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Evaluation on navigation environment of Luoyu port area for 400,000-dwt ULOC

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EVALUATION ON NAVIGATIONL ENVIRONMENT OF LUOYU PORT AREA FOR 400,000-DWT ULOC

By

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Declaration

I certify that all the material in this dissertation 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 dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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Facing success or failure,
It's no need to care too much.
Only if I've tried my best,
It's enough for my simple life.

Abstract

Title of Dissertation: Evaluation on Navigation Environment of Luoyu port area for 400,000-DWTULOC

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ULOC of 400,000-DWT class will greatly facilitate global trade of iron ore, promoting economic development of China. However, the navigational safety can not be ignored with up-sizing of port area. Compared with other smaller ships, the maneuverability of ULOC is obviously more affected by navigation environment such as current, tide, and channel. The safety of ULOC should be evaluated on the basis of local navigational environment.

This paper carries out qualitative and quantitative risk analysis on navigation environment in Luoyu port area according to the characteristics of ULOC of 400,000-DWTclass, and then proposes suggestions on targeted risk factors of ULOC to enhance navigation safety of Luoyu port area. It firstly introduces the information of environment of Luoyu port area including natural condition, channel, traffic flow as well as navigational support, and identifies the key requirements of ULOC. Then it adopts fuzzy comprehensive method to establish a model for evaluating navigational environment of Luoyu port area. Risk level of navigational safety of ULOC in Luoyu port area is revealed in concrete figure. Finally, it put forwards suggestions for port authority and maritime authority in Meizhou Bay to enhance the navigation safety and efficiency of Luoyu port area, as well as tips for seafarers to maneuver ULOC in Luoyu port area of Meizhou Bay.

KEY WORDS: ULOC; navigation environment; Luoyu port area; fuzzy comprehensive method;

Table of contents

List of Tables

List of Figures

List of Abbreviations

DNV-GL	Det Norske Veritas-Germanischer Lloyd
DWT	Deadweight tonnage
E	East
E_w	Elevation of wharf
ENE	East-North-East
ESE	East-South-East
L	Length
L_b	Length of berth
LNG	Liquefied Natural Gas
m	Meters
m/s	Meters/second
MSA	Maritime Safety Administration
MT	Ministry of Transport
N	North
NM	Nautical Mile
NE	Northeast
NNE	North-North-East
NW	North-West
NNW	North-North-West
PAMB	Port Administration of Meizhou Bay
PRC	People’s Republic of China
S	South
SE	Southeast
SW	Southwest
SSE	South-South-East
SSW	South-South-West
TEU	Twenty-foot Equivalent Unit
TML	Transportable Moisture Limit
ULOC	Ultra large ore carrier

VTS	Vessel Traffic Service
W	West
WSW	West-South-West

Chapter 1 Introduction

1.1 Background

China has become the biggest consumer and importer of iron ore in the world as 70% of iron ore is consumed in China. In 2020, China imported 1.17 billion tons of iron ore by seaborne trade, grew by 6.5% at annual pace. 80% of China's market demand for iron ore has been addressed through seaborne trade (Zhang & Singh, 2021). To meet the expanding need of market, adapt to the trend of gigantism of bulk carrier and guarantee the port capacity for loading and unloading iron ore, Chinese government had planned to construct ports capable of accommodating ULOC of 400,000-DWT class since 2015. By 2020, there are seven berths in four ports in China capable of handling such ultra scale vessel (MT &NDRC, 2015). In 2020, Chinese government had delivered an announcement on upgrading four more ports for handling ULOC over 400,000 DWT, among which Luoyu port area in Meizhou Bay located in Southeast China was the chosen one (MT & NDRC, 2020).

Luoyu port area in Meizhou Bay has been identified as a key terminal in Fujian Province, owning to its advantageous natural condition. It mainly handles solid bulk cargo such as ore, which are transferred to steel mills as well as industrial and mining enterprises in Taiwan Province, Fujian Province, Hunan Province and Jiangxi Province. With two deep-water berths constructed, the port railway operated and other terminal facilities completed, a relatively perfect transportation system has come into being, which has created favorable conditions for Luoyu port area to become the distribution center for iron ore in the southeast Asia. The upgrading of berth in Luoyu port area to a level capable of handling vessels of 400,000-DWT class will not only promote material exchange between Taiwan Province and mainland China across the strait, and also improve the rational distribution of iron ore berths in China. It will fill the gap in the demand of a center for iron ore distribution in Fujian Province and southeast China. With the size merits of gigantic ore carrier, there has been an up-sizing trend of iron ore carrier on China-Brazil route under the economic and environmental pressure (Scott, 2016). The competitiveness of Meizhou Bay will be directly improved in iron ore transportation by lowing the unit shipping cost through economy of scale. Louyu port area will become a spot market for iron ore trade in Southeast Asia in near future. However, when we look into bright future of Meizhou Bay, it is essential for us to take a close look at navigational safety of Luoyu port area in the expansion, which is the prerequisite for the bright future. What kind of hazards are there and what kind of risk control is needed for accident prevention?

Mehdi & Schröder-Hinrichs (2019) define risk as "combination of the probability and consequences of undesirable events that arise due to a permutation of passive hazards and active failures in a system or a process". Even when the probability of undesirable event is low, if consequences of undesirable events are very serious, the risk level will also be high. Navigational environment of Luoyu port area is quite complicate, where fishing boats, LNG vessels and oil tankers come and go in this area. Collision accidents would result in catastrophic consequences, especially when LNG vessels and oil tankers are involved.

As it is provided in Chapter V of SOLAS Convention (IMO, 1974) that contracting states is obligated to carry out arrangements relating to meteorological service, ice patrol service, hydro-graphic service, vessel traffic service as well as search and rescue etc, it is revealed that navigational environment is an important basis to ensure safety of navigation for ships and protect the safety of human life and property at sea as well as marine environment. Especially for ULOC, when it navigates in restricted waters, the impact of navigation environment on safety is much more prominent. In addition, the cargo on board is iron ore, including iron ore fines, which has been classified into Group A in IMSBC Code by amendments in 2017. Cargoes of Group A are those may liquefy when the moisture content exceed TML. Intensive swing or vibration caused by wind or wave could lead to the phenomenon of free surface, which result in loss of stability of ULOC (IMSBC Code, 2017). Hence, it is essential for us to carry out risk analysis and risk management on the local navigational environment of Luoyu port area for navigational safety of ULOC.

1.2 Purpose and significance of the study

1.2.1 Purpose

As Rodrigue (2020) classified ships above 300,000 DWT carrying iron ore as ULOC class, ore carriers above 400,000 DWT definitely belong to ultra-large scale ships, which indicate large inertia and huge displacement, resulting in poor performance of stopping as it takes longer time and distance to stop a ULOC. Compared with other smaller bulk carriers, ULOC is very unique in terms of maneuverability with bigger block coefficients and poorer directional stability. When it sail in low speed or shallow water area, the turning ability of ULOC will be prone to be influenced by natural conditions such as wind and turning area. When encountering other ships, it is much more difficult for ULOC to take timely and efficient actions to avoid collision (Zhang, 2017). In case of ship collision, grounding, oil spilling or sinking, it will cause huge loss to economy and environment. As a consequence, competent authorities in Luoyu port area have to take precautions for safety of ULOC based on local environment.

This paper analyzes the risk factors of navigational safety of ULOC in Luoyu port area from the environmental perspective and provides scientific basis for formulating preventive measures in advance, which will serve the seafarers, operators of port area and maritime authority. The result of this paper will promote systematic and standardized management of navigational safety of ULOC above 400,000-DWT entering and leaving Luoyu port area and enhance navigation safety condition in Luoyu port area. When all hazards are identified, it will exert positive influence on preventing marine accidents in Meizhou Bay.

1.2.2 Significance

Currently, only few researches have been conducted on navigation safety of ULOC from the environmental perspective. After review, it is found that most of research abroad concentrates on navigation safety of container ships while literature involving systematic analysis on the subject of ULOC is quite limited. In contrast, there are much more researches on ULOC in domestic literature, but they are mainly analyzed qualitatively. In this paper, a quantitative analysis on navigation safety of ULOC is conducted from the environmental perspective. The research results of this paper are of great significance to enhance the navigation safety of ULOC in the water area, reduce marine accidents, enhance port capacity and better serve the development of the iron ore trading center in Southeast Asia.

1.3 Development and research status

1.3.1 Research status abroad

Since 1970, Fujii, Yamanouchi and Mizuki had conducted quantitative analysis on some factors affecting the frequency of collision and grounding accidents in Marine Traffic. In 1995, probabilistic risk assessment had been brought into maritime industry by Roeleven et al. A large number of scholars such as Soares & Teixeira (2001), Park et al. (2016) and Endrina et al. (2018) had conducted research on theory and development of risk analysis applied in marine traffic. Mokhtari et al. (2011) conducted bow-tie based risk analysis framework on risk management of sea ports and offshore terminals.

