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A New Method to Measure the Passing Capacity of Coastal Waterway Considering Service Level by Simulation Computation

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Abstract: In this paper, a new method to measure the passing capacity of coastal waterway channel is proposed considering service level by computer simulation technique. The passing capacity of coastal waterway channel is first defined by the number of standard ship passing the channel at the required seaport service level. Then the conversion coefficient between the standard ship and other ships is given, which will provide theoretical bases for design, planning and extension of seaport channels. Finally, an application is presented to evaluate the proposed method, and the results show that the larger the ship, the more efficient the waterway channel.

Key Words: *passing capacity, waterway channel, standard ship, seaport service level*

1. INTRODUCTION

With marine ships' developing trend of growing larger, the construction of large-scale deep-water berths has been in a new development time. Gradually, the scales of channels and navigation conditions are becoming the bottlenecks of restricting seaport development. Therefore, it’s urgent for the departments of port planning and construction to determine the passing capacity of coastal channel at different service levels and to evaluate the service status of channels reasonably.

At present, much of the researches focus on the passing capacity of inland rivers channel, which is determined by the possible tonnage of cargoes or vessels within the certain technical performance of vessels and a matrix organization during a certain time (it may be a day, a month, a year or the whole navigation time) (Yu and Ren, 1985). Tonnage of cargoes is called passing capacity of cargoes and tonnage of vessels is called passing capacity of vessels. The scholars of waterway engineering have successively proposed many calculation methods of inland river channels including West Germany formulation, Yangtze River formulation, Chuan River waterway formulation, open waterway formulation, Sunan Canal formulation, Hongda Wang formulation (He et al, 1992; Yangtze River waterway bureau, 2004; Wang, 1998). However, there are obvious differences between inland water and coastal waterway channels. Besides weather conditions, navigation dimensions and rules, the channel passing capacity is also affected by operation scheme, berth conditions and seaport service level. Therefore, the method of calculating inland river passing capacity can not be used to deal with that of coastal waterways.

This paper proposes that the passing capacity of coastal waterway is defined by the number of standard ship passing the channel considering the required port service level. Then the conversion coefficient between the standard ship and other ships is given, which will provide theoretical bases for design, planning and extension of seaport channels. Finally, an example is presented to evaluate the proposed method.

2. DEFINITION AND THERORY OF PASSING CAPACITY OF COASTAL CHANNEL

2.1 Definition of the passing capacity of coastal channels

Generally, the passing capacity of inland river channel is represented by summing the traffic volume of upstream and downstream (Chen et al, 1992).While in marine traffic engineering, the passing capacity is defined as the capacity of a waterway dealing with vessel traffic, which is expressed by the maximum of ships in unit time (Wu and Zhu, 2004). Based on the definition of inland river passing capacity and the related conceptions in marine traffic engineering, a new method to measure the passing capacity of coastal waterway is proposed by the number of standard ships that have passed the waterway in one year under the normal state of port operations, given the specified channel and ship speed. Figure 1 shows the general layout of the costal waterway channel and seaport.

