Risk Assessment on Ship's Oil Spill of Yangtze River Main Line Wharf

Li Shangyu¹*, Deng Jian¹²³
¹Wuhan University of Technology, Wuhan University of Technology, Wuhan, Hubei, 430063, China
²Hubei Key Laboratory of inland navigation technology, Wuhan University of Technology, Hubei, 430063, China
³National Water Transport Safety Engineering Research Center, Wuhan University of Technology, Hubei, 430063, China
*Corresponding author’s e-mail: 2678929060@qq.com

Abstract: With the rapid development of the inland shipping in recent years, the risk of wharf pollution from ship is increasing. Thus, it is necessary to make a scientific assessment on ship pollution risk. This paper proposes a risk assessment according to the ship pollution at regional port by using a typical petrochemical wharf in Wuhan section of Yangtze River main line as an example, carries out a comprehensive evaluation from the aspects of risk identification, risk probability and risk level calculation, and pollution consequence prediction. The results of the wharf risk assessment are important for the development of the ship pollution risk counterplans.

1. Introduction
Yangtze River, known as “golden waterway, is the longest river in China. The golden waterway of the Yangtze River is responsible for 85% of the commodities transportation along the river and 90% of the foreign trade good transportation in the middle and upper reaches of Yangtze River. In recent years, with the implementation of the national strategy called Yangtze River economic zone, there are rapid growth on the volume of cargo and the number of vessels on the Yangtze River waterway, including oil products, dangerous chemicals which have a great impact to the water environment easily. The volume of transportation is also increasing year by year, and a number of dangerous goods loading and unloading port also increase steadily, which leads to the risk of ship’s oil spill along the river. There are nearly 500 water intakes for life and industry along the Yangtze River, involving a population about 140 million people. Most of the intakes are open water sources. If the pollution accident happens, it will cause disastrous consequences. Thus, it is necessary to make a scientific pollution risk assessment of ships in the wharfs along the Yangtze River, so as to lay a foundation for the formulation of preventive measures.

In recent years, the international community has done a lot of research on ship pollution risk, and discussed the application of probabilistic technique, artificial neural network, analytic hierarchy process, and grey theory prediction method in probability simulation and prediction of oil spill accidents. In 2000, Australia made an assessment on the pollution risk on its ships along the coast. Then, New Zealand and other countries followed and carried out risk assessment. Based on the risk management theory, the United States and Canada made an assessment on the oil spill risk and its protection capability of their waters and compiled software. In March 2004, Marine Environment Protection Committee of the International Maritime Organization adopted the proposal submitted by Russia and set up a working
panel to develop guidelines for oil spill risk assessment and response protection assessment. In 2006, the Marine Environment Response Area Activity Center (MERRAC) of the North-West Pacific Action Plan (NOWPAP) initiated a regional study of spill risk assessment and developed risk assessment guidelines. In terms of the specific theories and methods of ship oil spill risk assessment, foreign scholars have applied a lot of methods such as stochastic theory method, finite element method and fuzzy mathematical method to ship oil spill accident. But on the whole there are relatively few studies on the ship’s oil spill in inland waters.

2. Introduction to The Research Object

Taking a petrochemical wharf in Qingshan Yangluo port of Wuhan along the Yangtze River main line, as the risk assessment object to evaluate the ships pollution risk at the wharf. The petrochemical port area is located in the lower reaches of Wuhan section of the Yangtze river, which is the largest petrochemical industrial base in the midland. The research object of this paper is a petrochemical wharf engaged in warehousing, with an annual designed cargo handling capacity for 1 million tons. The wharf has a 5000 tons berth, mainly transporting diesel, gasoline and other goods. The details are shown in the following table:

| Name               | Types of transportation | Maximum Berth | The number of berths | Cargo handling capacity per year (Million tons) |
|--------------------|-------------------------|---------------|---------------------|-----------------------------------------------|
| Yangluo Oil Depot  | Diesel, Gasoline        | 5000          | 1                   | 100                                           |

Figure 1. The geographical location of the harbor area
3. The Steps of Risk Assessment
In order to carry out a scientific risk assessment on ship’s oil spilt of the wharf, the process proposed in this paper of the assessment is shown in the following figure, mainly including five steps: status analysis, risk identification, source term analysis, risk impact prediction and risk assessment.