Fuzzy logic had been introduced for maritime risk analysis by Sii et al. (2001). They quantified safety modelling in an case study of fuel system failure in a vessel's engine room. It is suggested that the approach was quite practical in maritime safety analysis with advantageous merits in case of tremendous uncertainty where the safety information is insufficient and vague.

Balmat et al. (2009) developed a modular and hierarchical structure on the basis of fuzzy logic to define risk factor of an individual ship. They proposed to combine static risk factor of ship's characteristics and dynamic risk factor of the weather conditions to calculate a risk factor for each ship. Through fuzzy logic, the uncertain situation could be converted into data of probabilities and risk analysis on individual ship would be much more efficient.

Zaman et al. (2014) used data of automatic identification system and expert judgement to establish fuzzy Failure Mode and Effect Analysis mode to evaluate risk of ship collision in Malacca Strait. To establish the model based on fuzzy philosophy, the paper explored ten hypothetical scenarios according to AIS data. The function value drawn from each scenario was created to determine risk rating. It comes to the conclusion that "human error in general" is the top one risk for ship collision in Malacca Strait while "failure of machinery and electricity system " is the lowest one.

Kuzu et al. (2019) applied fuzzy fault tree analysis to comprehensively analyse ship mooring operation. The paper performed quantitative risk analysis on a real case of MT Zarga accident. They firstly established a Fault Tree diagram, then transformed possibilities of failure from expert judgement into probability of occurrence, and finally made prediction on a Minimal Cut Sets and Top Event. It was found that high risk existed in mooring operation and measures on improving safety during mooring operation was finally discussed accordingly.

Akyuz et al. (2020) integrate fuzzy logic with bow-tie approach in comprehensive risk analysis on cause and failure of cargo liquefaction on board ship. The paper divided basic events into two groups as known failure rate event and unknown failure rate event, and set fuzzy matrix by converting possibilities of unknown group from expert judgement into probabilities. Rating of probabilities of occurrence would be determined finally and maritime authorities could take actions to prevent cargo liquefaction correspondingly.

Adenya et al. (2016) carried out experimental simulation of springing response for 550000 DWT ore carrier from the perspective of ship architecture. He conducted assessment on the motion and load response of a 550,000-DWT ore carrier to establish the influence of stiffness on springing response of the ore carrier in wave.

1.3.2 Domestic research status

Zou (2017) carried out field study on safe berthing of bulk carrier above 400,000-DWT in Dongjiakou port area of Qingdao Port. He summed up characteristics of local marine environment in Dongjiakou port area, and analyzed risk factors of local environment such as meteorology, hydrology, and traffic condition in detail. Based on the risk factors, corresponding measures for safety management of berthing of bulk carrier above 400,000-DWT in Dongjiakou port area were proposed. Although the analysis is comparatively comprehensive, it is only qualitative analysis with subjective experience, which dose not include probability of failure caused by risk factors and priority of management measures.

Zhang (2017) applied Maneuvering Model Group to study the maneuverability of ultra large bulk carrier of 400,000-DWT class. His paper simulates the turning movements of ULOC when ship navigates under different conditions namely different load, water depth and speed. It is concluded that ULOC has good maneuvering performance under full load condition.When navigating in shallow water area, the turning area for ULOC is larger while the turning ability becomes worse. It would take longer distance and time to stop ULOC with larger inertia. However, the simulation does not take external factors such as wave and wind force into consideration, which might be quite different from practical situation.

Wang (2016) carried out risk evaluation on pilotage of 400,000-DWT ore carrier in Qingdao Port. The paper adopts fuzzy comprehensive approach to conduct quantitative risk analysis on pilotage. When a piloting task is completed, the pilotage scheme would be optimized accordingly and the actual data of pilotage would be embodied into a database of piloting scheme for ULOC. With the rating of risk evaluation, pilots could choose the most suitable scheme from database. The piloting scheme would be much more practical and scientific as the database is made up of real piloting data.

Yang et al. illustrated the safety risk of ULOC when the cargo on board is iron ore fines. If the cargo exceeds the TML (Transportation moisture limit), it is prone to liquefaction. Free surface effect would exert negative influence on ship stability, leading to capsizing or sinking of ULOC. The paper focused on risk mitigation and setting safety barriers to prevent influence from factors such as moisture, temperature and vibration triggered by swells.

Xu (2021) used analytic hierarchy process and fuzzy logic to establish a risk analysis model for Dafeng port area of Yancheng Port. The thesis firstly identified all risk factors in Dafeng port area and then classified them into four groups. Every subset of evaluation would be determined to a risk level by expert judgement, which would derive the final coefficient. After risk analysis, it is shown that navigational environment such as bad weather, high traffic flow and current had increased the probabilities of marine accidents in Dafeng port area. The thesis finally proposed measures and cautions for seafarers and pilots to make a reference when navigating in Dafeng port area.

1.4 Objective of the study

The purpose of this paper is to carry out qualitative and quantitative risk analysis on navigation environment in Luoyu port area according to the characteristics of ULOC of 400,000-DWT class, and then proposes suggestions on targeted risk factors of ULOC to enhance navigation safety of Luoyu port area. The main contents of the study include the following aspects:

(a) overview of navigational and environmental information of Luoyu port area in Meizhou Bay;

(b) identification and analysis of targeted risk factors of Luoyu port area;

(c) analysis of navigation safety of 400,000-DWT vessel calling at Dongwu port based on fuzzy comprehensive method;

(d) proposal of suggestions on risk prediction and reduction for ULOC calling at Luoyu port area, and measures for improving navigable condition of Luoyu port area.

1.5 Research methods

(a) Literature analysis. Read a large number of literature to understand the relevant study on risk analysis, navigation environment and safety evaluation conducted by domestic and foreign scholars.

(b) Field study. Visit local maritime administration, port authority, Quanzhou VTS, and meteorological departments to collect relevant data of Meizhou Bay, as basic data for the analysis of risk factors of Luoyu port area.

(c) Delphi method. Based on the data analysis on environment of Luoyu port area and the research results of domestic and foreign scholars in the field of risk evaluation on navigation safety, evaluation criteria for risk factors are set up. Consulting experts on risk identification for evaluation model and weighting value of risk factors by emailing questionnaires.

(d) Fuzzy mathematics. Fuzzy mathematics is used to calculate risk level of the established model. Risk rating for risk factors could be displayed. A exact number for indicating risk level of navigation safety of ULOC in Luoyu port area is obtained through calculation.

Chapter 2 Overview of the navigational environment information of Luoyu port area

2.1 Natural conditions

2.1.1 Meteorological conditions

Located in southeast Fujian Province, Luoyu port area of Meizhou Bay is characterized with sub-tropical monsoon climate. Statistics from nearest weather stations, named Xiuyu weather station, is introduced as follows:

(a) The annual average temperature in Meizhou Bay is 20.2℃, while the highest temperature is 39.2℃ and the lowest is 0.2℃. The average annual precipitation in Meizhou Bay is 1316.6mm, and the maximum precipitation is 1966.4mm. Rainfall concentrated in spring and summer from March to August. Rainstorms mainly appears in July to September of the typhoon season. The average number of thunderstorm days over the years in this area is 30 days, with a maximum of 40 days and a minimum of 16 days. The annual average number of foggy days in local area is 11 days, with a maximum number of 23 foggy days and a minimum of 2 foggy days. According to the statistics of typhoon from 2010 to 2020, the area has been swept by 31 typhoons or tropical storm, with an average frequency of 3.1 times per year as shown in Table 1. (FMA, 2021)

Table 1 Statistics of annul number of typhoon from 2009 to 2020

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number	5	2	1	5	3	3	4	3	2	1	2

Source: Fujian Meteorology Administration, edited by author

(b) NE or NNE wind dominant in other months with a frequency of 45%. The strongest wind in this area is NE direction with the maximum wind speed of 27 m/s, and the second strongest wind is SE direction with the maximum wind speed of 23 m/s. Statistics indicates that the annual average number of days with wind force larger than 6 gale is 18.4 days. Detail of wind condition and rose diagram of wind direction is displayed in table 2 and figure 1 respectively.

Table 2 Statistics of wind condition in Luoyu port area

Wind direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maximum speed（m/s）	14	21	27	17	12	9	23	11	16	15	14	16	9	15	10	8
Average speed（m/s）	4.5	7.2	9.3	9.1	6.2	4.0	4.5	4.8	7.0	7.4	6.8	5.4	2.9	3.8	3.5	3.5
Frequency（%）	3	13	27	14	5	2	2	4	13	4	2	1	1	2	1	1

Source: Xiuyu weather station, edited by author

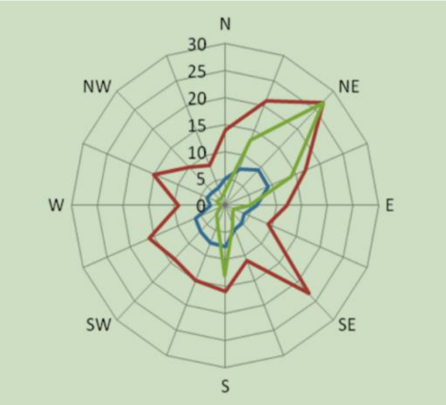

Figure 1 Rose diagram of wind direction in Luoyu port area
Source: Xiuyu weather station, edited by author

(c) Hydrological conditions

The tide in Meizhou Bay belongs to regular semi-diurnal type, with a quite large tidal range. The average tidal range is above 460 cm with the maximum tidal range of 759 cm and the minimum tidal range of 185 cm. The average duration of rising and ebb tide in the bay was 5 hours 46 minutes and 6 hours 25 minutes respectively. The tide in the main channel of Meizhou Bay is reciprocating, while the velocity of rising tide is 1.0 ~ 1.4m/s. The duration and tidal level of rising tide at different sites are shown in Table 3. (TIO, 2020).

