Traffic Flow based Safety Analysis of Ship Nighttime Navigation in Houshi Port

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Abstract: In this paper, the traffic flow based safety analysis of ship nighttime navigation in Houshi Port is analyzed, including natural environment such as meteorology and hydrology, as well as navigation environment such as channels. The influence of night navigation on navigation safety is analyzed based on ship traffic flow. Finally, according to the factors affecting the safety of night navigation ships, the problems and risks of night navigation is given, and the corresponding security measures and suggestions are put forward. This study can help reduce maritime traffic risks, greatly improve port navigation safety, and help the construction of Xiamen international shipping center.

Keywords: Traffic flow, night navigation, safety

1 INTRODUCTION

The scientific and stable opening of night navigation is an active and beneficial exploration for the port to improve its development mode. It is also a major practice for ports and shipping industry to tap the potential, reduce costs and increase efficiency. In September 2019, the Central Committee and the State Council issued the outline for the construction of a transportation power, proposing to promote the transformation of transportation development from pursuing speed and scale to paying more attention to quality and efficiency. Opening the night navigation restrictions of ports in China in a scientific and prudent manner and in line with local conditions can significantly improve the handling capacity of ports without significantly increasing the investment of port enterprises. However, there are obvious differences between night navigation and daytime navigation, including natural factors and human factors.

2 RELATED WORK

In the area of ship navigation at night, Li studied the impact of bridge lighting project on the safety of ship navigation at night[1]. Zhu made the environmental risk assessment of ships navigating through channel waters at night[2]. Shen discussed the influence of LNG ship entering and leaving Wenzhou port[3]. Zhao made the evaluation of navigation risk for inland-river passenger ships at night-time through improved uncertainty measurement model[4]. Zhang studied ship collision accident situation at sea[5]. Li studied nighttime voyage

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restrictions in Chinese ports[6]. Cockcroft made statistics of ship collisions[7]. Tao made countermeasures for night navigation in Jiangsu section of the Yangtze River following the opening of 12.5m deep water channel[8]. Zhu made quantitative analysis of the visual effect of glare on the night navigation[9]. Liu discussed night navigation and measures in Dagukou district[10]. Lin discussed the risk of towing 10000-ton ship in Guangzhou port at night[11].

Recently traffic flow has been used for maritime risk assessment. Co-occurrence analysis of collision hotspots with maritime traffic features was made[12]. Automatic Identification System (AIS) data was used to analyze the ship traffic demand in port waters and the space temporal dynamics of ship traffic[13].A ship traffic flow model based on cellular cellular automaton was proposed[14]. In the navigation capacity estimation, the structural characteristics of traffic flow and various constraints were combined, and K-means was used to identify the structural characteristics of traffic flow based on the actual operating conditions[15]. AIS data and indicators in the ship database was used to compare the ships involved in the accident with those without such records[16]. The maritime traffic situation complex network was constructed, and the importance of ship nodes reflected the conflict risk and the complexity of traffic structure[17].

Although plenty of research achievements have been made in the safety of ship night navigation, there is almost no research on the impact of ship traffic flow on night navigation safety. This study makes up for this gap and discusses the safety of ship nighttime navigation in Houshi Port based on traffic flow.

3 TRAFFIC FLOW ANALYSIS

3.1 Environment

Houshi 3# berth is located on the north side of the coastline of Houshi port and in the cargo operation area of the overall planning of Xiamen port. The geographical coordinates of its location are 24 ° 21 ′ 30 ″ N, 118 ° 05 ′ 54 ″ E. The geographical location is shown in Figure 1.

Figure 1. Overview of satellite map of Houshi 3# berth.

Houshi 3# berth is a 150000 ton berth. The hydraulic structure of the wharf is designed to berth 200000 ton bulk carriers. The total length of the wharf coastline is 422m, and the designed annual throughput is 4.5 million tons.

Houshi channel is connected from point B of the main channel of Xiamen port to the 100000 ton coal wharf apron of Huayang power plant through the south side of Wuyu Island, with a voyage of 8.5km. For the segment from point B to point I, the design bottom elevation is -13.9m, and the design width is 250m, which meets the one-way navigation of 100000 DWT ships by tide. This first 70000 ton channel has been put into use since January 25th, 2018. The outer section of the channel uses the original 100000 ton A-B segment of main channel in Xiamen Bay and the 100000 ton channel B-H-I segment of Houshi Power Plant. From point I at the end of the 100000 ton channel of Houshi Power Plant, a new channel has been built along the deep channel of the channel to point L near Houshi 3# berth. The new channel is about 7.06km long, 180m wide and with the average water depth of -12.3m.

