Research on Ship Traffic Management in Port Area Based on the Construction of Ship Domain

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Abstract: With the development of globalization and international trade, maritime transport has become the engine of world economic development. On the other hand, the increase in the number of ships has also caused a large number of maritime accidents, which has brought a series of problems to the ship traffic management. Therefore, this study will start with the analysis of ship yard and ship traffic, and take Ningbo Zhoushan Port as an example to analyze the traffic flow density and hot spots in the port area. The results show that it is easy to gather ships in the channel and port area, which increases the risk of ship accidents. Therefore, the port authority should conduct more reasonable ship traffic management in these areas, which provides a basis for the port authority to improve the ship traffic management.

Keywords: ship domain; ship traffic flow analysis; DP(Douglas–Peucker) algorithm; ship traffic management

1 INTRODUCTION

Maritime transport plays an irreplaceable role in international trade and the global economy. More than 80% of international trade in goods is carried out through maritime transport, which is even higher for most developing countries. At the same time, the demand for trade makes maritime transport more and more busy, and the design or construction of ships tends to be large-scale, specialized and rapid[1]. In this case, various ship accidents occur from time to time.

Ship accidents have had a huge adverse impact on people's production and life. The International Maritime Organization (IMO) has also made mandatory requirements for the equipment that different ships need to carry. At present, the most common and widely used in academic research is the Automatic Identification System (AIS).

AIS broadcasts the dynamic information of the ship (including ship position, speed, route, course, turning rate, destination and estimated arrival time) and static information (including ship name, ship MMSI ID, message ID, ship type, ship size and current time) every 2 to 10 seconds; The collected AIS data sources can be used to ensure navigation safety, mainly including ship traffic analysis, route estimation, collision prediction and route planning.

AIS data is widely used in collision prediction and ship traffic analysis, and one of the most important applications is to build the ship domain. The ship domain is a generalization of the safe distance between ships. The reason why it is introduced into the maritime navigation safety analysis is that it is observed that the safe distance is different in all directions. The concept of

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the ship field was first put forward by Fujii and Tanaka (1971). It is defined here as "a two-dimensional area around a ship[2]. Other ships must avoid this area, which can be regarded as an avoidance area". After that, the ship domain was widely used for navigation safety assessment and ship traffic flow management.

As an application of AIS data on the other hand, ship traffic analysis evaluates navigation safety from a macro perspective. Through this kind of analysis, we can find congestion points in the port area, areas with high ship density and areas with fast navigation speed. After obtaining these parameters, we can put forward correct suggestions for ship traffic management.

The ship traffic analysis puts forward suggestions on ship traffic management from a macro perspective. However, it cannot reflect the ship traffic conditions in the port area in the micro context. Therefore, this paper first proposes a theoretical method to build the ship domain. Through the macro ship traffic analysis, combined with the analysis of the micro ship domain, we can more accurately put forward more appropriate suggestions on the ship traffic management in the port area.

Through the construction of the ship field and the analysis of ship traffic, this study gives targeted advice on ship safety. It is beneficial for the Port Authority to strengthen the ship traffic management in the port area. It also further improves the research on the scope of ship traffic.

2 METHODOLOGY OF INTELLIGENT ALGORITHM FOR SHIP TRAFFIC MANAGEMENT

2.1 Ship Domain Construction Algorithm

An important indicator to be used in the research of ship traffic modeling, navigation safety assessment and ship collision avoidance decision-making in confined waters is the ship field, which is the generalization of the safe distance between ships. Since the observed safe distance in each direction is different, the ship field is introduced into the ship traffic research. According to different research methods, it can be divided into three categories: experimental data statistics, expert knowledge based and analysis based.

Wang et al., (2010) proposed the "quaternion ship field" based on analytical research methods [3]. The size of QSD (Quaternion Ship Domain) is determined by quaternion Q including four radii (R_{fore}, R_{aft}, R_{starb}, R_{port}). $f()$ is the boundary of QSD, and its shape is controlled by the parameter k, which can be described by the following formula (1):

$$QSD_k = \{(x,y)|f_k(x,y;Q) \le 1, Q = \{R_{fore}, R_{aft}, R_{starb}, R_{port}\}, k \ge 1\} \quad (1)$$

Boundary function $f()$ Expressed as:

$$f_k(x,y;Q) = \left(\frac{2x}{(1+sgnx)R_{fore}-(1-sgnx)R_{aft}}\right)^k + \left(\frac{2y}{(1+sgny)R_{starb}-(1-sgny)R_{port}}\right)^k \quad (2)$$