Table 3 Duration and tidal level of rising tide at different sites（m）

site / duration	CHONGWU	JIANYU	DOUWEI	DASHENGDAO	LIYUWEI	XIUYU
One hour	4.94	5.10	5.30	5.35	5.54	5.88
Two hours	4.79	4.94	5.12	5.17	5.34	5.66
Three hours	4.55	4.70	**4.86**	4.90	5.06	5.34
Four hours	4.24	4.38	4.51	4.55	4.67	4.93
Five hours	3.69	/	/	/	/	/
Six hours	**3.21**	/	/	/	/	/

Source: TIO, edited by author

Statistics of the nearby Xiuyu Short-term (1978-1980) Wave Observation Station indicates that the sea area is dominated by currents of NE direction with a frequency of 26%, of which the maximum wave height 1.4m. The secondary wave is in the ENE direction with a frequency of 17% , of which a measured maximum wave height 1.2m. In accordance with the topographic conditions in Meizhou Bay and the data of tide and current, Luoyu Port Area of Meizhou Bay Port is mainly affected by the wave of SSW-N and S-SSE direction.

2.2.2 Navigation environment

(a) Port Condition

Luoyu Port Area is subordinated to Dongwu Port area of Meizhou Bay, which includes five ports area namely Xinghua Port Area, Dongwu Port Area, Xiuyu Port Area, Xiaocuo Port Area and Douwei Port Area. There are 54 commercial berths for accommodating ships over 1000 DWT, and 29 berths for ships over 10000 DWT in Meizhou Bay. The designed capacity for cargo throughout in Meizhou Bay is 148.62 million tons per year including 90,000 TEU of containers, as well as 100000 passengers per year. Dongwu port takes the transportation of coal, ore and other bulk dry cargo as central task, and also accommodates LNG vessel, passengers vessel and general cargo ship. According to the national plan, the shoreline of the wharf for Luoyu port area is 4,189 m, the land area is about 4290000 m^2, while the total 15 berths for vessels above 50,000-ton class would come into service. (PAMA, 2020)

Located at 119°00 '09 "~ 119°01' 55"E, 25°09 '37 "~ 25°11' 54N, Luoyu Island covers an area of 860000 m^2, with a natural shoreline length of 4400 meters, and depth of water channel in the west of the island reaching 25 meters. It is actually an excellent location for berthing gigantic vessel. From the perspective of geography and topography, Berth NO.9 in Luoyu is the only suitable location for berthing ULOC of 400,000-DWTclass, which has been put into operation from 2018. The detailed parameters of berth NO.9 is listed in table 4.

Table 4 Main parameters of berth NO.9

Name	**berth NO.9**
Structure of wharf	Gravity wharf
Length of berth	386m, 54
angle	6.98°~186.98°
Elevation of top-surface	+9.0m
Elevation of wharf	-23.5m
width	116m
Elevation of turning area	-21.5m
Dimension of turning area	847.5*678m（for vessel of 300000-ton class）
Annual throughout capacity	1.6 million tons

Source: Port Administration of Meizhou Bay in Fujian Province, PRC

(b) Navigational channel condition

The third phase of construction of the main channel of Meizhou Bay was completed on May 17, 2019. The overall length of the channel is about 52.1km, and it is divided into the section outside the bay with navigable width of 500m and elevation of 23.0m and the inside section with navigable width of 350m and elevation of 21.5m, which can satisfy the needs of 300,000-ton bulk carriers navigating in single-way when tide is rising as well as Q-MAX LNG carriers. The information of navigational channel for Luoyu port area is shown in figure 2 and turning angle of each point is listed in Figure 2.

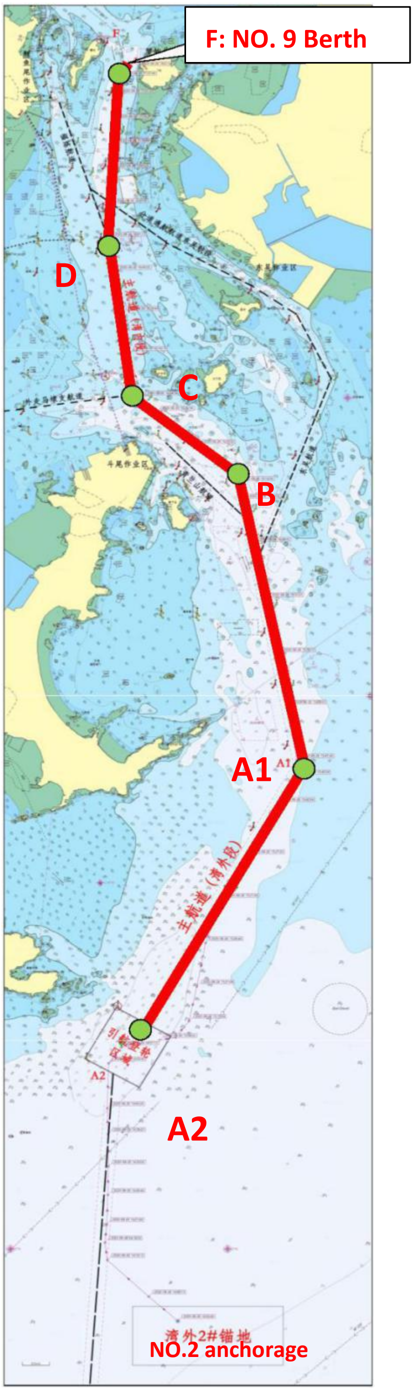

Figure 2: Schematic diagram of channel for ULOC
Source: Port Administration of Meizhou BAY in Fujian Province, PRC, edited by author

Table 5 Key information of the main channel of Meizhou Bay to Luoyu area

section	Turning point	location	length	course angle	Turing angle
Outside the bay	A3	24°45′07.40″ 118°59′47.21″	11.4	4°34′~184°34′	
	A2	24°51′18.30″ 119°00′16.72″	12.7	30°09′~210°09′	25°35′
	A1	24°57′16.76″ 119°04′01.26″	10.5	349°00′~169°00′	41°9′
	B	25°02′49.77″ 119°02′47.55″			37°28′
Inside the bay	B	25°02′49.77″ 119°02′47.55″	4.7	320°32′~140°32′	37°28′
	C	25°04′30.07″ 119°00′41.47″	5.7	358°01′~171°01′	39°29′
	D	25°07′32.68″ 119°00′08.27″	7.1	3°59′~183°59′	12°58′
	F	25°11′23.47″ 119°00′24.02″			
total			52.1		

Source: Port Administration of Meizhou BAY in Fujian Province, PRC, edited by author

In accordance with the duration and tidal level of rising tide with 90% guaranteed ratio at different sites introduced in table 3, to enter the port area, ULOC of 400,000-DWTclass could take the route by ULOC of 300000-ton class for reference. The detailed process is introduced as follows:

The ULOC shall set sail from the NO.2 anchorage outside the bay 3 hours before the high ride at the speed of 7 knots. At this time the tidal level is 3.21m, and it will take 1 hour to arrive at Site A2, where pilot embark on the vessel. And then it will take about another 1 hour to navigate from Site A2 to Site B at the average speed of 12 knots as the distance is about 23.2 km. When the vessel reaches Site B, it is about 1.5 hours before the high tide. The vessel sails at an average speed of 10 knots for 4.7 km from Site B (DOUWEI) to Site C, at an average speed of 7 knots for 5.7km in section C-D , and at an average speed of 5 knots for 6.5km until it arrived at the quayside of LUOYU. Plus additional 40 minutes for berthing operation, the overall duration for sailing in rising tide is about 4 hours.

Although the draft of ULOC of 400,000-DWTclass is consistent with ULOC of 300000-ton class, it will take longer time for ULOC of 400,000-DWTclass to conduct berthing operation as more tugboats would be involved in the berthing process due to larger size. Taking the extra time for berthing into consideration, the overall time for ULOC of 400,000-DWTclass to enter into Luoyu Port area is about 4.5 hours when the tide is rising.

