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Safety evaluation and research of Caofeidian LNG terminal

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Safety Evaluation and Research of Caofeidian LNG Terminal

By

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DECLARATION

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

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

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ABSTRACT

Title of Research Paper: **Safety Evaluation and Research of Caofeidian LNG Terminal**

Degree: **MSC**

This paper is a research on the safety evaluation of Caofeidian LNG Terminal. The basic situation of Caofeidian Port and the safety evaluation are main content.

First, necessity of basic situation is introduced, including the environment and layout of this LNG Terminal and Caofeidian port, traffic condition of Caofeidian port, accidents statistics, harms of LNG and so on.

Then, in order to verify the safety of Caofeidian LNG Terminal, the safety assessment model is introduced which is suit for LNG Terminal. The method of fuzzy comprehensive evaluation is used in this chapter.

Finally, the calculation of the safety of Caofeidian LNG Terminal is did according the safety assessment model and the questionnaires of experts.

Keywords: Caofeidian port, LNG Terminal, safety evaluation, fuzzy comprehensive evaluation

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
CO2	Carbon dioxide
IAPH	International Association of Ports and Harbours
ICS	International Shipping Association
ISGOTT	International Safety Guide for Oil Tankers and Terminals
LGP	Liquefied Petroleum Gas
LNG	Liquefied natural gas
OCIMF	Oil Companies International Marine Forum
SIGTTO	The Society of International Gas Tanker and Terminal Operators
VTS	Vessel Traffic Service

Chapter 1 Introduction

1.1 The theme and scope of topics of this paper

1.1.1 Background

Liquefied natural gas is referred as LNG, and its main ingredient is methane. The manufacture and transportation process of LNG is a series of ultra low temperature liquefied treated, and transported by LNG ship. After liquefaction, its volume is about 1/600 of the same gaseous natural gas, and the weight is only about 45% of the same volume of water. Natural gas is a kind of clean and efficient energy. Right now, the environment is seriously polluted, the trade is increasing year by year from recent years, the proportion of natural gas in the energy has been increasing year by year. Increase the proportion of natural gas in energy consumption can alleviate the heavy pressure of energy and environment brought by the rapid economic development. In developed countries, natural gas consumption has accounted for about 25% of the total energy consumption, while in China, natural gas consumption only accounts for about 8% in 2010.

The resource of natural gas is not very rich in China. Only relying on domestic supply could not meet the growing demand for natural gas, therefore liquefied

natural gas demand will grow greatly. Customs data shows that the LNG import is about 17,000,000 tons in 2013, grow 20.1 percent compared to the same period. In 2014, the LNG receiving station will grow rapidly, shipping volume will increase. With the development of the LNG and the increase of Chinese imports, Chinese coastal LNG receiving station construction is speeding up. (Qi, 2007, P42-43)

In addition to the nine LNG receiving station including Liaoning, Guangdong, Fujian, Shanghai, Jiangsu, Zhejiang and Hebei, according to the current plan, there will be four LNG receiving station put into operation in this year. According to Clarkson's data, according to the current global ship orders in the schedule, there will be 37 new ships launching which can hold more than 100000 cubic LNG in 2014, the total deadweight is about 3000000 tons. According to the global LNG ships capacity, there will be 7 to 8 LNG ships can be disassemble which can hold 100000 cubic LNG or more and they are about 400000 deadweight tons, integrated can be seen, the shipping capacity of LNG will increase 2600000 tons deadweight in 2014, compared to the end of 2013, the growth is about 8.6 percent, so the shipping capacity growth is faster than that in 2013.

Beijing, Tianjin and Tangshan are located in the center of China's Bohai Sea Economic Zone where the high energy consuming industry, heavy industry, chemical industry, agglomerated industry, and population is concentrated relatively. Hence the higher the degree of dependence on energy. In order to meet the demand of natural gas of Beijing Tianjin and Hebei region, and to ensure the gas safety of Beijing Tianjin Hebei area, Petrochina Co Ltd builds this liquefied natural gas project in Caofeidian industrial zone. This project is located in Caofeidian new district of Tangshan City in the northeast of Hebei Province. The construction scale of the project is a special unloading berth for LNG ship whose capacity is from

80000 cubic meters to 267000 cubic meters. The annual handling ability of first phase project is 3500000 tons and the second phase is 3000000 tons.

1.1.2 The main contents of this thesis

This paper will combine the current situation of the construction and the safety research of special terminal for liquefied natural gas in domestic and abroad together. The overview characteristics of Caofeidian Port, including geographical location, hydrological characteristics, navigation conditions port facilities and navigation aids will be given. Safety evaluation and research of Caofeidian LNG Terminal will be done by introducing the fuzzy analysis method and the characteristics of Caofeidian Port.

1.2 Research status of LNG terminal security in domestic and abroad

1.2.1 Research status of LNG terminal security abroad

With the rapid growth of China's economic construction and the strengthening awareness of the environment, the demand for natural gas of economically developed coastal region is growing. Because the large-scale usage of commercial natural gas is late in China, and around the world, the construction and use of liquefied natural gas ships are still in the early stage of development, design and operation of LNG terminal is lack of international specialized safety standard. But in recent years, the improvement of technology formed the following model. Firstly, use the similar existing standards on trial, such as oil. Secondly, adjust corresponding standards according to the characteristics of LNG, and then, correct the corresponding

standards of ship and terminal operation, eventually lead to technological innovation of LNG system in the field of engineering. The current LNG safety standards is not so much a product of the process of system development, as it is the result of many specific single safety preventive measures taken together. They often come from practical experience of distribution transportation enterprises for many years. For example, the ship mooring and emergency shutting down system are key steps in the process of technical progress. And the motivation is very simple that to make the operator more secure and predictable. The current safety standards of LNG wharf design and operation which is generally accepted in the international arena can be divided into the following two categories, named basic standards and supplied standards

1.2.1.1 Basic standards

Many of the international organizations established a set of appropriate standard for minimum operation and safety after many years work. Most of these organizations are the non government organization. OCIMF combined with IAPH published the international tanker and terminal security guide named ISGOTT in 1978 for the first time. The basic operation standards in this book have been modified for many years, and this book puts forward some detailed guidelines and recommendations of some emergency taker operation. The design and safety standards which are widely used are some standards and recommendations of internationally recognized organizations, many of which belong to International Oil Co Marine Forum named OCIMF, International Shipping Association named ICS and the international oil and gas shipping and port operation association SIGTTO. These existing international standards provide terminal design standards, such as determination of the mooring force, determination the hawser pier location, loading and unloading arm position, size and spacing. At the same time, these standards also provided determination of

the design depth and width of approach channel.

1.2.1.2Supplementary standard

Some oil companies of foreign funded the survey work of storage and handling system on the oil tanker settings, ship to shore interface, ship berthing and mooring work safety, the mooring force and berth arrangement. The study shows that tanker experience is not fully applicable to the LNG ship for the operators due to the fact that current building of LNG ships are still in the early stages of development.

Although the basic standard can be used in the design process, the existing standards and recommendations are notable to meet the requirements when we need to analyze the specific operating conditions or to predict future operating risks during the operation, some more specific criteria are still needed. Therefore, the large foreign companies, such as Royal Dutch Shell companies who have accumulated a lot of LNG ship and dock experience, formed a whole set of safety standard which begin with the site selection of terminal. Therefore, supplementary standard can also called the enterprise standard. In recent years, the safety record of the LNG ships in the world shows that the widely usage of basic standard and supplementary standard in the terminal design reduce the operation risk greatly, and provide valuable experience for a final set of international LN safety standards.

1.2.2 Research status and development level in China

In recent years, domestic experts have conducted a study on the safety evaluation of LNG ships traffic security from various angles. By combining the system science and safety science, some scholars put forward a machine, environment and management theory to analyze and evaluate the system security. Lao Chunhao and others use the pre assessment of risk of American coast guard in the Shenzhen Port

liquefied natural gas ship navigation safety risk assessment, and perform the safety assessment of the LNG receiving station and LNG ship navigation using event tree analysis method and risk index method. Li Mingke analyze and appraise the risk of LNG ships in the shipping process and put forward the corresponding evaluation method in the study of the comprehensive safety assessment of liquefied gas carrier in the shipping process. Liang Chuan put forward the related requirements in the navigation environment of LNG ship in the study of navigation environment of liquefied natural gas ship.

