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Saturation point of traffic on the channel Based on the Ship Domain

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Abstract: In order to evaluate the dynamic navigation saturation point of the channel which becomes more and more complicated, according to the actual traffic data of the deep-water channel of Shanghai port, the uneven coefficient of vessel arrival was introduced to establish the calculation model of channel dynamic transit capacity and saturation point . Based on the traffic observation data of the deep-water channel, the dynamic saturation point of channel was analyzed with the established model. It turns out that the results of the saturation point of the deep-water channel based on the established model is basically in accordance with the actual situation.

Key words: *transit capacity ; ship Domain ; saturation ; uneven coefficient*

With the rapid development of the international shipping industry, there is an increasingly prosperous scene of the maritime transportation in our country, meanwhile, it occurs many problems. For example, the sea-route is becoming much more crowded, the ship density is also gradually increasing, the navigation environment is much more complex and the port throughput is increasing rapidly. In order to comply with the development trend of the port and meet the demands of the ship safety navigation, it becomes very necessary to analyze and evaluate the channel transit capacity and saturation point.

This paper sets out from the current situation of the deep-water channel in Shanghai port. According to channel existing navigation traffic data, the uneven coefficient of the ship random arrival was introduced to build the channel dynamic transit capacity and saturation model. Finally, the saturation point of traffic on the deepwater channel in Shanghai port was calculated and analyzed comprehensively.

I. MODEL OF CHANNEL TRANSIT CAPACITY

Drawing lessons from the concept of traffic capacity in road traffic engineering, seaport channel transit capacity (also known as the channel capacity), usually means that the possible transit maximum ship tonnage (taking as the ten thousands of ships per unit time as the measurement unit) in one specific channel section in one unit time (year, month, day) under certain ship technical performance and certain navigation conditions.

At present, there are many studies on the channel transit capacity , in which, LIU et al. [1] used queuing theory to calculate the capacity of the limited channel; Li Ziqiang [2] studied on channel capacity through the analysis of the traffic flow of the channel; and Dai Jun, et al.[3]discussed on the calculation method of the capacity of the port restricted channel by using the model of ship domain. In foreign literature, the research area is not wide enough, and to a great extent the methods are mainly based on model prediction and simulation analysis including many empirical factors, lacking of accurate and effective real traffic data to support, thus, the applicability is poor.

On determining of channel transit capacity, different calculation methods were put forward under ideal conditions, including West formula, the Yangtze River formula[4], formula of the Chuanjiang River, Wang Hongda formula, formula of Sunan Canal, Min Zhaobin formula, et al.

With regard to the channel transit capacity, considering that in different time scale, with different size, technical performance, speed of the navigation ships, the water depth, topography, tidal current will change accordingly, therefore, dynamic capacity of the channel is researched here. What the so-called dynamic capacity is the maximum ship transit tonnage in unit time under the real channel conditions and traffic conditions. At the same time, due to the specific constraints on the channel capacity caused by ship's different traffic behavior (crossing, overtaking) in the channel, the channel capacity is reduced to some extent. Then the dynamic channel capacity model is,

$$C_d = W \cdot \rho_{max} \cdot V \cdot a_1 \cdot a_2 \cdot a_3$$

Where, C_d is dynamic channel transit capacity; W is the width of the waterway; ρ_{max} is the theoretical maximum density of ships of per unit channel width. It is determined according to the shape and size of the shipdomain ; V is the average speed of the ship; a1 is the capacity reduction factor caused by the increasing ship flow density and the increasing ship's navigation resistance; a_2 is speed loss factor caused by ship crossing , orovertaking; a_3 is the channel depth change impact factor caused by tidal change .

II. MODEL OF CHANNEL DYNAMIC SATURATION

Channel saturation S is one of the important indexes to reflect the level of the service. Analogying the research results of traffic capacity in road traffic engineering, a new definition is made for the channel saturation. That is, the ratio of the ship flow Q in the channel and the transit capacity C of the channel [5].

S = Q/C[5-6]

Where, the ship flow Q is the ships quantity (or ship tonnage) in unit time under the real traffic conditions. In this paper, the data of the ship's traffic flow is observed and investigated in a continuous time period.

Using L (that is, LOA) as the coefficient for standard ship equivalent conversion, fully considering the ship tonnage scale, then we can reflect the actual traffic flow in the channel and the actual degree of congestion and risk level accurately, that the results of the study can be basically in accordance with the actual situation. Therefore, the uneven coefficient is introduced. That is, the difference traffic flow between the daytime and nighttime in the channel, usually, the traffic volume of the daytime D is greater than that of the night time N.

Uneven coefficient $\lambda_N = 1 + \dfrac{D - N}{Q}$

III. APPLICATION

3.1 Traffic observation data

In January 2014, we performed for a period of one month of AIS traffic observations to the D35 gate line of deep-water channel in Shanghai port. The data analysis is as follows.

3.1.1 Equivalent conversion for traffic flow

Table 1. Statistic number of ships arriving in January 2014

design type/m	*Ship number at port*	*ship proportion/%*	*equivalent conversion*
<50	357	6.6	90
50-100	42	0.8	21
100-150	1336	24.6	1336
150-200	2540	46.8	5080
200-300	1035	19.0	4140
≥300	120	2.2	720
total	5430	1	11297

According to data statistics, the total number of vessels in the 100~150m and 150~200m range is 71.4% of the total flow, while the length of the <100m is 7.4%, and the length of >200m is 21.2%. Therefore, the 150m was chosen as the standard Length L*, and other types of ships convert as the "converted traffic volume"[7] standards by Japanese traffic scholars. Finally, the results are shown in the fourth column of table 3-1. According to the ship domain model proposed on the basis of the Japanese scholar, it is a ellipse ship field which takes the ship as the center, long axis along the direction of the bow and stern line, while short semi axis along the direction of the ship, with its size of 6L/1.6L. For instance, the standard in the field of ship long axis and short axis is 600m,160m[6] respectively.