(c) Anchorage

There are totally 11 anchorages available for ships around Meizhou Bay, including 5 anchorages within Meizhou Bay, 3 anchorages at the mouth of the bay, and 3 anchorages outside Meizhou Bay. During the third phase of construction of the main channel of Meizhou Bay, a rectangular water area was set up as NO.2 anchorage in the southeast of the starting point of the channel, whose length is 4450 m and width is 1680 m. The depth of anchorage is above 29 m. The bottom sediments of the anchorage is mainly composed of silty clay and a small amount of silt, which contributes to better holding power of anchor. (PAMB,2020)

(d) Navigational obstruction

The navigation obstruction section of Meizhou Bay main channel is mainly concentrated in the southwest of Dasheng Island from Linji Reef to the north of Dasheng Island near the black reef, which is about 1.62 nautical miles long. In this section, there are 7 reefs and peak-tail sand shoals affecting the navigation channel. There are shallow shoals from south to southwest of Da Sheng Island. There is a shallow area of 1.6 nm^3 extending from northwest to southeast in the northwest of Daisheng Island. There is a shoal in the southeast of Panyu Island 1.4nm to the south of Yandun Mountain. There is a shoal in the southeast of Panyu Island that extends about 1.9 nautical miles.

Besides shoals and reefs, there are submarine pipelines in the relevant water area. Firstly, a submarine crude oil pipeline of Fujian Refinery Ethylene Project, which is routed to the following points: A (25° 09′ 57.31″ N, 118° 58′ 28.15″ E), B (25° 09′ 06.63″ N 118° 58′ 57.98″ E), C (25° 06′ 08.93″ N 118° 59′ 35.04″ E), D (25° 03′ 26.20″ N 119° 00′ 31.11″ E). Secondly, a submarine sewage discharge pipeline of Fujian Refining Ethylene Project, which follows the connecting points as point A 25°09′58.88″N, 118°58′29.56″E), B(25°09′07.27″N 118°59′00.16″E), C(25°07′29.02″N 118°59′20.29″E), D(25°07′30.19″N 118°59′27.31″E). Thirdly, sewage water pipelines of Quanggang Sewage Treatment Plant, which follow the connecting points as point A (25° 07′ 16.02″ N, 118° 57′ 47.15″ E), B(25° 07′ 29.27″ N, 118° 58′ 41.66″ E), C(25° 07′ 30.58″ N, 118° 59′ 20.41″ E) and point D (25° 07′ 14.86″ N, 118° 57′ 46.63″ E), E(25° 07′ 28.13″ N, 118° 58′ 41.91″ E), F(25° 07′ 29.60″ N/118° 59′ 29.98″ E). Fourthly, sewage discharge pipe of Quanhui Petrochemical Factory Zone, which follows the connecting points as point A (25° 00′ 40.4″ N/118° 59′

41.8″ E), B (25° 00′ 26.9″ N/119° 02′ 04.0″ E), C(24° 59′ 54.6″ N/119° 02′ 00.1″ E), D (25° 00′ 08.0″ N/118° 59′ 38.0″ E). Anchoring, blasting, sand mining and other operations or activities that endanger the safety of the pipelines are prohibited within the water area of 100 meters on both sides of the pipeline route. When the ship sailing through these special areas, prudent maneuvering of ships should be attached importance to. In addition to the intersection area of various navigation routes, narrow navigation waters, reefs, these special areas also include anchorage etc., as shown in Figure 3.

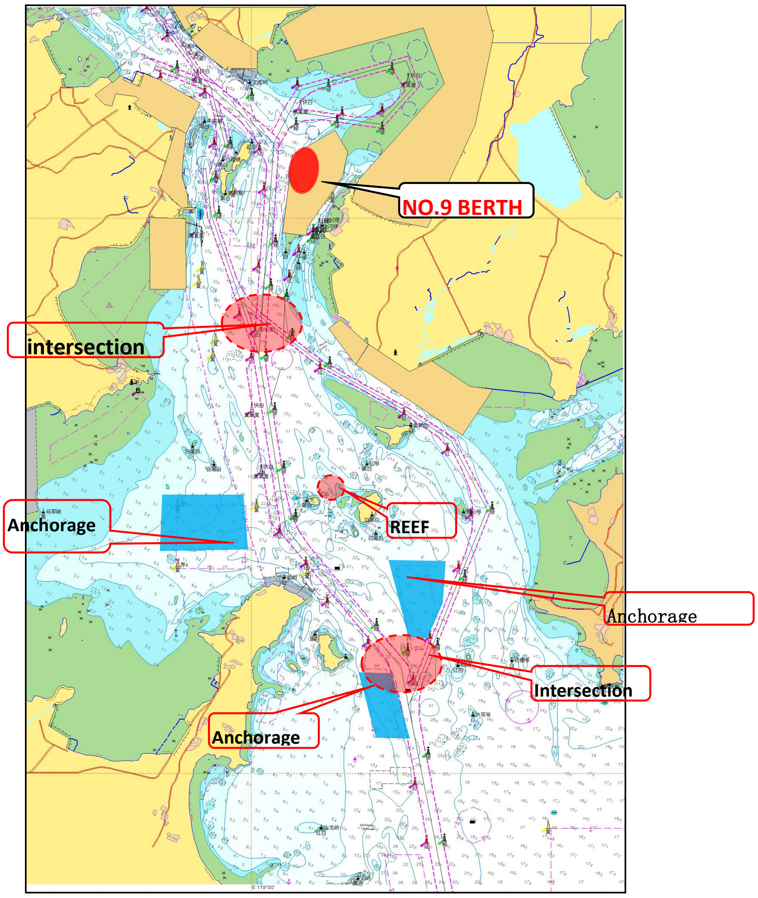

Figure 3 Special water area

Source: Port Administration of Meizhou BAY in Fujian Province, PRC, edited by author

2.2.3 Traffic environment

(a) Statistics of traffic flow

Choose an observation line A in the main channel of Meizhou Bay as located from 25° 0.25′ N，119° 2.38′ E to 25° 0.28′ N，119° 4.46′ E and the observation line B in the front channel to Luoyu area as located from 25° 9.4′ N，118° 59.97′ E to 25° 9.38′ N，119° 0.58′ E，indicated in figure 4.

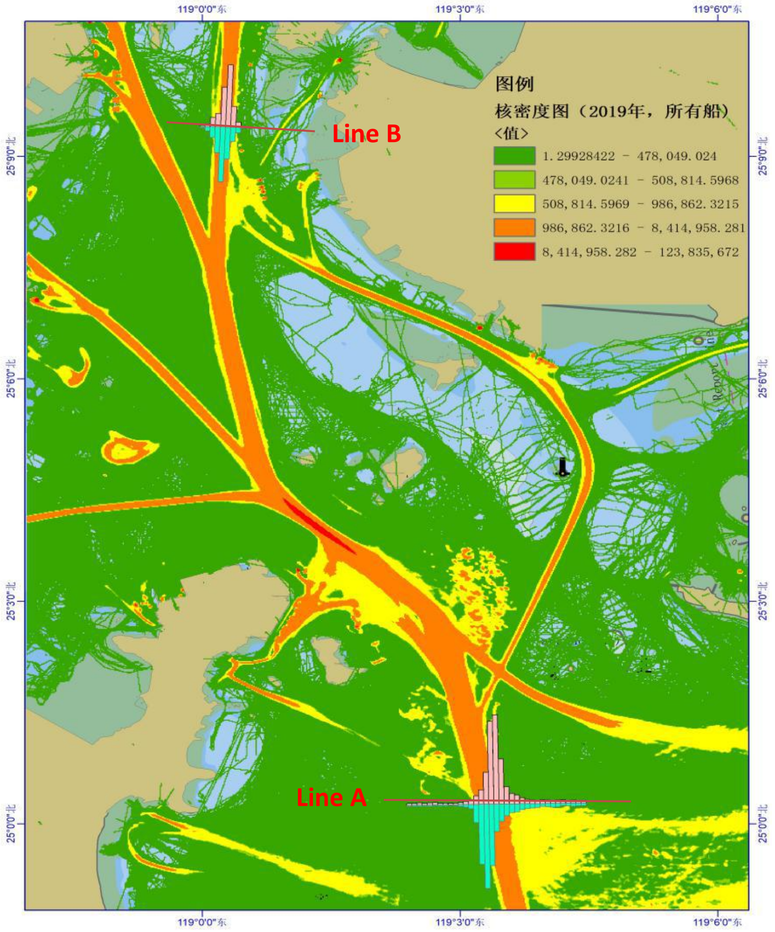

Figure 4 Observation line for traffic flow in Meizhou Bay and Luoyu port area

Source: Quanzhou VTS, edited by author

In 2018, the total number of ships passing line A was 16157, of which 6853 ships entering the bay and 9304 ships leaving. The average traffic volume through line A is 45 per day. The total number of ships passing line B was 7777, of which 3478 ships entering the bay and 4299 ships leaving. The average traffic volume through line B is 60 per day.

In 2019, the total number of ships passing line A was 18602, of which 9515 ships entering the bay and 9087 ships leaving away. The average traffic volume through line A is 45 per day. The total number of ships passing line B was 7628 of which 3892 ships entering the bay and 3796 ships leaving. The average traffic volume through line B is 21 per day.