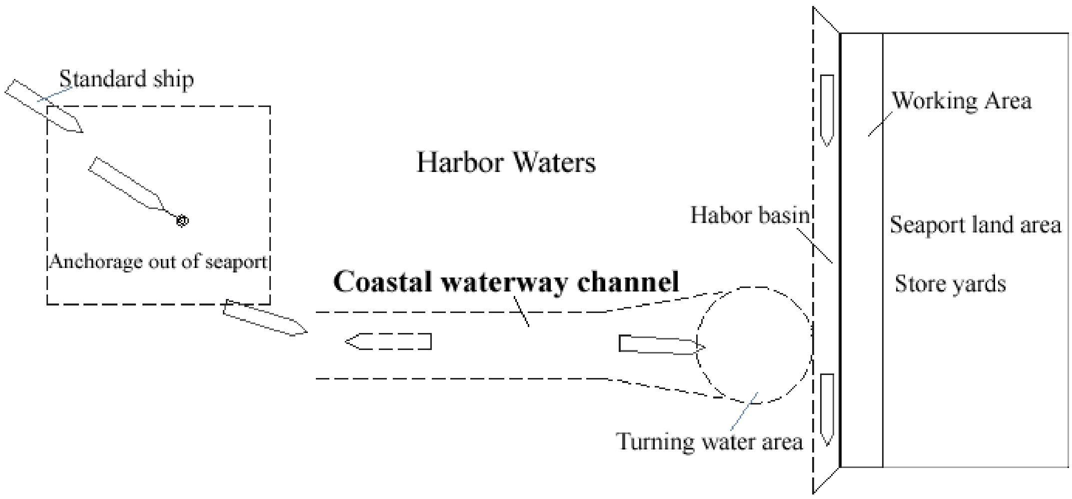


Figure 1 A general layout of the coastal water channel and seaport

In the definitions above, channel conditions include the line number of channel, water depth, tide-bound water level and channel navigation conditions. The normal state of port operations means each berth in a port works under normal production efficiency. Port service level, expressed by *AWT/AT* (denoted by *S*) is the ratio of the average waiting time to the average whole time in port, as illustrated in Equation (1). Standard ship is used for measuring the channel passing capacity, which should be the main type of the world fleet.

$$S = AWT/AT \tag{1}$$

Where *AWT* is the average waiting time; *AT* is the average whole time in port.

2.2 Calculation of ship conversion coefficient

Given the length of channel, the speed of ship, composition of vessels and cargoes, tide-bound water level and service level (AWT/AT, denoted by *S*) are all fixed, the channel passing capacity for seaport is equal to the number of standard ships which have passed the channel.

The steps of calculating ship conversion coefficient are as follows:

First: With given parameter values including the length of waterway channel *L*, the speed of vessels entering port *V*, the depth of tide-bound water level *d* and the arrival standard ship *b*, the service level S (*L*, *V*, *d*) and the corresponding number of passing ships C_b^s can be gotten by simulation computation.

Second: When the qualification including the speed of entering port *V*, the depth of tide-bound water *d*, the single arrival ship *i* are fixed, with the simulation calculation, we can obtain the service level, denoted by *S*(*L*, *V*, *d*) and the number of ships passing channel, denoted by C_i^s. The single arrival ship a means there is only one type ship arrives port neglecting the influence of mixed traffic. Virtually, the process whose result is the channel passing capacity for one type ship is the same as what is shown in the step one.

Third: When the qualification including the speed of entering port *V*, the depth of tide-bound water *d*, port service level *S* are fixed, the conversion coefficient is described as follow:

$$k_i^s = \frac{C_i^s}{C_b^s} \tag{2}$$

Where:

k^s_i: The conversion coefficient of the ship *i* when the port service level is *S*;

C^s_i: The number of a single type ship *i* that have passed the channel when the port service level is *S*;

C^s_b: The number of the standard ship *b* that have passed the channel when the port service level is *S*.

3. SYSTEM MODEL OF SEAPORT NAVIGATION OPERATING SYSTEM

Seaport navigation operating system for seaport, as an important subsystem of harbor production and working system, is a typical discrete event dynamic system. In this system, the discrete event (vessels entering the port) will change the number of anchor, the status of channel and berth and trigger off the handling equipment. Moreover, the handling machines can transform the states of the yards and silos. It is the sustained transmitting and transforming of the event that form the dynamic behaviors navigation and working system in a seaport.

The elements in the navigation and working system are listed in Table 1.

Table 1 Elements of ship operating system in seaports

The basic elements in system	The corresponding elements of ship operating system in ports
Entity	Ships, channels, anchorages, berths, handling machines, cargoes and so on.
Attribute	Vessels tonnage, cargo types, channels length, berth tonnage, handling efficiency and so on.
Time	Time of ships entering the port, time of ships leaving the port and so on
Interval	The time interval of two ship arrivals, time of ships waiting for the waterway, the time of ships in berth etc.
State	Berth busy or free, ships waiting for berth/being in berth/being on operations etc.
Event	Ships arriving in the port, ships entering / leaving the channel, ships leaving the port etc.
Activity	Berths serving for the vessels, ships waiting for the berth in the anchorage etc.
Regulation	First come first served etc.