Kijima and Furukawa (2003) can estimate the transverse and longitudinal radii of Q by estimating the blocking area parameters, as follows:

$$R_{fore} = \left(1 + 1.34\sqrt{(k_{AD})^2 + \left(\frac{k_{DT}}{2}\right)^2}\right)L \quad (3)$$

$$R_{aft} = \left(1 + 0.67\sqrt{(k_{AD})^2 + \left(\frac{k_{DT}}{2}\right)^2}\right)L \quad (4)$$

L is the length of the ship, k_{AD} is the advance distance gain, k_{DT} is the gain of cycle diameter, which can be expressed as:

$$k_{AD} = \frac{A_D}{L} = 10^{0.3591\lg V_0 + 0.0952} \quad (5)$$

$$k_{DT} = \frac{D_T}{L} = 10^{0.5441\lg V_0 - 0.0795} \quad (6)$$

The Python codes for building the ship domain are as follows:

Table 1. Ship domain construction code

```
import math
import matplotlib.pyplot as plt
v = input(‘Please enter speed:’)
def Gain_k(v):
    k_ad = 10**(0.3591*math.log10(v)+0.0952)
    k_dt = 10**(0.5441*math.log10(v)-0.0795)
    return k_ad, k_dt
def Quaternion(k_ad,k_dt):
    r_fore = (1+1.34*math.sqrt(k_ad**2+(k_ad/2)**2))*L
    r_aft = (1+0.67*math.sqrt(k_ad**2+(k_ad/2)**2))*L
    r_starb = (0.2+k_dt)*L
    r_port = (0.2+0.75*k_dt)*L
    return r_fore, r_aft, r_starb, r_port
k_ad, k_dt = Gain_k(v)
r_fore, r_aft, r_starb, r_port = Quaternion(k_ad,k_dt)
Q = [r_fore, r_aft, r_starb, r_port]
x = [[0,r_starb],[r_starb,0],[0,-r_port],[-r_port,0]]
y = [[r_fore,0],[0,-r_aft],[-r_aft,0],[0,r_fore]]
plt.figure(dpi=100)
plt.plot(x,y,color = 'blue')
plt.scatter(0,0,marker='*')
plt.grid(True)
plt.grid(color='black', linestyle='--',linewidth=0.3,alpha=0.3)
plt.xlabel('x(n mile)')
plt.ylabel('y(n mile)')
plt.xlim(-1,1)
plt.ylim(-1,1)
plt.show()
```

The input speed parameter is 20 knots, and the ship domain drawn by code is shown in Figure 1:

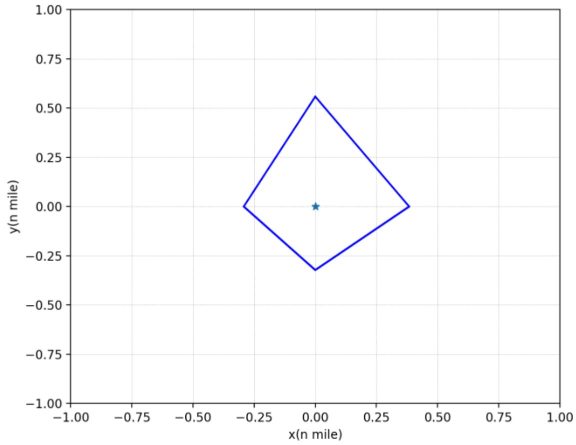


Figure 1. Ship domain construction

2.2 Analysis of ship traffic flow for traffic management

The traffic flow density reflects the busy traffic situation in different waters of the port. The linear density analysis is used to calculate the density of linear elements in the neighborhood of each output grid pixel. The unit of measurement of density is length unit/area unit. The length of the route can be obtained by generating the ship track, and the line density analysis can be used to generate the traffic flow density map through the route length/corresponding area [4].

After obtaining the spatio-temporal distribution of ship trajectory and traffic flow density, the ship domain is introduced into the spatio-temporal dynamic analysis. Kernel density analysis is used to calculate the density of point elements around each output grid pixel [5]. Unlike point density analysis, point density defines a neighborhood around each pixel, adds the number of points falling into the neighborhood, and then divides by the neighborhood area to obtain the density of point elements. The weight of points in the neighborhood is the same; Kernel density analysis is to calculate the density through the kernel function. The center pixel gets the highest value, diverges around in the search radius, and the pixel value of the neighborhood boundary is 0. The closer to the center, the higher the weight is, and vice versa. By building the ship domain, we can get the neighborhood and search radius that can keep ships safe. Applying these parameters to the nuclear density analysis, we can find the safe area or hot spot of the port waters.

