CONTAINER TERMINALS CAPACITY EVALUATION CONSIDERING PORT SERVICE LEVEL BASED ON SIMULATION

Ningning Li

Dalian Neusoft University of Information
Dalian 116032, China

Jingjing Yu
Guolei Tang*
Da Li
Yong Zhang

Faculty of Infrastructure Engineering
Dalian University of Technology
Dalian 116024, China
*E-mail: tangguolei@dlut.edu.cn

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Container Terminal, Throughput Capacity, Port Service Level, Simulation and Modeling.

ABSTRACT

Throughput capacity is the production capacity of port enterprise under constant exotic environment, and plays a significant role in production control. According to the analysis on influencing factors of throughput capacity and characters of operation system, this paper proposes a simulation model of container terminal operation system based on port service level. By changing input parameters, different simulation schemes can be obtained with the objective to define the relationship between port service level and throughput capacity of container terminals. And some reasonable suggestions can be given to improve the throughput capacity of container terminals.

1. INTRODUCTION

With the development of economy and the expansion of foreign trade, container throughputs of coastal ports have increased rapidly in China. So new container berths should be planned but with limited shoreline resources. The throughput capacity is an important issue involving respective interests from governments and enterprises. To save coastal port resources, and provide scientific and reasonable port resources for shipping lines, the throughput capacity of container terminal should be evaluated reasonably to determine an optimal berth numbers. In China, a mandatory Design Code of General Layout for Sea Port (MTPRC 2014) provides a set of procedures to evaluate container terminal capacities. However, the existing methods evaluate the throughput capacity without considering port service level and interactions between subsystems. Therefore, a practical approach to evaluate the throughput capacities of Chinese container terminals based on MTPRC (2014).

Many researches have been carried out on throughput capacity of container terminals. These achievements are mainly divided into the following three categories. The first one studies the port capacity using queue theory (Wang et al. 2008; Lee et al. 2014). For example, Wang et al. (2008) used Stochastic Petri Net to establish both a hierarchical model of the container terminal capacity and a dynamic model of subsystems to determine the capacities of the subsystems and detect the bottleneck of port system. However, as the data and the queue configuration are more sophisticated, the researchers have to resort to simulation (Demirci 2003, Quy et al. 2008, Imai et al. 2001, 2005, Wanke 2011, Tang et al. 2016, Azab et al., 2016). So the second one focuses on throughput capacities of specific container terminals/berths using simulation (Wang et al. 2004; Wu et al. 2013). For example, Wu et al. (2013) built a simulation model for barge berths of Kwan Chung container terminals to examine the relationship between berthing capacity and service level in terms of vessel waiting time. And the last one covers the impact analysis of the factors on container terminal capacities (Xie 2008; Liu 2009; Ding 2010; Zhang 2013) For example, Ding (2010) established a simulation model to estimate the throughput capacities of a container terminal under different combination patterns of the types of arriving ships. These researches provide invaluable information and insights regarding methodologies how to describe the stochastics characteristics of ship arrivals and berth service, how to evaluate terminal's service level, and how to simulate the ship-berth link planning operation.

Therefore, considering the stochastic and dynamic characteristics of port system (Demirci 2003, Quy et al. 2008, Tang et al. 2016), in this paper, on the basis of Chinese mandatory Design Code (MTPRC 2014), we establish a simulation model of container terminal operations, to estimate the throughput capacity in terms of port service level for container terminals using Arena simulation software (Arena 2017). And the deduced relationships between port service level and throughput capacity of container terminals which are main contributions of this paper, will provide some reasonable suggestions to container terminal planning.

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2. CONTAINER TERMINAL CAPACITY

According to Chinese mandatory Design Code of General Layout for Sea Ports (MTPRC 2014), when planning a container terminal, an important consideration is to provide a sufficient annual container-handling capability (terminal capacity). Obviously, the acceptable level of service provided by a terminal is not considered when evaluating terminal capacity. Therefore, in this paper, we define the container terminal capacity as the capacity of the container terminal, in terms of containers (Twenty-foot Equivalent Unit, TEU) that can be handled per year with an adequate service level.

The chosen indicator for port service level is the average waiting time / average service time ratio, expressed as S=AWT/AST, in which, AWT represents the average waiting time of ships in the port and AST represents the average service time required for loading and discharging a ship under normal circumstances.