According to the sailing line of ships waiting for service, the flow chart of ships in and out of the harbor passing the single line waterway is showed in the figure 2.

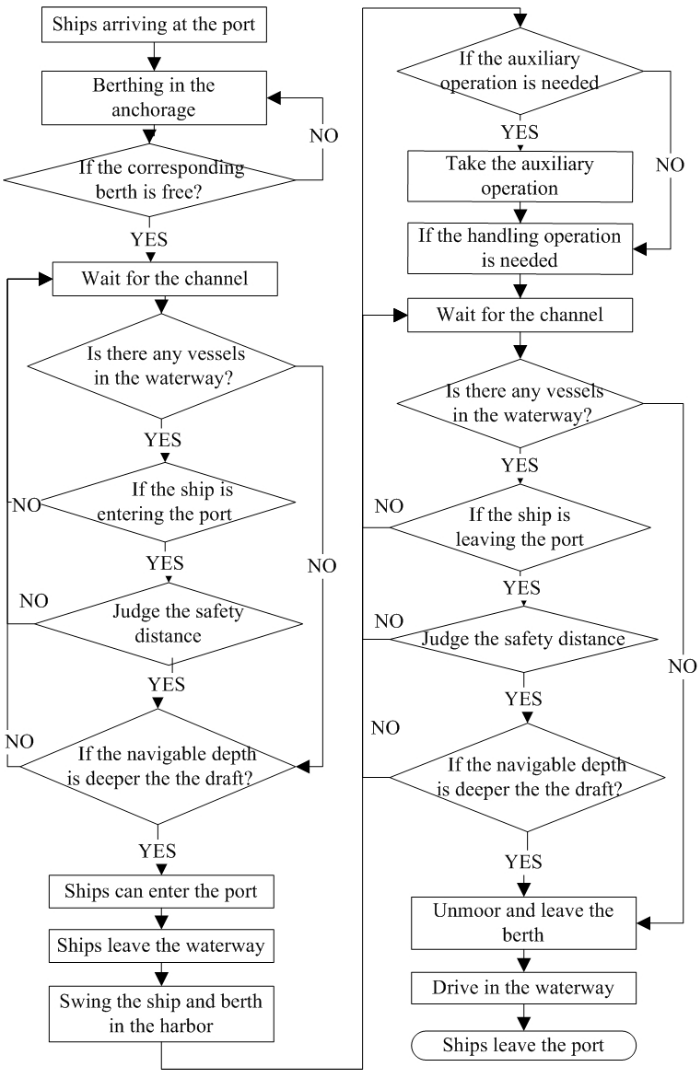


Figure 2 The operation flow chart of ships entering and leaving the seaport

4. SIMULATION MODEL OF SEAPORT NAVIGATION OPERATING SYSTEM

Because of the randomness of ships arriving in seaport, the seaport service state is stochastic. Because of too much elements, complicated configuration and fussy logic relation of ship navigation operating system, it is hard to obtain the results by normal analytic methods, but computer system simulation is a better way to solve these problems. The computer simulation technology always aids the design of berth and handling system, which can be used as a reference for simulating and calculating the passing capacity of waterway channel.

4.1 Introduction of simulation software: Arena

The paper makes use of Rockwell Arena 10.0 to model and simulate for ships navigation working system (Kelton *et al.* 2006). As current visual simulation software, Arena software provides modeling tools, abundant modeling templates and modules and process orientation simulation strategy. Arena is an extensible simulation software package, which can provide an integrated simulation circumstance and support all the steps in simulation research. Arena is an illustrated simulation system basing on hierarchical modeling idea, and synthesizes the SIMAN simulation language and Cinema simulation system which makes Arena have powerful and flexible simulation function. At present, Arena finds wide application in visual simulation field, such as production system, public system and service system.

