

Level of Service Evaluation Method for Waterway Intersections

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Abstract: Due to a lack of explicit collision avoidance rules combined with ineffective communication, waterway intersections are typically high-risk areas for vessel navigation. To address this risk, traffic management of waterway intersections is a common approach. However, there is a lack of a method to evaluate traffic management of waterway intersections. This paper proposes a method to jointly analyze vessel navigation information and environmental factors in waterway intersections using field theory, and the efficiency of navigation and the degree of orderliness in the process of navigating in waterway intersections are comprehensively evaluated. The method was applied to analyze Yuxingnao waters. The results show that the method can clearly verify navigation status of vessel and determine level of service. Therefore, this method can not only provides a guidance for vessel drivers to choose an area with high comfort level for navigation, but also an evaluation of routing system and traffic organization optimization.

Keywords: waterway intersections; field theory; fuzzy clustering; level of service

1. Introduction

With the increasing globalization of economy, the United Nations Conference on Trade and Development (UNCTAD) has indicated that maritime trade will continue to grow at an annual rate of 2.1 percent in the period 2023-2027. This predicts that there will be an increase in the number of vessels sailing at sea as well. As the world's largest maritime trading nation, China is also a major country in dry bulk and container trade. The number of vessels sailing through China's coasts and inland rivers exceeds one million each year [1]. Along with the prosperity of maritime industry, the phenomenon of vessel jams and vessel collisions occurs from one time to another. According to incomplete statistics from the European Maritime Bureau, as many as 3,200 vessel collisions, groundings, capsizes and other accidents occurred annually from 2016 to 2020 [2]. The number of vessels sailing along the coast of China has increased, but the area of the sea is limited. On the basis of ensuring the utilization rate of marine resources, ensuring the safety and efficiency of navigation has become a problem that cannot be ignored. Vessel navigation risk statistics show that waterway intersections are the high-risk area for vessel collisions. This is due to the fact that waterway intersections are common areas that connecting various waterways, which is characterized by heavy traffic and complex vessel encounter situations.

It is precisely because of the high density of traffic, the complexity of vessel encounters, and the ambiguity of navigation rules in waterway intersections [3,4], marine traffic management authorities have implemented routing system and traffic flow organization optimization in the complex area. However, how to evaluate the optimization effect? At present, there is a heavy reliance on historical data and lacks of a systematic method for evaluating the region as a whole. As we all know, level of service is a measure of the quality of traffic operational state under a certain transportation facility, which can evaluate advantages and disadvantages of navigation in a region from a macro perspective. Therefore, it is of high application value and practical significance to find a set of service level evaluation methods that conform to the navigation characteristics of waterway intersections.

2. Literature Review

Level of Services (LOS) was first proposed in Highway Capacity Manual (1965 edition) and has evolved for nearly 60 years [5]. Therefore, LOS methodology of highways is relatively mature compared with that in waterways. As such, methodology of waterway LOS was developed by drawing from successful experience in highway transportation [6]. Zhang et al. [7] learns from the mature theory of LOS on highway, uses qualitative methods to evaluate the LOS of waterway. In addition, even though the LOS method for waterways and ports have been already extensively addressed, a method to evaluate the level of service of waterway intersections has not been specifically developed [8–11].

As mentioned above, research with guidance about LOS of highways has found that the service measures, as well as the criteria for quantitative evaluation, are different when applied to different transportation facilities. LOS responds to a systematic evaluation of the quality of services in a region, which includes driving freedom, comfort, and safety. It is also an objective description of driver perception from the driver's own experience. Therefore, most of the research results on the road are based on human perception, and the selection of service measures need to agree with drivers' personal experience [12–14]. Kadali et al. [15] collected pedestrians' perceived level of service for different land utilization types and evaluated the level of service of mixed traffic by combining the number of passing vehicles, ease of road crossing, and safety. Papadimitriou et al. [13] evaluated highway service level by collecting data such as drivers' age, gender, driving experience, road familiarity, and vehicle capacity, then concluded that there are limitations in single service measure methods through perceptual data analysis. Yue et al. [14] evaluated the level of service of public transportation facilities by analyzing the factors of arrival time, waiting time, bus speed, and departure time. For the difficulty of considering the environmental factors in delay time, Martin et al. [16] developed a fuzzy model that can evaluate the level of service of a two-lane roadway by considering the effects of multiple factors based on drivers' perceptions. Different transportation facilities have different service measures, and a single service measure is becoming less popular. In addition, it was found that the evaluation results of the level of service in same area varied among different participants [17]. Therefore, it is important to find service measures that can reflect personal experience of users and differentiate the service quality of a particular transportation facility.

Considering the differences of transportation facilities, the service measures for waterway channels and ports cannot be used directly in waterway intersections. Similarly, since traffic management rules are different between highway intersections and waterway intersections, the measures used to evaluate intersections on highway cannot be directly applied to waterway. Therefore, choosing service measures which are consistent with the regulations of vessel navigation in waterway intersections is the focus of a good level of service research in it.

To summarize, although the research on waterway intersections has not been interrupted, there is almost no research on the evaluation of service level, and most of the research on waterway intersections is distributed in the aspects of vessel collision avoidance [18–21] and traffic conflict [22–24]. However, this part of research only focuses on analyzing the navigational status between two vessels at a micro level, and cannot take into account the navigational status of vessels in the whole water area at a macro level. If a systematic service level evaluation system for waterway intersections can be proposed, it can not only be linked with the service level evaluation of waterways and ports to complete the jigsaw puzzle of maritime navigation service level evaluation system, but also analyze the navigation status of the whole waterway intersections from a macro point of view to provide a guidance for the management of

maritime traffic.