(b) Statistics of ship type

According to the survey, VLCC and ULOC calling at ports in Meizhou Bay is comparatively frequently, about 16~20 times per month (among which VLCC was about 14~16 times per month, ULOC was about 2~4 times per month), and LNG vessels about 8 times per month.

From the statistics in Table 6, it is shown that the most frequent ship passing line A was liquid cargo vessels, followed by general cargo vessels and fishing boats.

Table 6 Number of ship passing line A in terms of ship type

Ship Type	Fishing boats	General cargo vessel	Passenger ships	Liquid cargo vessel	Others	Total
2018	4183	3510	76	6633	1755	16157
2019	4130	4374	5	7825	2268	18602

Source: Author

From the statistics in table 7, it is shown that the most frequent ship passing line B was general cargo vessels, followed by other vessels and fishing boats.

Table 7 Number of ship passing line B in terms of ship type

Ship Type	Fishing boats	General cargo vessel	Passenger ships	Liquid cargo vessel	Others	Total
2018	1360	2764	611	781	2261	7777
2019	798	2347	17	1006	3460	7628

Source: Author

(c) Statistics of marine accidents in related area

In accordance with data from Putian MSA, the marine accidents occurring in water area under the administration of Putian MSA from 2014 to2019 are mainly composed of collision, striking on reef and grounding accidents, accounting for 74 percent of the total number. The detailed data of marine accidents in related area under the administration of Putian MSA from 2014 to2019 are listed in table 8 in terms of accident classification.

Table 8 Statistics of marine accidents from 2014 to 2019 in related water area

types Year	collision	grounding	Striking a reef	fire	sinking	wind	others	total
2014	2	1	2	0	0	0	0	5
2015	2	0	1	1	0	0	0	4
2016	1	0	1	1	1	0	0	4
2017	2	0	1	0	0	0	0	3
2018	1	3	0	0	0	0	2	6
2019	0	0	0	0	0	0	1	1
Total	8	4	5	2	1	0	3	23

Source: PTMSA, edited by author.

2.2.4 Navigation support

2.2.4.1 Aids to navigation

The navigational facilities along the main channel of Meizhou Bay are complete and maintained in good condition, which can satisfy the need for ships in the area. A warning light pile was set at the south end of NO.9 berth to mark the position of the wharf, and a light buoy was set at the northeast boundary of NO. 10 berth to mark the water area to aid ship for navigational safety. (PAMB, 2020)

2.2.4.2 Tugboats available in the area

At present, tug boats available in Meizhou Bay are mainly operated by two shipping companies. There are totally 16 tugs above 4000 horsepower available for berth operation in Meizhou Bay. Horsepower of these tugs is introduced in table 9.

Table 9 Tugs available in Meizhou Bay

Number	Horsepower
2	6800
7	5200
4	4000
1	3400
1	3200
1	1800
16	74400

Source: Author

2.2.4.3 VTS

VTS of Meizhou Bay is composed of a center in Quanzhou (24° 54′ 12″ , 118° 35′ 42″ E) and two radar stations located at 25° 10′ 45″ N, 118° 59′ 24″ E and 25° 02′ 54″ N,119° 07′ 15″ E. It covers the water area enclosed by two report lines. The south line is from point 25° 01′ 39″ N/119° 07′ 18″ E to point 24° 57′ 57″ N/119° 01′ 56″ E, while the east line is from 25° 04′ 53″ N/119° 06′ 17″ E to 25° 06′ 44″ N/119° 06′ 02″ E. It is equipped with Radar Surveillance System, Ship Data Processing System, VHF Communication System and AIS, which effectively covers 25 nautical miles from the center. Timely services and a real-time assessment of the situation are provided through radio communication of VHF 10. (FJMSA, 2020)

Every year, MSA would entrust a third party to assess the performance of every VTS center in China. The "satisfaction rate" for maritime service would be quantified through questionnaires. Statistics of last three years reveals that "satisfaction rate" for VTS of Meizhou Bay is 95%, 96% and 98% respectively. (QZMSA, 2020)

Chapter 3 Analysis on basic requirements for Guaranteeing safety of ULOC in Luoyu port area

3.1 Particulars of ULOC

The navigation safety of ships involve a large number of factors and great uncertainties, which is complex and changeable. There are a variety of vessels sailing in Meizhou Bay, contributing to the complexity of navigation environment. In addition, the main channel for entry into Meizhou Bay is an artificial channel with a fixed route. The 400,000-DWT ULOC is an extremely huge vessel that is not easy to avoid in emergent situation. Before analyzing the detailed probability of occurrence with the influence of risk factors, it is significant for us to get the basic requirements of navigational environment for ULOC of 400,000-DWT to navigate through Meizhou Bay in terms of key risk factors.

Particulars of ULOC of 400,000-DWT class are listed in table 3.1-1, which is the subject of this paper. The technical requirements of VLCO will be analyzed in base of the following information.

Table 10 Particulars of ULOC

DWT（t）	Dimension (m)			
	LOA	Mould breadth	Mould depth	Draft at full load
400,000	362	65.6	30.5	23

Source: PTMSA, edited by author

3.2 Basic Requirements for ULOC of 400,000-DWT class

3.2.1 Length of berth

In accordance with Standards on General Design of Port (JTS165-2013) issued by Ministry of Transport, the length of berth is calculated by the equation:

$$L_b=L+2d$$

Hereby L refers to LOA of the ULOC and d refers to extra length. When L is longer than 320 m, d is determined at 35-40 m. Consequently, the required length of berth for the ULOC is 442 m.

3.2.2 Elevation of top-surface of wharf

In accordance with Standards on General Design of Port, the elevation of top-surface is calculated by the equation:

$$E_w=DWL+\Delta W$$

Whereas DWL refers to water level of designed berth and ΔW refers to extra height. For standard water level of designed berth, DWL is 7.30m, the extra height is 1.0~2.0m as the peak height of the wave with a return period of 10 ~ 15 years is recommended, therefore E_w=8.30~9.30m. For highest water level of designed berth, as DWL is 8.56m, the extra height is 0~0.5m, therefore E_w=8.56-9.06.

3.2.3 Elevation of channel

The elevation of channel is calculated by the equation provided in Standards on General Design of Port:

$E_c=\Delta H - D$

Whereas ΔH refers to water level of channel and D refers to designed elevation, the detailed elevation of main channel for different section is calculated accordingly, listed in table 3.2.

Table 11 Elevation of channel in different section（m）

Section of channel	Designed for ship	T	△H	D	Value of elevation
A3~A2	ULOC of 400,000-DWT class	23.0	3.21	26.13	-22.92（speed of 10 knots）
A2~B			3.69	26.53	-22.84（speed of 12 knots）
B～C～F			4.86	26.34	-21.48（speed of 10 knots）

Source: Author

3.2.3 Width of channel

The effective width of a single-way channel is calculated in accordance with the equation W = A+2C in Standards on General Design of Port, while the width of a double-way channel is calculated in accordance with the equation $W = C_1+A_1+b_{max}+A_2+C_2$

Whereas A refers to the track zone width, and A= n（L·sinγ+B). Here γ is leeway and drift angle of 10°, n refers to ship drift multiple of 1.59, and C refers to extra width between vessel and channel, which is the breadth of bulk carrier. B_{max} is the max value of breath of two encountered vessels.

In accordance with the above equation, the width of single-way channel and double-way channel are displaced in table 12 and 13 respectively.

Table 12 Required width of a single-way channel for VLCO of 400,000-DWT class（m）

Ship type	L (m)	B (m)	γ(°)	n	A (m)	c (m)	W (m)
ULOC of 400,000-DWT class	362	65.6	10	1.59	204.25	65.6	335.45

Source: Author

Table 13 Required width of double-way channel for VLCO of 400,000-DWTclass（m）

Ships	L (m)	B (m)	γ(°)	n	A (m)	c (m)	W (m)
Two ULOC s of 400,000-DWT class	362	65.6	10	1.59	204.25	65.6	605.3
	362	65.6	10	1.59	204.25	65.6	
One ULOC of 400,000-DWT class and one of 300000-ton class	362	65.6	10	1.59	204.25	65.6	613.05
	334	60	10	1.59	187.6	90	

Source: Author

There is a width of 500 m from Chongwu to Douwei section (A3 to B section) of the main channel of Meizhou Bay. The navigable width of B-F section within the bay is 350m.

3.2.4 Dimensions of anchorage

When the single anchor leg mooring system is adopted for ULOC, the circle radius of the water area occupied by a single anchor position can be calculated in accordance with the equation where the wind is larger than 7 gale,

$R=L + 4H + 145$,

Where L refers the LOA of designed ship, and H refers to the depth of anchorage. Hence, requried R for ULOC is 635 as the length of ship is 362 and the depth of anchorage is 29 in NO.2 anchorage outside Meizhou Bay. Currently, the water area of NO.2 anchorage is 7.5km2（4450m×1680m), which is large enough for ULOC.

