A SIMULATION MODEL FOR DETERMINING THROUGHPUT CAPACITY OF CONTAINER TERMINALS

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ABSTRACT

Throughput capacity is a vital factor that dominates the suitable time of expansion of container terminals. By analyzing the operation system of container terminals and realizing its complexity, this paper established a simulation model of container terminals to imitate the realistic operation process and determine the throughput capacity of a container berth under various influence factors. The simulation results can be used by decision makers to choose appropriate throughput capacity under required service level and decide the optimal number of berths arranged continuously. The simulation model will be beneficial to guide the construction of container terminals.

Keywords: container terminals, throughput capacity, simulation model, service level

1. INTRODUCTION

As the national economy and external trade continue to expand, seaport container transportation maintains a rapid development in China. Construction of specialized container terminals has been becoming a hot topic in Chinese coastal ports. A good match between throughput capacity and transportation demand is the foremost factor to guarantee the reasonable construction of container terminals, so as to avoid duplication of investment and waste of resources. Thus, throughput capacity is one of the main bases to assess whether the scale of current terminals can fit transportation demand. Besides, the fitness of terminals judged by the throughput capacity is the basis for the government to approve infrastructure projects of terminals and conduct shoreline management. Therefore, it is necessary and urgent to research into throughput capacity of container terminals under the background of accelerated terminal construction and limited excellent shoreline resources, which can not only help to utilize resources efficiently, but also guarantee the investment rationality of terminal constructions.

Currently, the main research methods on throughput capacity are queuing theory and simulation methods. Liu et al. (2008) analyzed the impact of container liner arriving rule, group layout of berths, trend of large vessels and other factors on throughput capacity of container terminals by queuing theory. Shabayek and Yeung (2001) studied the influence of seasonal factors on vessel service time of container terminals. To some extent, due to the complexity of the port operation system, queuing theory models can not accurately reflect the actual operation situations. Therefore, most researchers tended to use simulation methods to study the throughput capacity of terminals. Peng (2004) built a simulation model for a berth of Tianjin Port using object-based computer animation simulation language AUDITION, and the result showed that yard capacity constraints throughput capacity. Yazdani et al. (2005) presented the development of a simulation application called “Port Process Simulator”, which can simulate the port operation scenarios to provide recommendations for end-user to make decisions about increasing throughput capacity. Li, Yu, and Yang (2010) built a container terminal simulation model to simulate the influences of annual operating days, handling amount of a single vessel , service levels and other factors on throughput capacity of container terminals, but it ignored the impact of berth tonnage. Ding (2010) studied the throughput capacity under different combinations of arriving vessels by building simulation model, and found that optimizing the combinations of arriving vessels can improve the utilization of berths and throughput capacity. Ng and Wong (2006) built a simulation model by using simulation language PROMODEL to study the impact of vessel traffic flow interference on throughput capacity within the Hong Kong container terminal. Kia, Shayan, and Ghotb (2002) investigated the positive impact of ship-to-rail direct loading on throughput capacity of a container terminal using the real-time statistics by computer simulation. Longo, Huerta, and Nicoletti (2013) developed a simulation model to recreate the complexity of a medium sized Mediterranean seaport and analyzed the performance evolution of such system with particular reference to the ship turnaround time.

However, the abovementioned models focused only on some essential characteristics of the operation of container terminals, there is little research that takes into account all the other important features such as berth tonnage, handling efficiency of quay cranes, daily working hours, and hauling distance of import and export containers to discuss appropriate throughput capacity of a container terminal.

Therefore, this paper proposes a simulation model to study the impact of all important influence factors on throughput capacity of container terminals using the discrete event simulation software Arena 10.0. The remainder of this paper is organized as follows. In the next section, the composition of container terminals, definition of throughput capacity, model assumptions and analysis of influence factors are separately introduced before the establishment of simulation model. And then, a case study is presented and the throughput capacity is discussed in terms of service level. Finally, the conclusion is briefly described.

2. SIMULATION MODEL OF CONTAINER TERMINALS

2.1. Composition of Container Terminals

The operation system of container terminals can be divided into five subsystems which are vessels berthing/unberthing subsystem, loading/unloading subsystem, horizontal transportation subsystem, storage yard subsystem and gate subsystem, respectively. Nevertheless, there is not only physical relationship between each subsystem, but also event relationship generated by the interaction of entities and resources. An organic whole system is thus formed by all subsystems through traffic flows. Therefore, when studying throughput capacity of container terminals, both the design of each subsystem and their inner relationship should be considered.

