	

3000cSt)		

(3) The influence area and the movement tendency have very important significance to evaluation ship oil spill pollution hazard. And the influence area and the movement tendency of oil spill mainly include: sensitive area and the geographical features of oil spill position, and closed or semi-closed area, etc.

Table3-19: Influence area and movement tendency (Sensitive area-value)

Influence area and movement tendency	Values	Remarks 1	Remarks 2
Affect the sensitive area	30	Closed or semi-closed area, 一 1-5; Populous area, +5; Aquatic resources, +10; Landscape area, +5	Man-made structures, +1; Gravel, +2; Cobbles, +3; Sand, +4; Mud and silt, +5;
Close to the sensitive area	20		
Stay away from the sensitive area	10		

3.5 Calculation examples

In calculation examples, this paper chooses three representative ship oil spill accidents in Shanghai Port in recent years.

Example 1

Accident: "Da Wang" vessel collided with "Da Yong" vessel in Yangtze River estuary

Time: April 17, 2001

Oil spill quantity 638 tons, thus value = 30

Flash point <28 ℃, wind power <5, thus value = 15

Phenylethylene, low viscosity, thus value = 10

Affecting the sensitive area and aquatic resources, thus value = 40.

$$[30, 15, 10, 40] * \begin{bmatrix} 0.23 \\ 0.40 \\ 0.05 \\ 0.32 \end{bmatrix} = 26.39$$

Example 2

Accident: "SIAM BRIFGE" vessel oil spill accident

Time: April 7, 2009

Oil spill quantity 126.5 tons, thus value = 30

Flash point >60 ℃, wind power 6 >5, thus value = 10

Heavy fuel oil, low viscosity, thus value = 20

Affecting the sensitive area and aquatic resources, thus value = 35.

$$[30, 10, 20, 35] * \begin{bmatrix} 0.23 \\ 0.40 \\ 0.05 \\ 0.32 \end{bmatrix} = 23.24$$

Example 3

Accident: "T.Y 6" vessel collided with "Atlantic businessman" in deeper-water channel

Time: May 18, 2012

Oil spill quantity 10.185 tons, thus value = 20

Flash point >60 ℃, wind power 6 >5, thus value = 10

Heavy fuel oil, low viscosity, thus value = 20

Affecting the sensitive area, aquatic resources, mud and silt, thus value = 45.

$$[20, 10, 20, 45] \ * \begin{bmatrix} 0.23 \\ 0.40 \\ 0.05 \\ 0.32 \end{bmatrix} = 24.23$$

Through the calculation of ship oil spill accidents in Shanghai Port, the operational numerical can be used as the accident judgment standard. According to the Shanghai Port ship oil spill pollution emergency plan, we can perform the corresponding emergency procedure.