Chapter 2 Characteristics of Caofeidian terminal

2.1 The basic situation of Caofeidian LNG Terminal

2.1.1 Location

Caofeidian Docklands of Tangshan Port is located in the northeast of Hebei Province. Farther northeast, Caofeidian is about 170km away from Qinhuangdao City and 60km away from the Jingtang Harbor, and about 120km away from Tianjin city, about 70km away from Tianjin Xin Port. The LNG Terminal is located in Caofeidian Docklands of Tangshan Port, where geographical coordinates is 38 ° 55'N, 118 °30'E. (Caofeidian port authority, 2013)

This project location is shown in Figure 2-1

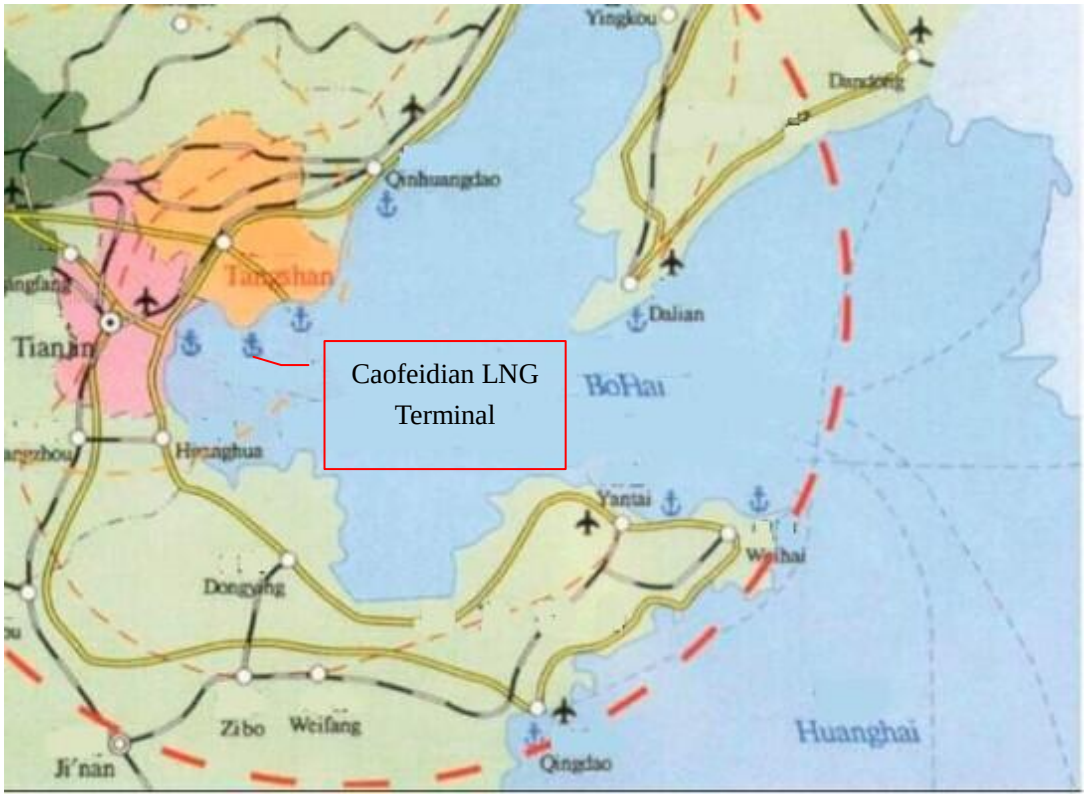

Figure 2-1 Location of Caofeidian LNG Terminal

Source: Coastal port layout planning of Hebei province

2.1.2 Neighboring environment of Caofeidian LNG Terminal

The project is located in the south of the Caofeidian Docklands, whose surrounding environment as follows.

The northwest side of this project is Caofeidian storage yard of ore terminal project. The west side of this project is Sinopec 300,000 tons crude oil terminal project and Caofeidian ore terminal project. The east and south of this project are both sea. The surrounding environment is shown in Figure 2-2.

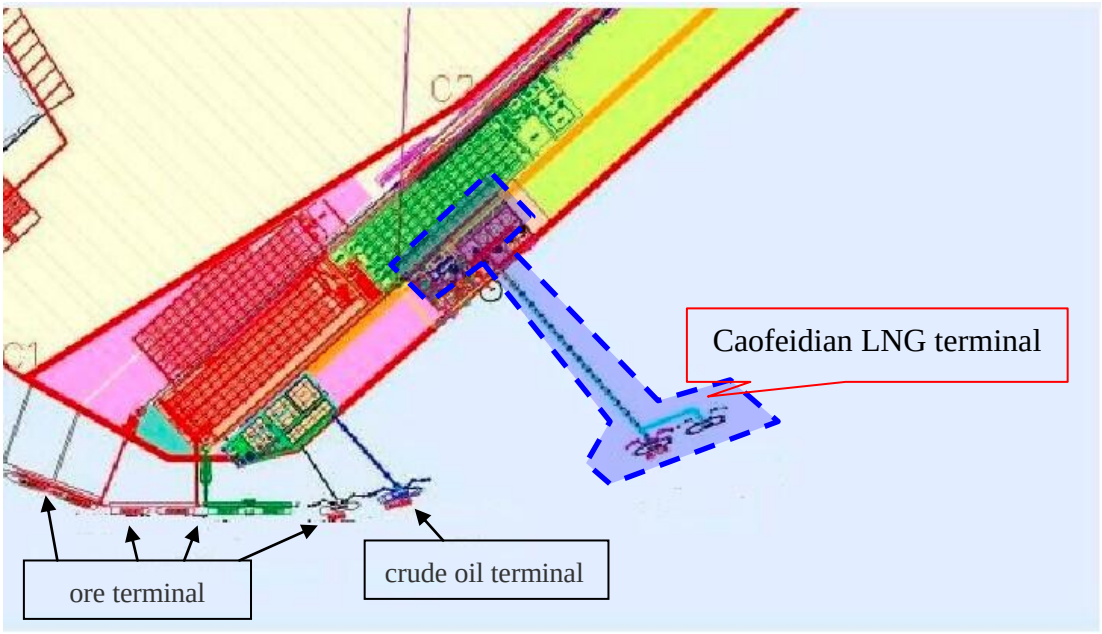

Figure 2-2 Surrounding environment of LNG Terminal

Source: Coastal port layout planning of Hebei province

2.1.3The scale of Caofeidian LNG Terminal

There is a special unloading berth which can receive LNG from LNG ships that from 80,000m^3 to 270,000m^3.

The annual handling capacity ability of first phase project is 3,500,000 tons, and the second phase of the project is 3,500,000 tons. In addition, there is a workboat wharf. The total investment of this project is 1,069,018,100 RMB. (Caofeidian port authority, 2013)

2.2 The overall layout of the terminal

2.2.1 The arrangement of terminal

The total length of LNG Terminal is 430m which use the Butterfly plane layout type, and there are one working platform, four berthing dolphins, six mooring

dolphins and one control platform near after the working platform. The size of working platform is 45m multiplied by 28m, and the height of the top is 10.5m. The piers use supported bridge structure whose span is 60m, and the bridge deck width is 14m, net width of 13.5m, the height is 10.5m which is the same with working platform. Every span has a pipes deformation compensation platform. The LNG Terminal and land are connected with bridge whose length is 1,899m and the width is 15m.

Working ship berth is on the southeast of receiving station, outside of the revetment, and 317m away from piers center line.

2.2.2 The arrangement of waters

The width of the berth waters is 110m. The ship swing waters use elliptic, the long axis along the flow direction is 1000m length, the short axis perpendicular to the flow direction is 700meters which could meet the turnaround of its largest designed ship.

2.2.3 The arrangement of rear area

The receiving station in the rear area consists with LNG tank area, process unit area, tank station, utilities and auxiliary production area, the first station metering zone, torch facilities, cold energy utilization zone, administrative life zone, covering an area of 47.5ha. The details are as follows.

2.2.3.1 LNG tank area

There are three LNG storage tanks of the first phase and five LNG storage tanks of the second phase in this area. There is circular channel around the three LNG storage tanks of the first period for maintenance and fire fighting vehicles.

2.2.3.2 Process unit area

The process unit area is located on the south of LNG storage tank around which there

is a circular fire channel. There are shell and tube type LNG gasifier, submerged combustion vaporizer, fuel gas heater, LNG high-pressure pump, BOG compressor and condenser, gas meter and pipeline pigging transmitter in this area.

2.2.3.3LNG tank station

There are ten loading place for LNG truck and also the reserve land.

2.2.3.4 Utilities construction area

Utilities construction area is located on the east of LNG tank area, lay out the total power distribution room, emergency generator, air compressor, instrument air dryer, sewage treatment facilities, the production of water and water pressure tank and other major public facilities, at the same time, lay out the chemical storage shed, shed oil storage, waste storage shed and other auxiliary facilities.

2.2.3.5 Sea water pump station area

The sea water pumping station area is arranged near the pier side, there are seawater glycol heat exchangers, water pump and fire pump technology of seawater in this area for process and fire water.

2.2.3.6 Administration zone

There are main control station of receiving station, laboratory, exchange and training center, administration building, fire station and medical center, car and bike parking shed.

The overall layout of the LNG Terminal is shown in figure 2-3.