This paper is organized as follows. The next section provides a detailed description of research methodology. Then, this paper describes how to quantify LOS by using defined service measures and analyze the actual data. Section 4 discusses the rationale and feasibility of the algorithm. Last section concludes this research and future directions are discussed.

3. Materials and Methods

3.1. Our proposed approach

The purpose of this research is to provide a reasonable service level evaluation method for waterway intersections. The method can provide a guidance for the evaluation of routing system and the optimization effect of traffic organization, as well as for vessel driver to be able to choose a more comfortable navigation area.

LOS of a water channel at sea can be evaluated by using density in the region, but waterway intersections are two-dimensional plane, and the service measures of water channels cannot be directly applied to waterway intersections because of different service facilities. In addition, the evaluation effect of service level is built on the drivers' objective evaluation, which needs to focus on human perception. Vessels navigating in waterway intersections are affected by vessel's position, spacing, speed, heading and other vessel information and environmental factors such as wind and flow. How are you able to comprehensively consider these complex factors is the focus of solving the problem of service measures. The operation by driver is like a force that drives the vessel to move in the process of traveling. However, field theory can coordinate physical system, transportation system and social system, and has been widely used in vessel collision avoidance [18,25,26], which can reasonably quantify the risk value of vessel. In this paper, field theory is used to transform driver's perceptual force (pressure felt in the driver's mind) influenced by vessel information and environmental factors into Newtonian force experienced during vessel navigation [27]. The comprehensive analysis of Newtonian forces considers each vessel in driver's environment as a ship field. Finally, by combining AIS data to analyze the navigation status of vessels in waterway intersections and considering superimposed area share of ship fields in the region, the service measure of degree of orderliness of vessel is proposed, which fully takes into account the navigation safety of vessels in waters. On this basis, an evaluation system of service level of waterway intersections is established by combining with the efficiency of navigation.

3.2. Access to LOS Service Measures for waterway intersections

3.2.1. Selection of Service Measures

Choosing suitable service measures determines the degree of effectiveness of service level evaluation. Therefore, some principles apply when selecting service measures under the premise of ensuring safety: it should be able to be personally experienced by drivers; service measures can be quantified into numerical representation; each quantized value of the service measures can only correspond to one service class uniquely; different service levels can be well differentiated. Service measures that conform to the navigation regulations of vessel in waterway intersections are selected from the variables of degree of orderliness, efficiency of navigation, delay time, density and so on. Since most vessels in waterway intersections avoid obstacles by steering rather than waiting and stopping, the delay time is difficult to measure. Density only reflects the number of vessels in the area and ignoring the key information such as vessel position, encounter situation, navigation environment, etc., which makes it

difficult to characterize the real state of vessels navigating in waterway intersections. Therefore, the service measures selected on the basis of ensuring the safety and efficiency of navigation are as follows:

The efficiency of navigation: It responds to how efficiently vessels pass through the area. This is obtained by calculating the average time taken by a vessel in the region from the time it enters to the time it leaves. and is expressed as efficiency of navigation (EON).

The degree of orderliness: It is the core service measure of LOS in this paper. The service measure takes into account the multiple factors existing in waterway intersections. Based on the driver's perception, factors such as distance, conflict situation, excellent navigation environment, and relative speed among the vessels are used as guiding factors to comprehensively consider the effect of real navigation environment on the driver's psychology in waterway intersections. The method of calculating the degree of orderliness (DOO) is much complex, and it is calculated as follows.

3.2.2. Calculation of Service Measures

1. Construction of a microscopic ship field

Waterway intersections are high-risk areas for collision in vessel navigation. An important reason for this phenomenon is that vessel navigation in some of the waterway intersections is not in a high degree of order, and unorganized vessel navigation situations have led to a high density of vessels in individual areas of waterway intersections.

How to reflect safety domain of vessel driver when the vessel navigates in waterway intersections? That is the important basis for the establishment of this service measure, i.e., from the real perception of driver. According to the analysis of vessel navigation environment, magnitude of the field generated by drivers when driving vessel movement changes with time. Therefore, this paper proposes a ship field model based on a two-dimensional Gaussian function. The two-dimensional Gaussian function is shown in Equation 1. A three-dimensional plot of the two-dimensional Gaussian function is shown in Figure 1.

$$f(x, y) = \frac{1}{2\pi\sigma_1\sigma_2} \exp \left[-\frac{1}{2} \left(\frac{(x-\mu_1)^2}{\sigma_1^2} + \frac{(y-\mu_2)^2}{\sigma_2^2} \right) \right] \quad (1)$$

where, x, y are two variables independent of each other; μ_1 is the mathematical expectation of variable x ; μ_2 is the mathematical expectation of variable y ; σ_1 is the standard deviation of variable x ; σ_2 is the standard deviation of variable y .

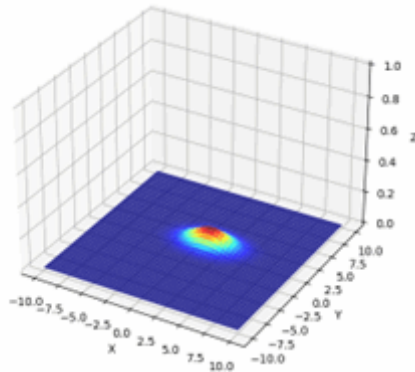


Figure 1. The two-dimensional Gaussian function three-dimensional graph.

