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Environmental damage risk assessment and emergency scheme of ship oil spill around Xiamen sea

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ENVIRONMENTAL DAMAGE RISK ASSESSMENT AND EMERGENCY SCHEME OF SHIP OIL SPILL AROUND XIAMEN SEA

By

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DECLARATION

I certify that all the materials in this research paper that are not my own work has been identified, and that no materials are 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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I have had 9 years of working experience in Maritime Safety Administration (MSA) in the government with a bachelor degree in Environment Engineering. However, I felt a sense of incompetence due to a lack of theoretical background as well as methodological training in the field of maritime. Therefore, I decided to pursue a master degree here because the program of MSEM provided by WAU and Dalian maritime university (DMU) fits my interests well. I am sincerely grateful to Xiamen MSA and World Maritime University for offering me this rare opportunity for a Post-Graduate Study.

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ABSTRACT

Title: ENVIRONMENTAL DAMAGE RISK ASSESSMENT AND EMERGENCY SCHEME OF SHIP OIL SPILL AROUND XIAMEN SEA

Degree MSC

Xiamen Sea becomes a high risk area of ship oil spill which will no doubt cause many losses to the coastal ecological environment and port-economy. This thesis first introduces the risk identification and source terms analysis of ship oil spill in Xiamen waters. According to statistical analysis of vessel traffic flow data and the oil spill's history records, some important risk parameters are identified and determined. By means of the comprehensive analysis between the happening probability of oil spill and harmful consequences index, the assessment results shows: the overall oil spill risk of the Xiamen waters is high. By adopting Risk matrix analysis method, combined with traffic management and oil spill response capability situation of Xiamen waters, the thesis analyzes the exiting main problems. At last, the corresponding risk preventive measures and suggestions based on the assessment results for Xiamen emergency scheme were put forward (till 2020).

Key words: Oil spill; Risk assessment; Xiamen Sea; Random scenario statistics; Emergency scheme.

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LIST OF ABBREVIATIONS

ADIOS	Automated Data Inquiry Oil Spills
DMU	Dalian Maritime University
DSSs	Decision support systems
EU	European Union
FSA	Formal Safety Assessment
FEMA	Federal Emergency Management Agency
IMO	International Maritime Organization
ITOPF	International Tanker Owners Pollution Federation
IOPC	International Oil Pollution Compensation Funds
MSA	Maritime Safety Administration
MSEM	Maritime Safety and Environment Management
NOAA	National Oceanic and Atmospheric Administration
OSRA	Oil spill risk analysis
PSC	Port State Control
UN	United Nations
VTS	Vessel Traffic Service
WMU	World Maritime University

CHAPTER 1 INTRODUCTION

1.1 Background

Shipping industry plays an important role in the rapid development of society and the global economy, since it has the characteristics of the low transportation cost and relatively high safety coefficient, about 90% of transportation activities of global trade are done rely on shipping, ship has become the main transport carrier of global trade (IMO, 2012). Offshore oil spills are of tremendous concern due to their potential impact on economic and ecological systems. A number of major oil spills triggered worldwide consciousness of oil spill preparedness and response (Pu Li, et al, 2016).

According to International Tanker Owners Pollution Federation (ITOPF) statistics, 1970-2015, except the cause of the war, the global Marine oil spill events from ship, a total of around 10000, approximately 81% of ship oil spill events less than 7 tons. Unsurprisingly, information from published sources generally relates to large spills, often resulting from collisions, groundings, structural damage, fires or explosions, whereas the majority of individual reports relate to small, operational spillages(ITOPF, 2015). Causes of Large Oil Spills：In the period 1970 to 2015, 50% of large spills occurred while the vessels were underway in open water; collisions and groundings accounted for 59% of the causes for these spills. These same causes accounted for an even higher percentage of incidents when the vessel was underway in inland or restricted waters, being linked to some 99% of spills.

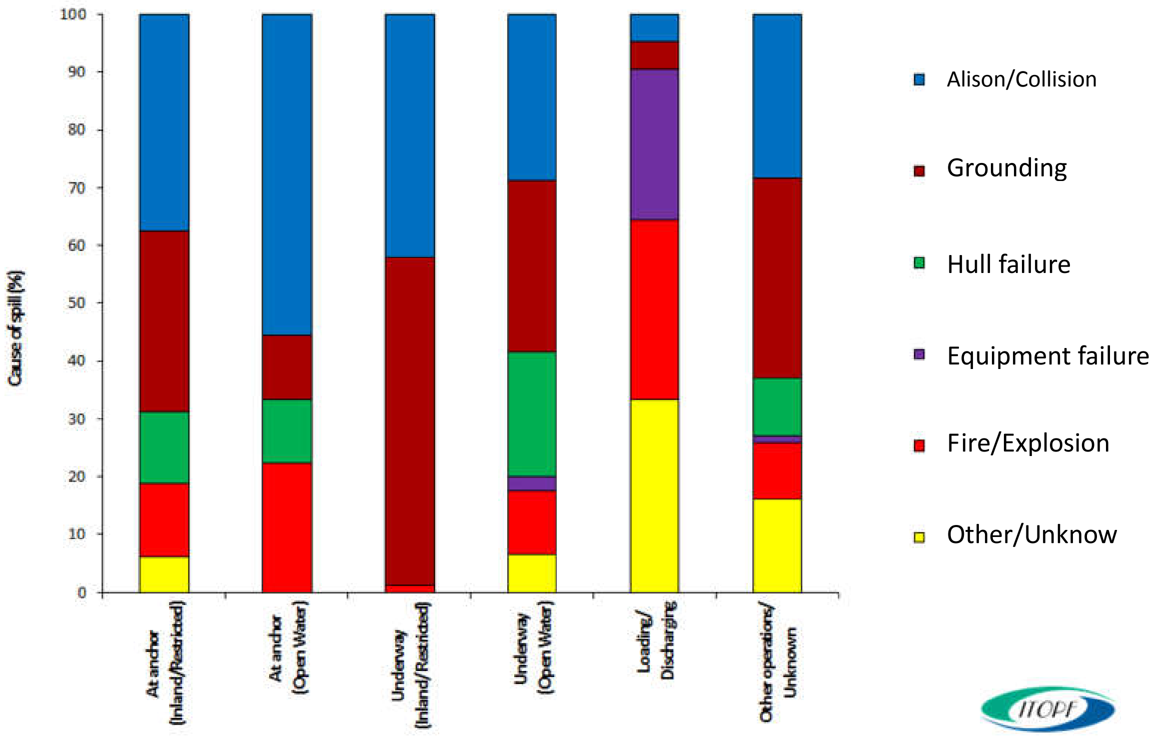

Figure 1.1： Top 20 Major Spills Table (from 1970 to 2015)

Source： ITOPF report 2015

Operation and accidental are primary cause of oil spills >700 tons, 1970-2015. (One bunkering incident occurred in this size category but has not been included in this figure)

Table1.1： Top 20 Major Spills Table (from 1970 to 2015)

Position	Ship name	Year	Location	Spill Size (tones)
1	ATLANTIC EMPRESS	1979	Off Tobago, West Indies	287,000
2	ABT SUMMER	1991	700 nautical miles off Angola	260,000
3	CASTILLODE BELLVER	1983	Off Saldanha Bay, South Africa	252,000
4	AMOCO CADIZ	1978	Off Brittany, France	223,000
5	HAVEN	1991	Genoa, Italy	144,000
6	ODYSSEY	1988	700 nautical miles off Nova Scotia, Canada	132,000
7	TORREY CANYON	1967	Scilly Isles, UK	119,000
8	SEA STAR	1972	Gulf of Oman	115,000
9	IRENES SERENADE	1980	Navarino Bay, Greece	100,000
10	URQUIOLA	1976	La Coruna, Spain	100,000
11	HAWAIIAN PATRIOT	1977	300 nautical miles off Honolulu	95,000

Table1.1 (continued)

Position	Ship name	Year	Location	Spill Size（tones）
12	INDEPENDENTA	1979	Bosphorus, Turkey	94,000
13	JAKOB MAERSK	1975	Oporto, Portugal	88,000
14	BRAER	1993	Shetland Islands, UK	85,000
15	AEGEAN SEA	1992	La Coruna, Spain	74,000
16	SEA EMPRESS	1996	Milford Haven, UK	72000
17	KHARK 5	1989	120 nautical miles off Atlantic coast of Morocco	70,000
18	NOVA	1985	Off Kharg Island, Gulf of Iran	70,000
19	KATINA P	1992	Off Maputo, Mozambique	67,000
20	PRESTIGE	2002	Off Galicia, Spain	63,000
35	EXXON VALDEZ	1989	Prince William Sound, Alaska, USA	37,000
131	HEBEI SPIRIT	2007	South Korea	11,000

Source：Source：ITOPF report 2015

According to the ‘BP World Energy Statistics Yearbook 2015’, China is the world's largest energy consumer in 2004, accounting for 23% of global consumption and 61% of global net increase. China's energy structure continuous improved, coal accounted for a record low. China's net oil imports rose 8.4% to 7 million barrels a day, and surpassed the United States as the world's largest oil importer.（China industry information net, 2016）, among them, about 90% of China's oil trade relied on shipping. In 2015, the water transportation industry in China also show a strong vitality, the national port cargo throughput of 12.75 billion tons, went up 2.4% year-on-year, the foreign trade cargo throughput of 3.664 billion tons, increase 1.0% year-on-year. The country has a water transport ships 165900, load 272.4429 million tons, China's shipping fleet tonnage in the fourth of the world, but most of the oil ship hull structure is relatively backward, the proportion of double hull structure of tanker accounting for little (Chinese ports net, 2016).

In recent years, China large accidents of spills mainly include: On November 23, 2002, "Tasman sea" full of crude oil tanker collided with other ships in the east of Tianjin Dagu sea area, leading more than 200 tons of oil spill, the result is 359.6 km2 of sea water is polluted, 82.79 km2 of sediment and 290 km2 of tidal flats is affected, a large area of western of Bohai Bay was polluted (Li shuhua, et al, 2004). On December 7, 2004, the panama "Modern Promote" collided with Germany 'IRENE' in Pearl River Estuary, leading more than 1200 tons of ship oil spill, total loss of 68 million Yuan (Zhou zhujun & Jiang yi, 2009). On April 3, 2005, Portuguese tanker "Elder Brother" stranding in Dalian new port, hundreds of tons of oil spill (Xinhua net, 2011). On July 16, 2010, due to violation operation in the injection of desulfurizer in to the pipeline, pipeline in storage tanks land fired, causing huge quantities of crude oil leaked out. Leaked oil affected the area around 100 km^2 of port, including 10 km^2 sea areas and 20 km of coastline by high level of pollution, the destruction of Marine ecological environment was more serious.

Xiamen is an important port of China's comprehensive transportation system, trunk port of container transport, the Southeast International Shipping Center and Main port to shipping to Taiwan, ranks top 20 container ports in the world. It has various types of berth that a total of 98 production berths at present, including 49 10000-ton berths. Port economic growth bring the risk of ship oil spill at the same time, especially as the quantity of vessels' entering and leaving the port and ship's tonnage increasing year by year. And Xiamen Sea is in the Taiwan Strait whose hydrology weather is bad and traffic density is big. The risk of large-scale oil spill in Xiamen is growing.

Xiamen sea area around the high sensitivity and precious natural resources, such as, Chinese White Dolphin Natural Reserve , Egret Natural Reserve, Amphioxus reserves and Mangrove National Nature Reserve which is difficult to restore after damage. Xiamen, Meanwhile, enjoy the reputation of 'International Garden City', 'China Excellent Tourism City', 'UN Habitat Environment Prize' and others both at home and abroad, Gulangyu island in Xiamen is a state-level scenic spot, known as the 'Sea Garden', 'The Island of Music', 'Exhibition of the World's Architecture', etc. Tourism industry has become a pillar industry of Xiamen. Therefore, once major oil spill pollution incident at sea occurs, there will have serious impact on the marine ecological environment and tourism of Xiamen.

Although oil spill accidents in Xiamen happened less than 10 in consecutive years, and mass of oil spill was in low level. However, since the ship number and tonnage escalating and takes account of uncertainty, oil spill and environmental damage risk is bound to increase. Therefore, by scientific analysis and assessment of the oil spills pollution accident, and puts forward corresponding preventive measures to reduce risk, and balance the risks and benefits to be optimal, has important theoretical significance and practical value.

1.2 The behavior of oil spill and the research status

1.2.1 The behavior of the offshore oil spill

After oil spill into the ocean, there are three aspects of dynamic behavior of the oil leak into the Marine environment mainly include drift, diffusion and weathering (Qu jingjun, 2008).

(1) Drift

Drift refers to the translational motion of oil film on surface moves from one location to another with the action of wind, tide and wave. In the wind current, pressure gradient flow, density flow, dilute under the joint action of currents and tide, together, the synthetic vector field construct oil film drift flow field. When the oil spill accident happen in offshore waters, the two most important factors determine track of oil spill is tide and wind drift. Normally the numerical method can be used to simulate the tidal current field. And wind current can be obtained by using simple empirical formula and relationships, i.e., set on the drift on surface is about 0.01 to 0.04 of the wind speed that determine drift angle, the typical value is 10 ° ~ 17 °, normal value is 1 ° ~ 20 °. In Xiamen coast and terrain dominant the influence of waters, wind direction and the direction of the wind current are basically consistent. As shown in figure 1.2 for marine oil spill drift.

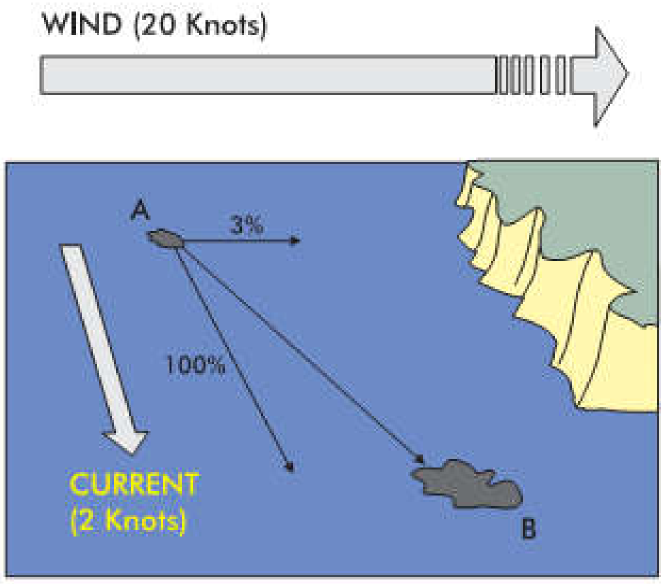

Figure 1.2 Influence of wind and current on the movement of oil at sea

(2) Diffusion

Initial stage into the marine environment, the oil film expand around itself under the action of its own gravity, net surface tension, inertia force, viscous force of oil-water interface, internal viscous force, etc., but this process is very short and is not the main factor of oil spill spread. Turbulent flow and shear flow effect plays a main role for the spread of the oil spill in marine environment. Because the average distribution of flow space has inhomogeneity lead deformation of the oil film (i.e., distorted or stretched). Ocean turbulence make spilled oil spread around, makes the oil film area change, and the turbulent diffusion function is a random process.

(3) Weathering process

The weathering process mainly includes evaporation, emulsification, dissolution, dispersion, photo-oxidation and biodegradation, etc., in the process of weathering, viscosity and density of the oil film also will change accordingly. As shown in figure 1.3.

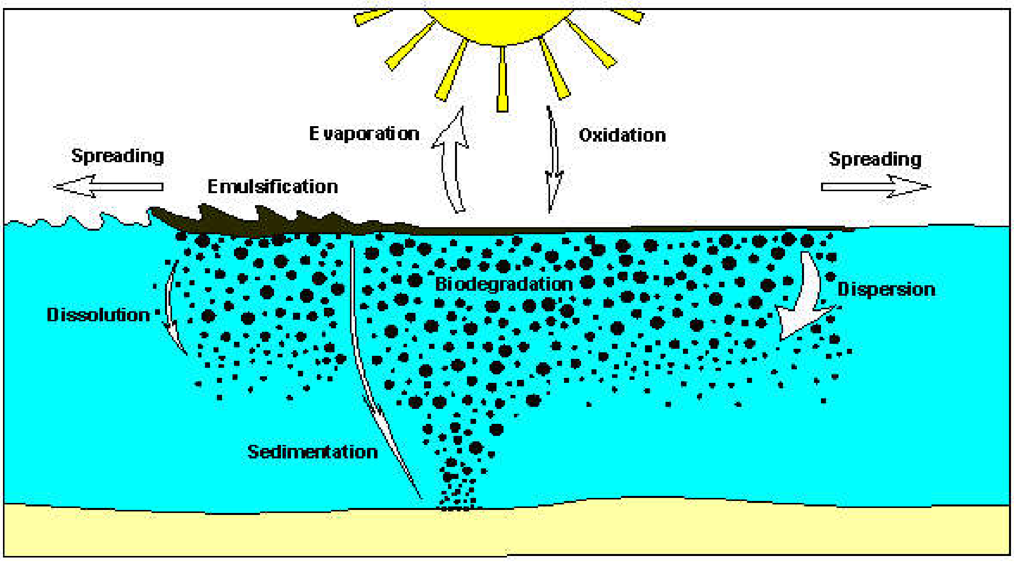

Figure 1.3 Marine oil spill weathering process

Each process through time are different, process such as drift, diffusion, evaporation, emulsification, dissolution and dispersion relatively are short duration, but the duration of photo-oxidation and biodegradation is longer, general sustain for months or even years, as shown in figure 1.4.