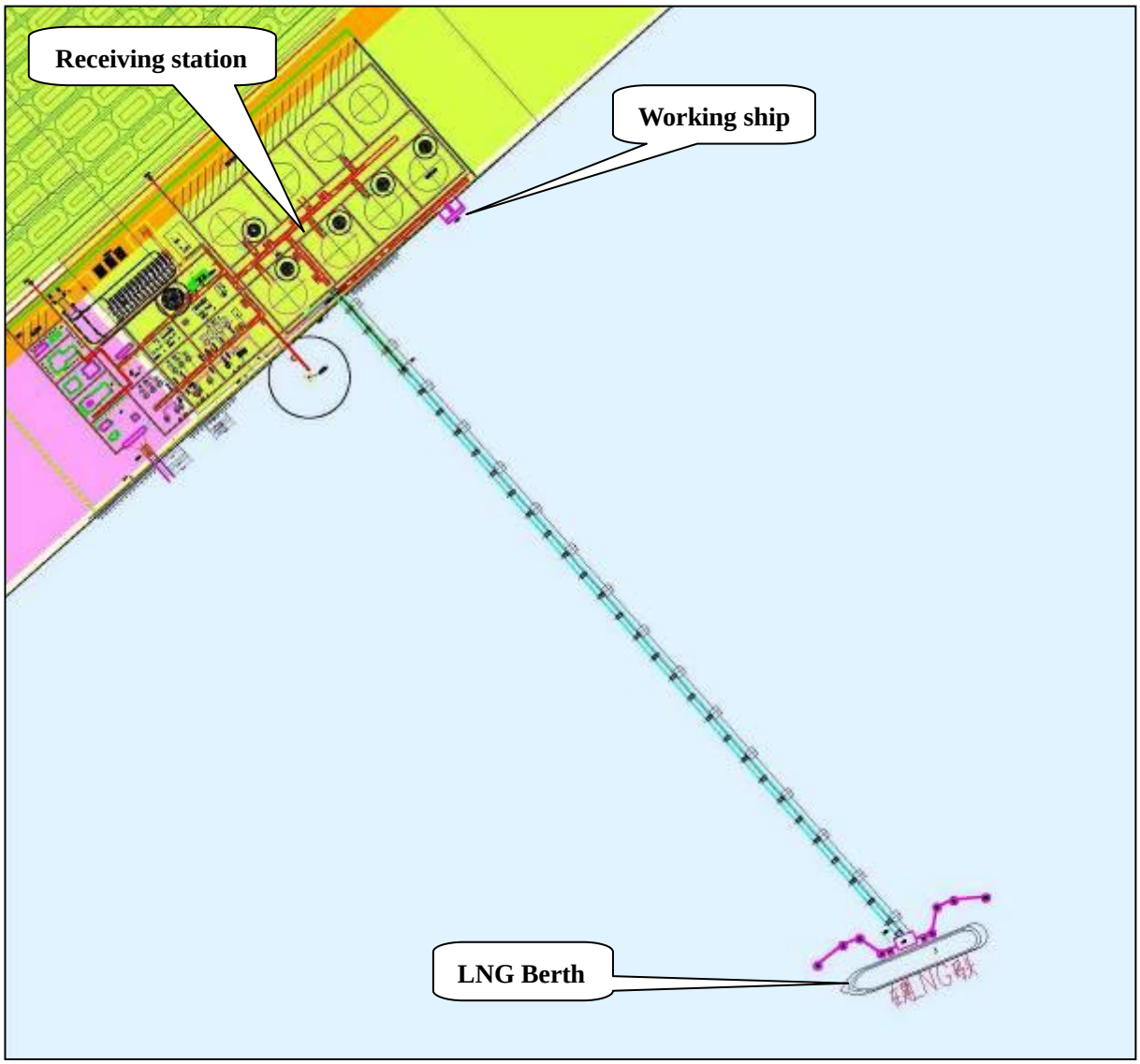

Figure 2-3 The overall layout of the LNG Terminal

Source: Coastal port layout planning of Hebei province

2.3 Fairway and anchorage

2.3.1 Fairway

The LNG Terminal set up special entrance channel for LNG ships. This terminal is

located in the head of Caofeidian Islands near the deep trough. The natural water depth is greater than the designed channel depth, so it is not necessary to excavate channel.

2.3.2 Anchorage

The existing and planning Anchorage Conditions of Caofeidian port are shown in the table 2-1.

Table 2-1 Anchorage table of Caofeidian port

Name	**Control point**	**Control point coordinate**		**Water area (km^2)**	**Depth of natural water (m)**	**purpose**
		North latitude N	**East longitude E**			
West anchorage	XA	38°55.2′	118°22.0′	35	10～22	Coal, container and general cargo ships
	XB	38°54.7′	118°25.6′			
	XC	38°52.0′	118°27.4′			
	XD	38°52.5′	118°21.5′			
East anchorage	DA	38°54.2′	118°33.4′	82	28～32	Oil tankers and bulk carriers
	DB	38°53.2′	118°42.8′			
	DC	38°50.2′	118°42.8′			
	DD	38°51.3′	118°32.9′			
West reserved anchorage	XA	38°55.2′	118°22.0′	30	12～18	Reserve forward anchorage
	XD	38°52.5′	118°21.5′			
	XE	38°53.1′	118°17.7′			
	XF	38°55.6′	118°18.2′			
East reserved anchorage	DA	38°54.2′	118°33.4′	46	15～25	Reserve forward anchorage
	DB	38°53.2′	118°42.8′			
	DE	38°57.0′	118°42.8′			

Source: Caofeidian MSA, (2013). Statistics of Caofeidian VTS.

According to the code for design of liquefied natural gas terminal, LNG ships shall be equipped with emergency anchorage, and the net safety distance between emergency anchorage and other anchorage should be greater than 1km. The

emergency anchorage of this project is located on the northwest of Caofeidian large bulk and oil tanker anchorage.

2.3.3 Navigation facilities

There is one eastern coordinates and two western coordinates on the corner of the turn circle of this project, and one anchorage buoy and four lateral buoys in anchorage. There are two couples of lighted buoy in the two sides of west channel of anchorage. Two glass steel lights whose diameter and height is respectively 2.5m and 2.5m are installed on the two outermost mooring piers of dock respectively.

2.4 Safety and environmental protection facilities

2.4.1 Fire system

The fire dangerousness of the liquefied natural gas ship unloading, storage, transportation, gasification and gas transmission process of LNG is the first grade. To guarantee the safety operation of receiving station, according to the characteristics of liquefied natural gas, the project set a series of fire fighting facilities, including fire water system of high expansion foam extinguishing system, dry powder fire extinguishing system, gas fire extinguishing system, fire extinguishers, fire alarm system and combustible gas detection system. This fire system is set in LNG tank area, process unit area, tank station, utilities and auxiliary production area, the first station metering zone, torch facilities and cold energy utilization zone.

2.4.1.1Docks area

Elevated fire cannons, outdoor fire hydrant, fixed type water spray system, fixed water curtain system, high expansion foam extinguishing system, dry chemical

powder, gas fire extinguishing device, fire extinguishers, fire alarm facilities, combustible gas detection and alarm facilities comprise docks area.

2.4.1.2 LNG tank area

Outdoor fire hydrant, fixed type water spray system, high expansion foam extinguishing system, dry chemical powder, fire extinguishers, fire alarm facilities, combustible gas detection and alarm facilities comprise LNG tank area.

2.4.1.3 Process area

Fixed fire water cannons, mobile water cannons, outdoor fire hydrant, fire hydrant box, high expansion foam extinguishing system, fire extinguishers, fire alarm system, the combustible gas detection and alarm facilities comprise process area.

2.4.1.4 Utilities programme area

Outdoor fire hydrant, mobile type foam fire extinguisher, fire extinguishers, fire alarm system, the combustible gas detection and alarm facilities comprise utilities area.

2.4.1.5 Seawater intake and torch area

Outdoor fire hydrant, fire extinguisher, fire alarm system, the combustible gas detection and alarm facilities comprise seawater intake and torch area.

2.4.1.6 Tanker loading area and the first measurement station

Fixed fire water cannons, mobile water cannons, outdoor fire hydrant, dry chemical powder, high expansion foam extinguishing system, fire extinguishers, fire alarm system, the combustible gas detection and alarm facilities comprise tanker loading area and the first measurement station.

2.4.1.7 Auxiliary production area

There are indoor fire hydrant, outdoor fire hydrant, fire extinguishers, fire alarm system, the combustible gas detection and alarm facilities in this area.

2.4.2 Communication system

The communication system includes telephone system, UHF wireless intercom system, amplifying system, local area network system, radio and so on. The telephone system and data transmission system access to the local communication system. These communication systems can ensure that beforehand warning information and emergency information can be communicated effectively to provide effective protection for emergency action.

2.4.3 Control system

The total control system of Tangshan LNG receiving station engineering project consists of the following independent system.

Distributed control system called DCS. Safety instrument system called SIS. Fire alarm system called FS. Combustible gas detection and alarm system called GS. Pipeline data acquisition and control system called SCADA.

2.4.4 Vessel traffic system

Caofeidian port VTS radar is located in north latitude 38 °55 '5.04 ", the east longitude 118 ° 30 ′ 37.26". The control room of LNG Terminal has one radar displayer connected to the radar station of maritime sector with optical cable to monitor the fairway, anchorage and ships in dock waters in real-time.

2.4.5 Laser berthing system

In order to guarantee the LNG ship berthing safety, prevent accidents from ships during berthing and unberthing, and provide traceability evidence after the accident, the project sets up one set of laser berthing system

2.5 Waterway traffic

So far, Caofeidian Port has built 54 berths. In 2013, the throughput of Caofeidian Port is 245,000,000 tons, and the port calls of entering and leaving reach to 48,769, Caofeidian port became to a integrated large-scale port. The berths in Caofeidian docklands are shown in the following table 2-2.

Table 2-2 The berths in Caofeidian docklands

Name	Annual cargo-handling capabilities	Number	Grade	Using time
Caofeidian crude oil terminal	20000000 tons	1	One 300,000-ton crude oil berth	2008.08
The first phase of Caofeidian ore terminal	30000000 tons	2	Two 250,000-ton berths	2005.12
The second phase of Caofeidian ore terminal	32000000 tons	2	Two 250,000-ton berths	2011.08
Caofeidian general bulk cargo 50,000-ton terminal	3500000 tons	2	Two 50,000-ton berths	2010.05
Initial stage of Caofeidian SDIC coal	50000000 tons	5	Five 100,000-ton	2009.09

terminal			berths	
Continued stage of Caofeidian SDIC coal terminal	50000000 tons	5	Five 100,000-ton berths	2013.05
The first phase of Shougang Jingtang iron and steel supporting terminal	12220000 tons	5	Five 50,000-ton berths	2012.10
Initial stage of Caofeidian general terminal	2200000 tons	3	Three 40,000-ton berths	2009.09
The second phase of Caofeidian general terminal	4000000 tons	3	Three 40,000-ton berths	2009.09
The third phase of Caofeidian general terminal	4100000 tons	2	One 40,000-ton berths and one 70,000-ton berths	2011.04
Caofeidian general bulk cargo terminal	10000000 tons	2	Two 100,000-ton berths	2011.06
Caofeidian multi-purpose terminal	3250000 tons	2	Two 40,000-ton berths	2013.05
Caofeidian lenovo general bulk cargo terminal	3050000 tons	2	Two 50,000-ton berths	2012.12
Bohai Bay production support base of China petroleum Offshore Engineering Co. Ltd	2240000 tons	11	Eleven berths for working ship	2011.09
Caofeidian LNG Terminal	6500000 tons	1	One LNG berth for LNG ship	2013.11

			from 80000m3 to 270000m3	
Caofeidian Wenfeng general bulk cargo terminal	6000000 tons	2	Two 50,000-ton berths	2014.01
The first phase of general terminal of Tangshan Caofeidian steel logistics Co. Ltd.	10490000 tons	4	Two 20,000-ton berths、Two 50,000-ton berths	2014.5
Total	249550000 tons	54		

Source: Caofeidian MSA, (2013). Statistics of Caofeidian VTS.