Inspired by the two-dimensional Gaussian function, ship field is established based on it. In the first place, to make the ship field more consistent with navigation reality, vessel position as well as vessel size are considered. The formulas are as follows:

$$a = L + R_f \quad b = B + R_s \quad (2)$$

$$R_f = \frac{\sum_{i=1}^{n_{ho}} D_{ho}}{n_{ho}} \quad R_s = \frac{\sum_{i=1}^{n_{cf}} D_{cf}}{n_{cf}} \quad (3)$$

$$Doo = \frac{1}{2\pi\sigma_f\sigma_s} \exp \left[- \left(\frac{(x-x_0)^2}{a\sigma_f} + \frac{(y-y_0)^2}{b\sigma_s} \right) \right] \quad (4)$$

Where, L is the length of vessel; R_f is the average value of vessel's following distance; B is the width of vessel; R_s is the average value of vessel's encounter distance; x_0 is the value of the horizontal coordinate of vessel's position; y_0 is the value of the vertical coordinate of vessel's position; σ_f is the adjustment coefficient of vessel's forward extended space; σ_s is the adjustment coefficient of vessel's side extended space; Doo is the quantitative value of the influence of surrounding vessels and environment.

Next, in order to make ship field model closer to the reality, it is necessary to take into account the complex encounter situations formed when vessel sails in waterway intersections. In addition to short distance, relative orientation between two vessels is the key to the formation of complex encounter situations. Therefore, it is necessary to take into account the change of vessel's orientation on the basis of vessel's localization. The formulas are as follows:

$$\begin{cases} u = (x - x_0)\cos\theta - (y - y_0)\sin\theta \\ v = (x - x_0)\sin\theta + (y - y_0)\cos\theta \end{cases} \quad (5)$$

$$Doo = \frac{1}{2\pi\sigma_f\sigma_s} \exp \left[- \left(\frac{u^2}{a\sigma_f} + \frac{v^2}{b\sigma_s} \right) \right] \quad (6)$$

Where, u is the horizontal coordinate after rotating according to the course of vessel; v is the vertical coordinate after rotating according to the course of vessel.

Finally, simulate the real-time effects of surrounding vessels (nearest vessel centered on this vessel) and the environment on the vessel and convert it into force. Substituting forces into the adjustment coefficients (σ_f, σ_s) to adjust the size of the field in real time to improve the accuracy of the model.

The process of vessel navigation will be affected by environmental factors. In this paper, we consider the effects of wind and flow on the construction of ship field. It mainly includes the drift caused by wind on the vessel, the effect of flow on the speed of vessel navigation, and so on.

The effect of wind on ship field formula is as follows:

$$v_f = \frac{V_a}{20} \quad F = M \times \Delta v_f \quad (7)$$

Where, v_f is the speed of vessel drifting under the effect of wind; V_a is the relative wind speed; M is the weight of vessel; F is the force on the vessel.

The effect of flow on ship field formula is as follows:

$$v_h = \begin{cases} V_c \sin(\theta_c) & \text{if } 0 \leq \theta_c < 90 \\ V_c \sin(180 - \theta_c) & \text{if } 90 \leq \theta_c \leq 180 \end{cases} \quad F = M \times \Delta v_h \quad (8)$$

where, v_h is the magnitude of the velocity of stream in the transverse direction of vessel; V_c is the magnitude of wind speed; θ_c is the beam angle of stream.

Considering the different degrees of influence on each direction of vessel. The force on the vessel is now divided into four categories according to quadrant where the force is located: the first quadrant force, the second quadrant force, the third quadrant force and the fourth quadrant force. In different quadrants, the forces act on the vessel in different directions after decomposition. The force

decomposition formulas are as follows:

If $0^\circ \leq \alpha < 90^\circ$:

$$F_f = F \sin \alpha \quad F_r = F \cos \alpha \quad (9)$$

If $90^\circ \leq \alpha < 180^\circ$:

$$F_l = F \cos \alpha \quad F_f = F \sin \alpha \quad (10)$$

If $180^\circ \leq \alpha < 270^\circ$:

$$F_b = F \sin \alpha \quad F_l = F \cos \alpha \quad (11)$$

If $270^\circ \leq \alpha < 360^\circ$:

$$F_b = F \sin \alpha \quad F_r = F \cos \alpha \quad (12)$$

Where, F_f is the forward force of vessel; F_r is the right force of vessel; F_l is the left force of vessel; F_b is the backward force of vessel; F is the quadrant where the current force of vessel is located; α is the angle of counterclockwise rotation of current force from the right direction of vessel.

So far, this paper has established a dynamic ship field model based on the two-dimensional Gaussian function, and the construction of ship field at microscopic level has been basically completed. The dynamic ship field model formulas are as follows:

$$\sigma_f = |F_f - F_b| \quad \sigma_s = |F_r - F_l| \quad (13)$$

$$Doo = \frac{1}{C\sigma_f\sigma_s} \exp \left[- \left(\frac{u^2}{a\sigma_f} + \frac{v^2}{b\sigma_s} \right) \right] \quad (14)$$

Where, C is a constant and C is taken here as 2π .