4.2 Simulation Model

For the emphasis of the current research work, this paper makes several reasonable assumptions to predigest the modeling process of ships navigation operating system as follows:

(1) The meteorological and hydrological conditions are stable in the navigation period of waterway channel;

(2) The rule of ships arriving in seaport has a close relation to the number of berths in the port. The harbor operates smoothly and its resources should be fully used of; ships are assumed to arrive randomly represented as Poisson distribution;

(3) The harbor should have enough berths, which can provide service of waiting for waterway channel and berth for vessels.

(4) The width of waterway channel should satisfy vessels navigation requirements.

(5) Ships should have well technical conditions, keep safe distance from contiguous ships, sail smoothly and not disturb other ships.

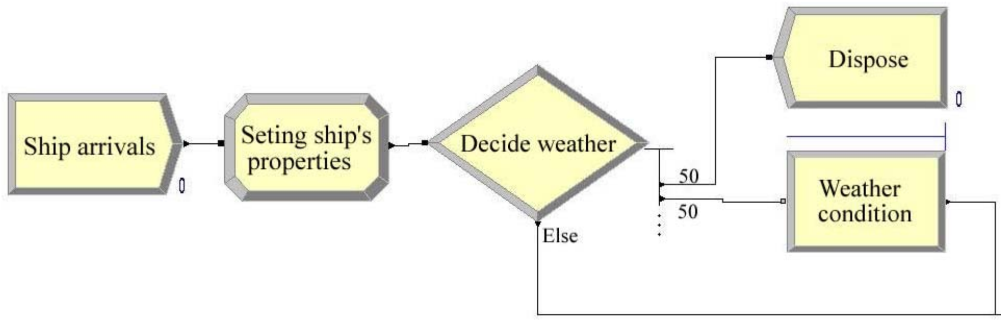
(6) Cargo are in plenty supply, and the quantity of vessels cargo-handling is stable.

(7) Handling efficiency of port machinery keeps stable.

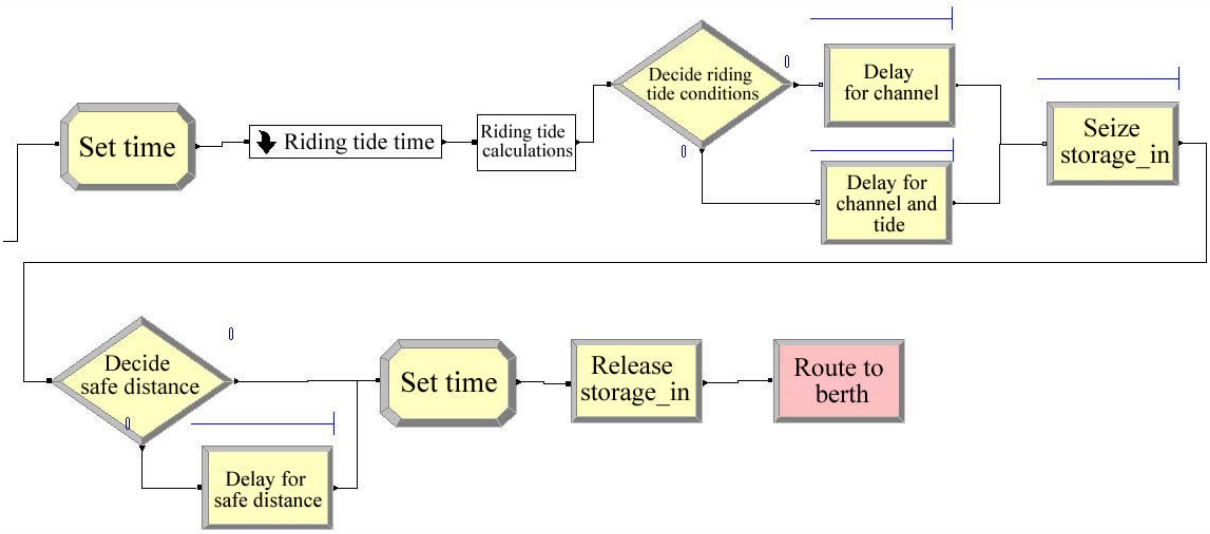
(8) The harbor provide well navigation establishment, navigation aid establishment and well tugs collaboration condition.