2.6 Ship traffic safety supervising actuality

2.6.1 The maritime management overview

The maritime department in this area is Caofeidian Maritime Safety Administration which set the Caofeidian VTS center. In order to strengthen and standardize the management of ship traffic, ensure the marine traffic safety in Caofeidian waters, improve the efficiency of marine traffic and protect sea environment, Caofeidian MSA formulated Caofeidian Port marine traffic management system and safety supervision management regulations carried out by Caofeidian VTS.

2.6.2 VTS

Caofeidian VTS is equipped with VTS system in 2007. The system is imported from German ATLAS company and is carried the most advanced system currently in China, and the type of this system is ATLAS VTS9760 system. The using of this

system plays an important role in the vessel traffic management in Caofeidian area.

Caofeidian VTS equipments include radar system, VHF communication system, information processing and display system, information transmission, recording and playback system and meteorological sensor system. The further functions which may be realized in the future include the data collection, data evaluation and processing, information providing, traffic organization, navigation services, support for a joint action. At present, the VTS scope of supervision is the waters area surrounded by the weft 38°43′.00N, longitude 118°15′.00E, longitude 118°55′.00E, and coastline. The LNG terminal is located in the coverage of VTS system.

2.7 Statistics and analysis of marine accident

According to the statistics of Caofeidian MSA, the number of marine accident from 2007 to 2013 is 49, and the detail data is shown in the table 2-3.

Table 2-3 Accident number of every year

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Number	13	10	9	5	7	2	3

Source: Caofeidian MSA, (2013). Statistics of Caofeidian VTS.

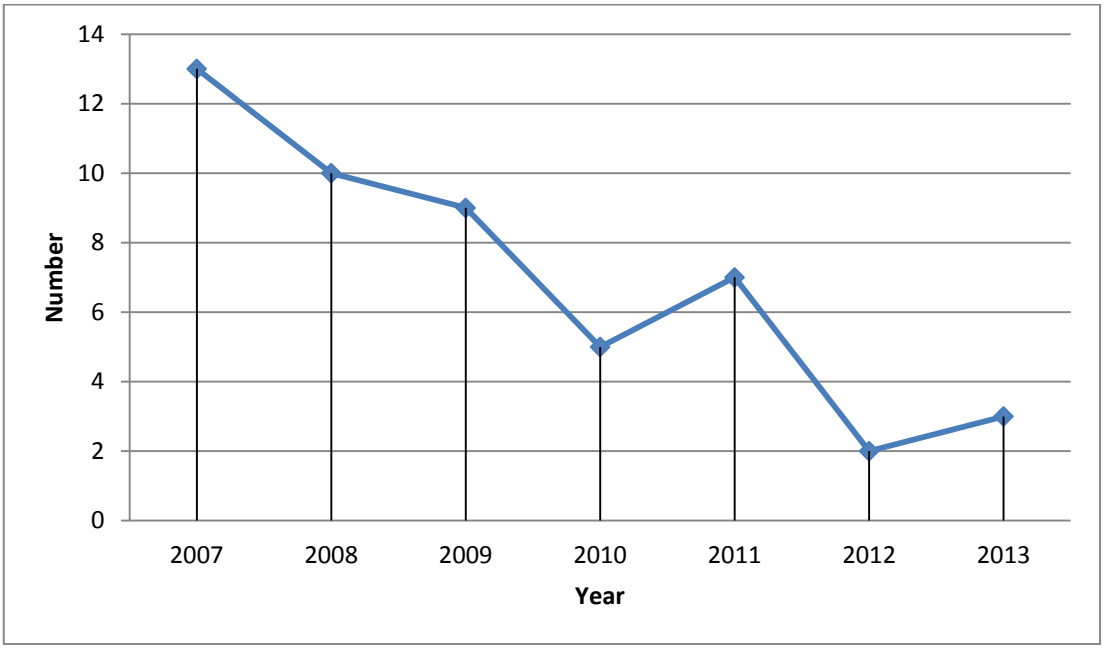

Figure 2-4 Accident number of every year

Source: Compiled by author

The above table and chart show that along with the development of Caofeidian port, the annual accident rate has a decreasing trend. And the following table 2-4 shows the accident number of every type.

Table 2-4 Accident number of every type

Type	Number	Percentage	Average annual number
Collision	11	22.45%	1.57
Stranding	5	10.20%	0.71
Aground	0	0.00%	0.00
Contact damage	1	2.04%	0.14
Fire	7	14.28%	1.00
Wind damage	1	2.04%	0.14
Re-board	15	30.61%	2.14
Other	9	18.37%	1.29
Total	49	100.00%	7.00

Source: Caofeidian MSA, (2013). Statistics of Caofeidian VTS.

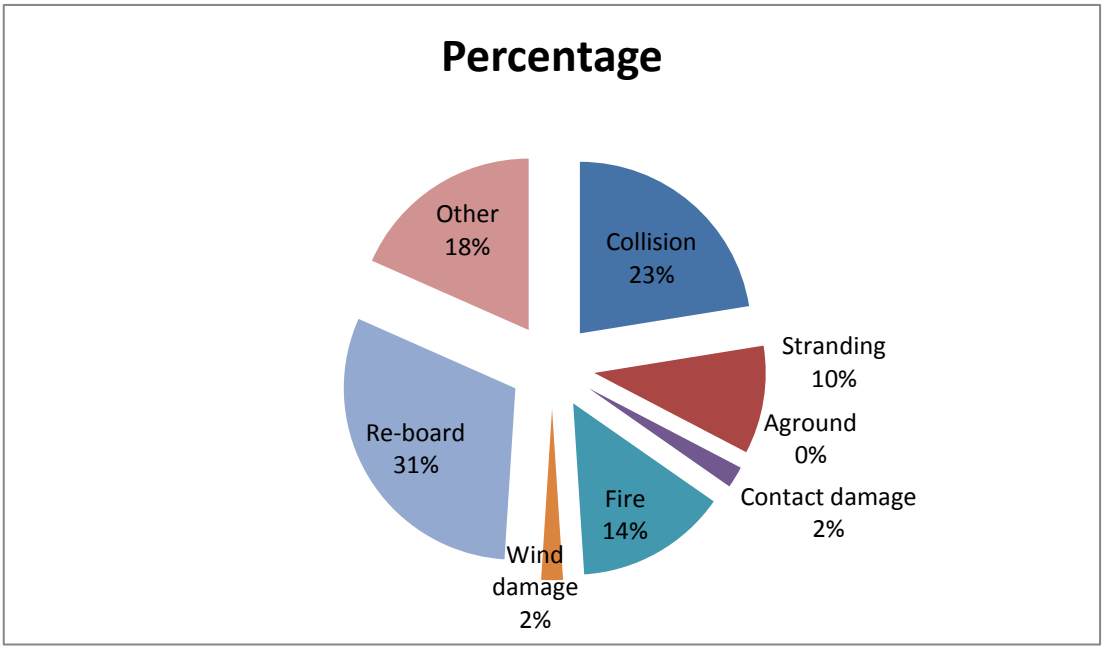

Figure 2-5 Percent of every type

Source: Compiled by author

The above table and chart show that the main types of accidents in Caofeidian port are re-board and collision. And the main reasons of these accidents are that more engineering ship working in Caofeidian before 2009 which have the poor status.

Chapter 3 Harm of LNG leakage

3.1 The leakage history of LNG

Natural gas is a kind of flammable and explosive gas. Once ignited or detonated will cause combustion and explosion accidents causing great losses of life and property. Although in the past 40 years of LNG transport history, whether in port or in bad sea condition, the transportation of LNG up to 80,000 times, the voyage up to 1,000,000 nautical miles, there is no great accident. There are eight shipping accidents resulted from the leakage of LNG. And there are seven incidents caused a certain damage of ship structure, two accidents of them result from stranding, but no leakage of NLG, and also caused no casualties in these two accidents. The main accidents are shown in table 3-1. But when it comes to LNG, we also think of two large LNG accidents occurred in American. The first accident occurred in October 20, 1944. The failure of a cylindrical tank named Cleveland from American causes all of the LNG release immediately, and then the nature gas flow into the nearby streets and sewers, nature gas cloud on fire immediately, the fire engulfed the other near tanks into the living area and business area, the fire weakened gradually after 20 minutes, but the dumping of a nearby spherical tank lead to 9400

gallons of LNG evaporating and igniting immediately. In total, 128 people died in the accident, 225 people were injured, the directly damaged area is 0.75 square miles, 30 acres land was destroyed completely. (Duan, 2013, P191-194) Another accident occurred in February 10, 1973, a LNG tank of one company named TETCO from American in STATENISLAND was broken because of the over-high pressure caused by spark produced when repairing which led to the over-high temperature. The consequence was that 37 people dead who repairing in the tank. (Duan, 2013, P191-194) So, although the LNG accident rate is very low, the consequence is very serious, it cannot be ignored.