A three-dimensional schematic of ship field in the region is shown in Figure 2a,b:

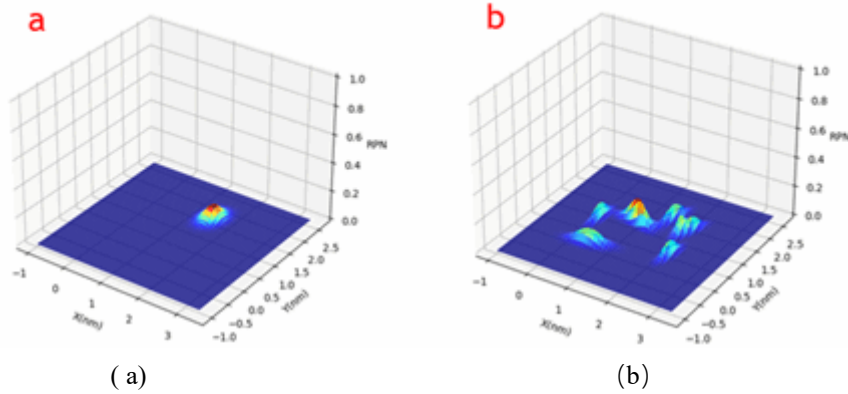


Figure 2. In waterway intersections: (a) a schematic of a single-ship field; (b) a schematic of a multi-ship field.

2. Macroscopic degree of orderliness analysis based on microscopic ship field

An overhead view of microscopic ship field is shown as Figure 3, which gives a clear indication of the extent of ship field's influence throughout the research area.

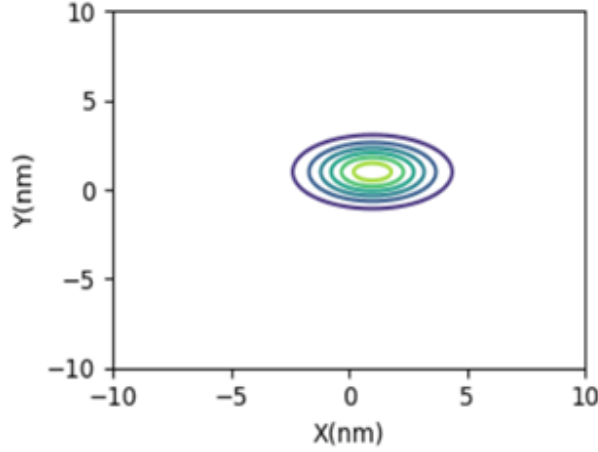


Figure 3. Overhead view of ship field in the region.

Based on the scope of influences of individual ship field. The positions and sizes of each ship field are analyzed at macroscopic level. Considering the influence of vessel conflicts and density on the degree of orderliness, the overall quantification of degree of orderliness in the research area is done through the size of superimposed area between ship fields. The quantitative formulas are as follows:

$$Area_{ij} = Area_i \cap Area_j \quad (i,j=1,2,3\dots n \text{ \& } i \neq j) \quad (15)$$

$$DOO = \frac{\sum_{i=1}^n \sum_{j=1}^n Area_{ij}}{ToArea} \quad (i,j=1,2,3\dots n \text{ \& } i \neq j) \quad (16)$$

Where, $Area_i$ is the size of the influence area of ship field i ; $Area_j$ is the size of the influence area of ship field j ; $Area_{ij}$ is the superposition area of ship fields i and j ; $ToArea$ is the total area of ship fields in the region; DOO is the value of quantitative degree of orderliness at this moment.

The conversion of a three-dimensional ship field into a two-dimensional graph is shown in Figure 4a,b:

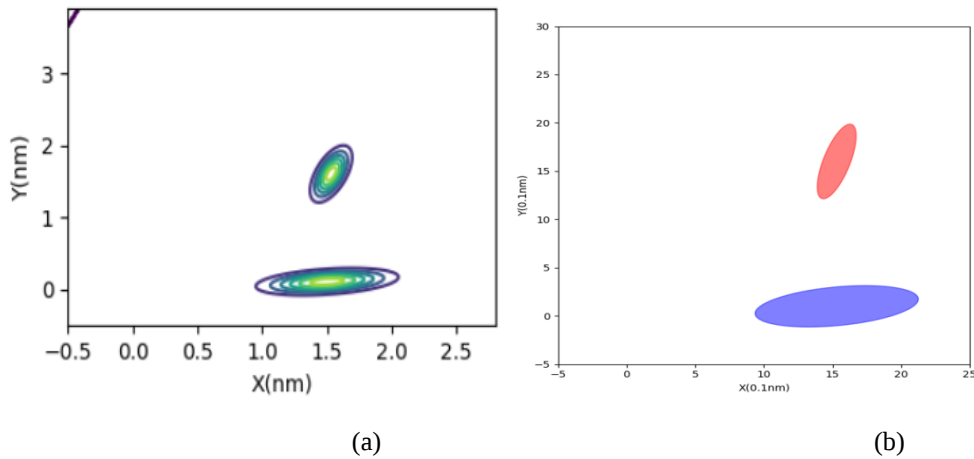


Figure 4. Comparison of ship field conversion calculations: (a) the three-dimensional ship field before transformation; (b) the two-dimensional graph of transformed.

3.3. The Proposed LOS Criteria for waterway intersections

3.3.1. Designation of LOS

LOS is a subjective evaluation of different transportation facilities [28]. HCM defines the level of service of a roadway as "Level of Service is a quality measure that describes the operational status of a

traffic flow, usually including speed and travel time, mobility, comfort, and convenience" [5]. Zhang et al. [7] defined the level of service of waterways by saying that "the level of service of waterways refers to the measure of service quality perceived by users of waterways in terms of safety, comfort, efficiency and economy". Therefore, the definition of the level of service on both waterways and highways is aimed at the objective evaluation of people. Reflecting the experience of drivers and the quality of service in terms of safety, comfort, efficiency and other aspects.