This sea area is dominated by southeast winds in spring and summer, and northeast winds in autumn and winter. There are often strong northeast or southeast winds in the afternoon of May to June every year. The average wind force is level 3-4. The maximum wind force is level 5-6, and the instantaneous maximum wind force can reach level 7-8. The annual average number of wind days with above level 8 is 6.3 days, and the average number of wind days with above level 6 is 27 days. Affected by the peripheral wind flow area, the wind force at the mouth of Xiamen Bay is significantly greater than that in the bay. The water area has large swells and poor sea conditions. In winter, the wind is mainly from north to northeast, and the wind waves are also mainly from East. Affected by the northeast monsoon from October to April of the next year, it may be affected by cold air since September in recent years. Gales above level 6 mostly occur from October to March of the next year, and gales above level 8

mainly occur from November to February of the next year. Poor sea conditions will bring great difficulties and risks to pilots' boarding and disembarking operations at night. The statistical characteristics of wind in this water area is listed in Table 1.

Table 1 Statistical characteristics of wind.

Parameter	Value
Annual average wind speed	2.5 m/s
Normal wind direction	East
Frequency of annual average wind speed	14%
Secondary normal wind direction	East South East
Frequency of secondary normal wind direction	12%
Strong wind direction	North North West
Measured maximum wind speed	20.7 m/s
Secondary strong wind direction	northwest
Measured maximum wind speed	20.0 m/s
Wind speed larger than level 6 strong wind days	33 days

The tidal pattern coefficient in this sea area is between 0.33 and 0.34, and the tidal type belongs to regular semidiurnal tide. Xiamen Bay is a strong tidal bay, and the tidal difference of 4.08m. The nature of the tidal current in this sea area belongs to the regular half day tidal current. The main stream of rising tide is northwest, and the main stream of falling tide is southeast, showing the characteristics of reciprocating flow. The current direction is consistent with the trend of isobath. The measured maximum current velocity during spring tide is 140cm/s and the current direction is 311 °. The measured maximum ebb current velocity is 123cm/s and the current direction is 169 °. The measured maximum current velocity during neap tide is 68cm/s and the current direction is 336 °. The measured maximum ebb current velocity is 73cm/s and the current direction is 171 °. According to the annual observation data of Houshi temporary observation station in 2005, the normal wave direction in this sea area is east with occurrence frequency of 62.56%. The secondary normal wave direction is east south east, and its occurrence frequency is 25.15%. The strong wave direction is east, and the secondary strong wave direction is east south east. The frequency of H4% above 1.3m in this direction accounts for 1.11% and 0.10% respectively. The frequency of H4% above 1.3m in the whole year accounts for 1.31%, and the period is not large. The period of above 5.0s in the whole year only accounts for 0.14%. There are many islands and reefs near the H ~ I ~ J section of Houshi channel, and there is abnormal turbulence in this section, which has a certain safety impact on the navigation safety of night navigation ships.

3.2 Traffic flow

The traffic flow direction reflects the complexity of the navigation environment in a certain water area and the difficulty of ships avoiding collision. To reduce the difficulty of avoiding

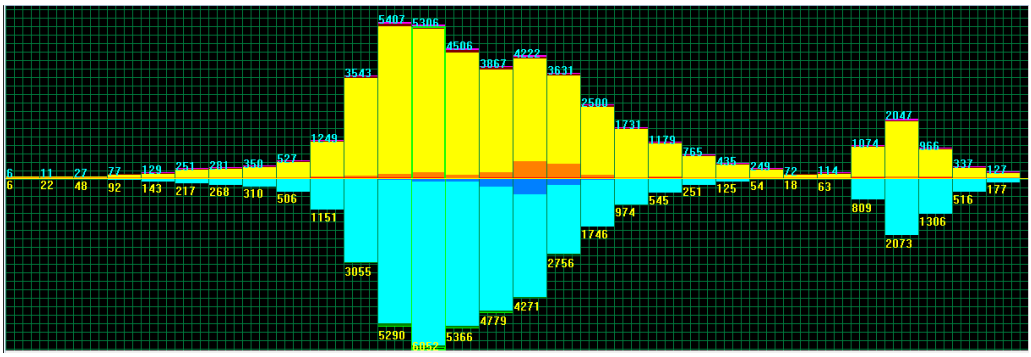
ships collision in narrow waters and separate traffic flows in different directions, many competent authorities in port waters and the International Maritime Organization (IMO) have widely adopted ship routing systems, and achieved good results.