Table 3-1 The main LNG accidents

Year	Name	Location	Status	Number of casualties	Loss of ship
1944	East Ohio Gas LNG Tank	Cleveland	None	128 death	No
1965		Canvey Island, UK	Moving cargo	Severe burn	Yes
1965	Jules Vernet		Loading	No	Yes
1965	Methane Princess		Repairing	No	Yes
1971	LNG ship Esso Brega	Italy		No	NO
1973	Texas eastern transimission, LNG tank	Staten Island	None	40 death	No
1973		Canvey Island, UK	None	No	Yes
1974	Methane Progress		Port	No	Yes
1975	Philadelphia Gas Works		None	No	Yes
1977	Arzew	Algeria	None	Frozen to death	No
1977	LNG Aquarius		Loading	No	No
1979	Columbia Gas LNG Terminal	Maryland	None	1 death 1 injured	Yes
1979	Mostefa Ben-Boulaid ship		Unloading	No	Yes
1979	Pollenger Ship		Unloading	No	Yes
1979	El Paso Paul Kayser Ship	Atsea		No	Yes

1980	LNG Libra		On sea	No	Yes

Source: Yang, C, K.(2006). *Study on Instantaneous Release of LNG Carrier*. Unpublished master's thesis, Dalian Maritime University, Dalian, China.

With the rapid growth of NLG trade and LNG ship voyage, the probability of LNG leakage is increasing, so full consideration should be given to the potential risk of leakage of LNG. Additionally, the international terrorism may also carry out attacks on such high-risk ship to pose a threat, so the marine transportation of LNG should be concerned by the international community.

3.2 The reasons of LNG leakage

There are many factors which can lead to LNG leakage, such as design, material selection, manufacture method, inspection and testing, assembly technology, skills of workers, safety operation and so on. Other important factors are receiving station location and design, loading and unloading equipment, communication system and emergency reaction ability.

LNG leakage accidents can be caused by collision, stranding, operational errors, the main propulsion device failure and terrorist attacks. (Zhang, 2006, P81-84) America has taken a series of measures to prevent these risks. All the LNG ships going into America must meet the requirements of international and domestic laws and regulations including ship material and structure, safety equipment, operator training. And before the LNG trade, the shipowner must submit the detailed information of ship and cargo list to America coast guard safety center for examination. If meeting the condition, trade can be carried out. Special security measures are taken for the LNG ship into the USA, delimit safety zone to prevent other ships to come near to

collision accidents, other ships are not allowed to pass this region, and the special ship to pilot the LNG ship, at the same time, sent the coast guard ships convoy to make sure the safety of LNG. (Yang, 2006) In summary, it has important significance to study the safe operation of LNG.

3.3 Characteristics of LNG

To understand LNG leakage potential harm, we should understand the definition and characteristics of LNG firstly. LNG is cooled to minus 162 degrees Celsius in standard atmospheric pressure, transform from gas to liquid substances. LNG is colorless, tasteless, non-toxic and non corrosive, its volume is approximately gaseous natural gas volume of, whose volume is only l/625 of the nature gas with the same weight, and the weight of LNG is only 45% of the water with the same volume, the calorific value of LNG is 52MMBtu. (Qi, 2007, P42-43) The main component of LNG are methane, also including a certain amount of ethane, propane, heavy hydrocarbons, small amounts of nitrogen, oxygen, carbon dioxide and sulfide. Compared with other chemical fuel, the combustion of natural gas only produce a small amount of carbon dioxide emissions dust and very small amounts of carbon monoxide, hydrocarbons and nitrogen oxides. Therefore, natural is a kind of clean energy.

As the main component of natural gas, methane, which itself is a non-toxic flammable gases. The main physical properties are in table 3-2.

Table 3-2 The main component of natural gas

molecular weight	16.043
Boiling point	111.8K
The triple point temperature	90.6K

latent heat of vaporization	121.75kcal/kg
Critical point temperature	190.7K
Critical pressure	4.56Mpa
critical density	162kg/m^3
liquid density	426 kg/m^3

Source: Yang, C, K.(2006). *Study on Instantaneous Release of LNG Carrier*. Unpublished master's thesis, Dalian Maritime University, Dalian, China.

Pure LNG is a colorless, tasteless, non-toxic and transparent liquid, and it is lighter than water, insoluble in water. When the steam temperature is higher than 110 degrees below zero, it is lighter than air. T he steam rises when there is leakage, and is easy to spread out, so the explosion hazard is smaller than that of LPG. Because its chemical property is stable, and cannot incompatibility with other gas products, LNG does not cause a dangerous reaction. (Zhang, 2009, P77-81)

Because LNG belongs to the mixture, the components of different goods will affect its physicochemical properties, the relevant data and advice should be given to ship by shipper before transportation. The followings are some typical commercial LNG data.

The boiling point of LNG is about 157 degrees below zero to 163 degrees below zero in standard atmospheric conditions, and the boiling point of pure methane is 161.5 degrees below zero.

The LNG density in the boiling temperature of atmosphere is 470-530kg/m^3, the density of methane in atmospheric boiling point temperature is 427kg/m^3.

The explosion limit of pure methane is from 5.3% to 14%.

The temperature of auto-inflammation of pure methane is 595 degrees Celsius.

Flash point of pure methane is minus 175 degrees Celsius.

Volume expansion coefficient of pure methane is 0.0026L/ ℃ at a temperature of minus 165 degrees Celsius. (Yang, 2006,)

3.4 Leakage state of LNG

Knowing the features of LNG, leakage state of LNG considering the full status of ship should be discussed. According to the damage location of ship and other occurrence of leakage, LNG may leak into the deck, or into the ballast tanks, cofferdams, and then flow into the sea. Then, according to the time of LNG lit, LNG may volatilize at different levels and spread in the air as the form of vapor cloud, and can also spread onto the surface of water in the form of liquid accompanied with volatilization and evaporation occurs. The potential consequences of LNG leakage are shown in the figure3-1.

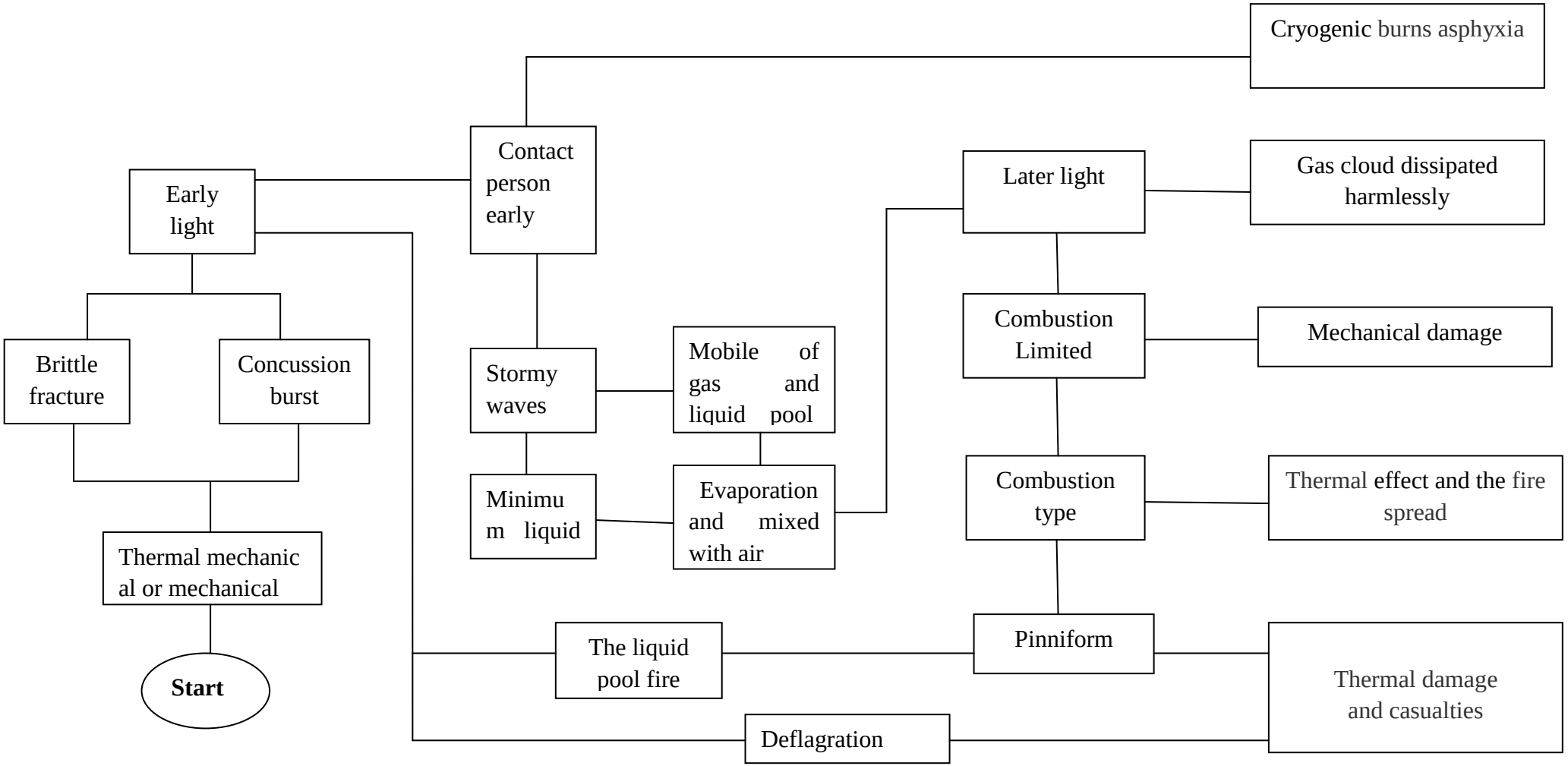
Cryogenic burns asphyxia
Contact person early
Early light
Later light
Gas cloud dissipated harmlessly
Brittle fracture
Concussion burst
Stormy waves
Mobile of gas and liquid pool
Combustion Limited
Mechanical damage
Minimu m liquid
Evaporation and mixed with air
Combustion type
Thermal effect and the fire spread
Thermal mechanic al or mechanical
The liquid pool fire
Pinniform
Start
Thermal damage and casualties
Deflagration

Figure 3-1 The potential consequences of LNG leakage
Source: Yang, C, K.(2006). *Study on Instantaneous Release of LNG Carrier*. Dalian Maritime University, Dalian, China.