2.2. Definition of Throughput Capacity

When determining the throughput capacity of container terminals, one needs to find a proper definition of throughput capacity. In general, throughput capacity of a container terminal is defined as the number of TEUs that a terminal can handle in one year under a specific service level in terms of AWT/AST. AWT/AST denotes the ratio of the average waiting time of a vessel to the average service time of a vessel at berth. *Design Code of Container Terminal for Sea Port(JTS165-4-2011)* recommends that large container terminals (more than 50,000 tons) with three continuous berths and above should select 0.1≤AWT/AST≤0.3, while small container terminals with less than two berths should select 0.4≤AWT/AST≤0.5. The change interval of AWT/AST during the analysis of simulation results is limited from 0.1 to 0.5.

2.3. Model Assumptions

The simulation model is based on the following assumptions:

(1) Berthing rule:

Fixed berthing dock mode, and first come first serve.

(2) Loading and unloading operation rule:

Unloading at first and loading at last.

(3) Device configuration and container truck scheduling rules:

The number of quay crane (QC) and yard crane (YC) is determined according to berth tonnage. The number of yard truck (YT) is deployed according to the number of QCs, and YTs follow the “shortest path” scheduling rule.

2.4. Analysis of Influence Factors

Throughput capacity of container terminals is influenced by a series of factors such as arrival interval distribution of vessels, effective berth utilization rate, handling amount of a single vessel, annual operational days of port, number of handling equipment, handling efficiency of QC, conversion coefficient of TEU, influence coefficient of advanced QCs, yard capacity, management level, etc. From the perspective of practicability and for simplicity, this paper focused on arrival interval distribution of vessels, effective berth utilization rate, handling amount of a single vessel, handling efficiency of QC, and operation time per day.

(1) Arrival interval distribution of vessels. According to the analysis of vessels’ arrival interval of Yantian International Container Terminals, Ningbo Beilun international Container Terminals and Nansha Stevedoring Co., Ltd of Guangzhou Port, we find that arrival interval distributions of vessels are all negative exponential. Hence, the arrival interval distribution of vessel in the simulation model is set as negative exponential distribution.

(2) Effective berth utilization rate. Effective berth utilization rate is an important indicator which can reflect port operation state. In this model, it is taken as 50%~70% according to Design Code of Container Terminal for Sea Port (JTS165-4-2011).

(3) Handling amount of a single vessel. This is one of the most sensitive factors in determining the throughput capacity of a container terminal. According to the practical research, handling amount of a single vessel is influenced by port scale, shipping line and traffic organization. For ocean-going shipping line, the value can be relatively large. For container terminal which is in the endpoint hub port status with point-to-point transportation form, this value may be larger. Take Nansha container terminal (which is in the status of south point hub port) as an example, the handling amount of a single vessel of internal trading shipping line can be up to 3000 TEU.

(4) Handling efficiency of QC. It’s related to mechanical property of QCs, technical level of operators, shipping lines distribution and traffic organization of container terminals, and handling amount of a single vessel as well.

(5) Number of main equipment. The number of QC is connected with port status. In general, mainline port serves larger vessels, and is equipped with more equipment, while feeder port serves smaller vessels, and its equipment is relatively less.

(6) Operation time per day. That is around-the-clock handling operation time and is generally taken as 22~24h. When berth is small and shipping line is less, it can be suitable reduced.

2.5. Establishment of the Simulation Model

Based on the above analysis and assumptions, the simulation model for determining throughput capacity of container terminals can be constructed by respectively establishing vessels berthing/unberthing module, loading/unloading module, horizontal transportation module, storage yard module and gate module, and connecting them with their logistic relationship, as shown in Figure 1. Figure 2 depicts the logistic model for vessel berthing/unberthing module.