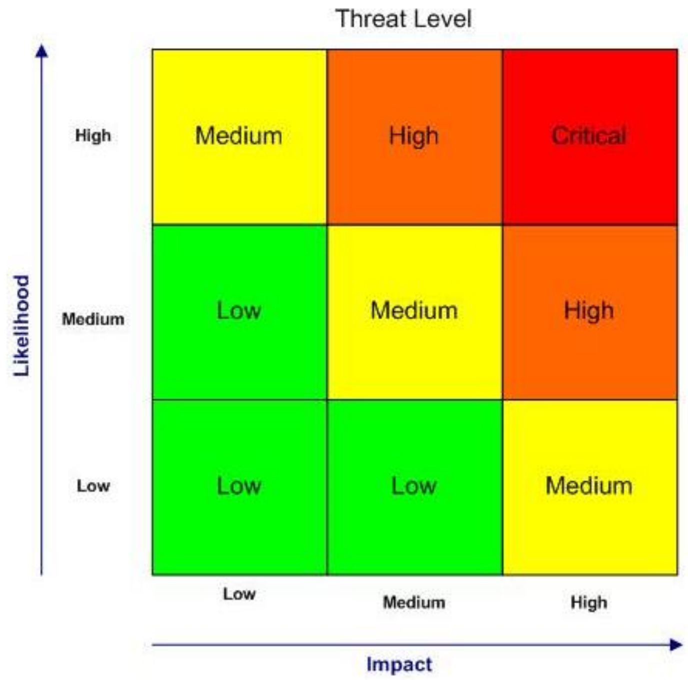


Figure 3-6 Comprehensive risk matrix diagram

Source: Li, P. F. (2000). *Ship oil spill environment risk assessment in Xiamen Port.* Unpublished master's thesis, Dalian Maritime University. Dalian, China.

Based on Table 2-2 and Appendix-1 and comprehensive risk matrix diagram, it can be seen that collision and improper operation is respectively the main reason of accidental oil spills and operational oil spills in Shanghai Port. And the probability of happening operational oil spills is higher than accidental oil spills. But, the harmful consequences of accidental oil spills is very serious, the comprehensive risk assessment results will fall into the red high risk area (see Figure 3-6). It means that the accidental oil spills risk assessment result in Shanghai Port is high, and need to take effective measures as soon as possible to prevent and reduce risks.

Chapter 4 Prevention measures and suggestions

4.1 The status quo of ship oil spill pollution prevention and emergency response in Shanghai Port

4.1.1 The status quo of ship oil spill pollution prevention in Shanghai Port

Shanghai Maritime Safety Administration (MSA) is the department managing prevention and control of ship pollution. In order to prevent and control ship oil spill accident and reduce the damage to people's life and property, it analyzes the main reason of ship pollution and takes positive measures to prevent and control pollution from ships (Lin, 2000, p. 7).

In order to prevent the pollution caused by vessel traffic accident, Shanghai Maritime Safety Administration actively takes the following measures: strengthen the declare for examination and approval, control of oil in bulk and chemical operation in Huangpu River waters; establish Vessel Traffic Services (VTS); provide radar and navigation services to dangerous goods vessels; compulsory pilotage and enforce security escort, ensure the security of ship carrying oil and chemical; strengthen the Port State Control (PSC) and the Flag State Control (FSC) to ensure that the ship is seaworthy; stop hanging paddle vessel registration.

In order to strengthen the management of the ship pollutants and prevent operational discharge pollution, Shanghai Maritime Safety Administration has adopted a series of management measures, including implementing qualification licensing system to high pollution risk enterprises; requiring enterprises to establish safety and pollution prevention management system; performing pollutant operation declaration and audit system; carrying out operator training and certificate system; building regular quality inspection system on operating equipment and equipment.

Shanghai Maritime Safety Administration adopts several measures to prevent and control the illegal discharge of pollutants in the operation of the ship. On the one hand, it relies on market-oriented means to establish a long-term vessel pollutant receiving system in Shanghai Port. On the other hand, it carries out specific rectification of ship pollution and strengthens the examination of equipment and the documents to reduce the occurrence of illegal dredge. Only in 2002, Shanghai Maritime Safety Administration investigated 1458 cases of various kinds of illegal dredge, penalty of $1.94 million (Lin, 2003, p. 4).

By the implementation of the management measures and the system, it greatly reduces the number of ship pollution accident. According to the statistics, the number of ship pollution accidents decreased from 96 in 1984 to 12 in 2012 (Lin, 2003, p. 5).

4.1.2 The status quo of ship oil spill pollution emergency response in Shanghai Port

In the aspect of software, Shanghai Maritime Safety Administration has formulated and perfected the spilled oil and chemical pollution contingency plans incorporated into the Shanghai city emergency plan. To strengthen the emergency response capability of pollution accidents, Shanghai municipal government holds a special maritime BBS on a topic every year. In addition, it holds regular mass oil and chemical accident emergency drill to test Shanghai waters vessel pollution accident emergency response system and to train emergency power.