4. Risk Identification
Identify and filtrate sources of danger or accident combined with Terminal stevedoring technology, ship type, operation and other data and divide the sources into shipwreck accident and operational accident for risk identification.
4.1. Accidental ship pollution
It is generally happened with ship traffic accidents, so the cause of the accident is similar to water traffic accidents. Shipwreck accident can be divided into navigation accidents and the accident of ship itself (integrity). The ship navigation accident refers to the cargo oil or fuel oil leakage caused by external collision, collision and grounding in the course of ship navigation. The accident of ship itself (integrity) refers to the internal causes of the ship, such as the ship structure design is defective or the ship is old, and the shipborne oil leakage accident caused by the hull damage because of ship's internal fire explosion. Ship pollution accident statistical analysis shows that although the reasons of shipwreck accident are various, the main reason is that the ship encountered some bad weather, the wind, flow, poor visibility, which cause the ship grounding, the fire explosion, severe wind and wave conditions under the ship beforehand or fractured structure.

4.2. Operational ship pollution
It means that the accidents that may occur in daily ship operation. In terms of the wharf, the main pollution accidents that may occur in the process of loading and unloading oil at the wharf, including the overflow of tank, leakage of pump and valve, leakage of pipeline, illegal discharge and so on.

4.3. Risk identification from the aspects of people, ship, environment, management and so on
Analysis of the factors that may lead to the risk occurrence are analyzed from the perspective of dock workers, seaman and outsiders from the aspect of people. Analysis of the possible ship pollution such as ship’s master and ships tonnage, and the carried goods from the aspects of the ships. Analyze the possible risks brought by the mutual influence between channel conditions and wharfs and mutual influence between wharfs and channels from the aspects of environment. Risks that may be caused by the relevant management such as jurisdiction maritime law enforcement departments, local relevant departments, wharves and ships are analyzed from the aspects of management.

5. Source Term Analysis
Source term analysis mainly analyzes the probability of ships pollution accidents and its scale. The accident scale mainly measures by leakage.

5.1. The Probability Prediction of Ship Pollution Accidents

5.1.1. The Probability Prediction of Operational Pollution Accidents
The main cause of operational ship pollution accident is the accidents occur during the loading and unloading of ships. The ships pollution accidents in the waters around the wharf are mainly accidental pollution. In recent years, the actual handling capacity of this wharf is about 175,000 tons, and the main
berthing ship type is 3,000 tons refined oil ship. It can be known that the ships entering and leaving this wharf are about 64 times per year.

There are few operational pollution accident and incomplete accident statistics in Wuhan, so this evaluation report is based on the domestic operational ship pollution accidents in inland port of the same type accident statistics (operational pollution accidents is about 1.2 x 10^-4 times/ship). Through analogy analysis, the probability of operational ship pollution accidents of this wharf is known, and it is calculated that the probability of operational ship pollution accidents of this wharf is 0.00768 times per year, about once in 130 years.

5.1.2. The Probability Prediction of Shipwreck Pollution Accidents
Shipwreck pollution accident is mainly caused by ship traffic accident. According to relevant studies, it is highly correlated with the ship traffic. The probability of shipwreck pollution accident is predicted according to the statistics and the ship traffic at the wharf, and the formula is as follows:

\[
P = \frac{\text{number of ship traffic accidents in XX year} \times \text{number of ships in the project} \times K}{\text{number of ships entering and leaving port in XX year}}
\]

In the formula, \(P\) is the probability of shipwreck pollution, \(K\) is the probability of pollution caused by shipwreck accidents. According to relevant studies in the Baltic sea, \(K\) is 0.25.

According to the statistics from 2009 to 2017, the relative frequency of ship traffic accidents in Wuhan is 0.4 times per thousand times. Thus, it can be calculated that the probability of shipwreck pollution accidents at each wharf is 0.0064 times per year, which is about once in 156 years.