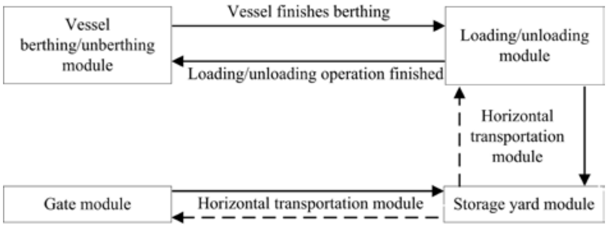

Figure 1: Logistic Relationship between Each Module of Container Terminal Operation System

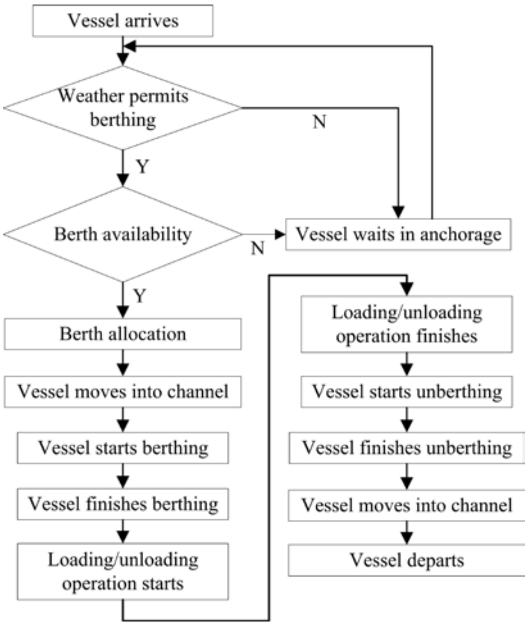

Figure 2: Logistic Model for Vessel Berthing/ Unberthing Module

Vessel berthing/unberthing module includes vessel arrives, vessel waits in anchorage, vessel moves into channel, berthing/unberthing and vessel departs. When handling operation is finished, vessels will leave the port through the channel. During the above processes, vessels are entities, which possess the resources of channel and berth according to the vessels' scale, tonnage and handling amount of a single vessel.

Loading/unloading module consists of vessels loading and unloading process. Vessel loading process means YTs carry containers to wharf apron, and then QCs transfer containers from YTs to vessels. Vessel unloading process refers to QCs transferring containers from vessels to YTs. In these processes, vessels are entities, and the type and scale of the containers need to be determined.

Horizontal transportation module contains receiving and dilivery of containers. Receiving of containers refers to containers transported from gate by external trucks or from berth by YTs to storage yard, while delivery of containers is exactly the opposite. In these processes, containers are entities, and trucks are resources. It is necessary to know where and when to pick up and deliver containers.

Storage yard module includes containers transfered from YTs to the storage yard by YCs, in which containers are entities, and slots and YCs in storage yard are resources.

Gate module is the boundry of simulation model for external trucks. In this process, containers are entities, and lanes are resources.

3. CASE STUDY AND DISCUSSION

3.1. Case Study

The values of the model's input parameters are chosen on the basis of empirical data and *Design Code of Container Terminal for Sea Port (JTS165-4-2011).* Vessel auxiliary operation time and berthing and departing time is set as a uniform distribution in 3h~5h. The passage time of empty entering port truck, loaded entering port truck, empty leaving port truck and loaded leaving port truck are triangularly distributed random variables with parameters (20,25,30) sec, (30,40,50) sec, (5,10,15) sec, and (30,40,50) sec, respectively. The proportions of import and export containers are all 50%. The ratio of operation machines between QC, YC and YT is 1:3:7. The parameter values of benchmark scenario of simulation experimental program are shown in Table 1. The remaining scenarios are simulated by automatically changing the values of parameters such as vessels' arrival interval (determined by number of arriving vessels), handling amount of a single vessel, handling efficiency of QC, and operation time per day around the values of benchmark scenario using the embedded VBA in Arena. Finally, the effect of different influence factors on terminal service level and throughput capacity under different tonnage and berths is achieved.

3.2. Result Discussion

Taking berths that can berth 100000 DWT container vessels (100,000-tons container berths) as an example, the influence of service level on throughput capacity of a berth is obtained by changing intervals of vessel arrival time. The repeat times of simulation for each change are 10, and the simulation result is shown in Figure 3. Similarly, the effect of handling amount of a single vessel on throughput capacity of a berth is shown in Figure 4.