1	10	100	1000	10000
Day		Week	Moth	Year

--diffusion

--drift--------------

--evaporation

------------------------------ dissolution

--- dispersion

--- emulsification --------------

--sedimentation------------

--------------------------------------- biodegradation --

-- photo-oxidation

Figure 1.4 Duration of marine oil spill different processes

1.2.2 Research status in china and abroad

(1) Oil spill drift forecasting model

Overseas, the study of the diffusion model of oil spill began in the 1960s. Blocker

(1964) established expansion diameter formula based the conservation of mass of the oil film (Blocker P C, 1964). Fay (1971) proposed the theory of three phase of oil film extension, namely the oil film of gravity to inertia force, gravity to viscous force and surface tension to viscosity force phase (Fay J A, 1971). Lehr, etc. (1984) established oil film diffusion model based on the study of the Fay (Lehr W J, et al, 1984). Elliot (1986) established a concept of "oil particles" (Elliot A, et al， 1986), the method can effectively overcome the divergence problem of traditional numerical simulation method, and successfully simulated crushing process of oil film. Since then, a large number of oil spill drift forecasting model in the world is the "oil particles" model, and gradually spread gradually from 2-dimensional drift of the oil spill to consider vertical movement under wave action (Zhao dongzhi, et al, 2006). Reed, etc.(1999) summarized on oil spill model research progress in the 20th century, and purposed that prediction of oil spill drift development mainly depends on the improvement of computing capacity (Reed M, et al, 1999). Over the past 10 years, super computer application is becoming more and more widely, quick prediction of 3-dimensional ocean environmental dynamics can provide support for the drift of oil spill prediction gradually. In 2010 in the ‘Deepwater Horizon’ oil spill in the gulf of Mexico, the United States Oceanic and Atmospheric Administration (NOAA) used six circulation real-time forecast model at the same time to support for prediction trajectory of oil spill (Liu Y, et al, 2011).

China started oil spill model research from the 1990s. Zheng lianyuan established 3-dimensional forecast model of oil spill, Lagrange method is applied to forecast the motion trajectory of oil spill barycenter (Zheng lianyuan, et al, 1994). Zhang cunzhi established a 3-dimensional dynamic forecast model of oil spill and application in Bohai Bay, the model simulation result is consistent with satellite data (Zhang cunzhi, et al, 1997). Liu yancheng etc. established the drift and diffusion model of oil spill based on GIS (Liu yancheng, et al, 2002). In recent years, China scholars try to synthesize dynamic environment model actively, have established a more comprehensive sea drift and diffusion model which achieved obvious progress and basically reached the international advanced level (Wang Shoudong et al, 2004; Liu qinzheng, et al, 2005; Liao guoxiang, et al, 2010; MouLin et al,2011).

In conclusion, on the research of oil spill drift and diffusion model, both China and abroad have achieved significant results, providing strong support sea oil pollution prevention and emergency treatment for each country. At present, the international mainstream oil spill drift and diffusion model adopted particles track method. This method adopts a number with characteristics of Lagrange ‘oil particles’ to represent oil spill, by the method of additional attributes gives each particle quality, volume, density and other attribute information, and then at each time step of simulate each oil particles dynamic transport diffusion in water body and the spread of drift on the sea under the action of sea environment power as current, wind and waves. Recording its information such as 3-dimensional space coordinates, weight, nature of change at the same time. Finally, determine the time-space distribution of oil spill in marine environment by the statistics of all particles.

(2) Weathering model of oil spills

Weathering model of oil spills is mainly used for prediction of oil spill properties change in marine environment (e.g., the rate of evaporation, viscosity and density) to provide important information for decision maker in the oil spill emergency. In general, Weathering model of oil spills can calculate oil film spread, evaporation, emulsification, dispersion, sedimentation process, et al,. At present, there are mainly two types in the world, one is based on the experience mathematical equation to calculate spilled oil properties change, the other is based on the experimental data.

The developed countries in Europe and America research on mathematical model of the weathering process earlier. In empirical model research, Stiver and Mackay established the mathematical model of the evaporation rate of petroleum hydrocarbon and oil mixture (Stiver W, Mackay D, 1984). Payne established the calculation of oil and suspended particles interaction model (Payne J R, et al, 1987); Delvigne and Sweeney based on the experiment established model used to calculate the dispersion process of oil spill (Delvigne G A, et al, 1988). At present, the well-known oil weathering models in the world are OWM business spilled oil weathering model developed by Norway SINTEF institute (Ole Morten Aamo et al, 1993; Daling P S, et al, 1997). NOAA developed ADIOS1 and ADIOS2 free weathering model (Lehr, W J, et al, 1992; Lehr, et al, 2002) get widely used around the world after 20 years development.

Domestic study of weathering process and model of oil spill began in the 1980s. Yang Qingxiao analyzed the progress of oil weathering process over the sea (Yang Qingxiao, 1984). Xu Xueren studied the photochemical oxidation of oil in the marine environment (Xu Xueren, 1987). Wang liansheng studied non-biological process of offshore oil (Wang liansheng,et al, 1988). Yang Qingxiao, etc. studied the emulsification of oil spill at sea under the action of broken waves (Yang Qingxiao, et al,. 1997). Yan ZhiYu used VB6.0 professional edition and ACCESS database software to establish the weathering forecast model of oil spill (Yan ZhiYu ,et al, 2001). Xu Yandong established Dalian bay weathering model for prediction of oil spill by referencing domestic and foreign applied weathering model (Xu Yandong, 2006). Compared with the study abroad, although China carried out weathering experiment research and some empirical model for certain types of oil, but unable to establish similar spilled oil weathering model such as OWM, ADIOS which based on mass of experimental data.

1.3 The origin and development of risk assessment

1.3.1 Risk assessment content

Risk refers to the degree of all kinds of things can happen in a certain state or period of time. Because of the different research purposes, the definition of risk is also different. American economist Haynes proposed risk is loss probability (Haynes J, 1895); Luo Zude puts forward risk is the uncertainty of a certain loss (Luo zude, 1990); William proposed risk is a threat can lead to the difference between the consequences (Williams C A, 1985); International union of geological sciences defines risk as probability of events adverse to health, property and the environment and the possible consequences of the incident , it can be show by product of probability and possible consequences of events (IUGS, 1998); Wu jinxu put forward "the risk is economic losses changes resulting from objective existence in a specific environment and during a specific period "(Ikeda S, 1998); the United Nations Humanitarian Affairs Ministry defined risk as: within a given area and time predicted values of people's life and property loss aroused by some disaster. In the 70s, the significant influence was Lawrence defined risk as risk value is the product of the possibility of threats and the severity of the consequences (Lawrence W W, 1976; Hu Erbang, 2009), namely:

R [damage/unit time] = P [accident/unit time] x C [damage/accident]

Later, the definition of risk be further refined, the value of risk is the product of possibility of a threat, the fragility of system and consequences severity (Li H, 2007).

1.3.2 Development and status quo at home and abroad

Foreign environmental risk assessment began in the 1970s, the main represented by industrial developed countries such as America (Liu yanghua, et al, 2011). In 1980, the American Risk Analysis Association was established, become a milestone in the history of risk assessment (Fiksel J, 1990). Risk Analysis Association of European established in Austria in the same year, determines the application of multi-disciplinary method in the field of risk assessment. At present, the application framework of ship oil spill risk assessment is controversial both in China and abroad. Since there still not have a universal standard program, its assessment framework mainly refer to the environmental risk assessment framework. Representative of environmental risk assessment application framework are: in 1983, the United States put forward the environmental risk assessment program, has become a guiding document and adopted by most countries and organizations, such as France and the Netherlands (Li H, 2007). Subsequently, the Asian Development Bank proposed risk evaluation procedure of environmental risk assessment diagram. Followed by Australia also established a risk management evaluation flow charts (AS/NZS4360:1999) (Queenland, 2000). In 1997, the IMO approved and recommended the Formal safety assessment (FSA) a guideline mentioned ship safety risk framework (Liu hong, 2010). But it should be noted that the FSA is the assessment guide in view of ship’s safety risk, the methods as the fault tree were established for ship security, were not necessarily suitable for Marine environment risk assessment, still need to do some revised to its evaluation procedures to be more appropriate for ship oil spill risk assessment.

China carry out the environmental risk assessment research began in the late 1980s. In 2004, the State Environmental Protection Administration issued Technical Guidelines for Environmental Risk Assessment on Projects (HJ/T169-2004), became China's basic principle for the conduct of environmental risk assessment. With the development of the research, some organizations or scholars put forward the integration framework of WHO risk assessment (World health organization, 2001), Project Behavior Framework which can evaluate multiple behaviors (Sutter, 1999), the extension framework integrating risk assessment and economic assessment (Druins, 2004), etc. Although, there are many risk assessment framework at present, but the core content of the framework is roughly consistent, mainly includes the following four steps: (1) Hazard Identification, mainly obtain risk source, risk receptor, the information of ways and means of risk communication; (2) Accident frequency and consequence estimation, mainly estimate the possibility of risk source happen sudden significant pollution accident, and estimate the losses of risk receptors by possible accident; (3) Risk calculation, mainly calculate results of environmental risk, namely the product of the accident possibility of risk source and the severity of the damage of risk receptor; (4) Risk mitigation, taking risk prevention measures according to specific circumstances, so as to control the risk within an acceptable level. In 2011, the China Maritime Safety Administration (MSA) formulated the *Technical Specifications for Risk Assessment of Marine Environment Pollution by Ship (trial draft)*, its basic evaluation process with reference to the *Technical Guidelines for Environmental Risk Assessment on Projects*.

The main problems of existing methods include:

(1) It is not reasonable to calculate accident probability only according to the ship's flow rate. Flow only said one aspect of ship navigation conditions of ports or channel, and the influence factors of pollution accidents includes several aspects: such as hydrology and meteorology, channel condition, traffic density, ship routing and reports, etc. Therefore, using the historical accident data statistics should be more objective.

(2) Simple according to determine damage consequences of pollution accident through the number of oil spill is one-sided, as the sensitive degree (e.g., the presence of large amounts of aquaculture, natural fishery, tourism resorts, rare nature reserve, etc.) is an important factor to determine the magnitude of the risk is in an area. For instance, protection countermeasures and oil spill emergency response strategy would be different for a low sensitivity region and a high sensitivity region.

(3) Although our country has made great progress of ship oil spill accident emergency management in present stage, using risk assessment conclusion to guide emergency management is still in infancy, and pertinence and feasibility of marine oil spill emergency management's ability scheme are insufficient.

1.4 Contents of the research

Based on related research in China and abroad, according to *Technical Specifications for Risk Assessment of Marine Environment Pollution by Ship (trial draft)* (China MSA, 2001), and reference to the FSA recommended by IMO and the *Guidelines for Coastal Marine pollution accident emergency capability Assessment* published by China MSA in 2008 (Liu hong, 2010), combining with the characteristics of shipping transportation and the natural environment in Xiamen, the author carry out ship oil spill accident risk assessment, determine acceptable risk levels, and put forward risk mitigation measure and suggestion about emergency management system, the main contents include:

(1) Risk identification and source term analysis

According to Xiamen present situation of sea transportation and the development planning of ports, through the study of vessel traffic flow statistics, and statistical analysis of historical oil spill accident, identify and determine the source term parameters as the main oil spill risk types, the type of spill oil, high-incidence area, the probability of accident, possible spill oil quantity in Xiamen sea area.

(2) Accident harm effect prediction

First of all, oil spill drift and diffusion model and spilled oil weathering model be established based on Lagrange Oil particles tracking method. Then, Random Scene Statistics Method for oil spill risk prediction be proposed to get important parameters such as pollution probability and the shortest time oil spill arrive sensitive environment resource. Harmful consequences index model be established to reflect mass of oil spill, the sensitivity of the environmental protection goal and its probability be contaminated at the same time.

(3) Risk assessment analysis

Integrated oil spill accident probability and the harmful consequences index, establish risk evaluation matrix, Xiamen sea area is used to evaluate the overall magnitude of the oil spill risk, and to determine whether the risk is acceptable.

(4) Countermeasures and preventive measures to reduce the risk

According to the result of risk identification and assessment, combining status quo of traffic management and the oil spill emergency ability of Xiamen sea, analyses the main problems, give some corresponding risk prevention countermeasures, put forward oil spill emergency management system construct scheme (2016-2020).

According to the evaluation of the paper the technology roadmap is as follows:

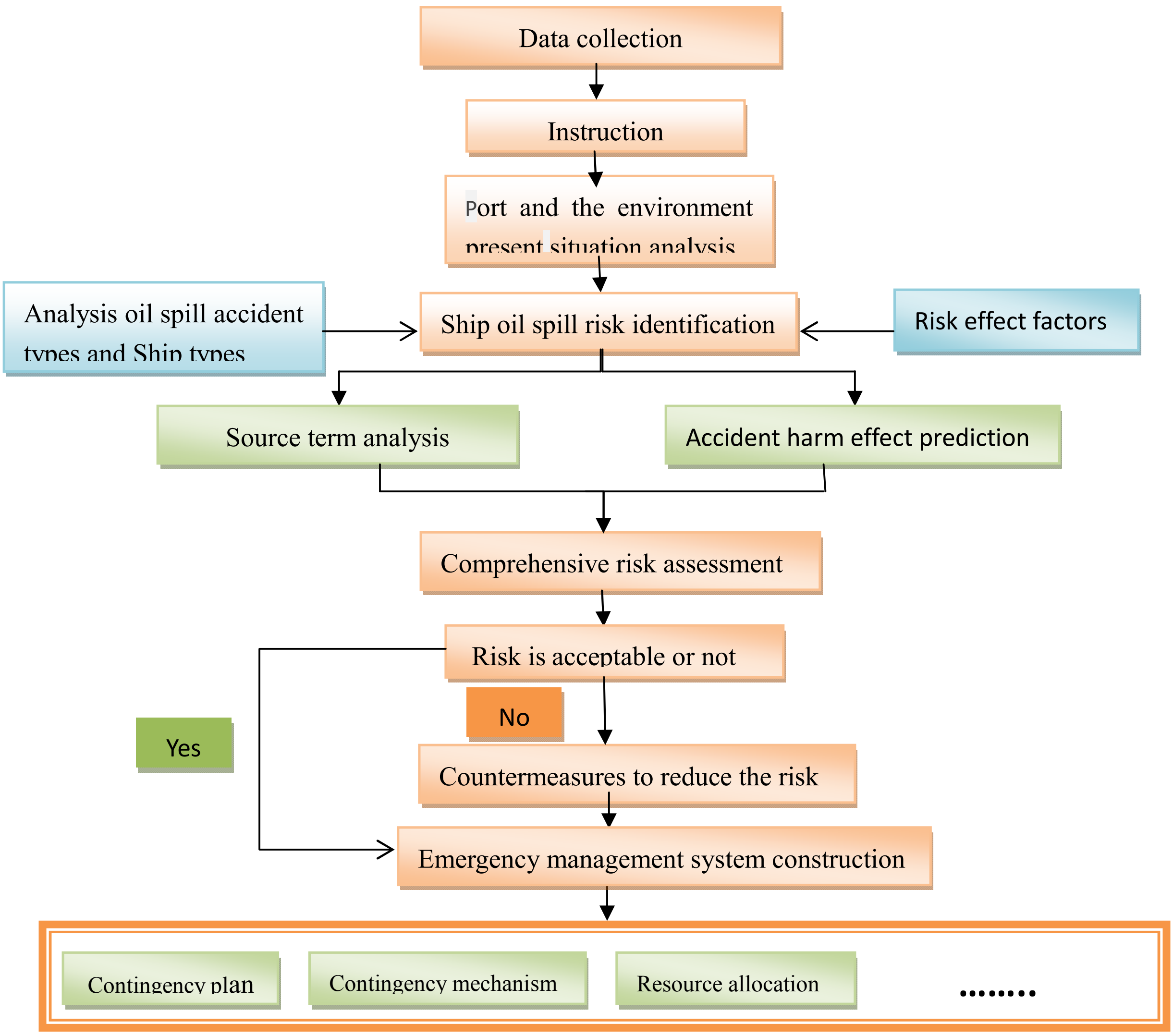

Figure.1.5 The structural relationship of dissertation

Source：Created by author

CHAPTER 2 Transportation and Natural Environment Present Situation Analysis

2.1 Xiamen sea traffic situation

2.1.1 Harbor district

Xiamen is an important natural deep-water harbor on the southeastern coast of China, natural condition is superior, the harbor periphery has big and small Kinmen islands as natural barrier, port waters wide, water is deep and the wave is small, less frozen and small silt, is a large, major multi-function deep-water port integrating inland harbors and sea harbors. Consist of Dongdu area, Haicang area, Xiang 'an port, passenger transportation docks, ZhaoYin area, Houshi area, Shima area, each port present situation as shown in table 2.1.1:

Table 2.1.1 Profile of the Xiamen bay port production berths

Port area	Berth length（m）	Berth number	Annual throughput capacity			
			Cargo（10000-ton）	Container（10000TEU）	Passenger（10000）	Vehicle（10000）
Dongdu	8635.61	51	3879	290	924.8	72
Haicang	8413.8	32	7340	620	0	0
Xiangan	679	5	295	0	97	22
Keyun	/	13	182	2	905	54
Zhaoyin	2730	13	3000	60	600	30
Houshi	770	2	1000	0	0	0
Shima	2380	30	1100	0	100	0

Source： Xiamen MSA unpublished data

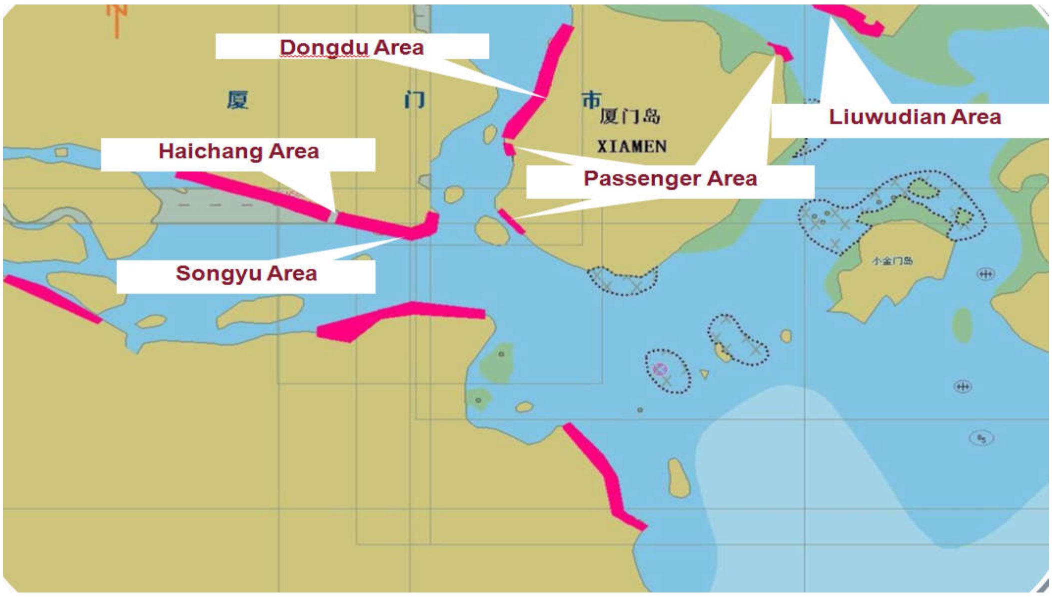

Figure 2.1.1 overall planning of Xiamen port

2.1.2 Fairways status quo

Xiamen has 8 main fairways. This one is the main fairway which can allow a vessel of 150,000 tonnages to sail in one way. Usually the fairway is two way, but because the vessel is too big, it occupy the whole channel and have to be one way. And this is the maximum capacity.

No. 1	For vessels of 50,000-100,000 tonnage
No. 3	For vessels under 10,000 tonnage
No. 4	For vessels above 10,000 tonnage
No. 5	For vessel of 1000 tonnage
No. 7	For dangerous-cargo vessels of 1000 tonnage

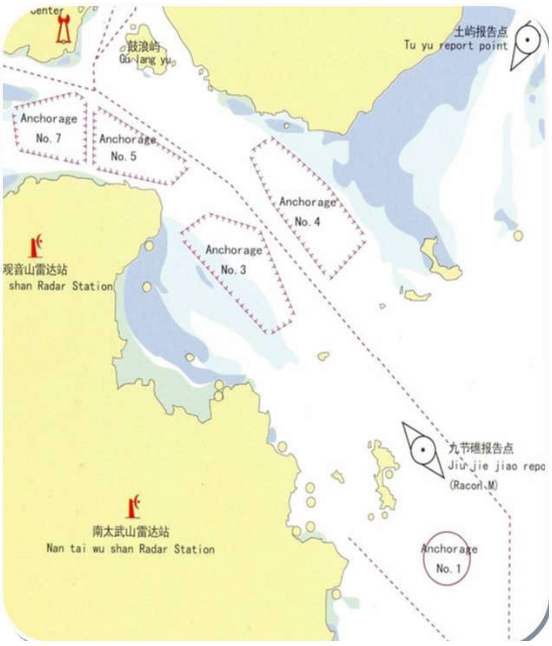

Figure 2.1.2 Xiamen Fairways diagram

2.1.3 Anchorage status quo

After the completion of the first phase of Ten 0000-ton channel in Xiamen bay, has completed five anchorage and 1 standby anchorage, respectively, from inside to outside is under thousand tons dangerous goods ship anchorage, thousand tons ship anchorage, 0000-tonne ship anchorage, under 0000-tonne ship anchorage and 5-10 0000-ton ship anchorage. The following table 2.1.2.

Table 2.1.2 Anchorage situation of Xiamen Port

Name	Water area（km^2）	Function	Remark column
1# Anchorage	1.54	External anchorage	**For vessels of 50,000-100,000 tonnage**
3# Anchorage	5.97	Temporary typhoon shelter	**For vessels under 10,000 tonnage**
4# Anchorage	6.4	Joint inspection、pilotage	**For vessels above 10,000 tonnage**
5# Anchorage	2.14	Inside anchorage	**For vessel of 1000 tonnage**
7# Anchorage	2.94	The special anchorage of dangerous goods	
TOTAL	**18.99**		

Source： Xiamen MSA unpublished data

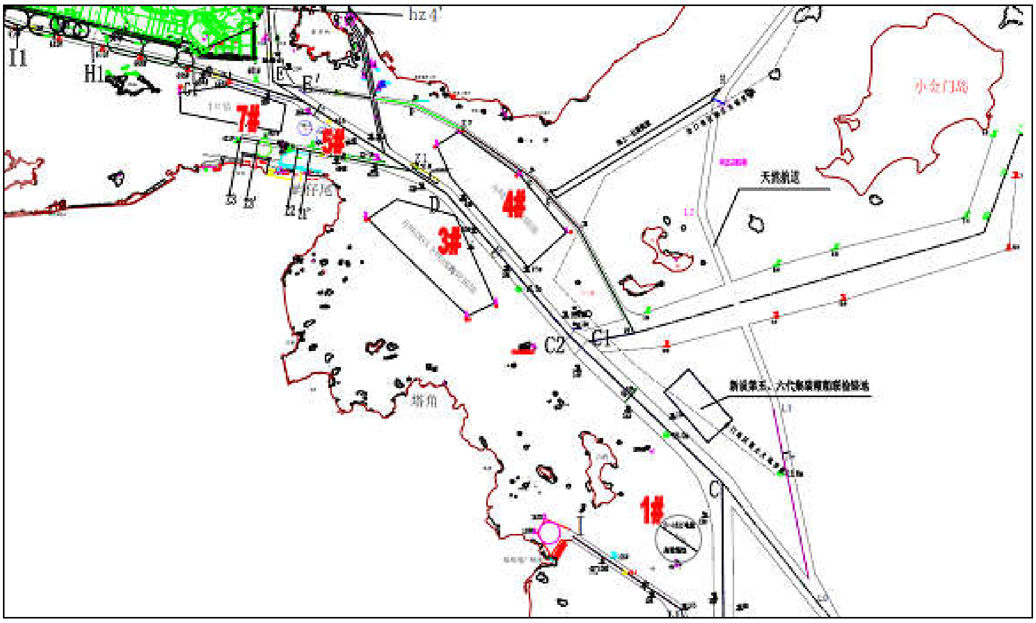

Figure 2.1.3 Anchorage position of Xiamen Port.
Source： Xiamen MSA unpublished data

2.1.4 Xiamen shipping traffic flow statistical analysis

According to related statistics, Xiamen ships form of entering and leaving the port in nearly five years can be found in the following table.

Table 2.1.3 Composition of inbound and outbound ships in Xiamen port in 2011~2015

Year	Total	Under 499GT	500～2999	3,000～9,999	10,000～49,999	Above 50,000GT
2011	214515	177621	19080	7627	6997	3190
2012	206286	170036	18045	7706	7127	3372
2013	242373	199653	22575	9044	7910	3191
2014	217015	180178	19265	7537	7011	3024
2015	172374	143234	15229	5364	6033	2514

Source：Xiamen MSA unpublished data

The main characteristics of the four aspects:

(1) The traffic flow is large and increasing, above 10000GT ship increased significantly, ship to large-scale development.

(2) There are many small and medium vessels and under 10000GT ships are the most important traffic composition of Xiamen shipping. Statistical data in 2013, under 499GT of Xiamen shipping traffic accounts for 82.4%, and the vessels under 10000GT reaches 95.4%, as shown in figure 2.1.4 and 2.1.5 is shown in figure.

(3) Non-transport Ships are numerous. Statistical data in 2013 on a ship, the carrier of Xiamen traffic was 70%, and basically are domestic ships (99.99%), as shown in figure 2.1.6.

(4) ship inward and outward the Xiamen port in 2015, cargo ship accounts for only about 18.1%, The top three of the cargo ship types are container ship (36%), other cargo (25%) and bulk carrier (21%) respectively, as shown in figure 2.1.6.

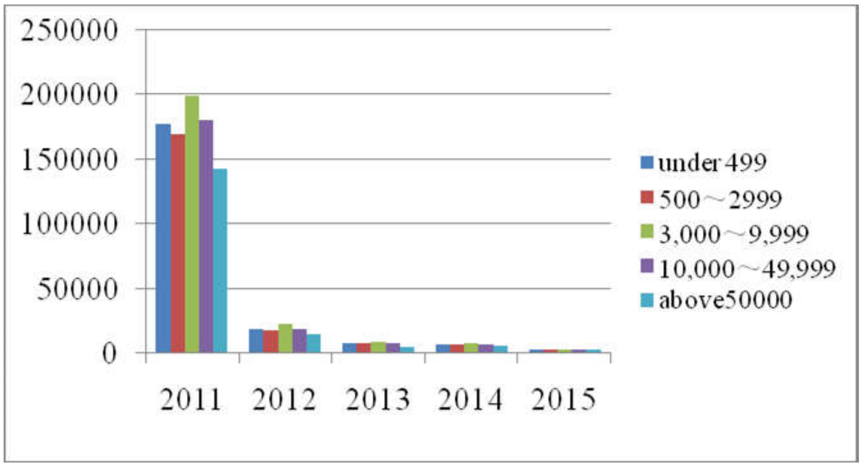

Figure 2.1.4 Ships in and out the port 2011-2015（according to the tonnage）
Source：Xiamen MSA unpublished data

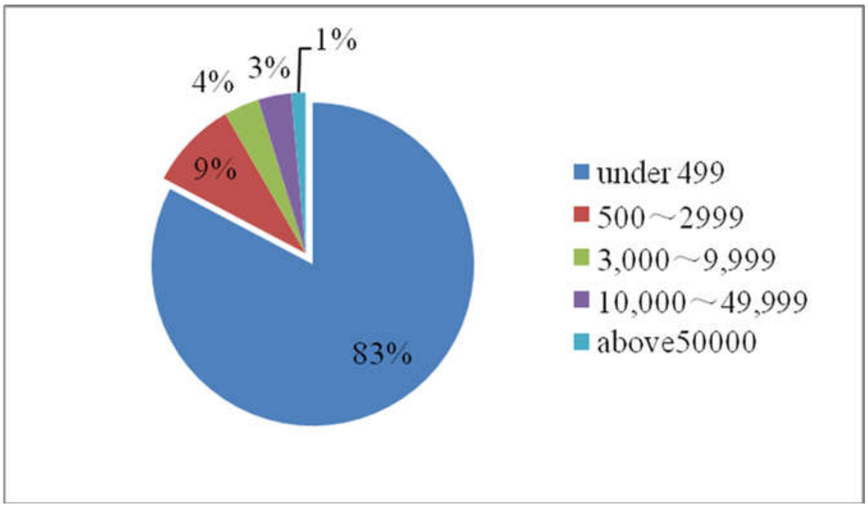

Figure 2.1.5　Proportional distribution of ships in and out the port in 2013（according to the tonnage）
Source：Xiamen MSA unpublished data

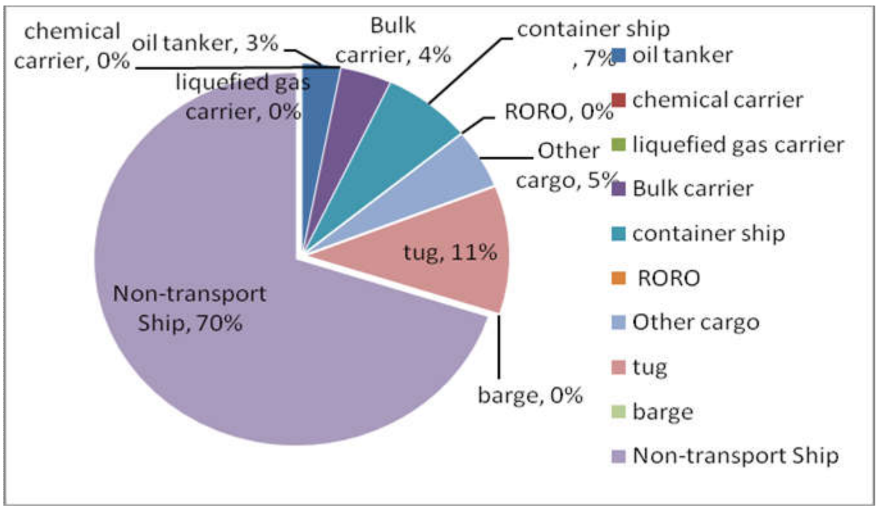

Figure 2.1.6 Proportional distribution of ships types in and out of port in 2015

Source：Xiamen MSA unpublished data

2.2 Natural Condition of Xiamen Port

2.2.1 Weather

(1) Temperature: See Tab.2.2.1The statistics of temperatures in Xiamen Port

Table 2.2.1 The statistics of temperatures in Xiamen Port

Type	Temperature
Average temperature	21.2℃
mean highest temperature	25.4℃
mean lowest temperature	18.2℃
extreme highest temperature	38.5℃（happened in July 26, 2003）
extreme lowest temperature	1.9℃（happened in December 23, 1999）

Source：Xiamen weather bureau published data

(2) Precipitation: Precipitation mainly happens from April to August. The monthly average precipitation is over 100mm, accounting for 67% of the whole year precipitation, among which June has the largest amount. See Table 2.2.2

Table.2.2.2 The statistics of precipitation in Xiamen Port

precipitation	depth（mm）
average yearly precipitation	1355.8mm
maximum yearly precipitation	1768.0mm（happened in 2000）
minimum yearly precipitation	1026.5mm（happened in 2004）
maximum daily precipitation	315.7mm（happened in June 18, 2000）

Source：Xiamen weather bureau published data

The number of rainstorm days is 37.4. See table 2.2.3 the statistics of rain fall intensity in Xiamen Port.

Table 2.2.3 The statistics of rain fall intensity in Xiamen Port

intensity	average yearly raining days
light	74.9
moderate	19.4
heavy	9.0
rainstorm	5.5

Source：Xiamen weather bureau published data

(3) Fog

The number of average yearly foggy days is 26. The maximum is 53 (in 1998) and the minimum is 20 (in 2002). The foggy days mainly happens from February to April and seldom in summer and autumn. Average yearly number of Heavy fog days with visibility of less than 1km is 3.2.

(4) Relative humidity

It is relatively humid from March to August and relatively dry from October to next February. The average humidity is 78%. The maximum humidity is 80% (in 1998) and the minimum humidity is 10% (in 1995).

(5) Wind

The direction of prevailing wind is E, with a frequency rate of 16.34%. The direction of second prevailing wind is ESE, with a frequency of 10.87%. The direction of strong wind is NW, of which the frequency of ≥6 scale is 0.02% and ≥7 scale is 0.01%. The whole year frequency of wind ≥6 scale is 0.04%. See wind rose diagram.

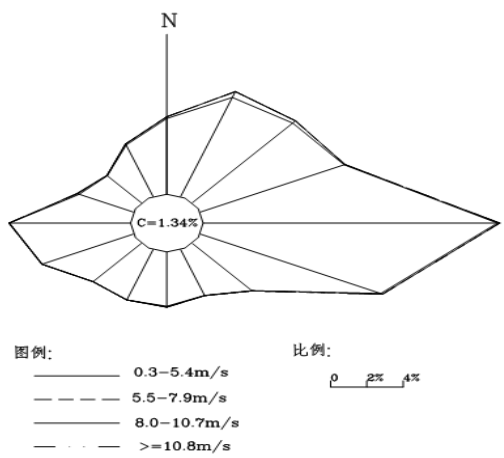

Figure.2.2.1 Wind roses of Xiamen

(6) Typhoon and tropical storm

Xiamen is often struck by typhoons, especially from July to September. According to the statistics in Typhoon Yearbook, there were 344 tropical cyclones in past 52 years, 6.7 per year in average and a maximum of 14 in a year (1961); there are 212 severe tropical storms in past 52 years, 4.2 a year in average; and 191 typhoons, 3.7 per year in average.