5.2. The Prediction of The Ship Pollution Volume

5.2.1. The Prediction of Operational Ship Pollution Volume
The operational pollution in the wharf front is mainly the operational leakage accident that may occur in the process of loading and unloading. According to relevant accident statistics and technical materials, generally speaking, when an accident occurs during loading and unloading, the loading arm shall leak for five minutes before stopping the pump, which can be used as the leakage volume of operational accidents. The normal handling speed of the cargo oil at this wharf is about 300 m^3/h, and the predicted operational leakage volume is 25 m^3.

5.2.2. The Prediction of Shipwreck Ships Pollution Volume
According to the design ship type, the main berthing ship type at this wharf is 3,000 tons refined oil ship, and the largest berthing ship type is 5,000 tons refined oil ship. Shipwreck pollution are mainly caused by ship fuel oil and cargo leakage because of shipwreck. Shipwreck pollution can cause accidents such as ship collision, grounding and hitting rocks in wharves, channels and anchorages. The oil spillage in a shipwreck accident can be predicted according to the main ship type, tonnage and its actual load rate.

The maximum possible leakage of water pollution accident: According to the boatload of the main ship type, it is calculated that all the cargo oil in one cargo has leaked out. Considering that the main type of ship at the wharf is a 3,000-ton refined oil ship, according to the survey, the number of cargos of such kind of ships is 8-12, which is based on an average of 10 cargos, and the cargo load rate is 90%. Therefore, the most likely maximum oil/LPG leakage at the wharf is 270 tons.

The maximum credible leakage of water pollution accident: Based on the total oil/LPG leakage of the largest ship type, considering that the largest ship currently parked in the harbour is a 5000-ton refined oil ship and the cargo load rate is 90%. Therefore, the most likely oil spillage at the wharf is 4,500 tons.

5.3. Ship Pollution Risk Rating
The risk matrix is used to identify the pollution risk level of the wharf in this paper, while the risk matrix is used to evaluate the risk level, and the acceptable level of the risk shall be determined according to the following requirements. At the bottom of the risk matrix, the probability is very small and the
harmful consequences are not obvious. The risk can be negligible or take no action for it is too small to require any response and is considered acceptable. At the top of the risk matrix, the probability is high, the harm is serious, and the risk is defined as unacceptable. In this area, risk handling measurement can be taken to reduce the risk to a low and medium risk. In the middle of the risk matrix, both probability and its result are medium, and the risk can be reduced by taking necessary measures. According to the pollution volume of ship pollution accidents calculated above and the frequency of ship pollution accidents, the risk level of the wharf is shown in the figure below, and the overall pollution risk of the wharf is at a low level.

![Pollution level of ships at this wharf](image)

**Figure 4. Pollution level of ships at this wharf**

6. The Prediction of Risk Impact

Based on the investigation and analysis of the water flow and meteorological data in the port area and its surroundings, the appropriate accident source has been selected, and the numerical simulation method is applied to simulate the diffusion process of ship pollutant in the water environment, and make a further analysis.

6.1. Simulation of Oil Spillage Movement Trail

According to the possible maximum oil spillage accident, water spillage diffusion prediction is carried out, and the typical persistent oil substances in production, storage and transportation are adopted. In the oil spillage accidents, the multiple accident points determined by risk identification are used as the starting points for prediction of oil spill drift over water. The meteorological data about wind direction and speed should analyze the historical data of the evaluation area for more than five years. The annual prevailing wind direction and speed, winter and summer prevailing wind direction and speed, and the most unfavorable wind direction and speed to the main sensitive targets should be selected as the simulation objects. In inland rivers, the dry season, median water period and wet season should be selected as the flow conditions.