2.3 Analysis of ship traffic in port area under the construction of ship domain

Through the analysis of ship traffic, we found that the areas with high ship traffic density and fast ship speed in the port area are obviously the areas with high navigation safety risk coefficient in the port area. By using the ship domain model described above, you can make a more accurate assessment of navigation safety in these hot areas and give better suggestions for ship traffic management.

According to the improved DP(Douglas–Peucker) algorithm, AIS data is compressed to generate the corresponding ship trajectory; Then cluster AIS data using DBSCAN (Density

Based Spatial Clustering of Applications with Noise) clustering algorithm [6]. In this way, the navigation safety risk points can be clustered to better manage the ship traffic in the port area.

3 CASE STUDY OF NINGBO ZHOUSHAN PORT

3.1 Introduction to the study area

Ningbo Zhoushan port is one of China's main hub ports, with obvious geographical advantages. It is located in the middle of the coastline of Chinese Mainland and faces the busy main channel of the Pacific Ocean. In 2021, Ningbo Zhoushan port completed a cargo throughput of 1.224 billion tons, an increase of 4.4% year-on-year. It has remained the first in the world for the 13th consecutive year; The container throughput reached 31.079 million TEUs, an increase of 8.2% year on year, and continued to rank third in the world. Therefore, it can be seen that it is very important to maintain the good ship traffic management level of Ningbo Zhoushan Port, which is conducive to the development of the city's economy and international trade. The location of Ningbo Zhoushan Port is shown in Figure 2:

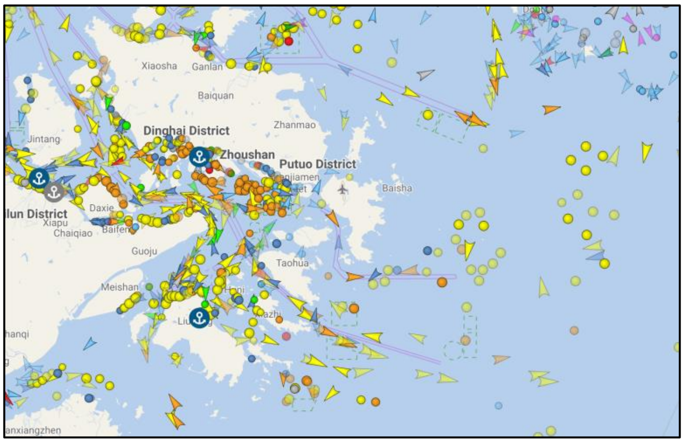


Figure 2. China Ningbo Zhoushan Port

It is precisely because of the continuous prosperity of international trade that more and more ships enter and leave Ningbo Zhoushan Port, which has also caused difficulties for port staff in ship traffic management, and ship accidents have also occurred from time to time. Table 2 shows the causes of accidents in Ningbo Zhoushan Port from 2010 to 2020:

Table 2. the causes of accidents in Ningbo Zhoushan Port

Cause of accident	***Total number of accidents(piece)***	***Proportion (%)***
Ship operators	1023	58
Port vessel traffic controller	61	3.4
Ship equipment	45	2.5

Natural environment	201	11.5
Navigable density	431	24.6

From Table 2, we can see that the errors of ship operators and the traffic density are the main causes of the accidents, so it is particularly important to analyze the ship traffic in Ningbo Zhoushan Port.

3.2 Ship Traffic Analysis of Ningbo Zhoushan Port

The ship flow of Ningbo Zhoushan Port is increasing day by day, and the ship traffic flow is very complex. We should use the improved DP algorithm. The idea of DP algorithm is: assuming that D1-D10 is the location point map of the ship's navigation track, the first step is to connect the cleaned ship's starting point, and then calculate the distance from all intermediate track points to this straight line, and compare these distances in turn to obtain the maximum distance D_{max}. The second step is to compare the maximum distance D_{max} with the initial threshold value. If $D_{max}$is greater than the initial threshold value, then the middle point will be rounded off. If D_{max} is less than or equal to the initial threshold value, Then divide the curve into two segments, perform the above operations on the two segments respectively, and iterate until compression is completed.