Based on assumptions above, a ship sailing simulation model based on standard ship is established according to workflow of vessels sailing, as shown in Figure 3.

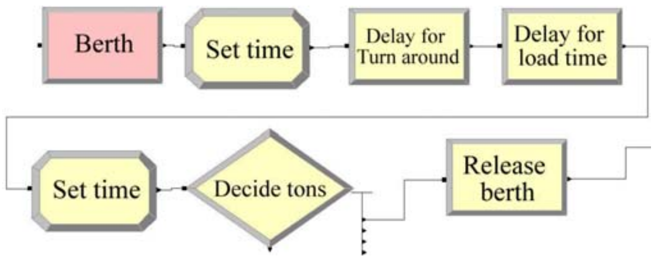
From arriving in seaport for service to leaving seaport, a ship will go through four sub procedures as follows: (a) waiting berth in the anchorage, (b) weighing anchor and entering harbor, (c) berthing and working, and (d) casting off rope and departing.



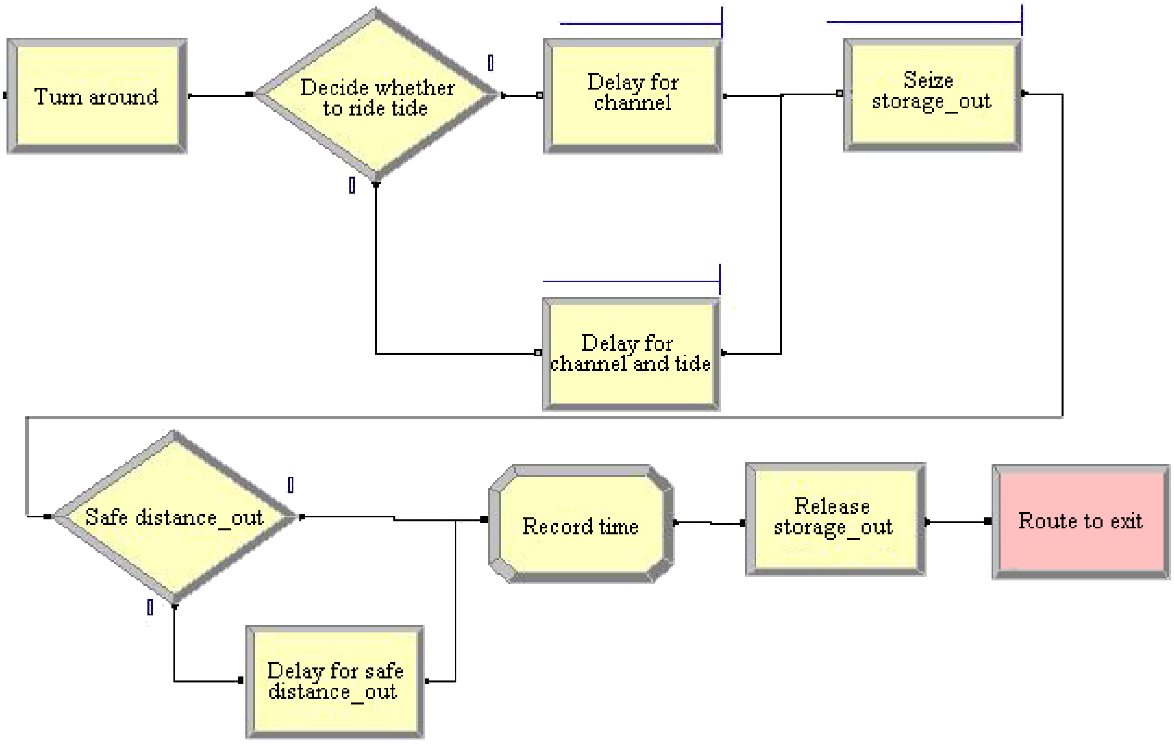
(a) Waiting berth in the anchorage



(b) Weighing anchor and entering harbor



(c) Berthing and working



(d) Casting off rope and departing

Figure 3 Simulation model of vessel berthing system in seaport

5. AN EXAMPLE

Known Conditions and Assumptions:

(1) The length of waterway channel (*L*) is 10000 m;

(2) The velocity of ships entering and departing port(*V*) is 6 kn;

(3) Neglecting the influence of tide;

(4) Ships arrival rate of each berth is shown in the following Table 2.

Table 2 The average rate of each berth in the bulk cargo seaport

Dead weight Tonnage (DWT)	Throughput (10000 tons)	Operating days per year (day)	Cargoes loaded and unloaded (ton)	Time of Loading and unloading (hour)	Average rate of ships arrivals (per hour/per berth)
35000	863.45	365	22000	7.33	25.60
70000	1587.88	365	43000	10.75	33.05
100000	2115.47	365	73000	14.60	41.45
150000	2766.32	365	139000	25.27	64.74
200000	3172.10	365	178000	29.67	74.33

5.1 Passing capacity of coastal waterway channel

Five different bulk cargo vessels are chosen in this study as shown in Table 2 and the standard ship is 100000 DWT bulk cargo carriers. Then the number of standard ship passing waterway channel one year and the level of seaport service *S* are all obtained by established simulation model, as seen Figure in 4. The fitting relation equation (3), calibrated by least squares technique, describes the relationship between the number of standard ship passing waterway channel each year and the seaport service level , and its goodness of fit $R^2 = 0.99942$.

$$C^S = \text{-}3674.44 + 16172.08 \cdot \left(\frac{0.66}{1+10^{11.03 \cdot (0.09-S)}} + \frac{0.34}{1+10^{3.83 \cdot (0.3-S)}} \right) \quad 0.05 \le S \le 0.9 \qquad (3)$$

Where S is the service level of seaport (*AWT*/*AT*); C^S is the number of standard ship when the arrival ship type is i and seaport service level is S, and also equals to the passing capacity of coastal waterway channel with the service level S.

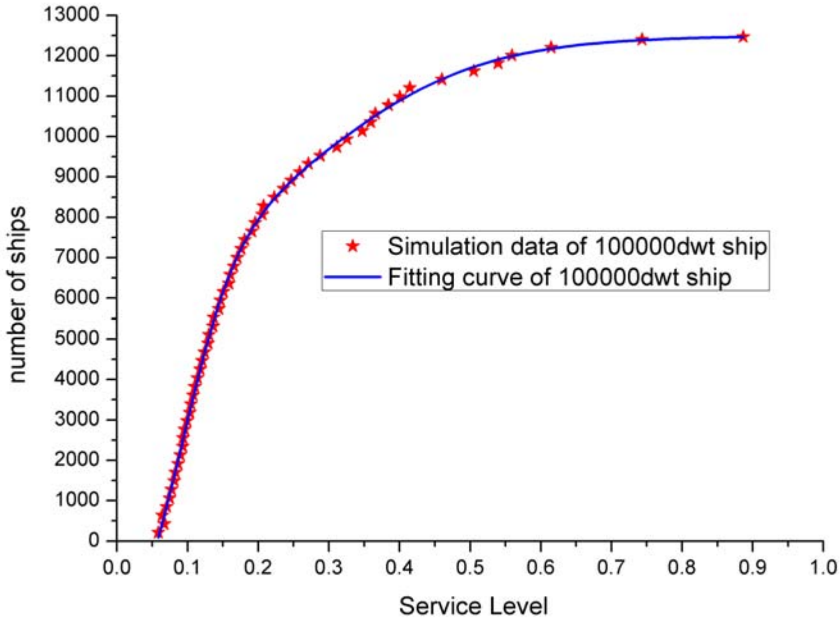


Figure 4 Relationship between the number of standard ship passing waterway channel one year C_b and the seaport service level S

If the incoming ships are other single type ones, we can also obtain the scatter graph of the number of ship passing waterway channel one year and the seaport service level S with simulation, as shown in Figure 5. After fitting curve using least squares technique, the relation equation is obtained, as seen in Equation (4), which describes the relationship between the number of other ships passing waterway channel one year and the seaport service level.