2.2.2 Hydrological information

2.2.2.1 Morning and evening tides

The flow field in Xiamen sea area is generated by tide wave flowing through Taiwan Straight washing over the bay. It is mainly powered by tidal oscillation. There are semi-diurnal tides and reciprocating flows, which experience a cycle process of low tide, flood slack, maximum flood, high tide, ebb slack, maximum ebb, and low tide. The tide range is large.

(1) The relationship between Xiamen zero point of the tide and relevant base level (Fig. 2.2.2)

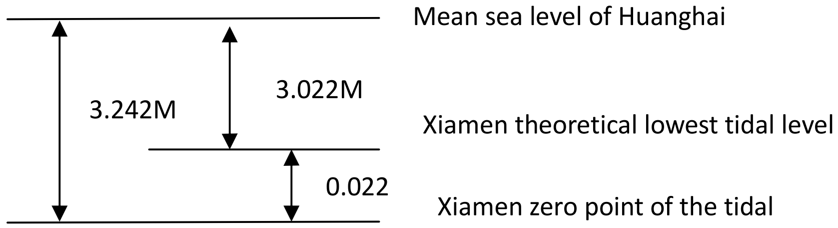

Figure.2.2.2 The elevation conversion relationship of Xiamen Port

(2) Tidal level eigenvalue (tidal level eigenvalue and elevation are calculated from Xiamen theoretical lowest tide level)

Maximum high tidal level: 7.17m (Aug. 23, 1959)

Minimum low tidal level: -0.13m (Jan. 30, 1983)

5.46m average high tidal level: 5.46m

1.47m average low tidal level: 1.47m

3.99m average tide range: 3.99m

2.2.2.2 Tide wave

(1) Change of tide wave

06h18min; average tide duration: 06h18m

06h7min; average ebb duration: 06h7min

41min; average high water interval: 41min

Average low water interval: 06h59min

Direction of tide flow is the same as the lay of the bay. Generally speaking, it flows into the port during the tide and flows out of the port during the ebb, slightly pressing the seashore and long reef with a speed of 2-3 knots (102.8-154.2cm/s). Generally, it is an east-west flow from the port to estuary of Jiulong River. Around Tajiao and Qingyu Island, the tide is northwest, and the ebb is southeast with strong riffles rushing towards Qingyu Island. The flow velocity reaches 3.3 knots (169.6cm/s). On the southeast of Gulangyu Island, the tide is northwest flow with a velocity of 2.3 knots (118.2cm/s), and the ebb is southeast with a velocity of 2.5 knots (128.5cm.s). Due to the impact of Jiulong River, the ebb duration is longer than the tide duration. The tide flow in west port area is in south-north direction, as well as the Baozhu Island.

(2) Tidal intensity

There are several high current areas such as Xiamen outer port, sea area on the south of Weitou Bay, shallow sea-route at Jiulong River estuary and waterway and narrow sea-route to the east of Xiamen Island. The flow velocity may exceed 1m/s (maximum of 1.8m/s). The weak current areas are inner bay (Baozhu Island sea area, Tongan Bay), shoal waters along the shore and south Dadeng sea area with the maximum velocity of 0.3-0.5m/s.

(3) Residual current

The residual current in west Xiamen Sea is mainly tidal residual current generated by the imbalance of tides and ebbs caused by certain landforms. The residual current in Jiulong River estuary is strong, normally exceeding 10cm/s. The port has once measured a surface residual current of 52cm/s.

2.2.2.3 Wave

The harbor mouth faces southeast, with Jinmen Islands, Dadan, Erdan, Qingyu and Wuyu islands being located around, which become the natural barriers of Xiamen Bay.

(1) Inner bay water area

Waves inner bay are mainly wind waves. The likelihood ratio between wind waves and surges is 89:11. The fetch is short and the wave length is low. The prevailing wave is northeast and the high wave is northeast by north. The maximum wave height is 1.3m and the average wave height is 0.2m.

(2) Outer bay water area

Waves outer bay are mainly surges. The likelihood ratio between wind waves and surges is 43:58. The prevailing wave is east and the high wave is southeast. The maximum wave height is 6.9m and the average wave height is 1m. The wave in this area changes in accordance with the shift of seasons.

2.3 Environmentally sensitive resources

2.3.1 Coastal nature reserve

Xiamen Marine nature reserve, including Xiamen rare Marine species national nature reserve, including the Chinese white dolphin natural reserve, egret natural reserve, amphioxus reserves and Jiulong river estuary mouth provincial Marine nature reserve of mangrove (Fang jianyong, 2008; Wang mengguang, 2008), its distribution is shown in figure 2.3.1.

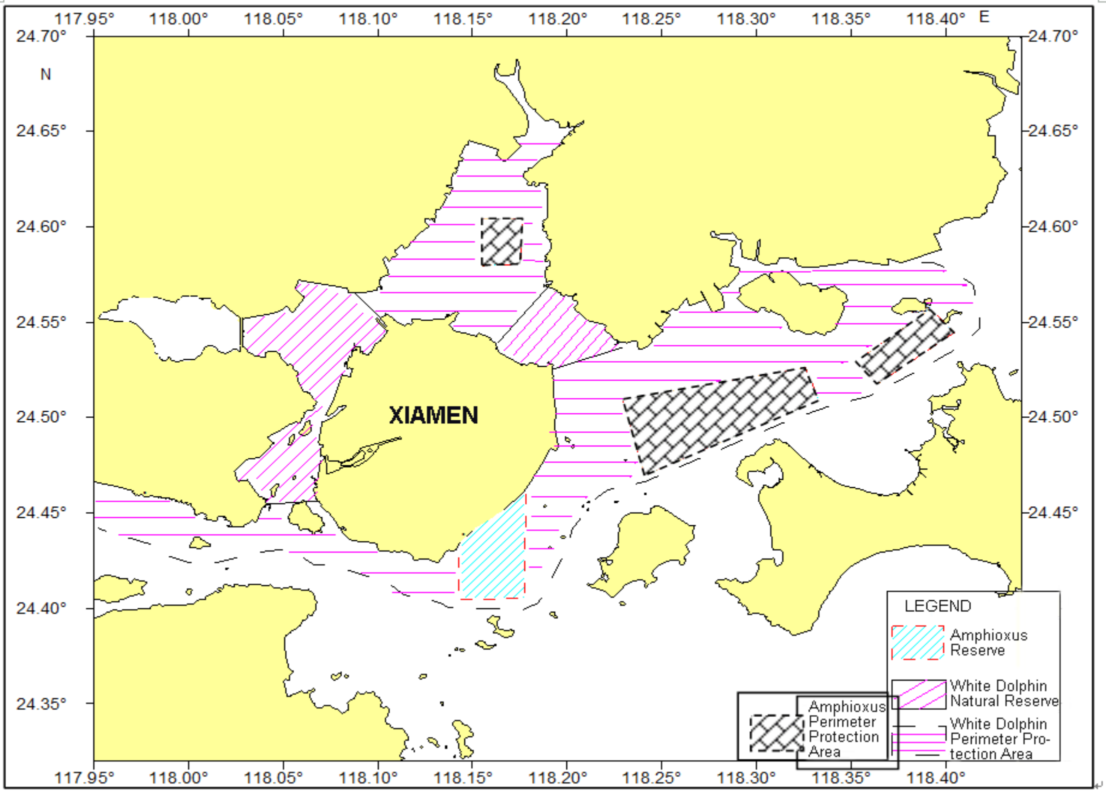

Figure.2.3.1 Distribution of Xiamen rare Marine species national nature reserve
Source：Xiamen Oceanic Administration published data

2.3.2 Coastal Tourism

Xiamen is a harbor city, distribution of extremely rich coastal tourism resources, tourism is one of the pillar industry in Xiamen. As soon as these regions have the oil spill pollution, not only make the seaside resort of serious harm, also can make sightseeing passengers are greatly reduced that can lead the Xiamen's tourism income a certain degree of impact and dent Xiamen's image, leave adverse consequences of the overall economy of Xiamen. Therefore, the coastal tourist area is classified as the second target (Qiu pingbin 2011). The specific tourist areas are shown in table 2.3.1.

Table.2.3.1 The classification of coastal tourist area

Classification		Coastal Tourism
Coastal scenery tourist area	key environmental sensitive tourist attractions	Jimei sightseeing tourist area
		Gulangyu island tourist resort (reserve) priority
	general environment sensitive tourist attractions	baozhuyu sightseeing tourist area
		huoshaiyu sightseeing tourist area
		dadend, xiaodeng and jiaoyu island
		Dongyu island bay ecological tourist area
resort tourism area	key environmental sensitive tourist attractions	Xiamen in the southeast coastal resorts
		Along the northern coast of jimei resorts
		Gulangyu island resorts (reserve) priority
	general environment sensitive tourist attractions	Almond shaped bay water sports entertainment
		Dalimu sports entertainment area
		Zhongzhai bay restort
		Dadeng sports entertainment area
		Baozhuyu north sports entertainment area
		Maluan bay sports entertainment area
		Wu Guan coastal resort area
		Crocodile island recreational fishing resorts

Source： Xiamen Oceanic Administration published data

2.3.3 Mariculture and Marine fishing area

In recent years, central and southern of Taiwan Strait waters fishery production no longer occupy the leading position of social and economic life in Xiamen, but that not stop the development of fishery production speed. Fishery pollution area it is difficult to restore after the oil spill , not only reduce the quantity and quality of products, can also affect the surrounding environment of tourism and the fisherman's normal life. Therefore, mariculture and Marine fishing area is listed as the third class protection targets. Xiamen mariculture zones concentrating in the Dacheng waters and north of Tongan bay, according to the regional characteristics, different ways of cultivation and breeding quality arranged in cross in the waters. In the waters, Marine traffic accidents and oil spill accident probability is low, belongs to the low accident area.

2.3.4 Water resource utilization area

Xiamen sea area water resource utilization is divided into two parts of the special and general industrial area with water. Special industrial water area: refers to desalination area in pukou village located in northeast region of Xiamen island, vessel traffic accident probability is low, and the oil spill risk is smaller. The general industrial water area: Divided in Tongan bay Aotou gas power station and Haicang Songyu power plant two partitions, one of the Songyu island power plant surrounding waters if happen oil spill accident, the water could be contaminated flow into Jiulong river estuary at high tide, lead power plants run abnormally, cause huge economic loss and inconvenience. So Haicang Songyu power plant catchment areas need to be priority protection.

CHAPTER 3 Risk Identification and Source Term Analysis

3.1 The content, scope and type of risk identification

Ship oil spill risk identification is based on the analysis of the historical oil spill accident to determine the accident source, hazards types and possible harm degree. Meanwhile, determine the major hazard sources, provides the basis for subsequent research. In general, the ship oil spill accident can be divided into two categories: operatively leaking oil and accidental leaking oil. Operatively leaking oil including four kind of situations: (1) pipeline damage due to various reasons caused oil spill when ship loading or discharging cargo oil or fuel at the berth; (2) aging of equipment or hose cause oil spill; (3) open wrong valve or equipment failure cause oil spill; (4) discharge oily water deliberately which violate the regulations, etc. Accidental leaking oil means oil spill due to reason as sinking, collision, fire or explosion, hull stranded, etc. In general, for a small level (less than 7 tons) of oil spill, operatively leaking oil is major type, for larger level of oil spill accidents (more than 10 tons), the main types are accidental leaking oil.

3.2 Identification and analysis of the material hazard

Xiamen port main are container and bulk berths, main oil of cargo ship loading are marine fuel oil and diesel oil. Fuel oil is very harmful as persistent oil, its main physical and chemical properties are shown in table 3.1.

Table.3.1 Physical and chemical properties of ship fuel oil

Oil types	Heavy diesel	Light oil IFO60	Medium oil IFO180	Heavy oil IFO380
Specific gravity （g/cm^3， 10℃）	0.86	0.90	0.96	0.992
Kinematic viscosity （cSt）	13.5 （20℃）	60.0 （50℃）	180.0 （50℃）	380.0 （50℃）
Cloud point （℃）	13	20	25	30
Flash point （℃）	65	80	120	130

3. 3 Risk material and hazard characteristics

By comparison results above we know 380 # heavy fuel oil as main fuel of cargo ships, is high viscosity oil, atmospheric volatile dissolution rate and the water solubility are low, condensation into pieces at lower temperature, semi-submersible in sea water. Fuel oil will have persistence pollution for marine and coastal, and damage marine water quality and biological. Hence, choose 380 # fuel oil as representative risk substances of the vessel pollution environment risk assessment, its risk characteristics and health hazard detailed are shown in table 3.2.

Table.3.2 Hazardous characteristics and emergency measures of marine fuel oil

CATEGORY	PROPERTIES	Heavy oil (IFO380)
combustion and detonation	hazardous characteristics	Its vapor and air form explosive mixture of fire, heat, or extremely easy combustion and explosion and oxidant strong reaction can happen, if encounter high fever, container pressure increases, there are cracks and the risk of explosion.
	extinguishing method	Foam, dry powder, carbon dioxide, sandy soil
	Storage and transportation matters need attention	Away from fire and heat source. Warehouse temperature should not be more than 30 ℃.Equipped with corresponding varieties and number of fire equipment. Have the technical measures for fire and explosion prevention. Banning the use of easy to produce the spark of mechanical equipment and tools. Should be paid attention to when filling velocity (no more than 3 m/s), and to have a grounding device to prevent electrostatic accumulation.

Table.3.2 (continued)

CATEGORY	PROPERTIES	Heavy oil (IFO380)
Toxicology	toxicity	LD_{50}：500～5000mg/kg（Mammals inhale）
	health hazard	The steam can cause eye and upper respiratory tract irritation, such as the concentration is too high, a few minutes can cause breathing difficulties, purple purple and hypoxia symptoms.
Leaking disposal	Evacuation leakage area personnel to safe areas, no irrelevant personnel enter the contaminated area, cut off power supply. Recommended emergency personnel to wear self-contained breathing apparatus, general fire wear protective clothing. Plugging in ensuring safety situation. Water spray mist can reduce evaporation, but not reduce the leakage in the limited space of flammability. Absorb with sand, vermiculite, or other inert materials, and shipped to the empty place to bury my collection, evaporation or burned. Such as a large number of leakage, should use the cofferdam asylum, and then abandoned after collection, transfer, recycling or disposal.	

3.4 Source term analysis

3.4.1 Xiamen sea ship accident statistics and analysis

Vessel traffic accidents are the direct factors influencing oil spills, traffic accidents occurred regions usual are also the spots oil spill are prevalent. According to main traffic accidents in Xiamen area 1997-2015 (economic losses more than 500000 Yuan or accidents ship over 1000 tons) statistics, a total of 69 traffic accidents occurred in 13 years that average 3.8 a year, the total economic loss over 100million Yuan. Most of the accidents are caused by collision (accounting for 47%), if these accidents more serious or response is not timely, it is easy to develop major oil spill accident, so these accidents have potential danger of oil spill.

(1) Xiamen sea maritime accident overall characteristic analysis

From the accident site, most accidents happened in Songyu fairway of Xiamen bay, because here is a vessel traffic flow junction point, sand carrier, engineering ship and passenger ferry in and out of the main fairway, Dongdu fairway, Haicang fairway meet here, make traffic flow in this point especially complex easily resulting accident.

Xiang 'an area also become the hotspot of the accident because of the new bulk cargo wharf and new airport construction in recent years, vessel traffic flow is increasing, many low standard ship in the area.