3. SIMULATION MODELING FOR CONTAINER TERMINAL OPERATIONS

3.1 Basic Assumptions

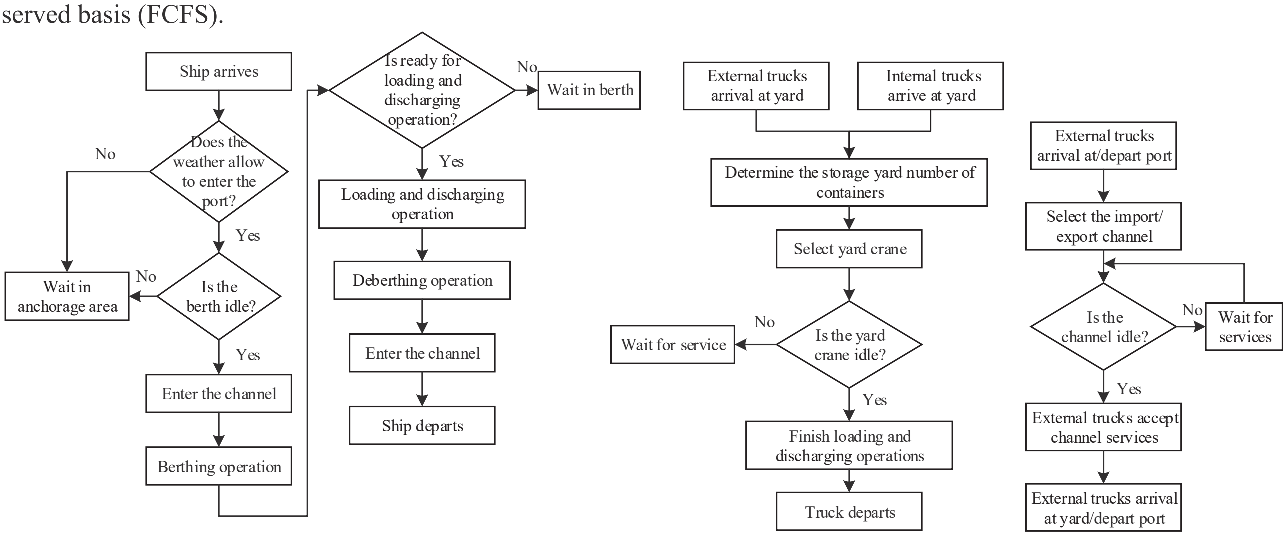
(1) Container ships are served on first-come-first-served basis (FCFS).

(2) The loading operation at apron starts once the discharging operation is finished.

(3) The quay cranes and yard cranes are equipped according to the berth tonnage, and based on the number of quay cranes, the internal trucks can be allocated with the principle of shortest path.

3.2 Simulation Model Implementation

In most container terminals in China, the orientation of the storage blocks is parallel to the shore. And rubber-tired gantry cranes (RTGs) are used for the yard operations, and internal and external trucks for the horizon transport between quay and storage yard, as well as between storage yard and landside interfaces (Ji et al. 2010). According to the logic model illustrated in Figure 1, we implement a simulation model to simulate the processes of Chinse container terminal, which covers five sub-models, which are ship berthing and deberthing sub-model, ship loading and discharging sub-model, horizontal transport sub-model, yard operation sub-model and gate operation sub-model.



(a) Container terminal Front Operation (b) Yard Operation (c) Gate Operation

Figure 1: The Related Logical Model of Container Terminal Operation

We establish the model using Arena software, and the Figure 2 shows the simulation model of container terminal operations using Arena. The modeling processes are described as follows:

(1) Ship berthing and deberthing sub-model simulates the process that the inbound ship travels through the channel from the anchorage and arrives at the berth, and after the berth service time for discharging and loading containers, the outbound ship deberths, travels through the channel and leaves the port. In this sub-model, the entity is the ship with some attributions, such as the dimension, tonnage and single ship loading and discharging capacity.

(2) Ship loading and discharging operation sub-model includes two processes: loading and -discharging. The loading process is that the internal trucks transport containers to the terminal apron, and then the assigned quay cranes load containers onto the ship. The discharging process is to unload containers onto trucks from the ship. In this sub-model, the entity is the container with assigned type and dimensions.

(3) Horizontal transport sub-model simulates the horizontal movement between the berth and yard or gate. In this sub-model, we set the container and yard truck as the entities, and its attributes of truck include the assigned yard block, and travel route.

(4) Yard operation sub-model simulates the loading and discharging process when containers are transported to the yard by trucks. In this sub-model, the entity is the container, and the resources are the bays for stacking containers and RTGs in the block of destination.

(5) The gate operation sub-model provides entrance roads for external trucks. The entity in this sub-model is the trucks, and the resources are the access roads.