3.3.2. Description of LOS

In highway traffic, HCM divides the service level of roads into six grades, which are A~F. However, due to the difference between the size of vessels and vehicles; The different media between vessels and vehicles, the braking time of vessels is much larger than that of vehicles, and the speed of vessels sailing is much smaller than that of vehicles; The traffic control between vessels and vehicles traveling at intersections is different, and vessels traveling in waterway intersections without red lights are accustomed to use steering to avoid obstacles, while vehicles are accustomed to choose braking and stopping when encountering red lights or blocking situations. Therefore, the six levels of service classified in HCM are not directly applied to sea. The overview of the level of service classification in waterways shows that it is customary to classify the level of service into four or five levels in waterways, and use fewer levels to redefine the level of service class. In addition, cluster analysis of AIS in multiple waterway intersections through big data shows that five levels seem to be more appropriate for vessel navigation conditions, as shown in Figure 5. In western countries, the representation of service levels from A to F can clearly express the order of service levels in terms of advantages and disadvantages, which is due to the customary cognition of western people from childhood to adulthood. However, through research, we recognize that classification is more common to be excellent, good, fair, passable, and poor. Each level of service is described as follows:

LOS Excellent: This class shows the excellent service. The number of vessels traveling in waterway intersections is low. There is little conflict among vessels and a high degree of freedom for vessel drivers to steer. And, there is a low density of vessels in the area. Therefore, a high degree of efficiency in vessel navigation with no risk of collision in waterway intersections.

LOS Good: This level shows good service. The number of vessels traveling in waterway intersections has increased, conflicts among vessels have increased, and the freedom of driving for vessels drivers has been slightly affected. The density in the area is still low, a small number of vessels are disorganized, and the efficiency of navigation has been slightly affected.

LOS Fair: This class shows fair service. There is a continuous increase in the number of vessels traveling in waterway intersections and a continuous increase in vessels conflicts. In addition, there is an increase in the density of the area, congestion can be perceived, the freedom of driving for drivers is reduced compared to the good class, the efficiency of navigation is reduced, and there is a potential risk of collision.

LOS Passable: This class shows the passable service. The number of vessels traveling in waterway intersections is high, conflicts among vessels are obvious. In addition, the freedom of drivers is reduced and they need good driving skills to pass safely through the area. The safety, efficiency of navigation and the comfort of drivers are reduced obviously. The navigation conditions of vessels in the region are unstable and are likely to collapse if disturbed.

LOS Poor: This class shows poor service. The number of vessels traveling in waterway intersections

reaches the capacity of the area. Vessel conflicts are obvious. Uneven spatial distribution of vessels and poor degree of orderliness lead to traffic paralysis. In addition, vessel navigation is inefficient and drivers can cut through even with good vessel craft, and the risk of vessel collision is high.

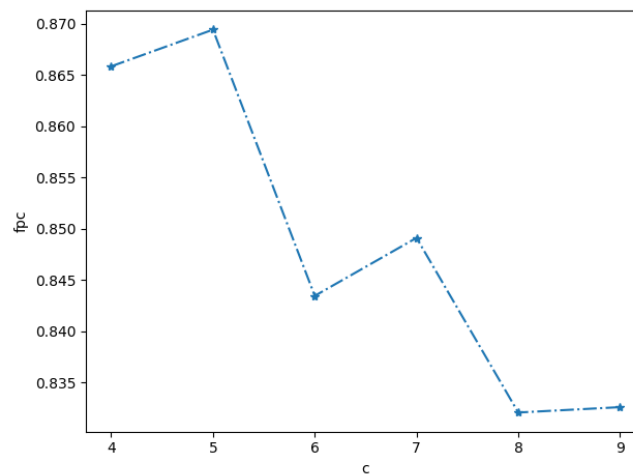


Figure 5. Graph of changes in clustering superiority (the larger fpc value the better clustering effect)

3.4. Quantitative Classification of LOS

The key point in the division of service level is to determine the boundary of each LOS. However, since LOS is an objective evaluation of drivers for traffic and service quality of waterway intersections, the boundary of each LOS is fuzzy and indeterminate. On the basis of fuzzy nature of service level evaluation caused by many factors, and taking into account that fuzzy clustering algorithm has been well applied in the process of determining LOS of road intersections [29,30], this paper uses the fuzzy clustering algorithm to determine LOS.

The LOS classification method in this paper needs to rely on an amount of AIS data. The LOS of waterway intersections is mined from the data, and then service measures are clustered and graded to obtain service level classification finally. Combined with data analysis library in python for screening and analysis, the last integration of machine learning library in python, sklearn, skfuzzy for fuzzy clustering analysis to determine LOS.

According to the screening and cleaning method of data, a 100G original data will be processed initially and extracted into a fixed format after the processing is completed. The prepared data is used to screen waterway intersections, and all the vessel distribution information in the screened waterway intersections is extracted at a time interval of 30s. The vessel distribution information at the current moment is obtained in Table 1.

Table 1. Vessel's details at a certain point in time.