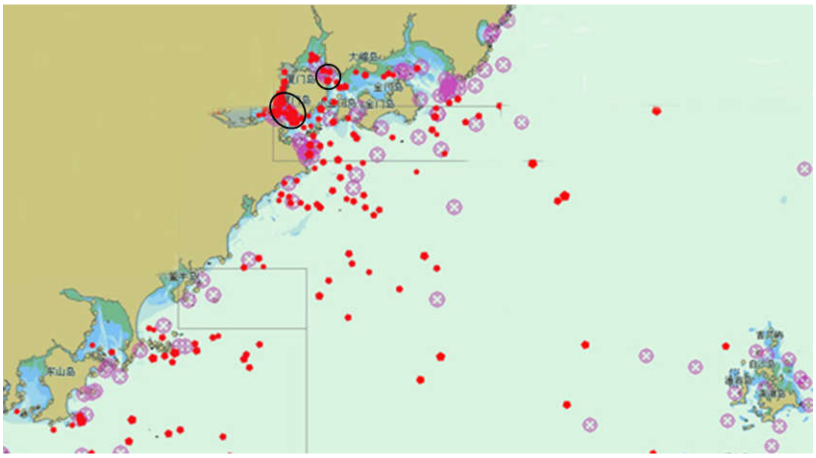

Figure. 3. 1 Distribution map of Xiamen ship traffic accidents and pollution accidents

Source：Created by author

Table 3.3 Xiamen sea water traffic accidents 2011-2015 (According to tonnage)

Tons / Year	Under 500GT		500-3000GT		Above 3000GT	
	Quantity	Proportion	Quantity	Proportion	Quantity	Proportion
2011	8	33%	10	42%	6	25%
2012	2.5	21%	6.5	54%	3	25%
2013	2.5	23%	5	45%	3.5	32%
2014	3	15%	7	35%	10	50%
2015	4	33%	5	48%	3	25%

Source：Xiamen MSA unpublished data

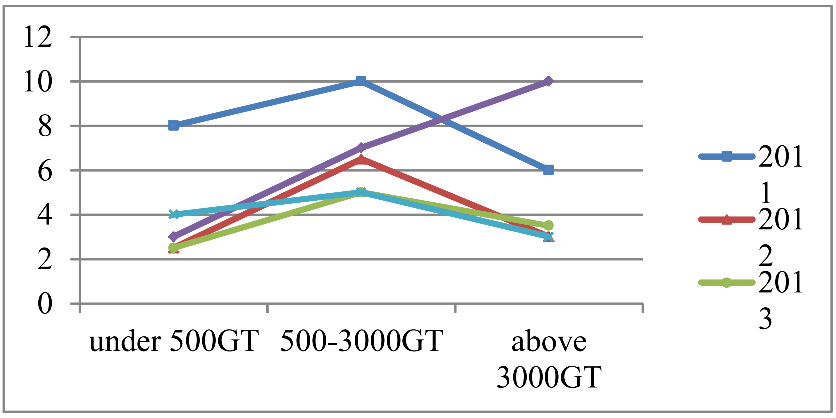

Figure 3.2 Xiamen sea water traffic accidents 2011-2015 (According to tonnage)

Source：Xiamen MSA unpublished data

Table 3.3 and figure 3.2 shows that Xiamen water traffic accident in 2011-2015, traffic accident by the small and medium-sized ships under 3000GT are majority, is mainly due to the crew quality in these ships are poor, security awareness are weak, etc. In 2014, traffic accidents by above 3000GT ships are more, 500-3000GT ships come second. In 2015, the number of traffic accident distributed throughout various tonnage of ship. In general, Xiamen waters' security situation of all tonnage of ships are not optimistic.

Table 3.4 Xiamen sea water traffic accidents 2011-2015 (According to types)

Tons / Year	Collision		Touch damage		Stranding		Sank		Others	
	Quantity	Proportion	Quantity	Proportion	Quantity	Proportion	Quantity	Proportion	Quantity	Proportion
2011	9	60%	3	20%	1	6.3%	1	6.3%	1	6.3%
2012	5	42%	2	17%	0	0	1	8%	4	33%
2013	9	82%	1	9%	0	0	0	0	1	9%
2014	7	50%	2	15%	1	7%	0	0	4	28%
2015	5	42%	2	17%	2	17%	1	8%	2	17%

Source：Xiamen MSA unpublished data

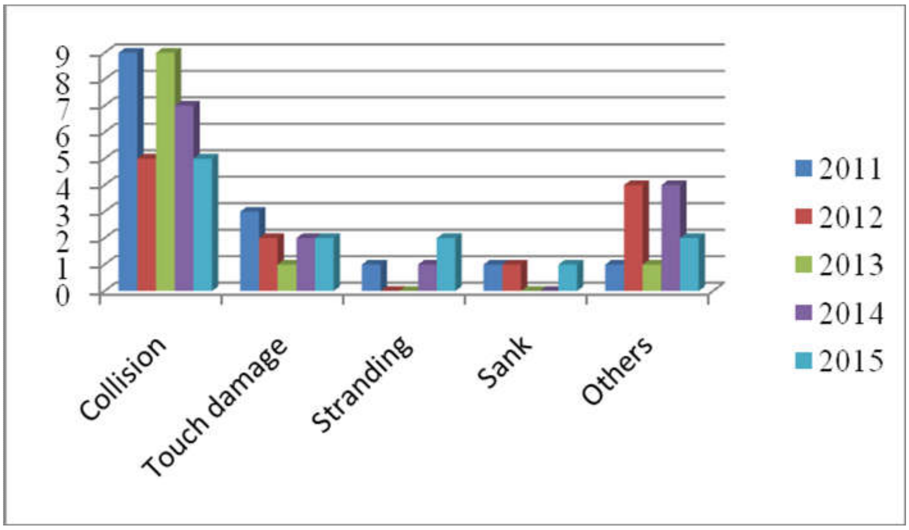

Figure 3.3 Xiamen sea water traffic accidents 2011-2015 (According to types)

Source：Xiamen MSA unpublished data

In table 34 and figure 3.3, collision is major accident type of Xiamen sea area, and in 2011-2015, water traffic accident number did not reduce significantly, the water safety situation is not optimistic, prevention of the ship collision accident is still the focus of the maritime traffic safety regulation in the future.

(2) Investigation statistics of Xiamen oil spill accident

According to investigation statistics, Xiamen ship oil spill accident statistics from 2001 to 2015, and Xiamen since 1973 major oil spill accident statistics, see table 3.5 and 3.6.

Table 3.5 Xiamen ship oil spill accident statistics in 2001-2015

NO	Time	Place	Perpetrator	Oil spill quantity (t)	Type
1	2001.9.20	Main fairway	Yun hong	90	accidental leaking oil
2	2002.7.26	Liu wudian port	Tian xiang	0.1	accidental leaking oil
3	2003.3.29	Xiang lu port	CRANE OCEAN	0.002	operatively leaking oil
4	2003.5.25	Dong du1#berth	Hua dingshan	5	accidental leaking oil
5	2004.10.2	Taiwan Strait	Wei chang	1.3	accidental leaking oil
6	2004.12.24	Huayang power station port	Hong ya	2	operatively leaking oil
7	2005.6.9	Haicang 10＃	Bao hang1208	0.004	operatively leaking oil
8	2006.3.1	Dong du2＃	Qian niuxing	0.015	operatively leaking oil
9	2006.7.31	Dongdu 3＃	He beihaoyun	0.1	operatively leaking oil
10	2006.8.16	Haicang 9＃	Ji da58	0.1	accidental leaking oil
11	2006.8.20	Dongdu 3＃	Feng kangshan	0.01	operatively leaking oil
12	2007.1.15	Maluan bay	Chu yang2	3	accidental leaking oil
13	2007.8.28	Huandao Road	unknown	——	accidental leaking oil
14	2008.10.8	Dongdu port	Hua hang1	0.02	operatively leaking oil
15	2009.10.4	3# Anchorage	Xin haiwang	0.1	operatively leaking oil
16	2009.11.15	Guomao port	Min xiamenshui 0005	0.02	operatively leaking oil
17	2009.12.17	Houshi electricity-coal port	Kawati	0.14	operatively leaking oil
18	2010.11.27	Dongdu 10#	Qian he 12	5	accidental leaking oil
19	2011.5.25	Guomao port	Haifeng zelpusi	Little	operatively leaking oil
20	2011.8.9	Dongdu port	Tian xiang13	0.9 oily sewage	operatively leaking oil
21	2011.11.28	Haitian port	Minxiamenyou0031	0.035oily sewage	operatively leaking oil
22	2012.4.25	Shihushan port	Rong xiang6	1	operatively leaking oil
23	2014.8.10	Xinhaida port	Xin qiuhe	51 oily sewage	operatively leaking oil
24	2014.10.5	Dongdu area	Hong yi68	3 oily sewage	operatively leaking oil

Table 3.5 (continued)

NO	Time	Place	Perpetrator	Oil spill quantity (t)	Type
25	2015.1.23	Xiandai port 3#	Da cheng	0.03	operatively leaking oil
26	2015.11.1	Xinhaida port	Hai gong169	0.05	operatively leaking oil
27	2016.1.29	Haicang 13	Xingzhongsheng	3	accidental leaking oil

Source：Xiamen MSA unpublished data

Table 3.6 Xiamen major oil spill accident statistics from1990 to now

NO	Time	Place	Perpetrator	Registry	SHIP Type	quantity	OIL Type	Cause
1	1995.4.30	Northeast of Xiamen sea	Nanyang 2	China	Tanker	200t	Light diesel	Collision
2	1995.5.21	Xiamen	Xiong yucheng	China	container	153t	Fuel oil	Collision
3	1996.3.8	Xiamen	Zhonghua1	China	Tanker	900t	Light diesel	Collision
4	**2001.9.20**	**Xiamen main fairway**	**Yunhong**	**China**	**Tanker**	**90t**	**diesel**	Collision

Source：Xiamen MSA unpublished data

From oil spills in Xiamen sea area following features can be summed up:

(1) Ship oil spills' frequency is decline in general, but scale of oil spills has increased risk;

(2) In general, ship oil spills and oil quantity have contingency and unpredictability;

(3) The collision and improper operation is the main reason for the accidental oil spill and operational oil spill respectively;

(4) Because of the development of small and medium-sized shipping companies in Xiamen, a large number of poor technical condition, long age and small tonnage ships come in oil transportation industry, and the ship equipped with the crew whose common quality is not high, as a result, these ships become important risk source of the oil spill accident.

3.4.2 Main types of oil spill and probability analysis

From the statistic of ship oil spill events, mostly belong to operational oil spill, but its quantity is small, generally below 10 tons. In another way, accident of oil spill less time, but its quantity is big, mostly more than 50 tons, even thousands of tons, have a great danger risk to the marine environment. Mainly reasons for oil spill incident are collision, sinking and stranding. Since 1990, all four major oil spill of Xiamen is caused by collision.

Table 3.5 show that, 18 times are operability oil spill in total 27 times, 1.3 per year on average, the operational pollution accident frequency is 1.3 times per year; 9 times are accidental oil spill, average frequency is 0.7 times per year, but its quantity is average nearly 11 tons/time compare with operability oil spill an average of 0.2 tons/time. Xiamen port cargo throughput a total of 17.55 million tons in 2015, ship accidents 1.14times/ 1 million tons; Accidents involving the ship a total of 3 ships, the total of more than 3000-ton cargo ship ships in 13911 in 2015 in Xiamen, the accident rate is about 0.22‰.

3.4.3 Analysis of frequently area occur ship accidents

Using Xiamen Vessel Traffic Service（VTS）history traffic data platform to analysis existing AIS ship track data, get the ships flow characteristics in Xiamen waters (as shown in figure 3.4). It can see that ships enter Xiamen sea converge in main fairway shunt in Gulangyu island, respectively to Dongdu fairway, Haicang fairway, ZhaoYin fairway and Xiagu fairway. So the main fairway and Dongdu fairway cross region near 7# anchorage is ships most densely sailing area. In addition, through Xiamen port navigation accident data statistical calendar year, from the point of the accident site, near Songyu fairway the number of accidents is more, mainly because this is a vessel traffic flow junction point, various types of ships form other fairways meet in this intersection, make that point of traffic flow is especially complex. Liu wudian fairway in Xiang 'an area also become the hotspot of the accident in recent years, because of construction of the new bulk cargo wharf and the new airport, the vessel traffic flow and low-standard ship are increasing.

Figure 3. 4 Ship AIS track charts of Xiamen waters（2016. July）
Source： Xiamen Vessel Traffic Service data

By comprehensive analysis, Xiamen high incidence sea areas occur ship pollution are as follows:

(1) Operational oil spills: occurs front the berth and near the port basin;

(2) Accidental oil spills: intersection of main fairway, Dongdu fairway and the 7 # anchorage, and Liu wudian fairway in Xiang 'an area.

3.4.4 Source intensity of Operational oil spill pollution

Operational oil spill accident mainly happened at the berth. According to China coastal accident statistics, operational oil spill accident leaked 4 tons/time on average. According to Xiamen port ship oil spill accident statistics from 1991 to 2015, 18 times operational accidents, 0.02 tons/time on average and the biggest time is 1 tons. The most serious operational accident mainly occurs when cargo ships refueling in the harbor, risk mainly comes from the connecting pipeline rupture and refueling overfill of tank, it is calculated as follows: adding fuel oil transportation mode is mainly form refueling ships to vessel, using oil arm on board whose general rate in 300 ~ 400 m^3/h, assume leak time for 2 minutes, an operational oil spill accident would leak about 10 tons.

3.4.5 Source intensity of accidental oil spills

Fuel quantity Cargo ship carrying relate to its main engine power, sailing speed and the continuous sailing time. In general, the vessel's fuel oil tank has a capacity of about 8-12% of the gross tonnage of the ship. International ships as long continuous sailing time, fuel load can reach 80% of the tank volume. Domestic ships generally refuel by voyage or by the month, more than 10000GT ships add about 300-500t every time. According to statistics, 5000GT ships are majority in and out of Xiamen Sea, loaded 600t fuel per voyage which general spread in three fuel oil tank average with 200t, if all fuel oil in a tank leakage that would be 200t. The biggest International ships to Xiamen port is 150000DWT container ships, maximum up to 10000t of fuel oil spread in 5-6 fuel oil tank, a tank with an average of 1600-2000 tons fuel oil. Fuel remaining carrying amount according to 1/2 of the maximum total carrying amount, 1 tank all fuel leakage would about 800-1000t. According to China's coastal ship accidental oil spills statistics, during 1973 to 2015, each accident leak an average of 215t oil. The largest is 1268 tons in the 7th December of 2004, the German container ship "Mediterranean fruma Iraq" in Pearl river mouth fuel leak caused by collision accident. Synthesize the above analysis, accidental oil spill in fairway or anchorage of Xiamen sea area, Most Likely Oil Spill Quantity may be 200t, the Largest Credible Accident Quantity may be 1000t.

3.5 Summary

By statistical analysis and evaluate locations, probability, number and variety respectively of possible operational and accidental oil spill accident of vessels entering and Leaving Port Xiamen sea area, the results are shown in table 3.7.

Table 3.7 Source term analysis results of ship oil spill accident in Xiamen waters

Type	High incidence area	Oil types	Probability	Most likely oil spill quantity	Largest credible accident quantity
Operational	Berth apron	marine fuel oil	1.0	≤1T	**≤10T**
Accidental	**Fairway crossroads**		**0.5**	**≤200T**	**≤1000T**

Source：Created by author

CHAPTER 4 Oil spill accident hazard impact prediction

4.1 Simulation of oil spill behavior

The simulation is carried out with the SINTEF Oil Spill Contingency and Response (OSCAR) 3-dimensional model system (Reed et al, 1999). OSCAR provides a basis for comprehensive, quantitative environmental impact assessments in the marine environment.

Key components of the system, shown schematically in Figure 4.3, are SINTEF's oil weathering model (Daling et al, 1997), a three-dimensional oil trajectory and chemical fates model (Reed et al, 1999), an oil spill combat model (Aamo et al, 1993), and exposure models for fish and ichthyoplankton, birds, and marine mammals (Reed et al, 1999). The system calculates and records the transient distribution in three physical dimensions plus the residence time of contaminant particles on the water surface, along shorelines, in the water column, and in the sediments. The model is embedded within a graphical user interface in WINDOWS, which facilitates linkages to a variety of databases and tools. The latter allow the user to create or import wind time series, current fields, and grids of arbitrary spatial resolution.