3.2.5 Depth of anchorage

The designed water depth of the anchorage outside the harbour shall not be less than 1.2 times the draft of the designed vessel at full load. When the wave height exceeds 2m with the wave cumulative frequency of 4%, the wave extra depth should be taken into consideration. The full load draft of the 400,000-DWT bulk carrier is 23.0m, and the extra wave height is 1.3m, and the minimum depth required for the 400,000-DWTbulk carrier is calculated to be 28.9m. The water depth of the NO.2 anchorage outside the mouth of Meizhou Bay is more than 29m, which can meet the anchoring needs of 400,000-DWT bulk carriers. However, as the NO.2 anchorage is characterized with features that shallow in the west and deep in the east, it is suggested to anchor 400,000-DWT bulk carriers in the deep water area on the east side to ensure safety.

3.2.6 Required power of tugboats

The required tow force for 400,000-DWT ULOC is calculated in accordance with the equation BP=（D/100000）×60+40

Whereas D is displacement of vessel, the result is shown in table 14.

Table 14 Required power for tugging ULOC

Ship type	400,000-DWT ULOC
DWT(t)	403844
Displacement(t)	456600
BP(t)	314
（HP）	20900

Source:Author

Bulk carrier of 400,000 tons requires total towing force of 314t during berthing operation, and the corresponding horsepower of 20,900. It is recommended for bulk carriers with length of 362 m to be equipped with 7 tugs above 4000 horsepower, including at least 4 tugs above 5,000 horsepower. Besides that, a tugboat of over 4000 horsepower should be prepared as a backup for emergency situation. At present, there are only 16 tugs available for berth operation in Meizhou Bay. Therefore, it is better to increase the number of tugs with high horsepower as tugs with high horsepower in the harbor would be in short supply when VLCC，LNG vessels and ULOC are operated in the same time.

3.3 Influence of ULOC on others

3.3.1 VLCC

ULOC of 400,000-DWT class can only navigate through the channel in a single-way route with tide-rising. During the process of entering or leaving, it will occupy the main channel of Meizhou Bay for at least four hours. Traffic control will be extended in the main channel of Meizhou Bay, which will exert great influence on the use of the main channel during this process. As the forward waters of Luoyu Island is the convergence point for the entry and exit of vessels in the upstream port area, when the 400,000-DWT bulk carrier enters or leaves the port, the navigation of ships passing in and out of Meizhou Bay will be affected by the traffic control. Ships in the upstream port area have to wait until the traffic control is lifted. Meanwhile, there are VLCC terminals in Douwei port area at the mouth of the bay. The interaction of ULOC with VLCC may only occur in section A3-B of the main channel. The traffic control for ULOC would also influence the entry time of VLCC.

3.3.2 LNG vessels

In addition, there are 54 LNG vessels entering the Meizhou Bay per year, with the frequency of one vessel per week. Every time when LNG entering or leaving Meizhu Bay, traffic control of 2-3 hours will be in operation. LNG ships are berthed on the port side, and they usually enter the port 45 minutes before low tide and leave the port about 27 hours after berthing in high tide. ULOC vessels also leave ports in high tide, which will conincide with the departure time of LNG vessels. Consequently, ULOC should avoid to leave the port at the same time as LNG vessels. Furthermore, both ULOC vessels and LNG vessels need the assistance of tugs for berthing operations. The number of tugs with high horsepower in the port area is relatively limited. As a consequence, it is necessary to increase the number of high power tugs correspondingly.

3.4 Potential hazard

3.4.1 Layout of turning area

The turning area for ULOC in Luoyu port area overlaps with the main channel of Meizhou Bay. Ships in Luoyu port area will interact with the ships in the upstream port area when docking and leaving. There is increasing risk of collision accidents.

3.4.2 Navigating in rising tide

The 400,000-DWT bulk carrier can only enter the port through the main channel of Meizhou Bay when tide is rising, which expand the risk of ship grounding.

3.4.3 Traffic control

The entry and exit of the 400,000-DWT bulk carrier requires traffic control on the main channel, occupying the main channel of Meizhou Bay for about 4 hours, which has a relatively large impact on the navigation of ships in the port area. During the traffic control period, if LNG vessels in upstream port area have to leave the terminal in emergency, the situation would be much more complicated.

3.4.4 Influence of ship traffic flow

There are a large number of vessels of different types sailing in Meizhou Bay, which enhance the complexity of the traffic flow. The entry channel of Meizhou Bay is an artificial channel with a fixed route. The 400,000-DWT bulk carrier is an extremely large vessel that need longer time and distance to stop, which are prone to be involved in collision accident.

3.4.5 Heavy weather

Strong convective weather occurs with high frequency in the coastal area of Fujian in summer. If ULOC encounters strong convective weather during the operation of entering or leaving the port, visibility will decrease sharply. Due to the limitation of the water area in the bay and the rainstorm, it would be much more difficult to avoid collision. In addition, in high humidity, ULOC are prone to free surface effect, resulting in loss of stability. In case of inclement weather, under the combined action of strong wind, wave and current, the ship may be at risk of losing anchor or breaking anchor chain, and end up in collision, grounding or even sinking.

Chapter 4 Evaluation on navigation safety of 400,000-DWT ULOC in LUOYU port area

As a complicated system composed of various parts, risk analysis on navigation safety is based on related logic of safety system engineering. Mathematical calculation of probability of accidents such as collision or grounding has become a traditional way of risk evaluation on navigation safety. Analysis on the data of marine accidents have also been conducted for risk assessment and drawing lessons to be learned, which is a post-fact method. To predict the safety situation in advance, scholars have adopted a variety of approaches to evaluate navigation safety, which includes Failure Mode and Effect Analysis, Event Tree Analysis, Risk distribution trees etc (Schröder-Hinrichs, 2020; Gul et. Al, 2017; Senol et. al, 2015). At present, the Grey Comprehensive Analysis and Fuzzy Comprehensive Evaluation are two typical methods that are widely used in risk evaluation on navigation safety.

Risk factors involved in any system can always be divided into two categories, namely certainty and uncertainty. The factors of uncertainty could be further divided into stochastic uncertainty and fuzzy uncertainty. Risk analysis on navigation safety involves too many correlative factors with uncertainty, which is difficult to be conducted quantitatively (Mahmood et. al, 2013). With the fuzzy logic, the qualitative assessment of risk factors could be transformed into quantitative analysis which can produce a relatively ideal result, including both objective data of risk factors and subjective expert judgement. In terms of uncertainty of navigation safety, the fuzzy comprehensive method would be applied in the paper.

4.1 Fuzzy comprehensive evaluation

4.1.1 Fundamental of fuzzy comprehensive evaluation

Fuzzy comprehensive evaluation method is used to assess entity which is influenced by various factors of fuzzy characteristics by means of fuzzy mathematics. The cornerstone of this method is treating the entity as a fuzzy set composed of many different types of factors, then establish fuzzy matrix of evaluation on risk factors, which reflects the relationship of limited sets of factors and sets of assessment on corresponding factors, finally synthesize the fuzzy matrix with weighting coefficient of these factors with fuzzy operator to get the evaluation of the item. (Zadeh, 1965).

4.1.2 Process of fuzzy comprehensive evaluation

(a) Step 1: Define a limited set A for risk factors of base layer, which is shown as A= (A_1, A_2, A_3, ... A_n), and if it is a two-layer evaluation, define subset A_1 as A_1 = (A_{11}, A_{12}, A_{13},.....A_{1n}), A_n = (A_{n1}, A_{n2}, A_{n3}........A_{nn}).

(b) Step 2: Admeasure the weighting set W of individual risk factor in relevant layer as W= (W_1, W_2, W_3,...... W_n) , where the sum of W equals to 1. The weighting set is composed of weight coefficient assigned to the individual risk factors, which could reflect the influence and function of every individual risk factor on the whole object. The weighting is usually obtained after subjective expert judgment is mathematically treated through AHP.

(c) Step 3: Specify a limited set V for assessment of the individual risk factor, which is shown as $V = (V_1,V_2,V_3,......V_n)$. Every individual risk factor could get a corresponding assessment set V.

(d) Step 4: Establish the matrix model of assessment as R, which is the relationship between Set A and Set V.

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ r_{31} & r_{32} & \dots & r_{3n} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nn} \end{bmatrix}$$

(e) Step 5: Synthesize W with R to get vector B as the evaluation of the object, which is displaced as

$$B = W \odot R = (W_1, W_2, W_3,...... W_n) \odot \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ r_{31} & r_{32} & \dots & r_{3n} \\ \dots & \dots & \dots & \dots \\ r_{n1} & r_{n2} & \dots & r_{nn} \end{bmatrix} = (b_1,b_2,b_3,.....b_n)$$

In this step, fuzzy operator would be used to calculate the result. With different models of operator, the result would be variant. In this paper, the principle of maximum membership would be applied.

（f）Step 6: Determine the final data of evaluation through defuzzification. Set a detailed criterion for evaluation as V=(very low, low, moderate, high, very high)=(1,2,3,4,5), and then transform the vector B into a score by method of weighted average.