Number	MMSI	Speed (kn)	Course	Width (m)	Length (m)	M (10t)	Lon(E)	Lat(N)
1	369296000	14	219	32	217	5278	122.31502	29.75127
2	228401800	7.6	286	61	400	19164	122.34175	29.74225
3	372926000	10.8	206	28	195	4237	122.32691	29.74684
4	563065100	10	131	28	195	4000	122.32108	29.74106
5	341988000	8.6	225	28	195	4266	122.31833	29.74899

6	563115100	13.2	192	28	170	2194	122.31886	29.74654
7	477222700	8.5	295	48	366	19000	122.3225	29.74849
8	636018382	12.4	213	27	176	3800	122.32026	29.74642

Extracting service measures from the prepared data, and the extracted data changed over time as shown in Table 2.

Table 2. Service measures over time.

Time (s)	0	600	1200	1800	2400
DOO	10.5	6.9	5.6	7.4	8.4
EON	26.2	25.8	24.6	28	28

The data of waterway intersections in the whole watershed is mined and summarized in the above method to complete. C-means fuzzy clustering algorithm is substituted to do clustering experiments. Firstly, the experimental data is divided into a training set and a validation set. Then, the number of clusters $c=5$. Finally, the iteration stopping threshold $erro=0.005$, and the fuzzy index $m=1.5$ (usually taken as 1.5~2.5) [31].

According to optimal clustering results, extract the clustered data under each cluster and standardized reduction, and extract maximum and minimum value boundaries of two service measures under each cluster to determine LOS. Considering the shortcomings of dual service measures, but that both service measures are equally important for measurement of service level, the final measure is determined by Equation 17. The results of LOS division are shown in Table 3.

$$EaO=0.5DOO+0.5EON \quad (17)$$

Where, DOO is the value of degree of orderliness after standardized reduction; EON is the value of efficiency of navigation after standardized reduction; EaO is comprehensive service measure.

Table 3. Criteria of waterway intersections LOS.

LOS	EaO
Excellent	0~5.2
Good	5.2~12.1
Fair	12.1~20.2
Passable	20.2~33.4
Poor	>33.4

So far, C-means fuzzy clustering is used to divide fuzzy boundaries by comprehensively analyzing the degree of orderliness and the efficiency of navigation to determine LOS measurement standard of waterway intersections.

4. Case Study

4.1. Data Preprocessing

Waterway intersections are characterized by heavy traffic, many types of vessels, and complex vessel encounter situations, which need to be mined and screened from the existing data to find out experimental analysis data ultimately needed in this paper.

Since there may be an amount of data sent to a same base station at the same time during the transmission of AIS data, which will cause the base station receiver to reach the limit of the data it can

accept at the same time, resulting in some of the AIS data missing, so it is necessary to clean AIS data before it can be used. The basic principles of AIS data cleaning are as follows:

1. MMSI, time consistent data de-emphasis;
2. Remove the data with less than 9 MMSI bits;
3. Static missing data such as vessel length and width: use the mean value of vessel size under a same vessel type to supplement.

In order to provide convenient time slicing in waterway intersections and show the complete distribution of vessels at the current moment, this paper chooses cubic spline interpolation method to interpolate vessel position and other information. Cubic spline interpolation algorithm has advantages of high flexibility, full consideration of the smoothness of function, high accuracy of fitted data and easy to interpret, which can fill the required AIS data more accurately and completely. It is difficult to calculate the distance between two vessels in latitude and longitude coordinates, so that Mercator projection method is used to convert latitude and longitude coordinates into right-angle coordinates.

Since position information in AIS data only represents the position information where AIS antenna is located, the calculation of vessel's spacing cannot be obtained by Euclidean distance using AIS position information directly. If vessel is compared to a mass point, the shape of vessel is ignored. Therefore, the shape and the bow direction of vessel should be fully considered. Hausdorff distance not only takes into account the shape of polygon, but also the relative direction of two polygons in the calculation of minimum distance between two vessels, which solves the problem of the calculation of minimum distance between two vessels [32]. The Hausdorff distance is calculated as follows:

On the one hand, centering on the vessel, a dynamic coordinate system of vessel is established based on the bow direction as shown in Figure 6, which changes with the change of the bow direction of vessel. Combined with the position information of surrounding vessels relative to vessel, the bearing of any surrounding vessel relative to owner can be obtained from Equation 18.

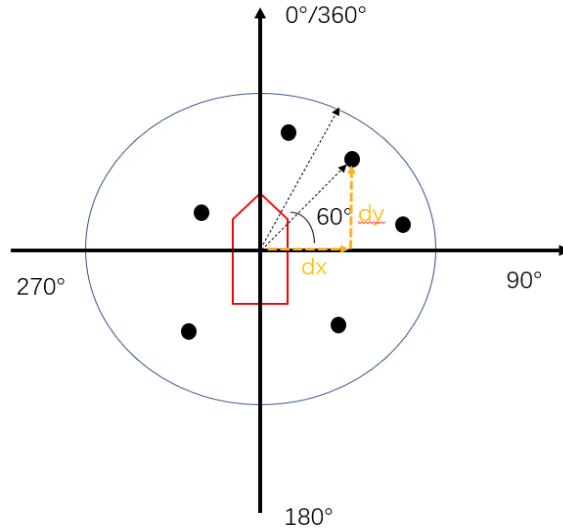


Figure 6. Schematic diagram of screening of surrounding vessels.

$$\theta = \arctan\left(\frac{Y_i - Y_0}{X_i - X_0}\right) \quad (18)$$

Where, θ is the steering angle; X_0 is the distance between own vessel and basic point in the direction perpendicular to the channel; X_i is the distance between target vessel and basic point in the direction

perpendicular to the channel; Y_0 is the distance between own vessel and the basic point in the direction along channel; Y_i is the distance between target vessel and the basic point in the direction along channel.