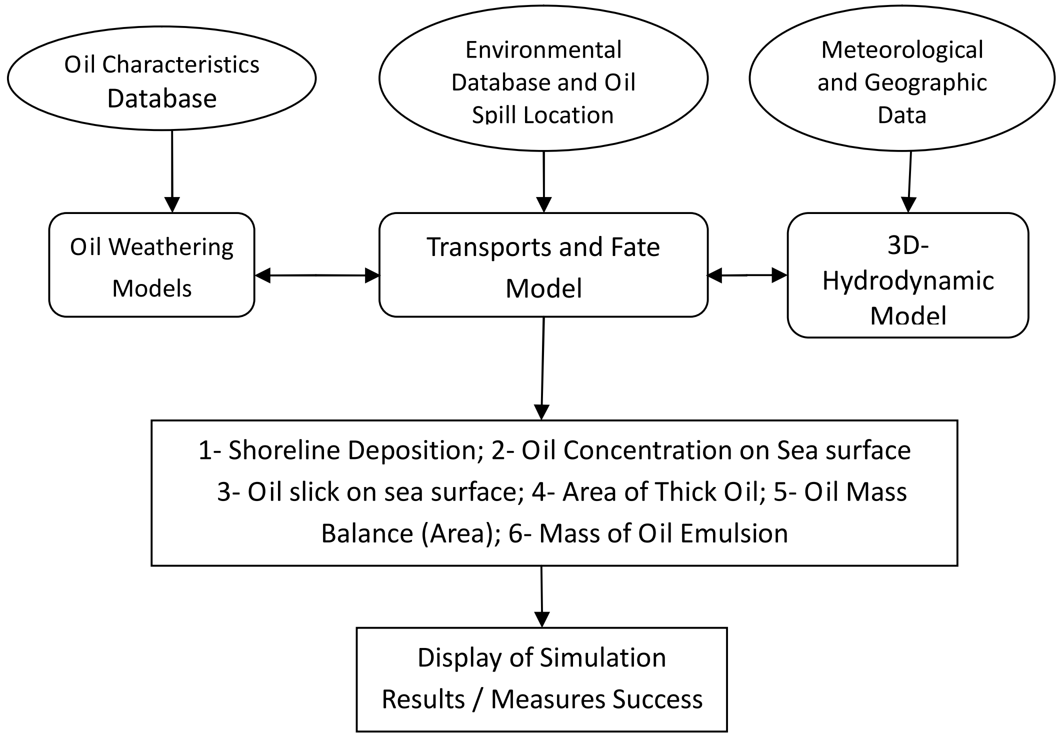

Figure.4.1 Schematic overview of the OSCAR system

4.1.1 Drift and diffusion

The movement of oil spill can be divided into horizontal flow and turbulent diffusion process, while horizontal flow can be simulated by the certainty method, the turbulent diffusion can be simulated by the random walk method. Oil spill is regarded as a large number of 'oil particles'. The dynamic distribution of these particles is analyzed to investigate the end-result of the spilled oil. Derived from the Lagrangian representation of fluid flow, oil particles spatial displacement in Δt can be expressed as:

$$P_{New} = P_{Old} + U_{Adv}\Delta t + \Delta L_{Dif} \qquad (4\text{-}1)$$

Type: P_{Old} for a single oil particles of original position; P_{New} for the new position; U_{Adv} for current velocity vector (by tide, wind current, residual current synthesis); $\triangle L_{Dif}$ for turbulent diffusion distance. Distance of Oil particles random movement due to turbulence diffusion which is expressed as (Lehr et al, 1984):

$$\Delta L_{Dif} = R \cdot \sqrt{6K_{\alpha}\Delta t} \quad (4\text{-}2)$$

Type: $\triangle L_{Dif}$ for distance on α direction by turbulent diffusion (α as x, y, z direction); *R* for random number uniformly distributed between [-1, 1]; K_{α} turbulent diffusion coefficient for α direction; Δt as the time step. For oil particles stochastic diffusion in the vertical direction, turbulent diffusion coefficient K_z use Ichiye (1967) formula:

$$k_z = 0.028(\frac{H_s^2}{T})e^{-2kz} \quad (4\text{-}3)$$

Type: H_s as the significant wave height; k as the wave number; T as a wave cycle; z as the depth.

4.1.2 Evaporation

The evaporation of oil spill is refers to mass transmission process that the lighter hydrocarbon component of oil volatiles into the atmosphere. Spilled oil evaporation is mainly affected by the oil film area, thickness, properties, vapor pressure, wind and other factors. The author uses the component model to calculate oil film evaporation (Reed et al, 1999):

$$dm_i / dt = K_e P_i A M_i F_i / (RT) \quad (4\text{-}4)$$

Type: m_i as the evaporation quality of components i; K_e as transmission coefficient of evaporation quality; P_i as the vapor pressure of components i; A as the oil film surface area; M_i for components of molecular weight; F_i is mole fraction of component i retained in the oil film; *R* as the gas constant; *T* as the temperature.

4.1.3 Emulsification

Spilled oil emulsification can be affected by factors such as wind, waves, the thickness of the oil, environmental temperature, degree of weathering, generally use moisture content to characterize degree of emulsification (Reed et al, 1999):

$$W(t+\Delta t) = W_m(t) - [W_m(t) - W(t)]0.5^{\frac{\Delta t}{t_{1/2}}} \quad (4\text{-}5)$$

Type: $W_m(t)$ as the maximum water content; $t_{1/2}$ as the wind affect half-life.

4.1.4 Dispersion

Dispersion of oil spill is referred to the process of formation of small droplets after oil spill into the water, can use dispersion model Delvigne and Sweeney (1988) established based on scattered experimental data of oil spill :

$$Q_{di} = C^* D^{0.57} SFd_i^{0.7} \Delta d \qquad (4\text{-}6)$$

Type: Q_{di} as diameter is speed of $d_i \pm \Delta d$ droplets of unit surface area into the water; C * as empirical coefficient related oil type and weathering state; D as energy of breaking wave in unit surface; S is the surface score covered by oil; F scores suffered a broken wave unit time; d diameter as oil droplets with i class size; Δd as interval between oil droplets diameter.

4.1.5 Dissolution

Dissolution of oil spill is referred to mass transport in the process of the petroleum hydrocarbon into the water, as well as evaporation process, dissolution process related to the mole fraction of each component in the oil. The author uses the SINTEF experimental formula (Reed et al, 1999):

$$dm_i / dt = K_d A(F_i S_i - C_i) \qquad (4\text{-}7)$$

Type: K_d as dissolution quality transmission coefficient; A as the oil droplet or the oil film surface area; F_i as the oil droplet or oil film i component mole fraction; S_i as the solubility of i components; C_i as the Mass concentration of i components in water.

4.2 Oil spill pollution impact prediction

Typical scenario simulation method to predict the oil spill drift diffusion range and damage degree, the meteorological conditions at the time of the accident only commonly consider throughout the year, the winter monsoon and unfavorable wind, tide of hydrological conditions generally only calculate the sharp rises and falls 2 times, usually only combined into 4 to 8 kinds of typical scene for calculation and simulation respectively. While the actual wind speed and direction impossible remain for several hours or even days, and don't consider other wind and tide is easy to miss the real adverse situation. Therefore, in this paper, a more advanced random scene statistics method is adopted for oil spill pollution impact simulation prediction. Main difference compare with typical method is that: the oil spill accident time is uncertain, can be any time in the past few years, can be randomly generated a number of different scenarios, for each scenario according to the historical meteorological data at the time to simulate calculate the oil spill drift diffusion, finally each scene simulation results will be statistically analyzed, integrally get probability, time and oil film thickness and other data of the sea oil spill drift diffusion influence different regions and coastline.

For statistically meaningful, time should span at least 3 years, pick up at least 100 spill sceneries randomly each year, a total of 300 oil spill sceneries. The wind field, the temperature and other meteorological data to choose Xiamen weather stations monitoring data during 2012-2015, the corresponding flow field data use Xiamen sea area of Marine dynamic simulation calculation results. According to the result of the accident source term analysis above, the amount of spill take 200t, leak time take last 2 hours. Predicted results are shown in figure 4.2.1 - figure 4.2.4 respectively.

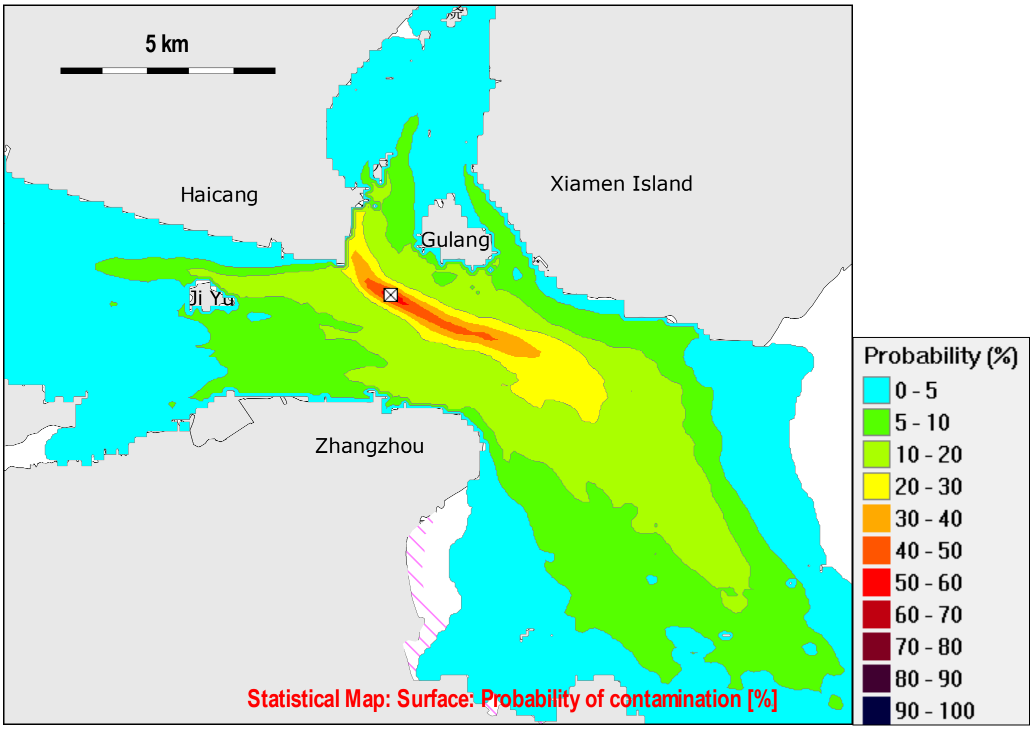

Figure 4. 2.1The pollution probability of oil spill draft and diffusion

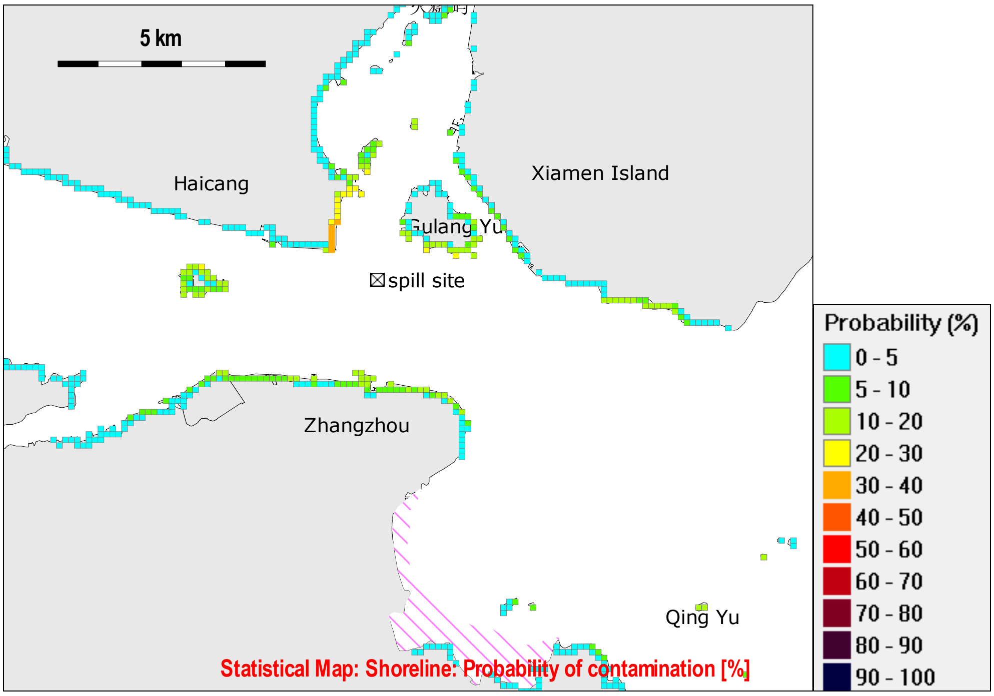

Figure 4.2.2 The oil spill pollution probability of shore line

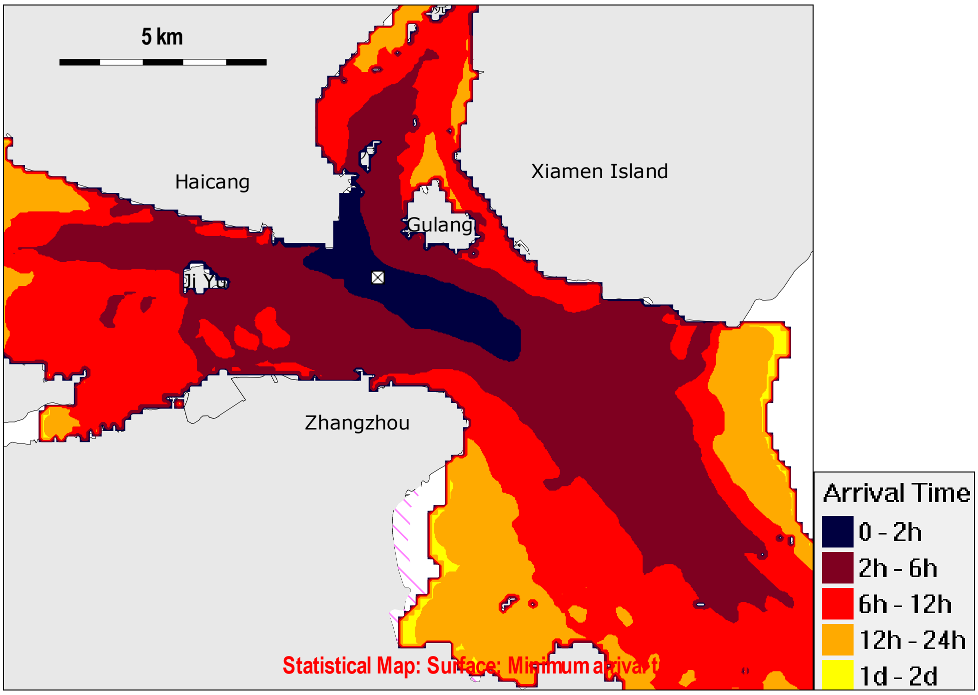

Figure 4.2.3 The fastest arrival time of Sea oil film

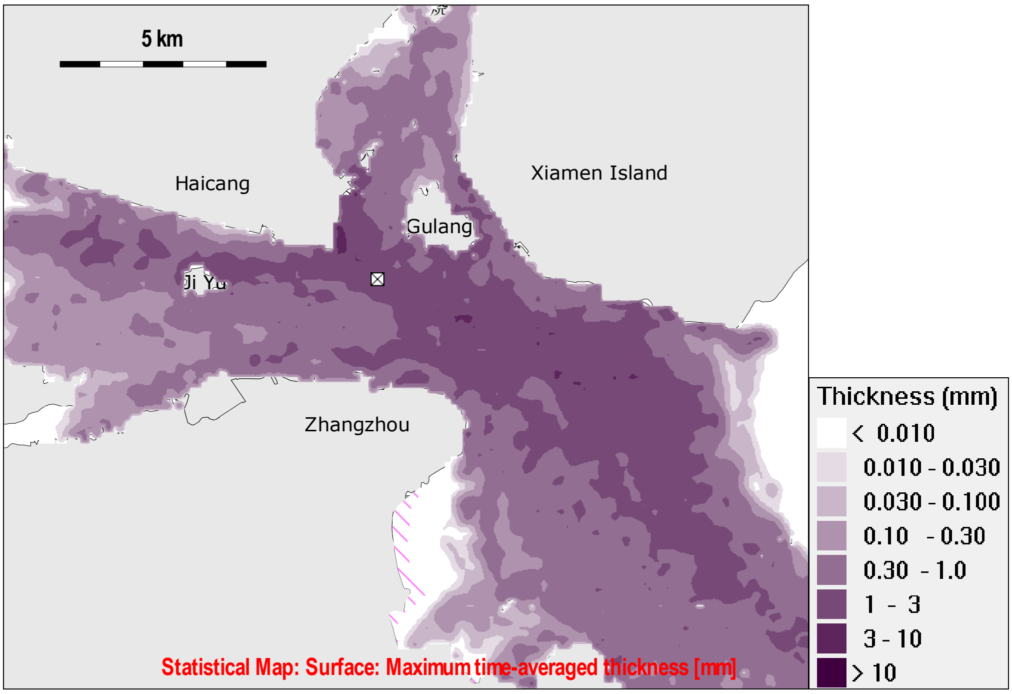

Figure 4.2.4 Maximal thickness distribution of sea oil film

The figures show that once big ship oil spill accident (200 tons) happen in the Xiamen main fairway junction, around oil spill site 4 to 16 km with a total area of 230 km2 of waters and 50 km long coastline could be oil spill pollution. Since the tide flow velocity is high around the main fairway, environmental sensitive area near the fairway would be more likely to be affected by the oil spill pollution. Gulangyu island, Dayu island, Jiyu island, south coast of Xiamen by the oil spill pollution probability varies from 10% to 15%, the shortest arrival time is 2 - 5 hours, the surface of the oil film thickness can be 5-20 mm, the overall harmful consequences is very serious.

Compared with the typical scenario simulation method, random scene statistics can reflect the uncertainty of the oil spill accident time, meteorological and hydrological conditions randomly combine into a variety of scene and simulate, the randomness and statistical unified mutually, make risk prediction analysis results more reasonable and reliable (China MSA, 2011), at the same time also can get important parameters be environmentally sensitive resources probability may be contaminated with oil spill and the fastest arrival time in conventional hydrogeological conditions, these parameters provide more scientific basis for regional oil spill emergency capability construction and prevent and respond measures.