In the aspect of hardware, at present, the Shanghai has 23 emergency teams and 585 staff, equipped with 41 water spilled oil recovery ships, including 2 specialized clean-up operation ship, 39 oil sewage receive ships, 17 oil skimmer, 5850 meters oil boom, 16 oil boom placing ships. In addition, it has 124 tons oil dispersants and 133 tons oil absorption felt (Wu, 2013, p. 6).

Through many years of construction, Shanghai Port has the ability to deal with 50 -ton ship pollution accident. In Huangpu River waters, the emergency power can arrive at the scene of the accident within 1 hour and monitoring and warning power will be there within half an hour. In the Yangtze River estuary waters, emergency power arrives at the scene of the accident within 3-4 hours, monitoring and warning power can arrive at the scene of the accident within 2 hours; In the northern Hangzhou Bay waters, emergency power can go to the scene of the accident within 2 hours, monitoring and warning power can arrive at the scene of the accident within 1 hours. In the coastal waters, including Da Yangshan and Xiao Yangshan waters, emergency power can arrive at the scene of the accident within 6 hours, monitoring and warning power can arrive at the scene of the accident within 3 hours.

4.2 The problems existing in the ship oil spill emergency prevention and disposal in Shanghai Port

4.2.1 The marine environmental administrative law system is still imperfect

At present, the legal system of prevention and control of vessel pollution in China mainly includes four aspects: international conventions, laws and regulations, local regulations and regulatory documents. Due to many management departments and different aspects, this system can only put forward general and abstract requirements to the prevention of ship pollution. However, normative documents puts forward management measures which have obvious effect in the practical management. With the administrative permission law taking effect in 2004, many management measures with a nature of mandatory, permission have been repealed. Ship pollution prevention regulations system is yet to be perfect, and in this process, there is no doubt that in some ways there will be a vacuum of management.

4.2.2 Existing structural contradictions between port economic layout and ship pollution prevention

For historical reasons, Gaoqiao and Wujing region have chemical, energy, and warehousing enterprise-concentrated area. The Huangpu River upstream waters has become a transit point of loading and unloading chemical products and petroleum goods, which causes large numbers of chemical tanker through drinking water protected areas. According to Shanghai urban development planning, the core area of the Huangpu will be a sightseeing area. Thus, it is important to reduce the loading and unloading work in the Huangpu River, in order to reduce the probability of pollution accident. Because oil wharves and berth do not form a relatively concentrated area, it brings great difficulties to take preventive measures.

4.2.3 Emergency response capacity is not enough to cope with major pollution accident

Shanghai Port has the emergency capacity to handle 800 - ton ship pollution accident, but have not enough ability to handle large-scale pollution under severe sea condition. If vessel pollution accident happens under severe sea condition or port waters, it must spend more time to clear pollutant pollution and request support. There are several reasons: Firstly, emergency equipment is not enough to remove the ship oil pollution. Secondly, the number of professional team and staff is not enough to deal with large –scale pollution, and its emergency ability is very limited. Thirdly, it needs a lot of money and stability of the financial security to build ship pollution prevention and emergency response system.

4.3 Ship oil spill pollution prevention and emergency response suggestion

4.3.1 Shanghai ship oil spill pollution prevention suggestion

4.3.1.1 Establish specific law to strengthen the centralized management

In the present laws and regulations system, ship oil spill pollution prevention and disposal in China are thought of as a management measures, not seen as a significant destructive disaster. Corresponding provisions of ship oil spill pollution prevention and emergency response disperse in the "Marine Environmental Protection Law" and "Law on Prevention and Control of Water Pollution", and the other relevant laws and regulations (Zheng, 2000).

In fact, ship pollution prevention and emergency response involve many factors and stakeholders. So it is necessary to establish special law for ship pollution prevention and emergency response. This is also no lack of precedent in China and the world, for example, the "China Fire Prevention Law" in 1998 and the "Oil Pollution Act of the United States" in 1990.