The traffic flow density in Houshi channel is relatively high. Take 2020 year as an example, the number of AIS messages while entering and leaving the channel was 108919, with an average daily traffic of 298. Among them, there were 105763 non transport ships, accounting for 97% of the total traffic, with an average daily traffic of about 290. Non transport ships are basically class B ships. Ship density refers to the number of ships per unit area of water at a certain moment, reflecting the density of sailing and stationary ships in the water. When the navigation density is high, ships need to frequently avoid collision on the route, or limit speed in order to maintain appropriate ship spacing, which easily leads to deviation from the route and increases the possibility of accidents.

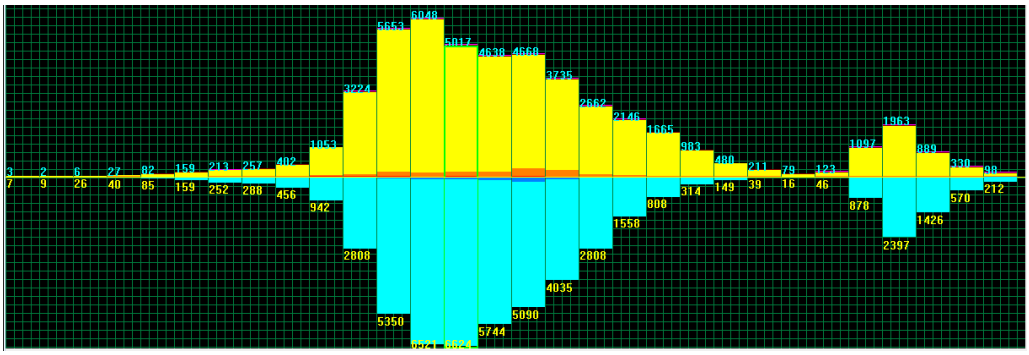
The AIS track and statistical data of ships were obtained, and the gate lines were set to statistically analyze the ship traffic flow entering and leaving Houshi channel in 2018, 2019 and 2020. The positions of gate line is shown in Figure 2. The gate line covers all AIS navigable ships entering and leaving Houshi channel.

Figure 2. Position of gate line.

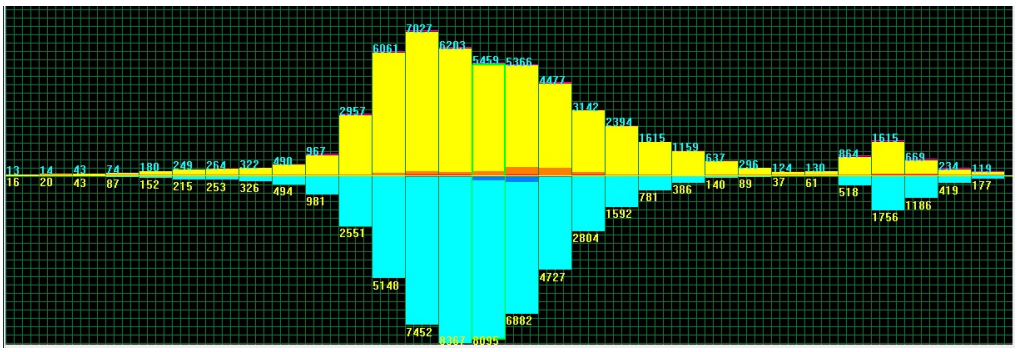
The statistics of AIS trajectory entering and leaving Houshi channel in 2018, 2019 and 2020 is shown in Figure 3.



(a) In 2018



(b) In 2019



(c) In 2020

Figure 3. Statistics of AIS trajectory entering and leaving Houshi channel.

The number of vessels entering and leaving Houshi channel waters in 2018-2020 is listed in Table 2.

Table 2. AIS vessel entering and leaving Houshi channel waters in 2018-2020.

Item	2018		2019		2020	
	In	Out	In	Out	In	Out
Total	44986	42989	47913	49657	53164	55755
Passenger ship	26	20	5	7	12	4
Cargo ship	1820	1773	1399	1064	1564	1252
Non-transport Ship	42147	40278	46230	48298	51434	54329
Tanker	617	559	191	215	94	98
Dangerous goods carrier	376	359	88	73	60	72
Class B	43647	41756	46636	48628	50705	53521
Draft >16	64	71	147	39	213	79
Length >180m	1005	940	963	949	1801	2040
90m<Length<180m	333	383	339	245	332	274
50m<Length<90m	1774	1662	1414	1024	2193	1765
30m<Length<50m	8356	7509	8399	7790	6508	6058

After taking sand from the sea near Nanding Island, sand vessels often cross the channel near point H of Houshi channel and enter Xiamen port. The main track is shown in Figure 4. When sand vessels cross Houshi channel at point H, sand vessels and nighttime navigation vessels often form a crossing encounter situation in Houshi channel, which hinders night vessels from changing direction at point H.