4.2 Application of FCE on Evaluation of navigation safety of 400,000-DWTULOC in Luoyu Port area

4.2.1 Fuzzy set of environmental factors

Generally speaking, the safety of any vessel is influenced by three types of factors, namely environmental factors, human factors and factors of vessel itself (Wu & Ma, 1998). As the human factors and hardware of vessels have commonalities, this paper only focus on the environmental factors related to Luoyu port area. Up to now, a large number of foreign and domestic scholars have done related researches on the selection of risk factors of navigation environment. For instance, Zheng & Li (2008) has identified 11 items of factors such as wind, maximum velocity, visibility, length of channel, the ratio of average ship width to width of navigable channel, traffic volume, etc. Arai (1994) classified 16 items of factors into three layers, which include topography, sea conditions, meteorology, traffic flow, etc. After literature review, field investigation and expert consultation, this paper analyses 13 factors and classifies them into 2 layers. The detail and classification of these factors are displayed in figure 5. The first layer is shown as: A = (A_1 Meteorology, A_2 Channel, A_3 Traffic flow, A_4 Navigation Support). The second layer is shown as: A_1 = (B_1 Wind, B_2 Current, B_3 Tide, B_4 Visibility, B_5 Wave), A_2 = (B_6 Ratio of width of channel to ship length, B_7 Depth of channel, B_8 Curvature of channel, B_9 Navigational obstruction), A_3=(B_{10} Traffic density, B_{11} Ship type), A_4=(B_{12} VTS, B_{13} Aids to navigation)

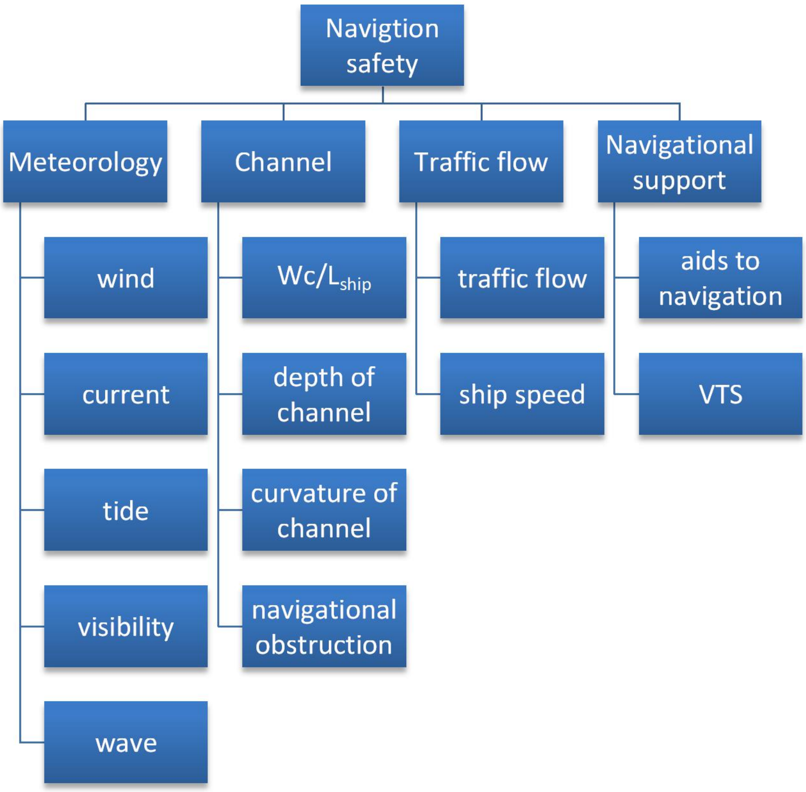

Figure 5 Risk factors of navigation safety of ULOC in Luoyu port area

Source:Author

4.2.2 Weighting set W of risk factors

With help from Putian MSA, questionnaires for setting weighting value were emailed to experts familiar with navigation environment of Meizhou Bay. Every expert gave a specific value from 1-9 scale for importance of individual risk factors at each level after making pairwise comparison. With all questionnaires inspected and value calculated, the result of weighting value for risk factors of each layer is displayed in table 15 and 16.

Table 15 Weighting value of first- layer factors

Risk factors	**Meteorology**	**Channel**	**Traffic flow**	**Navigation support**
Weighting value W	$W_1 = 0.287$	$W_2 = 0.382$	$W_3 = 0.203$	$W_4 = 0.128$

Source: Author

Table 16 Weighting value of second-layer factors

First- layer factors	**Second- layer factors**	**Weighting value**
Meteorology	Wind	$W'_1 = 0.186$
	Current	$W'_2 = 0.018$
	Tide	$W'_3 = 0.433$
	Wave	$W'_4 = 0.055$
	Visibility	$W'_5 = 0.308$
Channel	Ratio of width of channel to ship length	$W'_6 = 0.236$
	Depth of channel	$W'_7 = 0.119$
	Curvature of channel	$W'_8 = 0.408$
	Navigational obstruction	$W'_9 = 0.165$
Traffic flow	Traffic density	$W'_{10} = 0.621$
	Ship speed	$W'_{11} = 0.379$
Navigational support	VTS	$W'_{12} = 0.735$
	Aids to navigation	$W'_{13} = 0.265$

Source: Author

4.2.3 Evaluation set V of risk factors

In this paper, it is defined that the evaluation set V=(V1, V2,V3,V4,V5) = (very safe,

safe, borderline, dangerous, very dangerous). The degree of membership of all factors reflected on evaluation set V could be determined on basis of evaluation criterion and expert judgement. After the combination of expert consultation and quantitative analysis, the evaluation criterion for risk factors is shown in table 17.

Table 17 Criterion of risk factors

Criterion of Risk factors	Very safe	safe	borderline	dangerous	Very dangerous
Wind (days of wind gale≥7)	≤30	30~60	60~100	100~150	≥150
Current (max velocity in meters/second)	≤0.5	0.5~1.5	1.5~2.5	2.5~4	≥4
Tide (max tidal range /m)	≤2.5	2.5~5	5~7.5	7.5~10	≥10
Wave height (m)	≤0.1	0.1~1.25	1.25~4.0	4.0~6.0	≥6.0
Visibility (visibility≤1000 m/days)	≤10	10~20	20~30	30~40	≥40
Ratio of width of channel to ship length	≥1	0.8~1	0.5~0.8	0.3~0.5	≤0.3
Depth of channel (Ratio of extra depth of channel to ship draft)	≥10%	10%~8%	8%~5%	5%~3%	≤3%
Curvature of channel (°)	≤15	15~30	30~45	45~60	≥60
distance between channel and obstruction (NM)	>2.5	1.5-2.5	1.0-1.5	0.5-1.0	<0.5
Traffic density (ships/day)	⩽50	50~150	150~300	300~500	⩾500
Ship speed	≤3	3~7	7~10	10~15	≥15
VTS(satisfaction rate)	≥98%	95%~98%	92%~95%	92%~90%	≤89%
Aids to navigation (completion rate)	≥99%	99%~98%	96%~98%	95%~96%	≤95%

Source: Author

4.2.4 Establish the fuzzy matrix of membership

In accordance with data collected and criterion set in previous steps, the fuzzy matrix for A1, A2, A3, A4 is established as R'1, R'2,R'3, R'4 respectively as follows:

$$R'_1=\begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{bmatrix}=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \end{bmatrix}$$

$$R'_2=\begin{bmatrix} r_6 \\ r_7 \\ r_8 \\ r_9 \end{bmatrix}=\begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$$R'_3=\begin{bmatrix} r_{10} \\ r_{11} \end{bmatrix}=\begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$$R'_4=\begin{bmatrix} r_{12} \\ r_{13} \end{bmatrix}=\begin{bmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

4.2.5 Vectors of evaluation

The evaluation vector for risk factors at first layer could be obtained respectively with the function of membership.