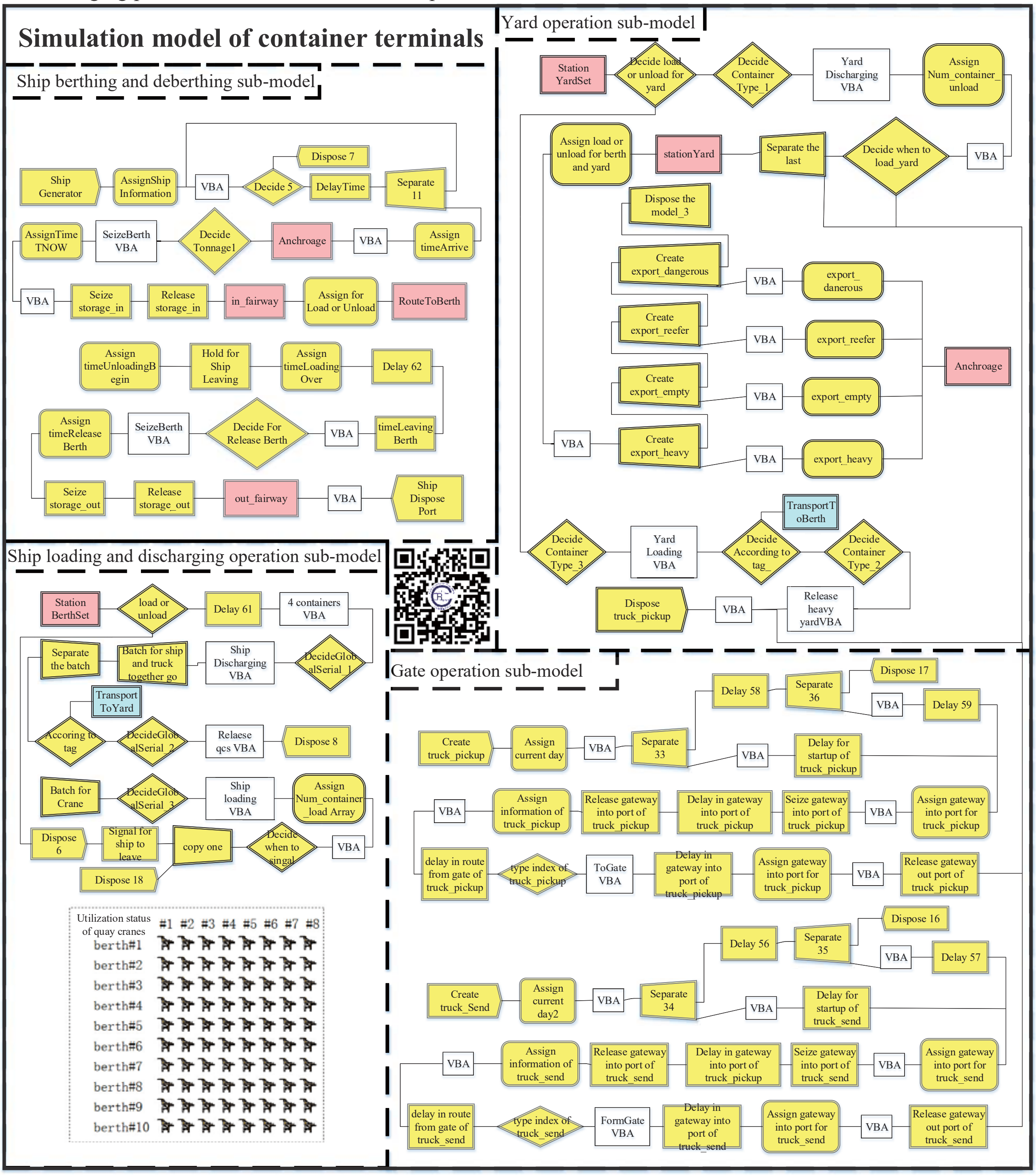


Figure 2: The Simulation Model of Container Terminal

3.3 Model Verification and Validation

To verify and validate the implemented simulation model that it is correctly implemented with respect to the process of throughput capacity, we take three effective measures: Firstly, the model is developed in stages and through sub-models in which each stage is individually examined by a subject-matter expert. Secondly, tracing approach is used throughout the model development phase. Via tracing, we compare the simulation results with manual calculations to check if the logic implemented in the model is as intended. Finally we take Yantian International Container Terminal (YICT) as the example. The actual throughput of YICT is 8.62 million TEU in 2010. And model parameters can be obtained according to the actual operation situation of YICT in 2010. Then the throughput calculated by using this model is 8.74 million thousand TEU, with the discrepancy of 1.39%. So the implemented simulation model is reliable and can be used for further study.