4.3.1.2 Establish a specific disaster prevention and emergency preparedness system

Safety and pollution prevention are related to the security and prosperity of Shanghai city, so the city disaster prevention and mitigation system shall specifically formulate the corresponding prevention and control of marine oil spill pollution and disposal plan. This plan includes ship oil spill emergency disposal mobilization mechanism, long-term mechanism, division of responsibilities and resource allocation problems. At the same time, according to the status quo and development trend of Shanghai oil transportation, it needs to build a system of ship oil spill emergency reserve fund. This fund is mainly used to set up the Shanghai oil/chemical spill emergency equipment and materials reserve, equip ship oil spill modern warning equipment and monitoring equipment, organize regular oil/chemical accident emergency drill, carry out professional training, and enhance prevention and emergency response capacity. The most important function of the fund is to pay for the contamination removal charge that offending ship cannot pay.

4.3.2 Using economic leverage and technical means to improve the level of ship oil spill pollution prevention

Because there is a huge pollution hazard, oil water transportation can be considered a high-risk industry. So it is necessary to use economic and technical means to improve the barriers to entry and improve the prevention ability of ship oil spill pollution.

4.3.2.1 Improve the ship engaged in oil shipping market barriers to entry

Due to the demand of oil transportation and high profit margins, many companies without the ability of carrier oil have joined into the oil shipping market. Even many self-employed and single ship companies are also involved. These companies and ships enter into the market by low price competition. This makes the companies originally engaged in oil transportation to participate in the low price competition.

It has adverse consequences for improving the quality of ships, the management of companies and the cultivation of the crew. Meanwhile, it also makes the risk of ship oil spill pollution keep rising. The worst is that the companies are unable to pay the cost of pollution clean-up and recover the damage to the environment after bankruptcy.

Through the adoption of compulsory insurance, it can make the ship companies get a profit at the expense of the environment and safety, gradually withdrawing from the oil transportation market. At the same time, this can regulate oil shipping market and reduce the number of the ship oil spill pollution accident.

4.3.2.2 Improve technical standard to improve the level of the carrier oil ship

The safety of oil shipping market depends largely on the technology of ship and the quality of the crew. Improving the technical standards, especially for special channel will help to reduce accidents and pollution.

The government can make some special standard for environmental sensitive area. In China, there is a precedent in the Yangtze River navigation road which has requirement on special J level area navigation. For sailing in enclosed water, reservoir, natural conservation area and important fishery waters, it also could put forward special requirements and standards aiming at improving the prevention ability of ship oil spill pollution. For example, in view of the Huangpu River upstream water conservation district and drinking-water protection area, it can put forward some specific technical standard to oil/chemical vessels, such as "double bottom double hull", total amount control of polluting goods loading and unloading, technical standard of ship type and age (Wang, 2006, p. 7).

4.3.3 Establish oil pollution damage compensation fund

The government levy ship oil pollution damage compensation fund which is a common practice in the world. It can not only reduce the ship company's operation cost, but also improve the prevention ability of ship oil spill. Marine oil pollution compensation has been relatively mature system in the world. That is, it provides a stable financial security by compulsory insurance of ship pollution risk and oil pollution damage compensation fund (Qu, 2008, p. 35).

Based on the principle of special funds for special purpose, a small part of the oil pollution damage compensation fund are took out for supporting the professional clean-up enterprise purchase sewage disposal facilities and equipment and keep a certain amount of material reserves. It also provides start-up capital for emergency response power. This all will help Shanghai to establish the prevention and control system of ship oil spill and keep its normal operation.

Chapter 5 CONCLUSIONS

Ship pollution accident diffusion range prediction model applies the principle of hydrodynamics to oil spill pollution diffusion. In practical application, it just needs to master the law of water working to simulate the diffusion scope of pollution. Due to the actual situation and different hydrological conditions, with the comparison between predicted values and the actual value, we have appropriately modified some experience parameters and more effectively simulated the value of a particular area. It is worth mentioning that the model has extensibility.