Methane is an asphyxiant substance, but it is harmless to the human body. In the LNG leak case, ultra low temperature of LNG begins to evaporate from the cargo hold tear, if LNG has not been lit, the LNG vapor concentration in the air is enough to lead the crew, pilot, emergency rescue personnel and exposed to LNG vapor cloud the other personnel asphyxia. But it is not the main problem that the asphyxia caused by LNG vapor concentration, the main problem is the combustible limit of LNG and the possibility of fire. When the low temperature LNG steam and skin contacting, cryogenic burns occurs. Because of the very low temperature of LNG, the complete performance of ship plate decreases, especially in the connection part of steel, the weld become brittle, resulting in the ship cabin damaged, if a great quantity leak can also make other cabins damaged.

Methane is a kind of greenhouse gas which has damaging effects on the atmosphere, and has serious impacts on the atmosphere ozone. The scientists found that the potential reason of global warming is the accumulation of greenhouse gas, the harm of methane into the atmosphere is more whose effect on global warming is 22 times as that of CO2. In the process of global warming for 20 years, the potential amount of methane is 63 times as that of CO2, so it is necessary to pay attention to control the leakage of methane. If the leakage LNG steam fire, it will cause serious damage to the surrounding personnel and property. The combustion of LNG vapor will produce two effects, one is the thermal load, and the other is pressure load. Thermal load is mainly based on the conversion rate of energy, heat flow, and the pressure load mainly considers the pressure density. Usually the burning degree of LNG vapor related to the mix degree of LNG vapor and the air around. So the LNG vapor ignited time is the important factor to analysis the thermal load caused by

LNG leakage, the LNG vapor ignited time determines the degree and type of thermal radiation. And the different results are shown in table 3-3.

Table 3-3 The different results of combustion

Heat flow exposed ten minutes (km/m^2)	Damaged level
35-37.5	Mechanical processing equipment, Chemical process equipment, Machinery
25	Can lightwood without flame
18-20	Can decrease plastic cable insulation
12.5-15	Can lightwood with flame

Source: Yang, C, K.(2006). *Study on Instantaneous Release of LNG Carrier*. Dalian Maritime University, Dalian, China.

Chapter 4 Research on safety assessment of Caofeidian LNG Terminal

It is necessary to do the research on safety assessment of Caofeidian LNG Terminal after understanding the harm of LNG leakage. The qualitative methods are used more than the quantitative methods in the analysis and research on special terminal for liquefied natural gas. (Wang, 2003, P195-401) Quantitative analysis and research on various factors affecting the safety of Caofeidian LNG Terminal with the method of fuzzy comprehensive evaluation will be given in this chapter.

4.1 The selection of evaluation method.

Theoretically speaking, there are three kinds of mathematical methods for quantitative assessment. The first is the method of classical mathematics, the second is the statistical mathematics method, and the third is the method of fuzzy mathematics. (Li, 1993) Classical mathematics is used to determine the problem in the study of mathematics, statistical mathematics and fuzzy mathematics is used to study the non deterministic problem. (Xu, 2007, P24-26) Statistical mathematics and fuzzy mathematics have substantial distinction, statistical mathematics study and process the random problem, namely, the possibility of events. Fuzzy mathematics deals with and studies the fuzzy problem, namely, the influence of events.

Statistical mathematics and classical mathematics is based on classic set theory, and fuzzy mathematics based on fuzzy set theory. The application of statistical mathematics expanded the application of mathematics from the inevitable phenomenon to accidental phenomenon, and the fuzzy mathematics expanded the application of mathematics from clear phenomenon to fuzzy phenomenon assessment. (Li, 1993) The navigation safety of LNG terminal is a complex system. It has many factors, which is difficult to use the precise mathematical to describe, and evaluating the safety of LNG terminal ascertain the influence factors, which is more suitable for the use of fuzzy mathematics method. The analytic hierarchy process, called AHP, is an analysis method combined qualitative analysis and quantitative analysis, is a powerful tool for the analysis of multi object and multi criteria. Considering the above factors and difference of the influence degree, the AHP analysis method is more suited. Therefore, the mathematical model is established by the method of combining fuzzy mathematics and hierarchy analysis, the fuzzy comprehensive evaluation model.

The steps to establish a fuzzy comprehensive evaluation model are as follows:

a. Establishment of the evaluation index system.

b. Determination of the evaluation index weight.

c. Determination of the degree of membership of evaluation indicators.

d. Establishment and application of the comprehensive evaluation model.

4.2 Establishment of the evaluation index system.

Setting up the right evaluation index system is the first step to establish a fuzzy comprehensive evaluation and also an important step for quantitative assessment of

safety of LNG terminal. Evaluation index system can be one level or multilevel. For objects of multi factors, the evaluation index system should be multilevel, to prevent the diminutive influence from ignore. To reflect all including factors correctly, the evaluation index system establishes two levels of evaluation index system according to analytic hierarchy process. According to the analysis and investigation, the evaluation index system is shown in figure 4-1.

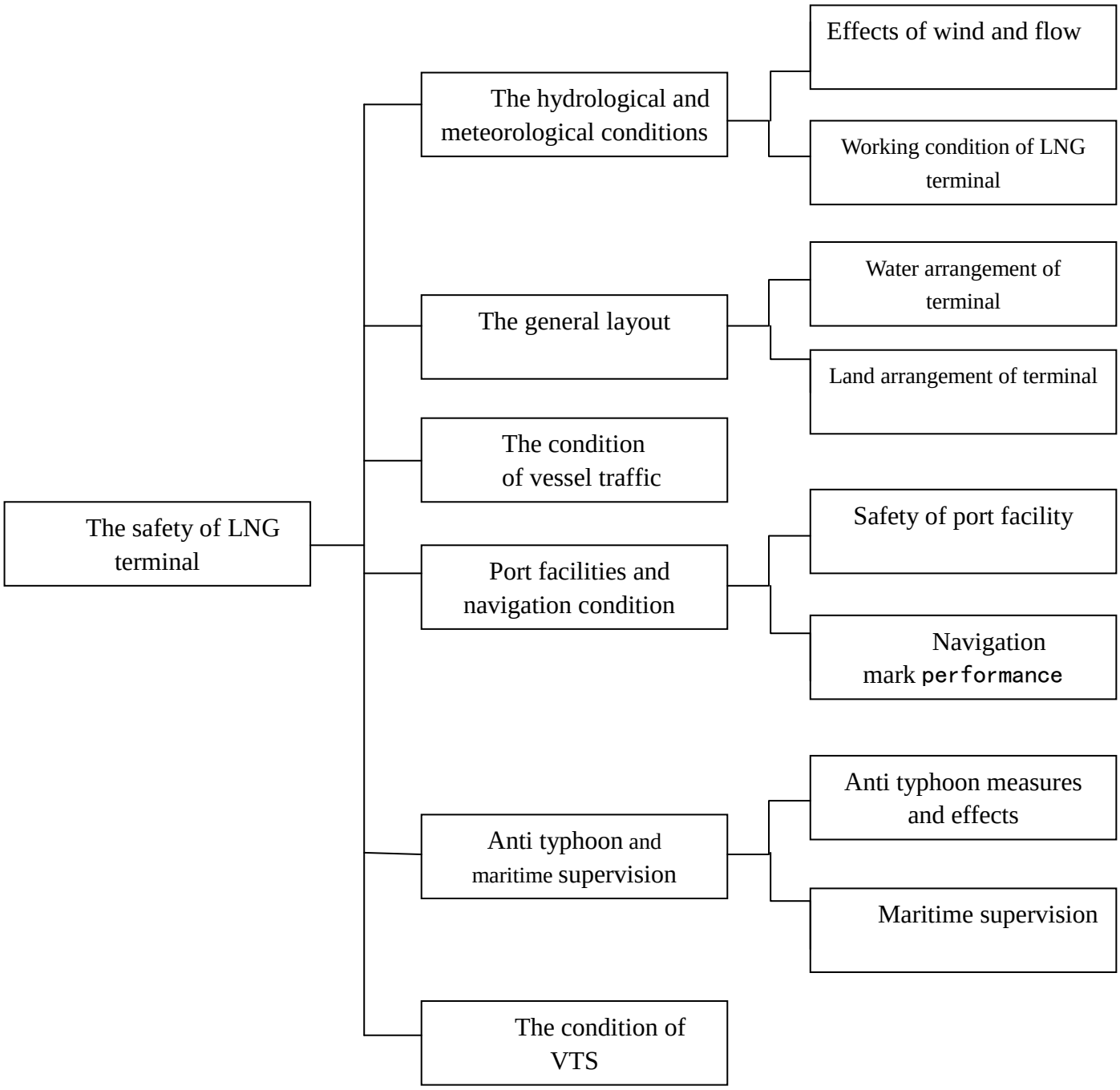

Figure 4-1 Evaluation index system

Source: Chen, J, H. (2007). *Safety Evaluation of Special Terminal for LNG*. Unpublished master's thesis, Dalian Maritime University, Dalian, China.