4. RELATIONSHIP BETWEEN PORT SERVICE LEVEL AND THROUGHPUT CAPACITY OF CHINESE CONTAINER TERMINALS

4.1 Simulation Setup

Container terminal characteristics include the number of berths and their tonnages, and distribution of berth service time. In this study, the simulation experiments evaluate 8 classes of n-DWT berths i.e., n = {10000t, 20000t, 30000t, 50000t, 70000t, 100000t, 120000t, 150000t}, and 6 options for the number of each class of berths, n_{bth} = {1, 2, 3, 4, 5, 6}, totaling 48 container terminal scenarios to be investigated.

The values or distributions of the simulation model parameters, are determined according to Chinese mandatory Design Code of General Layout for Sea Ports (MTPRC 2014). For example, the ships arrive rates follow Poisson distribution with the daily number of ship arrivals varying within certain ranges. Other parameters' values are listed in Table 1 and 2.

Table 1: Some Model Parameters

Model parameters		Value
Time (h)	Auxiliary operation and berthing time	3~5
Efficiency of yard handling equipment (TEU/h)	Heavy container yard	40
	Empty container yard	60
	Dangerous container yard	40
	Refrigerated container yard	40
Gate inspection time (s)	Ingate empty trucks	TRIA(20,25,30)
	Ingate loaded trucks	TRIA(30,40,50)
	Outgate empty trucks	TRIA(5,10,15)
	Outgate loaded trucks	TRIA(30,40,50)

Table 2: Model Parameters of equipment

Tonnage DWT (t)	Design efficiency of quay crane(TEU/h)	Number of quay crane per berth	Number of trucks per quay crane	Number of RTGs per quay crane
10000	40	2	14	8
20000	40	2	14	8
30000	48	3	21	12
50000	48	4	28	16
70000	48	4	28	16
100000	60	5	35	20
120000	80	5	35	20
150000	80	5	35	20

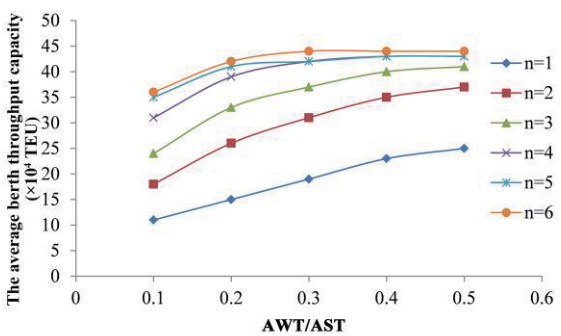
4.2 Analysis and Discussion

Running the simulation model, the relationship between port service level (AWT/AST) and average berth capacity (P_t) of container terminals with the corresponding of change in the number of berths for different tonnages of berths can be obtained:

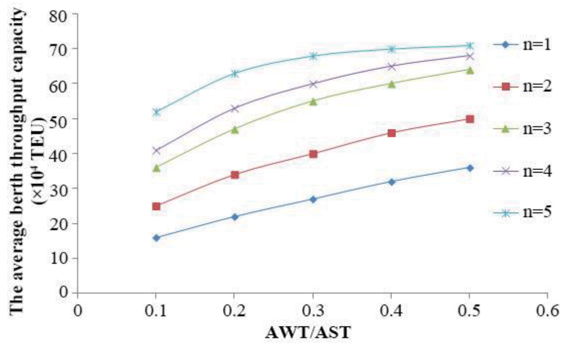
(1) As shown in Figure 3, given the same number of berths, the terminal throughput capacity increases with the values of AWT/AST. And the relationship between terminal capacity and AWT/AST follows an exponential function with monotone increasing.

(2) As shown in Figure 4, given the same value of AWT/AST, when the number of berths is larger than 3~5, the throughput capacity of marginal berths drops rapidly. Therefore, a terminal with 3~5 berths is relatively economic and reasonable design.