The original ship track and the ship track compressed by DP algorithm are shown in Figure 3 (a) and (b):

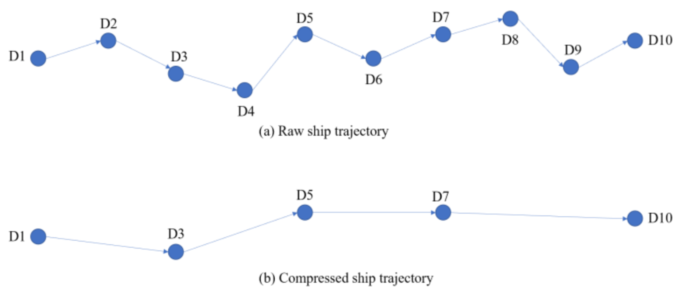


Figure 3. DP algorithm

In this study, AIS data of Ningbo Zhoushan Port from July 1 to July 15, 2020 are selected, and the ship traffic flow drawn after compression by DP algorithm is shown in Figure 4:

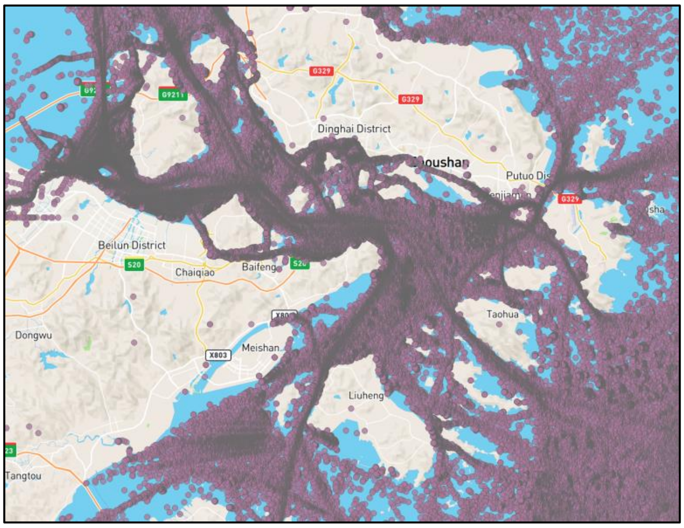
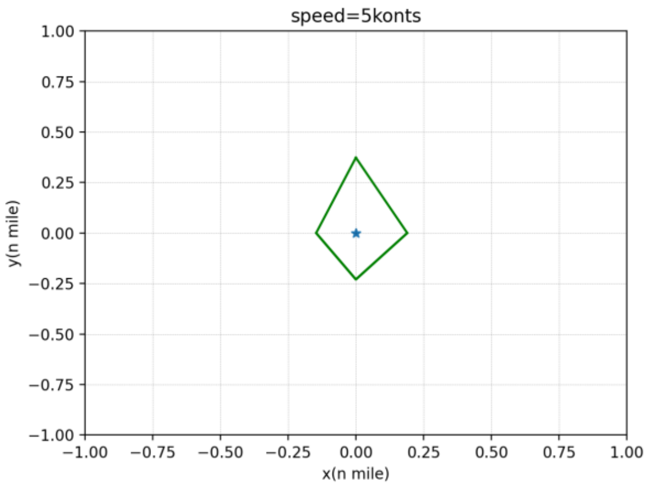


Figure 4. Ship traffic flow

It can be seen from the density map of ship traffic flow drawn that the density of ships sailing in the channel is large, and there is a large risk of navigation in the water area where the channel intersects. In addition, since many of the port areas of Ningbo Zhoushan Port are surrounded by small islands, it can be found that the density of ship traffic flow in the port area is also large, so sample ships can be selected to build the ship field in these areas as a basis for improving ship traffic management.

3.3 Building the Ship Domain and Improving Ship Traffic Management

The sample ships were selected in the waters with high traffic flow density, and the results of building the ship domain are shown in Figure 5 and Figure 6:



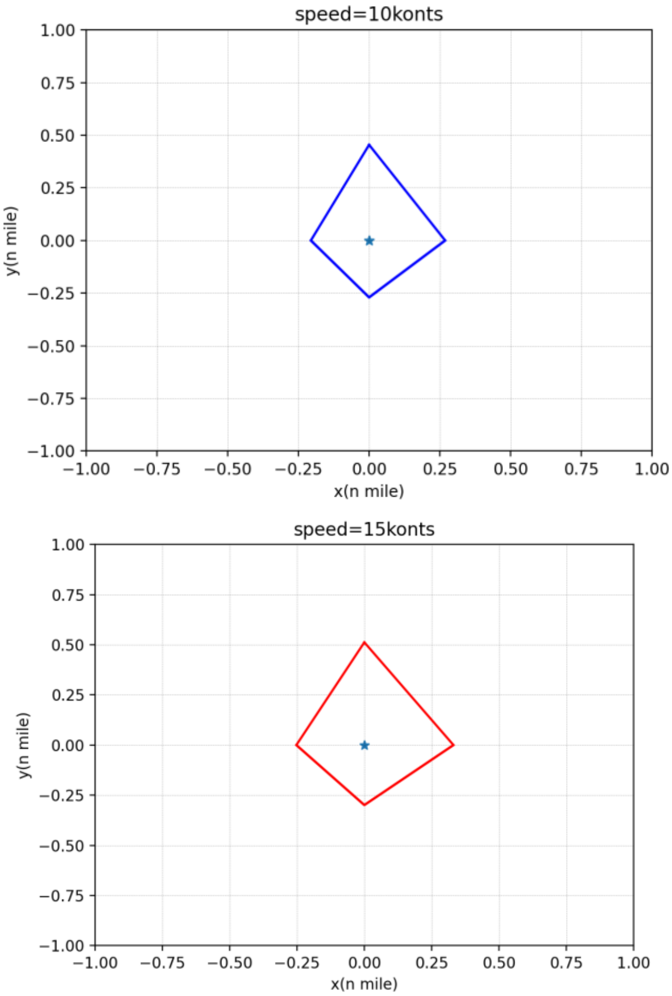


Figure 5. Ship domain with speed of 5, 10 and 15 knots

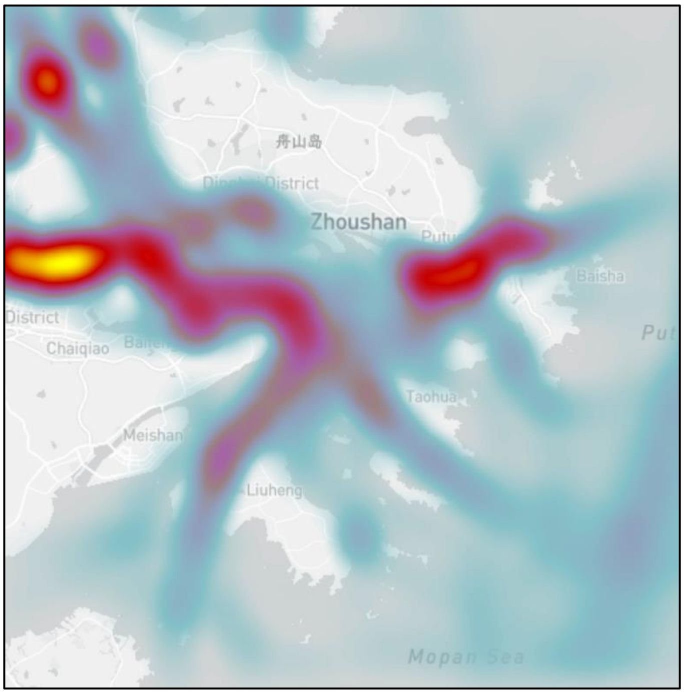


Figure 6. Hot area of the port

Figure 5 shows the size of the ship field under different ship speeds. As the speed increases, the ship field will gradually become larger. Therefore, the port authority should set speed limit areas at special locations in the port area to ensure good management of ship traffic.

Figure 6 shows the temporal and spatial dynamics of ship traffic in Ningbo Zhoushan Port. The area marked in red is the area with high ship density. In this area, sample ships are selected for research, and the ship field is constructed to mark the locations where navigation risks may occur. It can be found that a large number of ships are gathered near the channel and around the islands, so the port authorities should manage and optimize the ship traffic in these areas more strictly.

4 CONCLUSION AND PROSPECT

This research is based on the analysis and processing of AIS data. Through the construction of the ship field and the analysis of ship traffic, it has found the navigation risk areas and hot spots in the port area, and has applied this method to the case study of Ningbo Zhoushan Port. The results show that it is easy to gather ships in the channel and in the port area, which is prone to ship accidents. Therefore, the port authorities should optimize the ship traffic management in these areas, to achieve efficient and sustainable port development.

Through the research results, the ship field and ship traffic analysis can be used as indicators to evaluate the ship traffic management, which has guiding significance and practical value for the ship traffic management of Ningbo Zhoushan Port and other ports. However, as an important hub port, Ningbo Zhoushan Port, with the increasing number of ships entering and leaving the port, various safety and management problems have also become prominent. Therefore, it is necessary to carry out a ship traffic analysis of Ningbo Zhoushan Port.

This study uses the methods of ship field and ship traffic analysis to discuss the situation of the case port, but there is still work to be improved, mainly shown as the impact of other ship safety indicators on the ship traffic analysis, such as considering the impact of different ship types, different course and other factors on the ship traffic safety, which will become the key points of the next study.

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