On the other hand, the coordinate system is established according to the method shown in the Figure 6 to screen the surrounding target vessels. The specific calculation of the distance between two vessels is as follows.

The set of coordinates for the own vessel is $Q = [q_1, q_2, q_3, q_4]$. The set of coordinates for target vessel is $O = [o_1, o_2, o_3, o_4]$.

$$H(Q, O) = \max(h(Q, O), h(O, Q)) \quad (19)$$

$$h(Q, O) = \max(q \in Q) \min(o \in O) \|o - q\| \quad (20)$$

$$h(O, Q) = \max(o \in O) \min(q \in Q) \|q - o\| \quad (21)$$

$$D = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2} \quad (22)$$

Where, D is the Euclidean distance, $H(Q, O)$ is the Hausdorff distance between two vessels; $h(Q, O)$ is the minimum value from each point of the set of own vessel to each point of the set of target vessel, then, takes the maximum value; $\|q - o\|$ is the Euclidean distance between own vessel and target vessel.

4.2. Appliance

Zhoushan Maritime Bureau issued a recommended navigation law for vessels in Zhoushan Yuxingnao waters on June 7, 2023. Zhoushan Yuxingnao waters routing system, traffic organization optimization program officially implemented. Two months of 6G data in December 2021 and June 2023 were selected for test, the location of test data selection is shown in Figure 7.

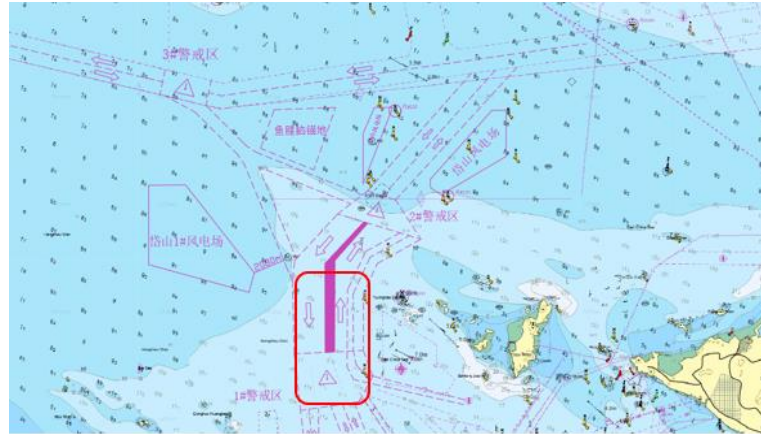
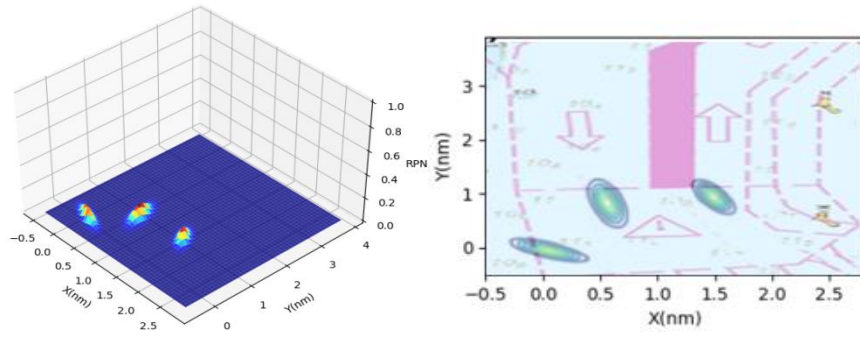
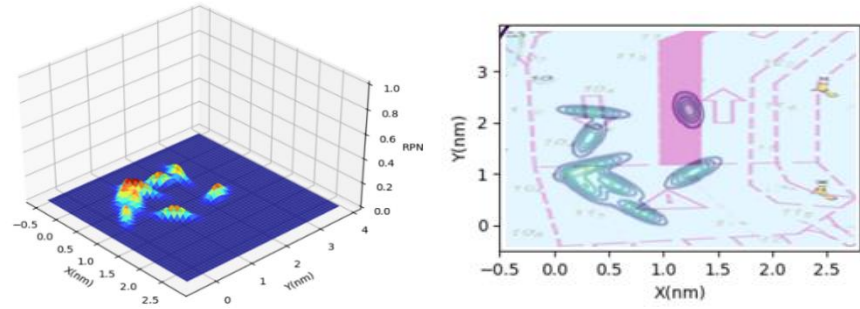


Figure 7. Optimized routing system scheme for Yuxingnao region

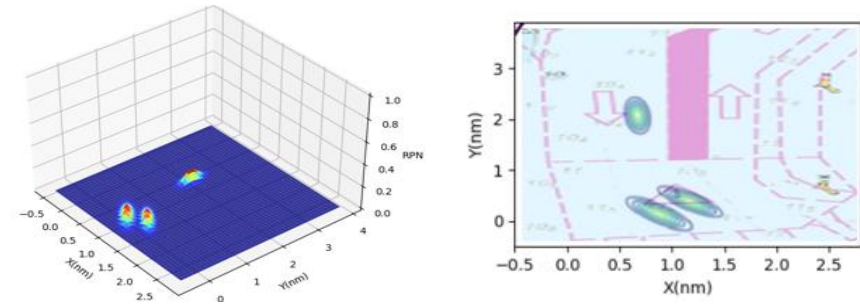
This system is established based on AIS data. Therefore, the visualized representation of AIS data can be used to get a clear picture of vessel movement status under the current service level. The maritime traffic management department can manage vessels by observing visualized vessel traveling status. As shown in Figure 8.