According to the damage degree, ship oil spill pollution hazard evaluation model is closely related to the type and quantity of oil spill accident, pollution influence area and the movement tendency of oil spill. By means of using Analytic Hierarchy Process (AHP) theory the actual situation of Shanghai Port, it can calculates the damage degree of an oil spill accident and adopt the corresponding emergency response measures.

Ship pollution accident technical quantitative model and ship oil spill pollution hazard assessment method can quickly get the pollution range and influence degree with fewer parameters. This better provides a basis for starting the emergency response measures and mobilizing emergency power. Thus, it can effectively avoid the blindness of emergency response, and improve the efficiency of emergency disposal and the effect.

REFERENCES

Chen, A. G., & Zhou, Z. J. (2001). Marine oil spill damage assessment technology in China. *Guangzhou maritime college journal, 30* (3), 225-232.

Chen, W. J. (1998). *Ship safety and management.* Dalian: Dalian maritime university press.

Jiang, Q. Y. (1993). *Mathematical model*. Beijing: Higher Education Press, 23-32.

Jiang, X. L. (2010). China's energy security research under the background of economic globalization. *Journal of Wuhan University, 30* (11).

Lei, X. P. (1998). Harbor chemical accident emergency preparation point analysis. *Journal of Dalian Maritime University*, *26* (5).

Li, L. J., (2002). *Pearl River mouth waters spill information system research.* Unpublished master's thesis, Dalian Maritime University. Dalian, China.

Li, M. F. (2000). Analysis of ship pollution accidents in recent years. *Environment Protection in Transportation*, *26* (3).

Li, P. F. (2000). *Ship oil spill environment risk assessment in Xiamen Port.* Unpublished master's thesis, Dalian Maritime University. Dalian, China.

Li, P. F., & Huang, J. L. (1999). Fuzzy comprehensive evaluation in the application of the port of ship oil spill zoning. *Environmental protection in transportations. 20* (2).

Lin, K., & Lei, S. Y., & Yang, J. L. (2003). Analysis on "3.24" serious oil pollution accident. *Environmental Protection in Transportation*, *30* (3), 225-232.

Liu, Y. (2002). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Dalian Maritime University. Dalian, China.

Liu, Y. C., & Yuan, S. L., & Lin, J. G. (2001). Marine oil emergency response for the development of geographic information system. *Journal of Dalian Maritime University, 30* (2).

Ma, H., & Wu, Z. L. (1998). Harbor waters ship manoeuvring comprehensive evaluation of environmental risk. *Journal of Dalian Maritime University*, *30* (3).

Qu, J. J. (2008). Dalian Changxing island marine oil spill prediction and prevention strategy. *Journal of Dalian University of Technology,* (4), 29-35.

Shi, X., & Yuan, Q. (2007). *Shipping in the Yangtze River basin water pollution effects and regulation research.* Shanghai: Shanghai Jiao Tong University Press, 25-32.

Shao, Z. P., & Zheng, Z. Y., & Yang, D. (1999). In the 90s maritime traffic quantitative statistical analysis of research results. *Journal of Dalian Maritime University*, *25* (2).

Song, R. T. (1997). Marine fuel oil spill cause analysis and preventive measures. *Marine Technology*, *26* (5).

The "7.16" major oil spill accident happened in Dalian Xingang port in 2010. Source: Retrieved June 6, 2014 from the World Wide Web: http://image.baidu.com/i?ct=503316480&z=&tn=baiduimagedetail&ipn

Wang, G. S. (2003). *Port bulk chemical accident harm appraisal and emergency response measures.* Unpublished master's thesis, Dalian Maritime University. Dalian, China.

Wang, L. F. (1990). *An introduction to the analytic hierarchy process.* Beijing: China Renmin University Press, 212-214.

Wang, S. D., & Shen, Y. M. (2006). Research on the numerical prediction of o il spill. *Journal of Dalian University of Technology,* 6-12.

Weng, Z. Y., & Zhu (2000). Xiamen port and its nearby waters vessel traffic safety assessment. *Journal of Dalian Maritime University, 30* (3), 12-22.