4.3 Determination of the evaluation index weight and the degree of membership of evaluation indicators.

4.3.1 Determination of the evaluation index weight

The determination of the evaluation index weight is to construct the pairwise comparison matrix with the expert investigation method, and then calculate the weight of each assessment index according to the pairwise comparison matrix. The evaluation index weights of LNG terminal are shown in table4-1.

Table 4-1 Evaluation index weights of LNG terminal

First Item	Weight	Second items	Weight
The hydrological and meteorological conditions	0.14	Effects of wind and flow	0.40
		Working condition of LNG terminal	0.60
The general layout	0.22	Land arrangement of terminal	0.45
		Water arrangement of terminal	0.55
The condition of vessel traffic	0.20		
Port facilities and navigation condition	0.17	Safety of port facility	0.52
		Navigation mark performance	0.48
Anti typhoon and maritime supervision	0.12	Anti typhoon measures and effects	0.39
		Maritime	0.61

		supervision	
VTS conditions	0.15		

Source: Chen, J, H. (2007). *Safety Evaluation of Special Terminal for LNG*. Unpublished master's thesis, Dalian Maritime University, Dalian, China.

4.3.2 Determination of the degree of membership of evaluation indicators.

The establishment of evaluation set and value set. The safety assessment grade of LNG terminal is shown in table 4-1.

Table 4-1 Navigation safety assessment rating for LNG terminal

Grade	Performance
5	The safety of LNG terminal is better.
4	The safety of LNG terminal is good.
3	The safety of LNG terminal is general.
2	The safety of LNG terminal is bad.
1	The safety of LNG terminal is worse.

Source: Compiled by author

Membership degree of each evaluation index can be obtained by safety evaluation grade and membership function of LNG terminal. According to the actual value of evaluation indexes, membership degree of each evaluation index in different LNG special terminal security level can be obtained through membership function of the safety of LNG special terminal, so that every element r_{ij} of matrix R in fuzzy comprehensive evaluation model can be obtained.

In this paper, the safety grade V of LNG terminal is divided into five levels. They are better, good, general, bad and worse. The corresponding score F is 5, 4, 3, 2 and 1.

4.4 Evaluation standards

4.4.1Safety evaluation standards of LNG terminal

The safety of LNG terminal is better.

The site selection is reasonable, including collision resistant is good, convenient transportation and far away from living areas, beach and other industrial zones, in the constant wind beneath. Wind, wave, flow almost have no effect on vessel operation, the whole year can meet the requirements of port entry and departure of large LNG ship, loading or unloading operations. The port facilities and navigation facilities performance is good, VTS system is advanced and maritime supervision is in place.

The safety of LNG terminal is good.

The site selection is far away from living areas, beach and other industrial zones. Wind, wave, flow have effects on vessel operation, port entry and departure in special conditions. The port facilities, navigation facilities, VTS system and maritime supervision are complete.

The safety of LNG terminal is general.

The site selection is away from living areas, beach and other industrial zones. Wind, wave, flow have effects on vessel operation, port entry and departure every year. The port facilities, navigation facilities, VTS system and maritime supervision are general.

The safety of LNG terminal is bad.

The site selection cannot meet the requirements of reasonable, which is not far away from living areas, beach and other industrial zones. The terminal can only meet the

small LNG ships. Wind, wave, flow have more effects on vessel operation, port entry and departure every year. The port facilities, navigation facilities, VTS system and maritime supervision are not complete.

The safety of LNG terminal is worse.

The site selection is not reasonable, near the living areas, beach and other industrial zones. Wind, wave, flow have serious effects on vessel operation, port entry and departure every year. The port facilities, navigation facilities, VTS system and maritime supervision are not lacked.

4.4.2 Safety evaluation standards of every factor

4.4.2.1 Effects of wind and flow

The wind, flow effect is smaller. There is no wind or breeze and the water flow velocity is very little.

The wind, flow effect is small. The wind direction and wind speed is fixed, the water flow velocity is small.

The wind, flow effect is general. The wind power is acceptable for ship, the water flow velocity is fixed.

The wind, flow effect is big. The wind power and the water flow velocity are both big.

The wind, flow effect is bigger. The wind power and the water flow velocity are both very big.

4.4.2.2. Working condition of LNG terminal

Working condition of LNG terminal is better. The maximum wind speed, maximum wave height, the maximum flow velocity can meet the requirements of

LNG ship berthing, unloading and berth unloading.

Working condition of LNG terminal is good. The maximum wind speed, maximum wave height, the maximum flow velocity can meet the part requirements of LNG ship berthing, unloading and berth unloading.

Working condition of LNG terminal is general. Two items in maximum wind speed, maximum wave height, the maximum flow velocity can meet the requirements of LNG ship berthing, unloading and berth unloading.

Working condition of LNG terminal is bad. Only one item in maximum wind speed, maximum wave height, the maximum flow velocity can meet the requirements of LNG ship berthing, unloading and berth unloading.

Working condition of LNG terminal is worse. There are not any items in maximum wind speed, maximum wave height, the maximum flow velocity can meet the requirements of LNG ship berthing, unloading and berth unloading.

4.4.2.3 Land arrangement

Land arrangement is better. The site selection of terminal is appropriate, convenient transportation, safe and reliable, is connected with the city planning and port layout at the time, in the constant wind beneath.

Land arrangement is good. The site selection of terminal is appropriate, convenient transportation, safe and reliable, is connected with the city planning and port layout at the time.

Land arrangement is general. The site selection of terminal is acceptable, convenient transportation, safe and reliable, convenient transportation and far away from living areas, beach and other industrial zones, in the constant wind beneath.

Land arrangement is bad. The site selection of terminal is not appropriate, near living areas, beach and other industrial zones.

Land arrangement is worse. The site selection of terminal is not appropriate

seriously, close to living areas, beach and other industrial zones.

4.4.2.4 Water arrangement

Water arrangement is better. There are enough depth and width of water which can meet the port entry and denture and berth operation of LNG ship.

Water arrangement is good. The depth and width of water can meet the port entry and denture and berth operation of LNG ship.

Water arrangement is general. The depth and width of water can meet the port entry and denture and berth operation of simple ship.

Water arrangement is bad. The depth and width of water cannot meet the port entry and denture and berth operation of simple ship.

Water arrangement is worse. The depth and width of water are far short of the requirements.

4.4.2.5 The condition of vessel traffic

The condition of vessel traffic is better. Terminal water has a nice view, no influence of individual ship, traffic flow is smoothly and crowded degree maintained at a very low status without the risk of collision. The condition of vessel traffic can meet the daily operation of the large LNG ship.

The condition of vessel traffic is good. Terminal water has a nice view, traffic flow is smoothly and crowded degree and collision possibility is very low. The condition of vessel traffic can meet the daily operation of the large LNG ship.

The condition of vessel traffic is general. Ships in this water can run smoothly, but the congestion happens frequently.

The condition of vessel traffic is bad. Terminal waters is narrow and the congestion happens frequently. The navigation condition of large LNG ship is bad.

The condition of vessel traffic is worse. Terminal waters is very narrow which

cannot meet the daily navigation of LNG ships.

4.4.2.6 Safety of port facility

Safety of port facility is higher. Terminal is in seismic favorable site, the security level of the main hydraulic structures and revetment of LNG terminal are class A.

Safety of port facility is high. Terminal is in seismic favorable site, the security level of the main hydraulic structures is class A, and the the security level of revetment is class B.

Safety of port facility is general. Either he security level of the main hydraulic structures or revetment of LNG terminal is qualified.

Safety of port facility is bad. Terminal is in seismic unfavorable site, and neither he security level of the main hydraulic structures nor revetment of LNG terminal is qualified.

Safety of port facility is bad. Terminal is in the earthquake prone zone, and neither he security level of the main hydraulic structures nor revetment of LNG terminal is qualified.

4.4.2.7 Navigation mark performance

Navigation mark performance is better. Hydrological and meteorological conditions, condition of navigation mark waters, vessel traffic situation and ship technical condition are all up to standard.

Navigation mark performance is good. There are three items of all which are hydrological and meteorological conditions, condition of navigation mark waters, vessel traffic situation and ship technical condition are up to standard.

Navigation mark performance is general. There are two items of all which are hydrological and meteorological conditions, condition of navigation mark waters, vessel traffic situation and ship technical condition are up to standard.

Navigation mark performance is bad. There is only one item of all which are hydrological and meteorological conditions, condition of navigation mark waters, vessel traffic situation and ship technical condition are up to standard.

Navigation mark performance is worse. All the hydrological and meteorological conditions, condition of navigation mark waters, vessel traffic situation and ship technical condition are not up to standard.

4.4.2.8 Anti typhoon measures and effects

Anti typhoon measures and effects are better. Detailed anti typhoon plans and emergency plans are formulated according to the features of LNG ships, and the terminal have the clear communication with navigation department, shipper.

Anti typhoon measures and effects are good. Anti typhoon plans and emergency plans are formulated according to the features of LNG ships, and the terminal have the certain communication with navigation department, shipper.

Anti typhoon measures and effects are general. Anti typhoon plans or emergency plans are formulated according to the features of LNG ships, and the terminal have the communication with navigation department, shipper in special condition.

Anti typhoon measures and effects are bad. There are no anti typhoon plans and emergency plans, and the terminal have not the communication with navigation department, shipper.

Anti typhoon measures and effects are worse. There are no preparation for anti typhoon, management of terminal is confusion and the terminal cannot communicate with navigation department, shipper.

4.4.2.9 Maritime supervision

Maritime supervision is better. Maritime supervision is in place and the facilities are completed.