Table 1: Parameter Values of Benchmark Scenario

Vessels tonnage [10,000 tons]	Reference value				
	Handling efficiency of QC [TEU/h]	Vessel arrival number per year [vessels/berth]	Quayside cranes number [unit/berth]	Handling amount of a single vessel [TEU]	Operation time per day [h]
1	40	470	2	TRIA(200, 600, 1000)	24
2	40	410	2	TRIA(300, 7500, 1200)	
3	48	510	3	TRIA(600, 1050, 1500)	
5	48	430	4	TRIA(800, 1650, 2500)	
7	48	330	4	TRIA(2000, 2500, 3000)	
10	60	410	5	TRIA(2000, 2500, 3000)	
12	80	360	5	TRIA(3000, 3500, 4000)	
15	80	400	5	TRIA(3000, 3500, 4000)	

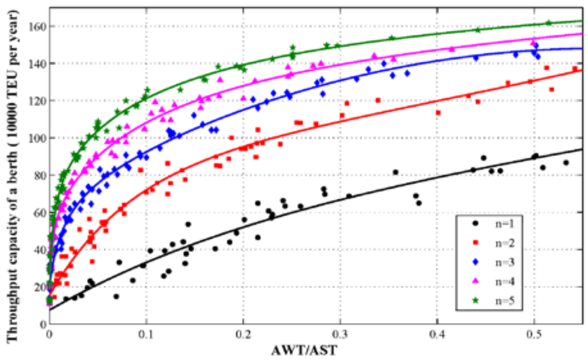

Figure 3: The relationship between AWT/AST and throughput capacity of a berth under n continuous 100,000-tons berth combination

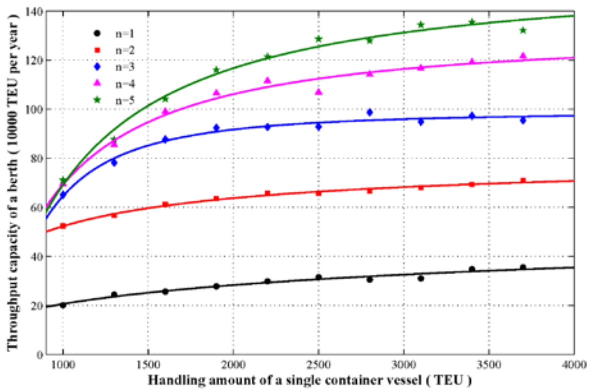

Figure 4: The relationship between handling amount of a single vessel and throughput capacity of a berth under n continuous 100,000-tons berth combination and AWT/AST=0.1

It can be seen from Figure 3 and Figure 4 that:

(1) Throughput capacity of container terminals increases with AWT/AST under the same number of berths. When container terminal is arranged in 4 continuous berths, the throughput capacity of a berth is 1,270,000 TEU under AWT/AST=0.2, and increases by 190,000 TEU than that under AWT/AST=0.1, a gain of about 17.6%. However, the increment of throughput capacity is obtained at the expense of lower service level.

(2) Throughput capacity of container terminals is greatly influenced by the number of continuous berths under the same service level. When AWT/AST equals 0.1, the throughput capacity under 4 continuous berths increases 160,000 TEU than that under 3 continuous berths, which is an increase of about 17.4%. The result shows systematic influence of multiple continuous berths, which is conductive to the reasonable berth allocation and equipment scheduling.

(3) Throughput capacity of container terminals increases with handling amount of a single container vessel under the same number of berths. When container terminal is arranged in 4 continuous berths and AWT/AST equals 0.1, the increase of handling amount of a single container vessel from 1,500TEU to 2,000TEU will result in the increase of throughput capacity of a berth from 940,000 TEU to 1,060,000 TEU.

(4) Multi-berth arrangement can improve the sensitivity of throughput capacity of a berth to handling amount of a single container vessel. Generally speaking, when the handling amount of a single container vessel increases with the same amount from a certain value, the throughput capacity of a berth under the situation with more continuous berths increases significantly more than that with less continuous berths.

4. CONCLUSION

The simulation modeling using computer software is a practical approach to research over the complex large system and to tackle problems that can hardly be solved by mathematical method. Therefore, this paper proposes a simulation model of container terminals to determine the throughput capacity of a container berth under various influence factors. By running the simulation model and analyzing the data obtained, the impact extent of each influence factor on throughput capacity can be found, and the result can be used to determine the optimal number of berths that are arranged continuously under certain conditions. Since the construction of container berths involves hugely investment, the simulation result can play an important role in the reasonable planning of newly planned or expanded container terminals.

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