Wu, H. C. (2013). The tanker oil spill pollution prevention and emergency maneuverability. *China water transport*, *26* (2).

Xiao, J. K. (2001). *Ship oil spill risk assessment model and application research.* Unpublished doctoral thesis, Dalian Maritime University. Dalian, China.

Xiao, J. K., & Yin, P. H. (1999). Grey topological analysis method in the application of the trend prediction of oil spill. *Environmental protection in transportation, 20* (6).

Xiao, J. K., & Yin, P. H., & Yan. Z. Y. (2001). Marine oil spill trend of multilevel grey evaluation analysis. *Journal of Dalian Maritime University. 27* (1).

Yan, Z. Y. (2001). *The research and simulation of weathering process of oil spill.* Unpublished doctoral thesis, Dalian Maritime University. Dalian, China.

Yan, Z. Y., & Xiao, J. K., & Yin, P. H. (2000). The research of oil evaporation process. *Journal of Dalian Maritime University*, *30* (4), 221-232.

Yan, Z. Y., & Xiong, D. Q., & Yin, P. H. (2001). The weathering of oil spill model analysis. *Journal of Dalian Maritime University*, *30* (3), 225-232.

Yang, W. H. (2004). *Marine pollution forecast local parsing algorithm.* Unpublished master's thesis, Shanghai Maritime University. Shanghai, China.

Yin, P. H. (2000). *Ship pollution prevention technology.* Dalian: Dalian Maritime University Press.

Yu, G. F. (2007). Marine oil spill damage reduction research. *Journal of Dalian Maritime University, 13*(3), 15-19.

Zhang, L. (1998). Oil pollution emergency plan formulation and implementaion. *China Water Transport*, *16* (6).

Zhang, Z. Y. (1996). Discussion and suggestion on national marine oil emergency response. *Marine Technology*, *26* (5).

Zhang, Z. Y. (2000). Reason and preventing measures analysis on oil pollution from ships. *Environmental Protection in Transportation, 35*(1), 27-29.

Zheng, L. Y., & Sun, Y. L. (1994). Three dimensional model of oil spill. *Qingdao Ocean University Journal,* 6-12.

Zheng, W. B. (2003). A River of sudden pollution accident simulation model. *Environment Science and Technology*, *26* (1).

Zheng, Z. Y., & Wu, Z. L. (1998). *Port of evaluation mathematical model of* *navigation environment risk.* Dalian: Dalian international maritime technology exchange meeting proceedings.

Zhou, B., & Liang, G. W. (2009). China's coastal ports ship oil spill accident analysis and countermeasure research. *Marine technology*, *20* (9), 16-20.

Zhou, Y. P., & Liu, Y. M., & Yin, P. H. (2011). The comprehensive assessment of Marine oil spill emergency response simulation training scheme. *World shipping*, *30* (5).

APPENDICES

APPENDIX 1 Shanghai Port ship oil spill accidents data--2004-2013

	Date	Ship	Quantity of oil spill(Tons)	Reason
1	2004.02.26	H.YANG	30	collision
2	2004.07.05	Z.P. 01016	0.01	improper operation
3	2004.07.11	D.L.Y 3	0.05	improper operation
4	2004.08.23	N.H. 8	0.05	improper operation
5	2004.08.28	H.Q.L.X	0.03	improper operation
6	2004.09.23	J.H 1	0.015	improper operation
7	2004.11.09	J.L.XING	0.003	improper operation
8	2005.01.11	K.FA	0.2	improper operation
9	2005.02.02	W.S.X.F 069	0.1	collision
10	2005.02.08	B.F.Y.G 1	0.002	improper operation
11	2005.03.01	JADE C	0.01	improper operation