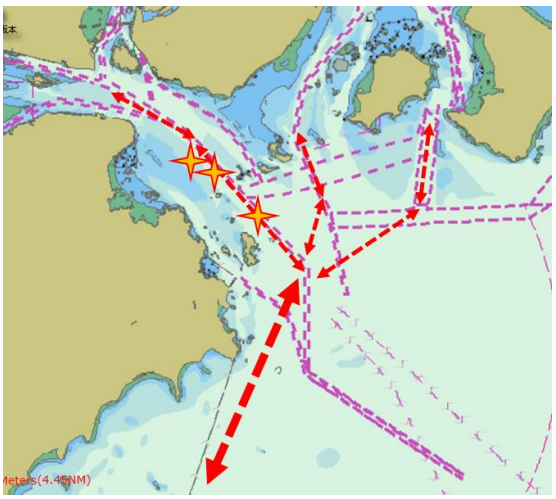


Figure 4. Main sand ship tracks in the channel waters.

The wharf berths near Houshi channel are mainly the coal wharf of Houshi Power Plant and the comprehensive wharf of Houshi Power Plant. The closest distance between the west line of Houshi channel and the wharf of Houshi Power Plant is about 260m, which is relatively close. When the ships at this berth sail in and out of the port at night, due to the limited sight and the influence of background light near the wharf, the judgment and mastery of the ship dynamics near the water area by the night navigation pilot may not be timely. Meanwhile, the wave generated during navigation may affect the stability of the ships at the wharf of Houshi Power Plant.

3.3 Influence of ships in construction waters and fishing boats

The ships in construction waters of Houshi channel project may enter and leave Houshi channel at night, and even occupy a certain navigable water area in the channel, forming an encountering situation with night navigation ships. This hinders the normal navigation of night navigation ships. When nighttime sailing ships pass through Houshi Power plant wharf, they should strengthen their lookout and decelerate appropriately.

There are many fishing boats in the waters of Houshi channel. These fishing boats may cross the channel in disorder, pass intensively, and even occupy the channel for fishing. Fishing boats often have dim lights at night, and may not even turn on the lights. Radar is not easy to detect or even cannot detect, which brings great risks to night ships.

Xiamen Bay Estuary has strong winds and waves and poor sea conditions. During night pilotage, it is not only difficult but also risky for pilots to board the ship. When sand ships entering and leaving Xiamen Port cross Houshi channel at H point, they cross with night ships in Houshi channel, preventing night ships from changing direction at H point.

4 SAFEGUARD MEASURES

4.1 Measures

Before entering and leaving the port, the pilot should be fully familiar with the distribution of obstacles and flow field characteristics of this segment, and maintain sufficient vigilance and drive cautiously. The pilot shall make full use of all navigation facilities and allocate sufficient flow pressure difference to keep the ship running in the channel. The position of ships should be confirmed through AIS, radar, very high frequency (VHF), etc., so as to strengthen communication and avoid mutual influence. The safety awareness and responsibility awareness of the crew should be strengthened, to ensure that the ship navigates strictly within the approved navigation area or operating waters. The vessels shall ensure that the equipped AIS, VHF and other equipment can be used normally, and display the specified lights in accordance with the requirements of the 1972 international rules for preventing collisions at sea and the coastal port signal regulations. Optimizing lighting and shielding light sources should be taken to minimize the impact on the safety of nighttime navigation vessels. When sailing at night, the ships should adopt safe speed throughout the whole voyage. According to the characteristics of radar, electronic chart, AIS and other navigation aids, the pilot should pay full attention to the influence of scene light. When the background light is bright, the ship speed should be reduced appropriately. The safe speed of night navigation ships shall be

determined according to the visibility, navigation density, background brightness, natural conditions of water areas and other conditions at that time.