Prediction method: The oil parcel model can be used to simulate and predict the drift and expansion of the oil spill on the water surface and its diffusion and transport in the water. For pollutants in inland rivers, at least the weathering processes such as volatilization, dissolution, sedimentation and adsorption should be considered. The concentration model should be used to simulate the prediction of chemicals.
A typical scenario simulation method should be used in risk assessment to predict and analyze the spread and damage of the oil spill on the water surface and in the water. The prediction period can be determined according to the characteristics of the oil, but it should not be less than 24 hours. The parameters of typical inland river pollution accidents are shown in the following table. The simulation results can give the influence time, contaminated area or length of the oil on the sensitive protective target and the shoreline based on the drift location, extended area, surplus, thickness distribution and concentration of the oil at every moment.

| Leak location | The type of oil and oil spillage | Typical wind direction | Wind speed | Channel Flow |
|---------------|---------------------------------|------------------------|------------|--------------|
| Black spot    | Typical oils/chemicals identified by risk identification; Possible maximum water oil leakage /chemicals | Winter prevailing wind direction | The average wind speed of winter prevailing wind direction | Wet Season |
|               |                                 | Summer prevailing wind direction | The average wind speed of summer prevailing wind direction | Median Water Period |
|               |                                 | Unfavorable wind direction | Unfavorable wind speed | Wet Season Median Water Period |

Table 2. Simulation parameters of typical water pollution accidents
6.2. The simulation of the fate of oil spillage

After oil leakage into water, there will be evaporation, dissolution, emulsification, sedimentation, shoreline adsorption, biodegradation, photochemical action and other processes. As for gasoline and diesel, evaporation and shoreline adsorption are the main fate of oil spill. The shoreline adsorption of oil will be various in different conditions. Therefore, in this study, the fate of oil spillage is simulated without wind and without considering the shoreline adsorption.

6.2.1. The fate simulation of gasoline leakage (without considering shoreline adsorption)

As can be seen from the simulation renderings that, because the high volatility of gasoline itself, gasoline volatilization reaches more than 80% after 4 hours, and gasoline volatilization is exhausted after 14 hours.
6.2.2. The fate simulation of diesel oil leakage (without considering shoreline adsorption)

As can be seen from the simulation renderings that, because the high volatility of diesel fuel, the volatility of diesel fuel reaches more than 40%, and the volatility is close to 50% after 20 hours. But the gasoline and diesel stay on the water longer.

![Image: Figure 7. The fate of diesel oil leakage simulation](image)

Therefore, from the over point of view, the cargo of this wharf is mainly light oil and non-persistent oil, which can volatilize quickly, so there is relatively small impact of pollution.

7. Conclusion

This paper takes a typical petrochemical wharf in Wuhan section of Yangtze River main line as an example, proposes methods of the ship pollution risk assessment for reginal wharf, carries out the comprehensive evaluation from the aspects of risk identification, risk probability and risk level calculation, pollution prediction and so on. The results of the wharf risk assessment are important for the development of the ship pollution risk counterplans.

References

[1] MOHAMMAD T T. Experimental investigation of oil leakage from damaged ships due to collision and grounding[J]. Ocean Engineering, 2011, 38(17):1894-1907.
[2] BARDOSY A, PEGRAM G S. Copula based multi-site model for daily precipitation simulation [J]. Hydrologic Earth System Science, 2009(1):55-58.
[3] MOONJIN L. Pollution risk assessment of oil spill accidents in Garorim bay of Korea[J]. Marine Pollution Bulletin, 2015(2):297-303.
[4] CHENG Y C, LI XF, XU Q. SA R observation and modeltracking of an oil spill event in coastal waters[J]. Marine Pollution Bulletin, 2011, 62(2):350-363.
[5] SEBASTIAO P, GUEDES S C. Uncertainty in predictions of oil spill trajectories in open sea[J]. Ocean Engineering, 2007, 34(3):576-584.
[6] Suffling R. An Index of Ecological sensitivity to disturbance, based on ecosystem age, and related to landscape diversity [J]. Journal of Environmental Management, 1980, 10(3):253-263.
[7] Rodriguez E, Vila L. Ecological sensitivity atlas of the argentine continental shelf International [J]. Hydrographic Review, 1992, 69(2):47-53.
[8] Biek R, FunkW C, Maxell B A. What is missing in amphibian decline research: Insights from ecological sensitivity analysis [J]. Conservation Biology, 2002, 6(3):728-734.
[9] Jaglap TG, Komarpant DS, Rodrigues R S. Statusofa seagrass ecosystem: An ecologically sensitive wetland habitat from India[J]. Wetlands, 2003, 23(1):161-170.