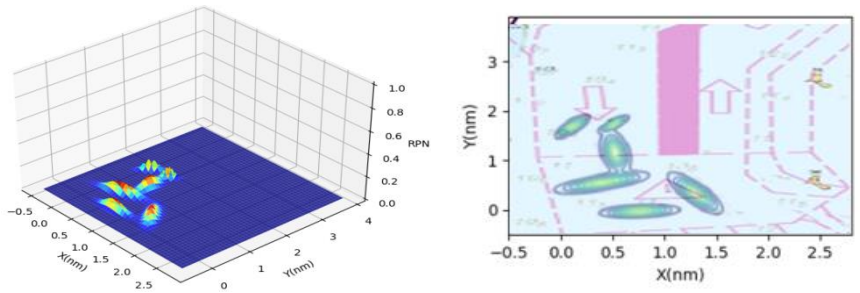
(a)



(b)



(c)



(d)

Figure 8. (a, b) shows the state of vessel at a point in time before the implementation of routing system; (c, d) shows the state of vessel at a point in time after the implementation of routing system.

Table 4. Time Piece Percentage of LOS.

Cyclicity	Date	Excellent (%)	Good (%)	Fair (%)	Passable (%)	Poor (%)
First Week	21.12	1.2	54	44.8	0	0
	23.06	1.7	62.1	36.2	0	0

Second	21.12	4	46	49	1	0
Week	23.06	7.8	40.1	51.3	0.8	0
Third	21.12	0	0.9	96.3	1.9	0.9
Week	23.06	5.2	50.5	44.3	0	0
Fourth	21.12	0	35	61	4	0
Week	23.06	2.5	37.9	57.8	1.8	0
One Month	21.12	1.4	34	63	1.4	0.2
	23.06	4.4	47.6	47.4	0.6	0

As shown in Table 4, it can be seen that LOS varies with the time period. However, the overall distribution across 5 classes matches generally well. The analysis of routing system and traffic organization optimization strategy for Yuxingnao region shows that the percentage of time slices with excellent and good service ratings increased, and the percentage of time slices with passable and poor service ratings decreased. Therefore, it is an indication that LOS in the region has improved. The percentage of time slices with fair, passable and poor service level has decreased significantly, indicating the correctness of the decision to implement the routing system and traffic organization optimization in this region, and the optimization system has achieved a certain optimization effect. However, the proportion of time slices with excellent service level after optimization is only 4.4%, and there is still further optimization space.

5. Discussion

The fact that most of LOS researches are distributed in ports and waterways. However, LOS service measures established based on ports and waterways cannot be directly applied to waterway intersections. At present, there is a lack of a complete LOS evaluation system based on waterway intersections. This research proposes a method applied to waterway intersections from driver's perception. In order to combine various complex factors to give a reasonable quantitative service level evaluation standard for waterway intersections, this research tries to use field theory to internalize the influencing factors that drivers can experience into physical forces acting on the vessel. Finally, it generates a psychological safety field for driver around the vessel, which is one of the innovations of this paper distinguishing it from others.

The safety and efficiency are always two most concerned aspects of vessel navigation. Combined with the analysis of safety and efficiency of navigation, two service measures, namely, degree of orderliness and efficiency of navigation, were proposed and comprehensively considered in waterway intersections. On the basis of the above, by mining and analyzing a large amount of historical AIS data, LOS of waterway intersections was classified into five levels. Such as excellent, good, fair, passable, and poor. Then each level is described in detail, giving a quantitative evaluation standard that conforms to historical navigation of vessels. The reasonability of method is fully demonstrated. The method was applied to analyze Yuxingnao waters. The results show that the method can clearly verify the navigation status of vessel and determine level of service, which indicates that the evaluation system is scientific and feasible.

6. Conclusions

LOS is an important factor for evaluating the traffic performance of waterway intersections. Although the LOS has been relatively mature on highways and widely researched on waterways and

ports, none of them can be directly applied to waterway intersections due to the differences in transportation facilities. In this paper, it is found that the complexity of vessel navigation in waterway intersections is higher than that in ports and waterways by analyzing the data of vessel navigation. Therefore, this method combines vessel information such as position, spacing, speed, and heading with field theory, and takes into account environmental information such as wind and flow. Next, influences such as pressure in driver's mind and environmental factors are transformed into forces that drive vessel's movement. A method applied to waterway intersections is proposed for the first time by comprehensively considering safety and efficiency.

In order to test the feasibility of method, a total of 6G data before and after the traffic organization optimization in Yuxingnao waters were collected for case study. The case study shows that using this approach enables quantitative segmentation of LOS in the region and provides a clear picture at various time periods. The data comparison before and after the optimization of routing system and traffic organization can also clearly show the effect of the region after optimization. This greatly promotes the quantitative evaluation of advantages and disadvantages of routing system and traffic organization scheme, and is beneficial to the improvement of the navigation management level of waterway intersections and whole waters. In addition, this method can evaluate LOS of a region in time by establishing ship fields on its own through vessel navigation data and environmental data, which will further promote the realization of intelligent supervision and dispatch coordination in waterway intersections.

However, there are limitations to the method. Determining LOS is dependent on human subjective evaluation. Therefore, it is a concern to improve the evaluation system by collecting subjective evaluation of drivers. In addition, the method can complete a post-assessment of LOS in waterway intersections. How to further improve service measures and predict LOS of waterway intersections? This is an important direction of future research.

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