To ensure the safety during night navigation, the pilot shall notify the engine room to prepare the engine before the start of nighttime navigation, and arrange the first mate to prepare the anchor at the bow of the ship to make it available at any time. Houshi channel is located within the coverage of vessel traffic service (VTS), and the vision of VTS watch keepers is wider than that of pilots. Ship pilots should pay attention to listening to Very high frequency (VHF), report the dynamics of the ship to VTS in time, and listen to the navigation safety information broadcast by VTS and the navigation dynamic information of other ships. This is conducive to avoiding uncoordinated actions between ships and ensuring the safety of ship navigation at night. All effective means can be used to strengthen the lookout. In addition to using radar for lookout during night navigation, pilots should make full use of AIS equipment to understand the dynamic information of ships with AIS equipment around, such as heading, speed, destination port and other information, so as to ensure navigation safety. At the same time, a formal and effective visual outlook should always be maintained. Drivers should maintain good psychology and sufficient physical strength. There are many differences between nighttime navigation and daytime navigation. Ship pilots should have a moderate sense of tension. At the same time, night navigation is easy to make people tired and distracted, and requires higher physical quality of ship pilots. Therefore, ship pilots should allow themselves to have a good rest and maintain sufficient physical strength before the start of nighttime navigation, so that they can devote themselves to nighttime navigation tasks with full mental state.

When sailing in the waters near the H point of Houshi channel, special attention should be paid to the dynamics of crossing sand ships. The possible navigation risks should be estimated, and corresponding emergency measures according to the actual traffic flow at that time should be preset. Before nighttime navigation, detailed night berthing operation procedures should be formulated. During night berthing, the wharf and berthing waters should be illustrated. The mooring piles, bumpers, berthing lights, etc. shall be in good condition and can be used at any time. The berthing waters and turning waters at the wharf apron should be fresh. All personnel related to the berthing operation of the ship shall be in place in advance, and all emergency facilities and equipment shall be available at any time. The opening of nighttime navigation in Houshi channel should be made known to all nearby ships.

All fishing vessels should be broadcast in the area by using the fishing vessel dedicated channel, so as to let all fishing vessels know about nighttime navigation and avoid fishing vessels occupying the channel. In combination with the actual situation of Houshi port area, fishermen should be clearly aware that there were ships in and out of Houshi channel at night, and it was strictly prohibited to engage in fishing activities in the channel. Urge fishing boats to correctly use AIS and VHF equipment, display correct lights at night, and reduce accidents caused by improper identification and poor communication. One hour before berthing at night, the loading and unloading machinery, goods and other facilities that hinder the berthing of the ship shall be moved away in accordance with the requirements of the pilot. The nighttime navigation plan of the next day every day should be regularly reported, so that the ships can reasonably arrange the plan and avoid affecting the nighttime navigation.

4.2 Steps of opening nighttime navigation

According to the analysis of the previous relevant research, it is suggested that the ships at Houshi 3# berth should start the night navigation step by step according to the classification and stages. The specific steps are as follows:

The first stage is the trial operation period, and the nighttime voyage of small bulk cargo ships with a length of less than 150m is opened first. During the trial operation, if there are ships entering and leaving the port at night, tugs should arranged to the vicinity of point I of Houshi channel at least 1.5 hours in advance. The channel should be cleared in advance, ensure that no fishing boats or other ships occupy the channel. Before the Houshi channel is clear, nighttime navigation ships should postpone entering or leaving the port. In view of the risk of pilots boarding the ship, night pilotage will not be considered in the first stage.

In the second stage, the operation of the first stage nighttime navigation will be recorded in detail and a post evaluation will be made one year after the trial operation. On the basis of meeting certain night navigation restrictions and effectively implementing relevant safety assurance measures and suggestions, gradually liberalize and carefully promote the night navigation of bulk cargo ships with a length of less than 180m. When the necessary wind and wave measuring equipment is added at the bay mouth and certain safety conditions are met, the night pilotage can be gradually released after expert evaluation.

4.3 Restrictions

To ensure the safety of night navigation and berthing and unberthing operations of ships in this berth, it is recommended to strictly abide by the following natural restrictions. Wind is below level 6. Try to choose the period of flat tide and slow flow, especially 2 hours before and after high tide or low tide, for berthing and unberthing. Avoid the period of rapid flow, that is, 2-4 hours after diversion. Wave height is below 1.5m. For example, when piloting at night, the wave height at the bay mouth is below 1.0m. Visibility is beyond 2000m.

5 CONCLUSION

The hydrometeorology and navigation environmental conditions in Houshi channel waters is investigated. The factors affecting the navigation safety of ships at Houshi 3# berth at night are analyzed. In view of the problems existing in the night flight, the corresponding safety assurance scheme and the suggestions of opening the nighttime navigation at different levels are put forward. A full assessment of the navigation environment is made. Although there are certain risks of navigation safety of ships at night, it is feasible to open night navigation at Houshi 3# berth, on the basis of meeting certain night navigation restrictions and effectively implementing relevant safety assurance measures and suggestions, through ship shore interaction, coordination and careful driving of pilots.

In future, different design ship types will be considered for nighttime navigation.

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