4.3 Oil spill accident hazard forecast summary

By the advanced stochastic simulation statistics method and comprehensive prediction, once of big ship oil spill accident (200 tons) happen in Xiamen fairway junction, around leakage location 4 to 16 km with a total 230 km^2 areas and the total of more than 50km length coastline could be pollution. The fastest time arrival environmental sensitive area is 2 - 5 hours which oil spill pollution probability is 10% -15%, the surface of the oil film thickness can be 5-20 mm, the overall harmful consequences is very serious., need special protection.

CHAPTER 5 Risk Assessment

5.1 Harmful consequences index model

Both theoretical and practical analysis shows that the oil spill damage associated with oil quantity and also with the sensitive degree of contaminated target and the possibility of pollution. Therefore, in sensitive waters, it is difficult to use the number of oil spill as single variable indicator to truly reflect the influence of oil spill pollution to sensitive target, more indexes should be evaluated so that the harmful consequences can be reasonably determined. Hence a new harmful consequences index model is established as follows:

$$C = lgA + \frac{Max(Pi \times Si) + \frac{\Sigma(Pi \times Si)}{n}}{2}$$

Formula: *A* leakage for pollutants; *Si* for the i_{th} sensitive coefficient of the environmental protection goal; Pi for the i_{th} probability environmental protection goal be contaminated (can be obtained by random scene statistics simulation calculation in the previous chapter). Index and the hazards level corresponding relations are shown in table 5.1 below.

Table 5.1The correspondence between harmful consequences index and hazard rating

Hazard rating	Index of the harmful consequences	Explain of harm extent	Harm extent
1	≤2	Accident level is general, -- spill under 10 tons, or caused a direct economic loss less than 2 million Yuan, less effect on the environment.	**Small**
2	2～3	Accident level is general, -- spill 10-100 tons, or caused a direct economic 2-10 million Yuan, medium effect on the environment.	**Medium**
3	3～4	Accident level is larger, -- spill 100-500 tons, or caused a direct economic 10-50 million Yuan, larger effect on the environment.	**Lager**
4	4～5	Accident level is major, -- spill 500-1000 tons, or caused a direct economic 50-100 million Yuan, major effect on the environment.	**Major**

Table 5.1 (continued)

Hazard rating	Index of the harmful consequences	Explain of harm extent	Harm extent
5	≥5	Accident level is special major, -- spill more than 1000 tons, or caused a direct economic more than 100 million Yuan, special major effect on the environment.	Special major

Source：Created by author

Stochastic simulation method is applied to predict the results, and the harmful consequences index of oil spill damage to sensitive targets is calculated, as shown in table 5.2.

Table 5.2 General average nature of ship oil spill the harmful consequences Index results

NO	Sensitive Target	Sensitivity Coefficient Si	Probability be Contaminated Pi	The shortest time of arrival	Oil film thickness（mm）	Harmful index Pi×Si
1	Gulangyu tourist area	20	15%	3hours	15	3
2	Jiyu protection area	20	12%	3hours	20	2.4
3	Dayu protection area	20	8%	4hours	10	1.6
4	South coast	20	10%	5hours	10	2
5	Songyu intake	20	10%	5hours	5	2
6	Songyu area	5	16%	2hours	20	0.9
7	Zhaoyin area	5	8%	5hours	10	0.4
8	Dadan and Erdan island	50	2%	15hours	1	1
	(Max(Pi×Si)+(∑(Pi×Si))/n)/2					2.33

Source：Created by author

The accidental ship oil spill damage effect index $= \lg 200 + \frac{3+1.66}{2} = 4.66$, if failed to take effective emergency measures, overall harmful consequences may lead to a major accident.

5.2 Risk matrix and assessment results

The accident probability analysis shows that the Xiamen sea area has a high probability of accident. The average accidental vessel pollution accident is 0.5, which means one oil spill is likely to happen every two years. Through the forecast, the oil spill accident happens, if failed to take proper emergency treatment measures to compound control of oil spill recovery, overall harmful consequences, to a major accident, grade 4. Combining the accident frequency and the harmful consequences, risk assessment matrix of accidental oil spill pollution is obtained as follows in figure 5.1.

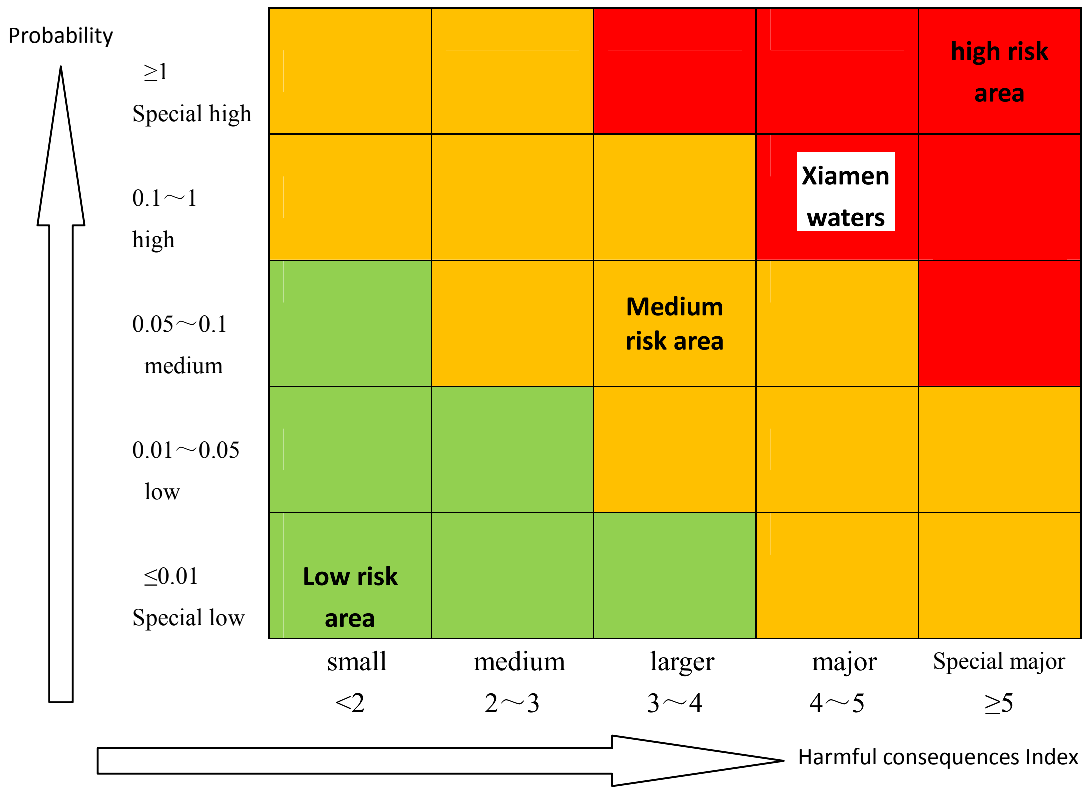

Figure. 5. 1Risk assessment matrix of oil spill accidental Xiamen waters
Source：Created by author

From comprehensive risk matrix diagram it can be observed that, due to average in and out of Xiamen port wharf ship oil spill accident probability is higher, and the harmful consequences is very serious, the comprehensive risk assessment results would fall into the red high risk area, namely the Xiamen sea ship oil spill accident risk assessment result for the high risk, general need to take effective measures to prevent and reduce the risk as soon as possible.

CHAPTER 6 Countermeasures and Emergency Scheme

6.1 Countermeasures for reducing the probability of oil spill accident

6.1.1 Prevent countermeasures for accidental oil spill

Elements referring to accident factors can be summarized as four aspects, ship technical conditions, human factors, management and environment. According to the analysis of the main accident scene in high-risk areas, certain aspects of hidden danger occuring together often lead to accidents. Accident prevention plan should be a combination of highest efficiency measures to prevent accidents. Due to accidental oil spill often happen in the fairways or anchorages, the MSA should pay more attention to investment and construction in the vessel traffic and personnel management.

(1)The improvement of the vessel traffic management

Practice indicates that the most effective way to prevent ship collision and grounding accident is to strengthen the management of navigational traffic order and apply advanced regulatory means to improve the maritime traffic management. Therefore, the practical risk management program could be: a. the implementation of key-route vessel traffic separation scheme on the basis of the existing traffic separation scheme implementation of in Xiamen sea area; b. the expansion of the scope of maritime traffic administration and service to monitor the whole process of the key routes via Vessel Traffic Services.

(2) The advancement of crew education and penalties

Ship collision and grounding accident closely related to human factors, such as the failure of watchkeeping, the unsatisfactory of radio communication duty, the noncompliance of traffic separation scheme and speed limitation, etc. On this basis, enhancing penalties for the violation of maritime traffic order to regulate illegal behaviors and strengthening retraining become important means to prevent maritime traffic accidents caused by human factors.

(3) The intension of high-risk ship supervision

Because of poor conditions of technology and management of the ships, especially large oil tankers and other large vessels sailing along the coast of China, it's not only hard to secure their own safety, but also easy to pose a serious threat to other ships and the coastal environment. The MSA should formulate special regulations, according to ship safety inspection records (including FSC), to determine the 'High-risk Ship' and its belong company, and then carry out strict monitoring, port-entering, and other measure to prevent catastrophic maritime-traffic accidents and pollution accidents.

6.1.2 Countermeasures for operational oil spill at sea

(1) Strict implementation of laws and regulations related to the prevention and control of marine pollution

According to 'Regulations on the Administration of the Prevention and Control of Marine Pollution to the Marine Environment', it's very vital to fulfill the enterprises' safety responsibility, and establish the refueling companies' rules and regulations. It's also feasible to strengthen the site supervision of refueling operation processes, penalize the illegal operations strictly, and even suspend their business if necessary. In addition, the MSA can raise the safety level of refueling ship, and accelerate the phase-out for old ships and single-hulled ships used as refueling ship by ending the *Regulations on Fujian waters shipping Refueling*.

(2) The reinforcement of education in crew qualification and pollution prevention management

By strengthening the crew education to enhance their sense of responsibility and develop good operational habits, the seafarers could have better skills to deal with an emergency, and take appropriate actions under different oil spill, such as, stopping all operations immediately, such as, closing all valves on the piping, sending spilled oil alarm signals, implementing ship's emergency response procedures on oil spill, etc.

6.2 The establishment of the emergency management system

In order to minimize these impacts, preparedness and response are always required for any oil spill, including the monitoring, prevention, reduction, response, and remediation of oil pollution (IMO, 1995; Ornitz and Champ, 2002; Tuler et al., 2007). Therefore, an oil spill response system is commonly based on the interaction of multiple organizations (Walker et al., 1995). U.S. FEMA-Federal Emergency Management Agency holds the opinion that emergency management is organized analysis, planning, decision-making and allocation of the available resources, aiming alleviation, preparation, response and recovery of the effects of the danger (FEMA, 1996).

6.2.1 The current situation of Xiamen marine oil spill emergency response ability

(1) Emergency plan system is gradually improved

In 2004, *Overall Emergency Plan for Accident for Xiamen Municipal People's Government* was issued. In April 2009, Xiamen issued the *Emergency Plan for Vessel Pollution of Xiamen Sea Area* which marked the qualitative leap of the vessel pollution accident emergency management in Xiamen Sea. In addition, bulk liquid dangerous goods docks, oil storage and transportation units, cleaning oil tank operation department, oil supply units and shipbuilding and repairing operation departments in the jurisdiction of Xiamen have compiled the ship pollution contingency plans, including ship oil pollution emergency plan which preliminary formed a relatively perfect pollution emergency plan system.

(2) The mechanism of the emergency system is gradually established

The Headquarter of Xiamen sea ship pollution emergency is a specialized command responsible for ship pollution emergency disposal work. By focusing on the prevention and control of pollution, source management，the use of science and technology, and the construction of emergency facilities, the pollution accident prevention coordination mechanism has been established preliminary which strengthens the guidance support of market operation mechanism of sea pollution clean-up companies, urges wharf enterprise to establish emergency management mechanism, improves the pollution emergency linkage mechanism in high-risk port area, and successfully sets up the emergency system which takes the MSA as command, the ship sewage disposal unit as the main force, the ship companies, pollution receiving unit, wharf owner and social parties as the supplement.

(3) Emergency monitoring capability is enhanced unceasingly

Xiamen MSA established vessel traffic management system during the period of the 11^{th} Five-year PLAN, and constantly improves the dynamic comprehensive law enforcement mode which takes ‘VTS as a platform for land and sea inspection ’ By this way, it takes advantages of the combination of VTS, AIS, CCTV systems and the maritime regulatory facilities efficiency, to provide 24-hour safety administration and service for ships. Xiamen MSA has configured software of oil spill drift model, to enhance the early warning, prediction, monitoring and disposal, the post-evaluation of sudden vessel pollution accident. Through the scientific analysis of pollution source information, the decision-making accuracy and efficiency is improved greatly.

(4) Emergency equipment and facilities construction are enhanced continuously

Xiamen Oil Spill Contingency Equipment Warehouse is a small contingency equipment warehouse with comprehensive clear and control capacity of 200 tons of oil spill for one time, and emergency service radius of 50 nm; Xiamen has six ship pollution clear units with Grade I qualification nationally and equipped with 14 oil spill emergency disposal ships and emergency equipment like oil containment boom, oil absorption material, oil spill dispersants. Thy effectively enhance the Xiamen coastal ship pollution emergency ability, Xiamen port enterprises perform risk assessment continuously, and equips with pollution prevention emergency equipment. Most of them have completed emergency capability construction.

(5) Emergency teams are taking shape

Xiamen has established the 'Vessel Pollution Accident Emergency Disposal and Investigation Expert Database ', including experts in various domains like the transport of dangerous goods, the ship pollution prevention, the environment resources, law and so on. The six ship pollution clear units have 23 top commanders, 60 on-site commanders and 300 emergency operation staffs. Xiamen port enterprises have established the internal pollution emergency teams, 28 people from these emergency teams have passed the training organized by the MSA.

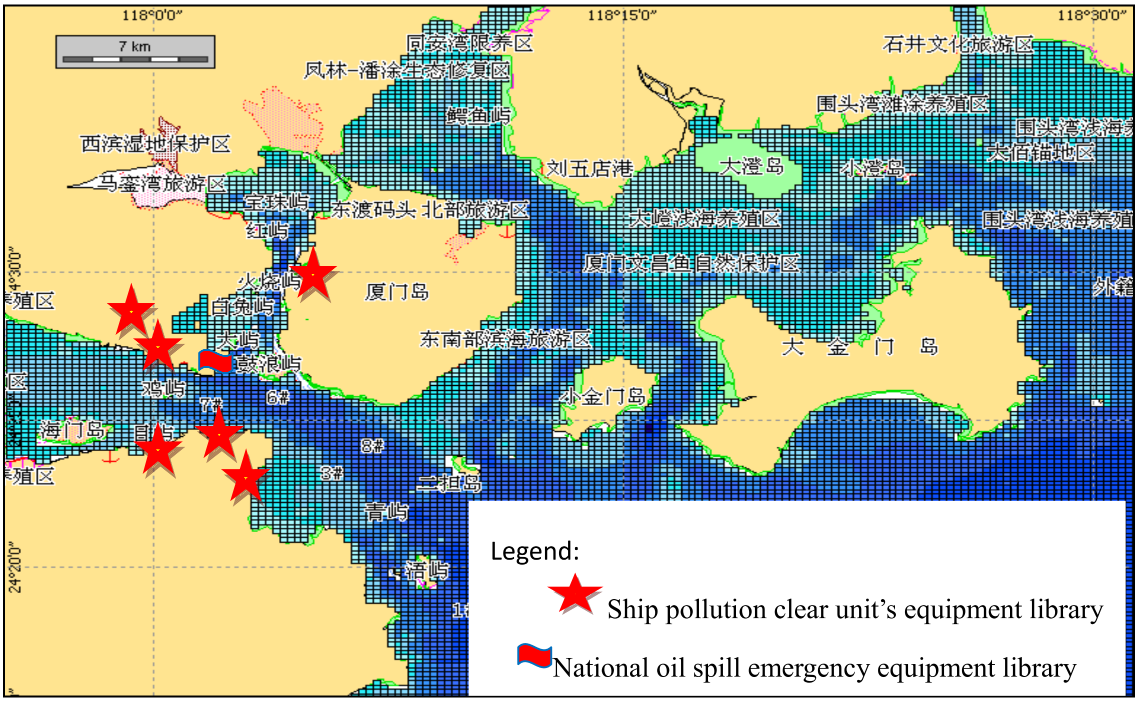

Figure 6.1：Distribution of oil clean-up resource

Source：Created by author

6.2.2 Problems of Xiamen marine oil spill emergency

(1) Emergency plan content needs to be updated

Since 2010, With the ’The Regulation of Prevention and Control of Marine Pollution to the Marine Environment‘ and its accompanying rules and standards went into effect, some content of ‘Xiamen Vessel Pollution Emergency Plan’ is not suitable for the new requirements and new standards of ship pollution emergency and, needs to be updated and revised timely such as the lack of maritime dangerous chemical accident emergency coordination; and sub-standard process in the emergency plan of port enterprises.