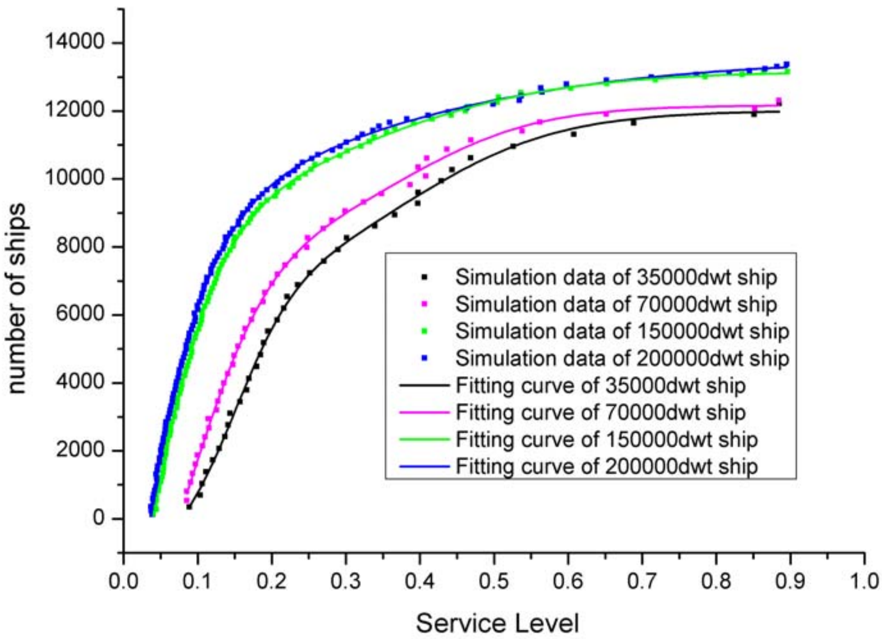


Figure 5 Relationship between the number of other ships passing waterway channel one year N and the seaport service level S

$$N_i = A_{1i} + \left(A_{2i} - A_{1i}\right)\left(\frac{p_i}{1+10^{(L_{1i}-S)h_{1i}}} + \frac{(1-p_i)}{1+10^{(L_{2i}-S)h_{2i}}}\right) \qquad 0.05 \le S \le 0.9 \tag{4}$$

Where:

S : The level of seaport service，calculated by AWT/AT;

N_i: The number of ship passing waterway channel when the arrival ship type is i and seaport service level is S;

$A_1, A_2, L_1, L_2, h_1, h_2$ *and* p: Regression coefficients and their values are shown in Table 3.

Table 3 Regression coefficients of equation (4) and goodness of fit R^2

DWT(t)	A_1	A_2	L_1	L_2	h_1	h_2	p	R^2
35000	-1592.97	12020.53	0.15	0.39	9.96	4.35	0.63	0.99835
70000	-6745.73	12172.80	0.09	0.40	7.62	4.95	0.80	0.99869
150000	-14692.80	13174.79	0.31	0.02	3.13	8.38	0.16	0.99951
200000	-28854.50	13590.39	0.03	-0.02	1.72	8.06	0.22	0.99941

5.2 Ships' conversion coefficient calculations

Figure 6 shows the relationship between ship's conversion coefficients K_i^S calculated by equation (2) and seaport service level S. After fitting curve, we can obtain the relation equation (5) between ship's conversion coefficient and seaport service level.