12	2005.04.08	GG CHEMIST	67	collision
13	2005.05.16	T.L.B.T	0.007	improper operation
14	2005.05.28	F.WANG	0.006	improper operation
15	2005.07.12	R.BELLA	0.06	improper operation
16	2005.07.15	Y.T 2	0.02	improper operation
17	2005.08.15	N.YANG	0.01	improper operation
18	2005.09.11	T.SHUN	0.015	improper operation
19	2005.09.17	C.Y.P	185.82	collision
20	2005.09.22	J.GLORY	0.95	stranding
21	2005.10.05	C.NAVARIN	1	improper operation
22	2005.11.05	G.H 6	0.4	improper operation
23	2005.12.01	M.LIAN	0.7	collision
24	2006.05.03	C.FORTUNE	0.035	improper operation
25	2006.07.04	H.T 1	0.015	improper operation
26	2006.07.07	K.F 2	1.2	improper operation

27	2006.07.17	H.Q 120	0.045	improper operation
28	2006.07.21	Y.L 79	0.1	improper operation
29	2006.08.06	J.R 1	0.005	improper operation
30	2006.08.13	I.BULKER	0.2	improper operation
31	2006.08.26	T.SHAN	0.01	improper operation
32	2006.09.19	K.P.D.K	0.7	improper operation
33	2006.09.27	H.G 403	9.6	collision
34	2006.12.12	Z.T.Y 11	18.11	collision
35	2007.01.03	Y.BIN	0.77	improper operation
36	2007.03.11	T.XIANG	20.33	collision
37	2007.03.23	E.JANEKE	5	improper operation
38	2007.04.09	S.D.Y 1221	45.33	improper operation
39	2007.04.20	S.L.Y	2.71	improper operation
40	2007.04.30	W.N.L.H 0719	1	sink
41	2007.01.03	S.S AURORA	0.75	improper operation

42	2007.05.26	S.J.SHAN	1	improper operation
43	2007.06.28	W.S.X.Y 008	0.08	improper operation
44	2007.07.13	H.Q 124	1	improper operation
45	2007.12.20	Z.C 118	47	collision
46	2007.12.25	W.H.S.F 276	0.05	collision
47	2008.01.26	C.CHENG	16.3	collision
48	2008.03.22	H.Z 8	0.05	improper operation
49	2008.08.23	G.ARROW	0.05	improper operation
50	2008.11.01	S.PASSION	1.5	improper operation
51	2008.11.14	D.STARIT	0.03	improper operation
52	2009.01.03	S.MOUNTAIN	9	improper operation
53	2009.04.07	SIAM BRIDGE AND MARITIME ANTIA	126.5	collision
54	2009.06.22	GLORIA	9.6	collision
55	2009.08.07	F.X.LING	0.1	improper operation

56	2010.01.19	X.H.LONG	2	improper operation
57	2010.03.28	D.Q 74	1.86	improper operation
58	2010.04.06	S.GARNET	14	collision
59	2010.04.24	X.Z.J.J.H 0996	2	improper operation
60	2010.10.08	C.L.J 3010	0.1	improper operation
61	2010.10.18	C.N.G 999	0.002	improper operation
62	2011.01.03	S.R 13	0.1	improper operation
63	2011.02.23	J.D 3	2	collision
64	2011.06.12	K.WISATA	1.16	improper operation
65	2011.09.11	H.Y 3	0.015	improper operation
66	2012.02.05	THERSEA	0.01	improper operation
67	2012.05.18	T.Y 6	10.185	collision
68	2012.06.25	MAXIMA AND JING FAN 1	161	collision
69	2012.06.28	C.N 98	0.2	improper operation

70	2012.11.15	H.SPRINTER	1.2	improper operation
71	2013.01.12	S.XING 1	10	collision
72	2013.01.03	CMA CGM FLORIDA AND ZHOU SHAN	613.278	collision
73	2013.04.18	H.J.YANG AND SPRING RAINBOW	0.012	collision
74	2013.09.06	QING XIN	0.025	collision
75	2013.09.16	F.RUN 1	5	improper operation
76	2013.10.09	GLANDEJI	0.4	improper operation