(2) Emergency mechanism still needs to be improved

When member departments of Xiamen sea pollution emergency center are dealing with the ship pollution accidents, problems like function overlap inefficient communication and coordination difficulty exist. Hence, the emergency resources among departments are difficult to be used and coordinated effectively, and the linkage mechanism is not yet fully established. At present, Xiamen have not set up specialized funds for the ship pollution emergency disposal. When dealing with emergency pollution accidents with uncertain responsible parties or insolvent shipowners, the clean-up companies often input a lot of manpower and material resources without basic compensation. And the drill of the ship pollution contingency plans and emergency personnel training become a mere formality.

(3) Emergency information system needs to be perfected

Xiamen sea pollution emergency center have configured the software of ‘oil spill drift model’, but cannot fulfill the task of simulation and prediction of chemicals spill drift diffusion, and is lack of information system which supports decision-making during the whole process from alarm to accident assessment, emergency command, and compensation. Besides, enterprises' oil spill monitoring signal has not been effective connected to the MSA.

(4) Emergency equipment structure is not reasonable

Firstly, oil spill emergency equipment that port enterprise equipped is usually small type, poor performance, and duplicate configuration. This kind of equipment can only meet the emergency needs of wharf apron waters. Meanwhile, large and medium-sized emergency equipment of ship pollution clear units is limited and hard to response to major marine and offshore oil spill pollution accident. Existing equipment location is scattered and lack of auxiliary equipment, such as, forklift and crane device which can provide support for large-scale emergency equipment to be transferred into emergency ships rapidly. Another problem is that the lack of equipment base of state level or even enterprise level while the traffic flow of Xiang 'an area is increasing and the risk of accidents is growing. It will take at least 3 hours for national oil spill emergency equipment to arrive the area, which will miss the best opportunity for pollution accident disposal.

(5) Emergency team construction needs to strengthen

Xiamen existing emergency teams including person from ship pollution clear units and enterprises. Most of them are part-time staffs. And it's still under-occupation. Both national oil spill emergency equipment base and port enterprises are lack of management and maintenance personnel and emergency operators. There are total of 143 people participating in the specialized clean-up training organized by the MSA or port authority in the six ship pollution clear units and the port enterprises in Xiamen. However, because most of them have low educational background and rarely participate in actual ship oil spill emergency actions, it's hard for them to adapt themselves to large ship oil spill emergency pollution accidents or Taiwan strait emergency needs.

6.2.3 Emergency management system construction plan (2016-2020)

In 1990, the U.S. congress established the Oil Pollution Act (OPA) to consolidate the existing federal oil spill laws under one program, leading to the first comprehensive law to specifically address oil pollution to waterways and coastlines of the country (NRC, 2003; Ramseur, 2012). In Canada, Transport Canada is the lead federal regulatory agency that is responsible for the regime based on a partnership between the government and industry (Turner, 2010). The Environmental Response Systems in Canada are in charge of developing and administrating the policies, regulations, and programs (Transport Canada, 2011). Based on the results of Xiamen sea area ship oil spill risk assessment and reference related to experience about ship oil spill emergency management in China and abroad, a whole consideration of Xiamen sea area of ship oil spill risk prevention, the author puts forward the construction of Xiamen Sea Emergency Management System Construction Scheme (2016-2020).

(1) Emergency plan

Revising the Xiamen Sea Vessel Pollution Emergency Plan and updating the content related to response to the maritime chemical accident emergency in plan is an effective way to clear all related departments' responsibility in oil spill and chemical spills of vessel pollution accident emergency and guide the revision and perfection of emergency plans of wharf, sewage disposal units ,the joint defense organizations of each port, , etc.. In addition, Xiamen Ship pollution emergency center should play a key role in the function of organization and coordination, clarify and refine the responsibility of various emergency linkage units, hold joint meetings regularly, and gradually improve the ship pollution emergency organization and management mechanism.

(2) Institutional and mechanism

To establish the Xiamen and coastal waters accident emergency response mechanism with "perfect system, professional team, resources to be planed as a whole, multiple linkage, funding guarantee for priority areas, social participation" , it refers to the marine pollution accident emergency disposal mechanism with the unified leadership of the municipal government, the basis of the Xiamen sea vessel pollution emergency plan, the core power consisting of public security fire control team in active service and Xiamen oil spill emergency equipment warehouse, the important participation of social professional clean-up teams, the multiple linkage including departments as ports, safety, environmental protection, marine and fisheries sector, the funding guarantee from finance departments, the overall use of the emergency resources, and the collaborative involvement of professional technical forces from port companies and volunteers .

(3) Allocation of resources

According to the development situation of Xiamen port, and the current allocation of the emergency resources, the author suggests to, first of all, expand the Xiamen small oil spill emergency equipment warehouse to medium oil spill emergency equipment warehouse to increase, the removal and control of oil spill capacity into 500 tons; secondly, build a secondary oil spill emergency equipment warehouse in Liu wudian area regarding to the weakness of oil spill emergency response ability in eastern port; third, guide the reasonable layout of ship pollution clear units to improve the efficiency of ship pollution emergency; fourth, carry out the safety responsibility in pollution prevention of port enterprises to accelerate the construction of pier prevention and control of marine pollution emergency ability; fifth, equipped with corresponding emergency facilities to promote the joint emergency defense against pollution for the wharf enterprises in the same wharf.

(4) Warning and surveillance

In order to form a surveillance monitoring information system by the three-dimensional (land, sea and air) and integrated a variety of technology, this paper suggests to construct marine oil pollution monitoring system of Xiamen bay in the way that each region installs warning and monitoring equipment to transmit the microwave data to the monitoring center, use satellite remote sensing and information extraction technology to monitor sea oil spill, use of the existing rescue helicopters carrying oil spill remote sensing equipment to monitor sea oil spills, configurate buoy tracking system to track the pollutants on the surface, promote port enterprises to equipped with shore-based oil spill monitoring alarm device, Establish pollution monitoring network shared the agencies of maritime, marine, environmental protection sector as well as enterprise units.

(5) Information transformation

Xiamen marine oil spill emergency information system mainly includes: report of accident information, exchange of the incident emergency information and release of the Xiamen Ship Pollution Emergency Center to establish a scientific and effective communication mechanism, construct different means of information communication, strengthen the establishment of information communication system, set up advanced technology of information management system, so as to ensure the efficiency of information communication and release. Please see detail in 6.1.

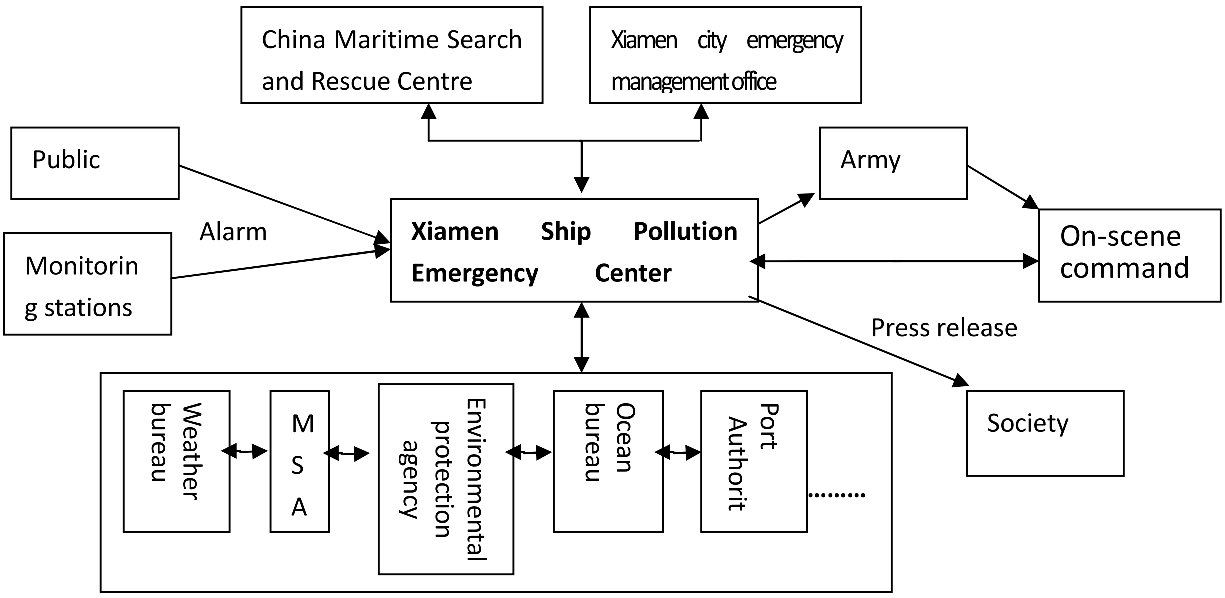

Figure 6.2 Information management system

Source：Created by author

(6) Decision support system

Oil spill emergency decision-making expert group is made of the senior experts of maritime, shipping, environmental protection, marine fisheries, petrochemical industry, weather, hydrology, firefighting, salvage and relevant technical staffs. The consultancy mainly refers to the classification society, navigation institute, dangerous goods counseling centers and other units. Recently, A few decision support systems (DSSs) have been developed aiming for supporting offshore oil spill response (Fingas, 2012; Ornitz and Champ, 2002) like OSIS (US Environmental Protection Agency, USEPA, 1995), or oil spill risk analysis (OSRA) model and the General National Oceanic and Atmospheric Administration Operational Modeling Environment (GNOME) (Beegle-Krause and O'Connor, 2005; Price et al., 2003). Government should develop Xiamen Offshore oil Spill Emergency Decision Support System, effectively integrate ship dynamic positioning supervision data realize real-time sharing of data between various departments, and provide information and technical support for emergency command and decision-making.

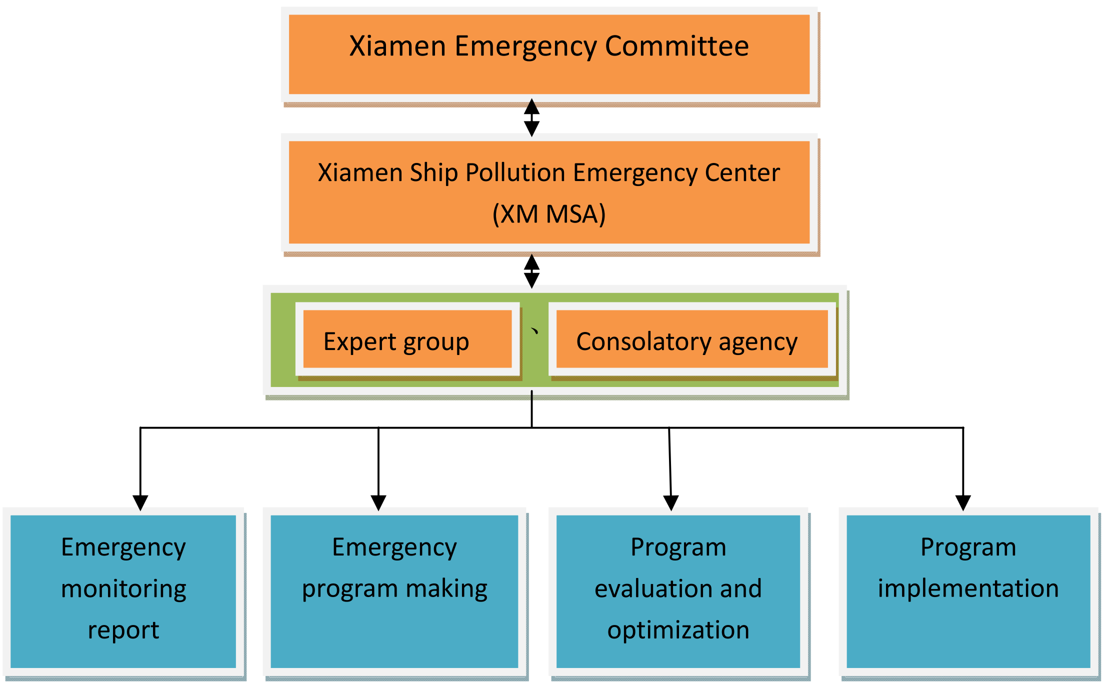

Figure 6.3 oil spill emergency decision-making system

Source：Created by author

(7) Logistics Support

General office of the municipal government is responsible for carrying out coordination and supervision for the "Plan" and propelling the recruitment of professional staffs. Xiamen MSA, Xiamen Port Authority, Xiamen Development and reform Commission (DRC) complete the related tracking and guidance. Also, the author suggests to make the compensation for emergency rescue and clean-up expenses as a priority by adopting political and technological support; provide political and technical support for the clean-up claim behavior according to clean-up claims procedures, give appropriate government subsidies and bonus to the unknown oil pollution accident emergency clean-up operation via increasing financial investment, and establishing vessel pollution compensation mechanism which conforms to the Local actual situation.

By 2020: Xiamen oil spill contingency equipment warehouse completes the scale expansion, builts 3-dimensional pollution surveillance monitoring system, perfect the emergency management system, builts s reasonable structure and well trained emergency teams, meets the requirements for Xiamen port waters and coastal waters ship pollution accident emergency. With the permission of meteorological conditions, if a ship pollution accident happens in harbor waters, ship pollution clear units, port enterprises and other important emergency power should arrive within 2 hours, and carry out the effective clean-up or guard actions within 4 hours. If a ship pollution accident occurs in the coastal waters, the government emergency power and ship pollution clear units should be able to arrive within 6 hours, carry out the clean-up or defensive action within 8 hours. The comprehensive clear control of oil spill total capacity in Xiamen coastal waters should reach 2000 tons. Each port area should have certain processing capacity for main leakage dangerous accidents.

CHAPTER 7 Conclusion and Outlook

7.1 Conclusions

(1) Ships call at the Port of Xiamen via the main fairways and their branches, thus oil spills can occur both on the fairways and at the berths. And the Nature Reserve for Chinese White Dolphins, adjacent to the harbour area, the Nature Reserves for Herons on Dayu Island and Jiyu Island, as well as Gulangyu Island, the tourist site, are among those sensitive to environmental damages.

(2) As is shown, the Port of Xiamen, from 2001 to 2015, had witnessed 27 oil spills, of which 18 were caused by misoperation and 9 were caused by ship-related accidents, with annual average numbers of 1.3 and 0.7 respectively. However, the average quantity of leaks from ship-related accident spills is approximately 11 tonnes, while that of leaks caused by misoperation is 0.2, making ship-related accidents the major threat of oil spills within the Xiamen waters.

(3) Risk identifications and comparison analyses indicate that misoperational leaks are mainly caused by overfill or ruptured pipelines during fueling, most likely oil spill quantity may be 1 tons, and the largest credible accident quantity may be 10 tons. While major accidental spills are more likely to happen at the junctions of fairway, most likely oil spill quantity may be 200 tons, the largest credible accident quantity may be 1000 tons.

(4) The Xiamen MSA data of recent years reflects that the number of vessels of 10,000 gross tonnages and above calling at Xiamen has steadily increased. It is estimated that by the year 2020 Dongdu, Haicang and Songyu harbors will have been visited by 10,000 above 10,000GT vessels, more than 3,500 of which will have been above 50,000GT. Thus, the risk of severe ship-related oil spills is increasing.

(5) As is anticipated by Random Scene Statistics, when an oil spill occurs at the junction of fairways without immediate containment, an adjacent area of 230 square kilometres will be polluted as well as a coastline extending over 50 kilometres, and there is a 10-15% probability that the Gulangyu Island, the Dayu Island, the Jiyu Island and the south coast of Xiamen will be affected. Oil will reach these sites within 2-5 hours, with the oil film as thick as 5-20mm, and could lead to a 4-level environmental damage, which is severe.

(6) This article proposes a new oil spill consequence index model which combines the quantities of leaks, the environmental sensitivities of protection targets and the likelihood of pollution. The outputs the model produces are more reasonable and reliable compared to the existing consequence assessment methods. Based on a comprehensive analysis of the likelihood of spills and the consequence index, by utilizing Risk Matrix and F-N Curve, a conclusion that there is a "high" risk of spills on the Xiamen waters is reached.

(7) This article, based on the study of the likelihood of spills on Xiamen waters, their consequences and the authority's maritime traffic control and emergency response system, analyzes the main problems and proposes that the Port of Xiamen be capable of cleaning and containing a 2,000-tonne oil spill by the year 2020 and to a certain extent, lesser jurisdictions be capable of handling accidents caused by the leaks of hazardous chemical to.

7.2 Outlook

(1) Such methods as Consequence Index Model and Consequence Classification Standards are theoretically feasible and produce reasonable results in assessing the case of the Port of Xiamen. Nonetheless, it requires more case studies to claim that

the methods can be adopted to assess other ports and inner waters.

(2) Despite that the method of Random Scene Statistics, which is used to anticipate and analyze the consequences of hazards, proves effective in revealing the uncertainty of when an oil spill could happen and produces reliable results, it requires more hydrometeorological information on wind direction, wind speed and temperature, which is collected for several years and by several weather stations. In addition, further study is needed to figure out the minimum simulating scenes required to support a statistical analysis.

Challenges remain in diverse aspects such as oil spill monitoring, analysis, assessment, contingency planning, response, cleanup, and decision support (Li Pu et al, 2016).

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