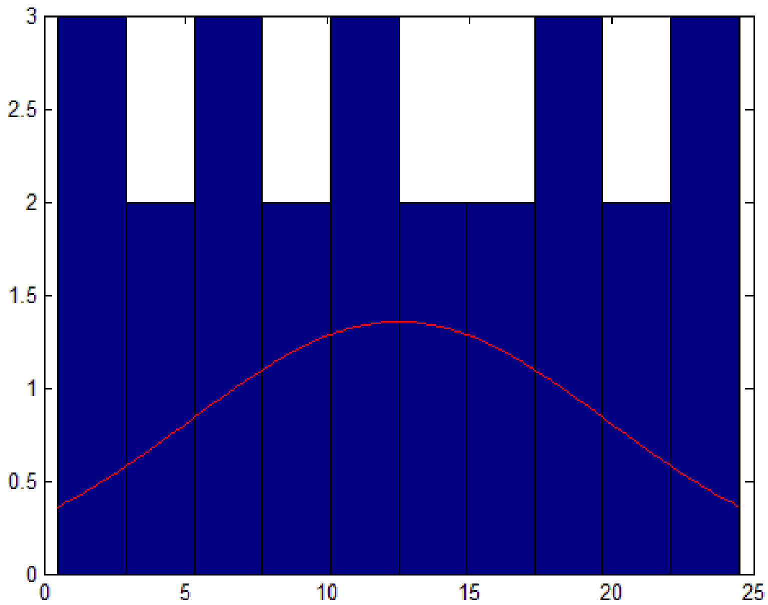
3.1.2 Channel

Yangtze Estuary is an important part of the construction of Shanghai international shipping center, in which the deep-water channel is the main channel of the Yangtze Estuary Waterway. After a successful construction, now it forms one bidirectional channel with total length of 92.2 km, 350-400 meters wide at the bottom [3]. Its main parameters are listed on Table 3-2 .

Table 2. Main parameters of the channel

fragments	*Length*	*turning radius*	*effective width*	*grade of side slope*	*design bottom elevation*
Inside Passage	10.0	1500 3000 6500 4500	350	1:30	-12.5
Yuan yuan the waterway	17.0				
up channel	21.8				
down channel	25.4		400	1:40	
outer channel	18.0				
total length	92.2km				

3.1.3 Ship speed



According to the statistical analysis of the observed data, the speed of the ship in the course of the passage obeys normal distribution , in which, the mean value is 12.5kn (converted to23.0km/h for convenient calculation)and the variance is 2.

3.2 Calculation of the channel transit capacity

In this paper, a_1 is 0.9, a_2 is 0.8, a_3 is 0.8, then the dynamic transit capacity in D35 gate section of the deepwater channel is:

$$C_d = W \cdot \rho_{max} \cdot V \cdot a_1 \cdot a_2 \cdot a_3 = 0.35 * \frac{1}{0.6 * 0.16} * 23.0 * 0.9 * 0.8 * 0.8$$

=48.3

3.3 Dynamic saturation analysis under the condition of uneven coefficient

The AIS traffic observations data to the D35 gate line of the deep-water channel was converted, shown in Table () ,it turns out that the average traffic flow (Q) is 15.7 per hour.

The dynamic saturation of the section S =Q/C=15.7/48.3=32.5%

According to analysis of the AIS flow observation, ship traffic conversion and special weather conditions and other multiple factors, the results show that average rate of sailing in the nighttime of D43 gate line was 33.46%, while rate of sailing in the nighttime under special conditions is 23.85%. Under the current condition of statistical data, the average uneven coefficient (λ 1) of vessel traffic volume in night and day is

λ_1=1+66.54%-33.46%=1.3308

Under special condition, the average uneven coefficient (λ 2) of vessel traffic volume in day and night is

λ_2=1+76.15%-23.85%=1.5230

The dynamic saturation of the day and night in this section (S_1) is

S1=S*λ_1=32.5%*1.3308=43.3%

Under special condition, the dynamic saturation of the uneven ship flow of the day and night in this section (S2) is

S2=S*λ_2=32.5%*1.5230=49.5%

When all ships stopped one hour, the dynamic saturation of ship flow in this section (S_d') is

Sd'=S*2=32.5%*2=65.0%

When all ship stopped 2 hours, the dynamic saturation of ship flow in this section (S_d'') is

S_d''=S*3=32.5%*3=97.5%

From above, it concludes that the channel reach saturation when all ships stopped two hours or more. Compared with the current situation of the deep-water channel in Shanghai port, it proves that the ship navigation is limited due to the bad weather, poor visibility, and tidal level and other hydrological reasons, and the calculation of the saturation of the channel is basically consistent with the actual situation.

IV. CONCLUSION

In order to evaluate the dynamic navigation saturation of the waterway which becomes more and more complicated, according to channel existing navigation traffic data, vessel arrival of uneven coefficient is introduced to establish a dynamic traffic capacity and saturation model to analysis the research on the deep-water channel in Shanghai port. By adjusting the value of different factors, comparing different conditions of the channel, It turns out that the calculated results of channel saturation was basically in accordance with the actual situation.

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