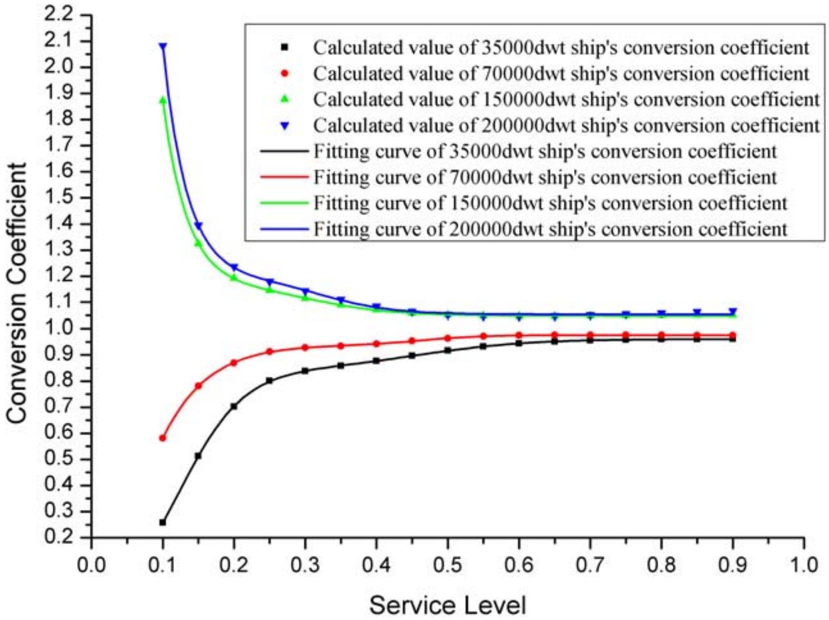


Figure 6 Relationship between ship's conversion coefficient and seaport service level

$$K_i^S = B_{1i} + \left(B_{2i} - B_{1i}\right)\left(\frac{q_i}{1+10^{(g_{1i}-S)d_{1i}}} + \frac{(1-q_i)}{1+10^{(g_{2i}-S)d_{2i}}}\right) \qquad 0.05 \le S \le 0.9 \tag{5}$$

Where:

S : Seaport service level is *AWT/AT*;

K_i^S : Type *i* ship's conversion coefficient with seaport service level is *S*;

$B_1, B_2, g_1, g_2, d_1, d_2$ and q: Regression coefficients and their values are shown in Table 4.

Table 4 Regression coefficients of Equation (5) and their goodness of fit R^2

DWT(t)	B_1	B_2	g_1	g_2	d_1	d_2	q	R^2
35000	-0.09	0.96	0.46	0.12	5.68	9.73	0.11	0.99996
70000	-1.83	0.98	-0.01	0.47	7.74	10.54	0.99	0.99984
150000	1.17	51.70	-0.04	0.31	-12.82	7.45	1.00	0.99987
200000	1.05	2067.41	-0.16	0.32	-12.83	-8.63	0.10	0.9992

The value of seaport service level is between 0.05 and 0.9 in this paper. When S is less than 0.05, seaport service level be unhindered by waterway channel which leads to the ship waiting time is just the time of waiting berth; When S is larger than 0.9, the port congestion is very serious, whose aftermath is vessels can not enter harbor because of the restriction of waterway channel. Based on Figure 4 and Figure 5, we can find the number of ships passing waterway channel is stable when S is larger than 0.9.

From Figure 6, the larger the DWT, the larger the ship's conversion coefficient when the service level is same, which means the larger the DWT, the more the number of ships passing waterway channel. The results show larger vessels make use of the waterway channel more efficiently.

6. CONCLUSION

In this paper, we research the passing capacity of coastal waterway channel, which is one of the most basic issue in port and harbor planning. The number of standard ship passing waterway channel at a certain seaport service level is proposed to describe the passing capacity of waterway channel. Then the seaport service level is converted into a fixed value, which can be used for comparing the passing capacity under different channel conditions. Also the concept of ship conversion coefficient is put forward, which will disclose that types of vessels vary considerably in waterway channel efficiency. Finally, the example shows that the larger the value of DWT (Dead Weight Tons), the more efficient the waterway channel.

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