Maritime supervision is good. Daily maritime supervision can be finished and the facilities are enough.

Maritime supervision is general. Maritime supervision facilities are general.

Maritime supervision is bad. Daily maritime supervision is lack and the supervision facilities are bad.

Maritime supervision is worse. Maritime supervision is misleading.

4.4.2.10 VTS conditions

VTS conditions are better. VTS facilities are advanced, the qualities of VTS managers are high, and using AIS as the favorable support and complement tool.

VTS conditions are good. VTS facilities are advanced, the qualities of most VTS managers are high, and using AIS as the favorable support and complement tool.

VTS conditions are general. VTS facilities are not advanced, the qualities of VTS managers are on different level who can ensure daily operation, and using AIS as the favorable support and complement tool.

VTS conditions are bad. VTS facilities fall behind, the qualities of VTS managers are low, and there is no AIS.

VTS conditions are bad. VTS facilities fall behind, the qualities of VTS managers are low who cannot use the facilities, and there is no AIS.

4.5 Expert evaluation

The membership of evaluation indexes is determined through the expert evaluation method and questionnaire.

In this paper, the expert group consists of 20 people assessing the level of each of the qualitative indicator which they belonged to V_1 toV_5. If there are n experts in 20

experts assess an indicator for the level V_i, the index membership of this indicator is r=n/20. After the evaluation of 20 experts on Caofeidian LNG terminal, the statistical evaluation results can be obtained.

Table 4-2 Statistical evaluation results of Caofeidian LNG terminal

Level and score / Indicators	Better (5)	Good (4)	General (3)	Bad (2)	Worse (1)
Effects of wind and flow		8	4	8	
Working condition of LNG terminal	3	13	4		
Land arrangement of terminal		9	8	3	
Water arrangement of terminal	5	15			
The condition of vessel traffic	10	5	5		
Safety of port facility	14	4	2		
Navigation mark performance	6	11	3		
Anti typhoon measures and effects	14	4	2		
Maritime supervision	14	6			
VTS condition	15	4	1		

Source: Compiled by author

4.6The calculation of safety evaluation of Caofeidian LNG terminal

4.6.1 Evaluation of underlying index.

Using the fuzzy comprehensive evaluation model can help to evaluate the safety of the Caofeidian LNG terminal. The first step is to do the fuzzy comprehensive evaluation for underlying index of single factor, and then does fuzzy comprehensive evaluation step by step up.

Single factor evaluation matrix of safety of Caofeidian LNG terminal can be obtained through processing the score result according to the evaluation of experts.

1. Single factor evaluation matrix of the hydrological and meteorological conditions, called R_1.

$$R_1 = \begin{bmatrix} 0 & 0.4 & 0.2 & 0.4 & 0 \\ 0.15 & 0.65 & 0.2 & 0 & 0 \end{bmatrix}$$

2. Single factor evaluation matrix of the general layout called R_2.

$$R_2 = \begin{bmatrix} 0 & 0.45 & 0.4 & 0.15 & 0 \\ 0.25 & 0.75 & 0 & 0 & 0 \end{bmatrix}$$

3. Single factor evaluation matrix of port facilities and navigation condition called R_4.

$$R_4 = \begin{bmatrix} 0.7 & 0.2 & 0.1 & 0 & 0 \\ 0.3 & 0.55 & 0.15 & 0 & 0 \end{bmatrix}$$

4. Single factor evaluation matrix of anti typhoon and maritime supervision called R_5.

$$R_5 = \begin{bmatrix} 0.7 & 0.2 & 0.1 & 0 & 0 \\ 0.7 & 0.3 & 0 & 0 & 0 \end{bmatrix}$$

4.6.2 Establishment and application of fuzzy comprehensive evaluation model.

Through the above steps, the LNG terminal safety evaluation index set $U\{u_1,u_2,u_3,\ldots u_n\}$, LNG terminal safety evaluation set $V\{ v_1, v_2,v_3,v_4,v_5\}$, evaluation index weight $W\{w_1,w_2,w_3,\ldots w_n \}$ and evaluation matrix R can be obtained. The result B can be obtained through the evaluation index weights $\mathbb{W}$ and evaluation matrix R.

$$B = W * R$$

W can be obtained from the weight of single factor given above.

$$W_1 = (0.4 \quad 0.6)$$

$$W_2 = (0.45 \quad 0.55)$$

$$W_4 = (0.52 \quad 0.48)$$

$$W_5 = (0.39 \quad 0.61)$$

Through the matrix synthesis calculation we can get.

$$B_1 = (0.09 \quad 0.55 \quad 0.2 \quad 0.16 \quad 0)$$

$$B_2 = (0.1375 \quad 0.615 \quad 0.18 \quad 0.0675 \quad 0)$$

$$B_4 = (0.508 \quad 0.368 \quad 0.124 \quad 0 \quad 0)$$

$$B_5 = (0.7 \quad 0.261 \quad 0.039 \quad 0 \quad 0)$$

From the score of factor A_3, A_6, we can get.

$$B_3 = (0.5 \quad 0.25 \quad 0.25 \quad 0 \quad 0)$$

$$B_6 = (0.75 \quad 0.2 \quad 0.05 \quad 0 \quad 0)$$

The first class comprehensive single factor judgment matrix R can be constructed according to the second class judgment result.

$$R = \begin{bmatrix} 0.09 & 0.55 & 0.2 & 0.16 & 0 \\ 0.1375 & 0.615 & 0.18 & 0.0675 & 0 \\ 0.5 & 0.25 & 0.25 & 0 & 0 \\ 0.508 & 0.368 & 0.124 & 0 & 0 \\ 0.7 & 0.261 & 0.039 & 0 & 0 \\ 0.75 & 0.2 & 0.05 & 0 & 0 \end{bmatrix}$$

The weight of the first class evaluation index given above, we can get W.

$$W = (0.14 \quad 0.22 \quad 0.20 \quad 0.17 \quad 0.12 \quad 0.15)$$

So, the judgment result of the first class is B.

$$B = W^{\circ}R = (0.42571 \quad 0.38618 \quad 0.15086 \quad 0.03725 \quad 0)$$

The safety assessment level of LNG terminal can be calculated out through doing the defuzzification calculation to B. The method of gravity center is used in the defuzzification calculation. The formula is

$$b = \frac{\sum_{i=1}^{5} b_i * v_i}{\sum_{i=1}^{5} b_i}$$

So,

$$b = \frac{0.42571 * 5 + 0.38618 * 4 + 0.15086 * 3 + 0.03725 * 2 + 0 * 1}{0.42571 + 0.38618 + 0.15086 + 0.03725 + 0} = 4.20035$$

Therefore, the safety evaluation results of Caofeidian LNG terminal is between good and better. The site selection is reasonable, the nearby waters can meet the requirements of port entry and departure of large LNG ship, loading or unloading operations. Wind, wave, flow almost have little effect on vessel operation.

Chapter 5 Conclusion

5.1 Conclusion

This paper introduces the development of LNG and LNG ships, characteristics of Caofeidian LNG Terminal, harmful LNG leakage, and focuses on the safety of this LNG Terminal through the fuzzy evaluation model. General speaking, the safety of Caofeidian LNG Terminal is between good and better. But this result can only used as theoretical basis to the safety management of Caofeidian LNG Terminal to certain extent. Because of author's limited professional knowledge, the research on the safety demonstration of Caofeidian LNG Terminal is not specific and comprehensive. Therefore, it needs further discussion and study in the future.

5.2 Prospects and suggestions

In order to ensure the safety of large LNG ship and Caofeidian LNG Terminal security, this paper puts forward the following security measures, hoping to make the security level improved.

5.2.1 Strict enforcement of maritime traffic control should be carried out to ensure the safety operation from pilot boarding waters to dock, and control the LNG ships reasonable.

5.2.2 Temporary traffic control should be taken when large LNG ship entering port by VTS center. There should be escort in the whole process of LNG ship entry and departure to ensure the safety of LNG in channel waters.

5.2.3 Special navigation safety management regulations for LNG ships should be made.

5.2.4 Caofeidian LNG Terminal should be equipped with high-quality and experienced pilot. In case of emergency, LNG ship must leave, pilot and tug should be ready.

5.2.5 Caofeidian LNG Terminal should be equipped with perfect navigation marks. If possible, electronic navigation marks can be used in adverse weather conditions.

5.2.6When accidents or other things might seriously affect the normal operation of LNG ship, maritime authority should inform the ship to listen to the information through specified channel, and the ship should listen and record this information seriously.

5.2.7 Terminal owner or operator shall establish emergency plan to prevent fire, explosion, or pollution accidents. Terminal owner or operator shall establish anti typhoon plan, in order to ensure the safety of the ship and terminal facilities.

5.2.8 Propose the establishment of the warning area around the LNG Terminal. Ships which have nothing to do with the terminal operation cannot enter the warning area.

5.2.9 In case of bad weather, suggested maritime administration should strengthen the inspection and management of this waters, if found any ships in distress or manipulate difficult, rescue should be organized timely.

5.2.10 Because the serious earthquake on July 28, 1976 in Tangshan area where this LNG terminal located in, relevant emergency plans should be made.

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Appendix A： Safety Evaluation of Caofeidian LNG Terminal questionnaire

（for experts）

Indicators	Level and score				
	Better (5)	Good (4)	General (3)	Bad (2)	Worse (1)
Effects of wind and flow					
Working condition of LNG terminal					
Land arrangement of terminal					
Water arrangement of terminal					
The condition of vessel traffic					
Safety of port facility					
Navigation mark performance					
Anti typhoon measures and effects					
Maritime supervision					
VTS condition					