(a) evaluation vector B_1 for risk factor of meteorology:

$$B_1 = W_1 \odot R'_1 = (0.186, 0.018, 0.433, 0.055, 0.308) \odot \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \end{bmatrix}$$

$B_1 = (0.186, 0.308, 0.433, 0, 0)$

(b) Evaluation vector B_2 for risk factor of channel:

$$B_2 = W_2 \odot R'_2 = (0.236, 0.119, 0.408, 0.165) \odot \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$B_2 = (0, 0.236, 0.408, 0, 0.119)$

(c) Evaluation vector B_3 for risk factor of traffic flow:

$$B_3 = W_3 \odot R'_3 = (0.621, 0.379) \odot \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$B_3 = (0, 0.621, 0.379, 0, 0)$

(d) Evaluation vector B_4 for risk factor of navigation support:

$$B_4 = W_4 \odot R'_4 = (0.735, 0.265) \odot \begin{bmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$B_4 = (0.5, 0.265, 0, 0, 0)$

Thereupon, the evaluation matrix for A1, A2, A3, A4 is established as follows:

$$R = \begin{bmatrix} 0.186 & 0.308 & 0.443 & 0 & 0 \\ 0 & 0.236 & 0.408 & 0 & 0.119 \\ 0 & 0.621 & 0.379 & 0 & 0 \\ 0.5 & 0.265 & 0 & 0 & 0 \end{bmatrix}$$

The evaluation vector B for meteorologic factors navigation safety of ULOC is calculated as follows:

$$B = W \odot R = (0.287, 0.382, 0.203, 0.128) \odot \begin{bmatrix} 0.186 & 0.308 & 0.443 & 0 & 0 \\ 0 & 0.236 & 0.408 & 0 & 0.119 \\ 0 & 0.621 & 0.379 & 0 & 0 \\ 0.5 & 0.265 & 0 & 0 & 0 \end{bmatrix}$$

$B = (0.186, 0.287, 0.382, 0, 0.119)$

4.5 Evaluation value of navigation safety of ULOC in Luoyu port area

In order to further evaluate the level of safety of navigational environment for ULOC in Luoyu port area, concrete figures are assigned to the evaluation set as $V = (V_1, V_2, V_3, V_4, V_5)$ = (very safe, safe, borderline, dangerous, very dangerous) = (1, 2, 3, 4, 5).

$$V = \frac{\sum_{n=1}^{5} b_n \times v_n}{\sum_{n=1}^{5} b_n} = \frac{0.186\times 1 + 0.287\times 2 + 0.382\times 3 + 0 + 0.119\times 5}{0.186 + 0.287 + 0.382 + 0 + 0.119} = 2.568$$

Based on the principle of weighted average, the final value is 2.568. The results show that the safety level of ULOC under the environment of Luoyu port area is between safe and borderline.

Chapter 5 Conclusion and Suggestions on safety management of ULOC in Luoyu port area

After systematic qualitative and quantitative analysis on navigation environment of Luoyu port area for ULOC, it is revealed that there is comparatively high risk in meteorologic factors and channel related factors. To enhance the safety of ULOC and lower the probability of marine accidents, the following suggestions are key measures to manage risk for different parties .

5.1 For port authority

5.1.1 Improvement of channel condition

With the calculation in Chapter four, the main dimensions of berth area, channel and turning area for 400,000-DWT ULOC are listed. To meet the requirements of ULOC, the berth area and turning area should be widened and shallow points in port area or channel should be dredged to the required elevation.

As 400,000-DWT ULOC have to enter or leave the port when tide is rising, it is essential to pay attention to the depth of waters. Relevant areas including berthing waters, turning waters and connecting waters should be detected or scanned regularly.

Especially after the heavy weather such as typhoon, survey should be carried out to find whether there is sedimentation in the harbour basin or not, which directly affect the depth of waters. Analyze the status and trend of the sedimentation and take corresponding measures if necessary. Monitor the settlement, displacement and tilt of the wharf regularly to ensure the safety of the wharf and vessels.

5.1.2 Service of navigational support

The tugboats in the port of Meizhou Bay tend to be in short supply. It is recommended for bulk carriers with length of 362 m to be equipped with 7 tugs above 4000 horsepower, including at least 4 tugs above 5,000 horsepower. It is suggested port authority should increase the number of high-power tugboats in the port accordingly. In addition, during the process of berthing, the choice of tugs should be decided according to the specific situation, including the wind and current condition. Attention should be paid to the safety of tugs to prevent backward towing or crosswise.

Rules and regulations for safety operation of ULOC shall be established by port authority. During the operation, the port should be on duty 24 hours a day. When unloading ULOC of 400,000-ton, it is suggested to arrange tugboats to be on guard in the nearby waters to ensure the safety of the mooring.

5.1.3 Test of moisture content

In case the cargo on board is iron ore fine, which has not been completely unloaded at this port and will be transported to next terminal, the port authorities shall check the relevant documents and data such as the inspection report of the solid bulk cargo and the report of moisture content. It is fundamental for port authority to verify that the MC of cargo should not exceed TML before ULOC weigh anchor. Carry out retesting to verify the moisture content in case of rainy day or high humidity. Take appropriate measures to prevent the moisture content of the goods from increasing when in high humidity. (DNV-GL, 2015)

5.1.4 Development of contingency plan

It is significant to develop an contingency plan for search and rescue as after the occurrence of an accident, effective and efficient rescue work could contribute to minimizing the casualties and property losses. Develop targeted contingency plans for different circumstances including poor visibility, typhoon, engine failure, collision, stranding, striking on reef, fire, explosion, man-overboard, oil pollution, etc. Organize periodical training and simulation exercise on SAR plan, which contribute to detection and correction of problems in procedures and facilities (Cornillou, 2020).

5.2 For maritime authority

5.2.1 Traffic control

As long as the 400,000-DWT ULOC enters or leaves port area, maritime authority should issue traffic control. No vessels are allowed to navigate from the opposite direction. During the one-way passage, a safe enough distance should be kept between vessels, which are not allowed to overtake the preceding vessel in the fairway to prevent suction of passing vessels.

In case of bad weather and sea conditions, corresponding maritime traffic control shall be strictly implemented on 400,000-DWT ULOC. Under the circumstances where beauveria wind level is larger than 6 gale, visibility at sea is less than 1000 m, daily rainfall is bigger than 25mm, or when there is thunderstorm, ULOC shall be prohibited from sailing, berthing or shifting to another berth.

5.2.2 Removal of obstruction

Urge the enterprises to strengthen the maintenance of the harbor basin and the turning area, clean up the obstruction in the harbor area in advance, and keep the relevant waters clean. Cooperate with fishery and port departments to remove barriers in the waterways on a large scale to avoid accidents caused by aquaculture. At the same time, the frequency of electronic cruise in the front waters of wharf should be increased to provide a high-quality navigable environment for ships.

5.2.3 Monitoring and on-site supervision

Make full use of VTS and AIS system for remote monitoring of the ship. Precisely monitor ship position, speed and course at every turning point, to ensure that the ULOC is operated on the established plan. Strengthen the communication and coordination with the pilots on board, and timely send the maritime patrol for escort when necessary. VTS should provide effective and efficient information service, traffic organization and navigation aid service to the vessel.

The local maritime departments shall strengthen the on-site supervision of the ULOC, and pay attention to the verification of their seaworthiness conditions, especially the draft forward and aft, and the moisture content of cargo on board, so as to ensure the seaworthiness of the vessels as well as safety and fitness of cargo.

5.3 For operation of ULOC in Luoyu port area

5.3.1 Caution in rising tide and bad weather

The ULOC of 400,000-DWT class has to enter or leave the Meizhou Bay in rising tide. The vessel is arranged to enter the channel section outside the bay when the tide level in is 3.21, which last for 6 hours and enter the channel section inside the bay when the tide level in is 4.86, which last for 3 hours. Before weighing the anchor, ULOC should carefully check the tide levels of Chongwu and Xiuyu tidal for every period of time on the day of their arrival. If there is a possibility of missing the tide level, any further operation should be stopped immediately and the voyage plan should be postponed.

In the course of sailing and turning, close attention should be paid to the drift and adverse deflection of the hull caused by wind and current, as well as the offset of the bow or stern caused by the different position of the ship's center of rotation. Keep enough safe distance between the ship and the wharf or surrounding obstacles.

5.3.2 Mooring operation

The maximum velocity of Luoyu port area is 1.31m/s, with the average tidal range of 4.60m and the maximum tidal range of 7.0 m. As a consequence, there is a risk of cable breaking accidents due to the rise or fall of the tidal level. After docking at the wharf, the mooring cable shall be adjusted to a level of proper and even stress.

The mooring cable shall be monitored and adjusted in time according to the changes of the tide and the unloading schedule, so that the mooring cable shall always be in a good stress state during the berthing period.

5.5.3 Speed control

When ULOC approaches the port for berthing, it has to sail through the NO. 10 light float of the main channel of Meizhou Bay 2 hours before the high tide of the Luoyu waters and control the speed at 9-11 knots. The turning angle at the NO.14 lightened buoy and NO. 20 lightened buoy in the main channel of Meizhou Bay is relatively large. To successfully pass the turning point, ULOC is suggested to navigate at the speed of 9 ~ 11 knots, with medium rudder angle of 10° ~ 15° and the steering rate of about 10°/ min ahead of time when the vessel is 2 ~ 3 times the length of the ship away from the turning point.

The speed of ULOC shall be controlled at about 6 knots when it passes through the NO.28 lighted buoy in the main channel. Before entering the connecting waters of Luoyu and the channel, speed should be controlled within 2 knots. Speed for berthing should be adjusted according to the wind and current situation appropriately. When the horizontal distance is 10 m, the normal speed should be controlled within 2 ~ 5 cm/s.

The remaining speed should be controlled at low speed as far as possible when ULOC sailing against the current into the dock area. When ship sailing along the current, the remaining speed of ULOC is determined to the velocity of current. If the velocity of current is high, the remaining speed shall not be too low to offset the effect of the current pressure after turning. At the same time, in order to ensure that the ship safely arrives at the wharf, the speed of the ship should be controlled at the minimum speed that can maintain the rudder effect. In case of loss of rudder effect, the ship can maintain the rudder effect with the engine working. During the voyage, various means should be applied to frequently detect the ship's position to ensure that the ship on the planned route.

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