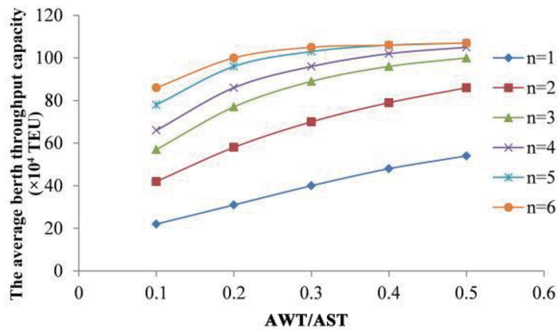
(3) Given the same number of berths, container berth can be divided into 4 classes (10,000/20,000 DWT), 30,000 DWT, (50,000/70,000 DWT), and 100,000 DWT based on throughput capacity with a certain port service level. The recommended terminal throughput capacity in terms of AWT/AST are listed in Table 3, which are used to evaluate the terminal capacity and determine the number of new berths.



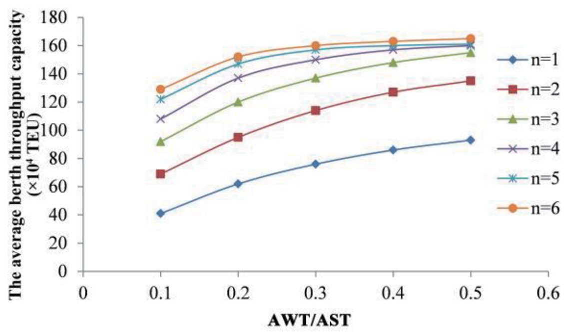
(a) 10,000/20,000 DWT Berth



(b) 30,000 DWT Berth

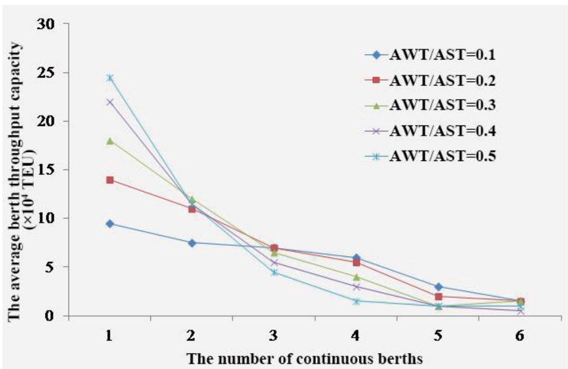


(c) 50,000 DWT Berth

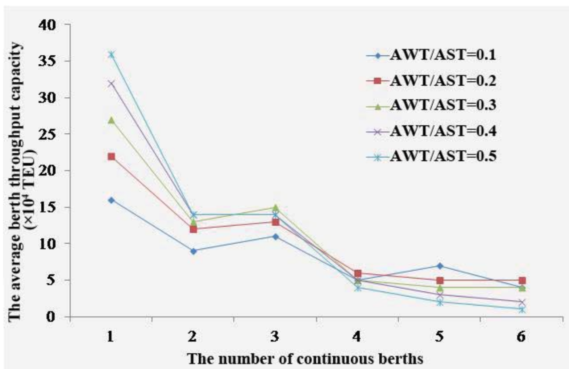


(b) 100,000 and above DWT Berth

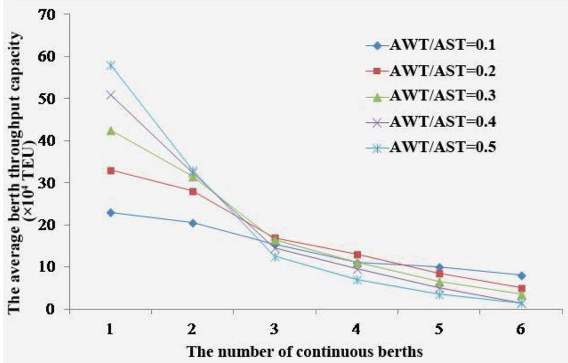
Figure 3: The Relationship between AWT/AST and Average Berth Throughput Capacity with Different Combination of Berths



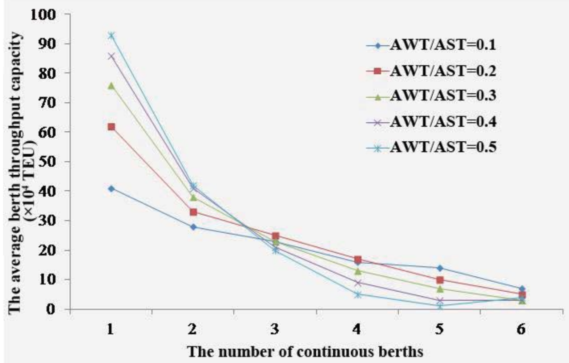
(a) 10,000/20,000 DWT Berth



(b) 30,000 DWT Berth



(c) 50,000 DWT Berth



(b) 100,000 and above DWT Berth

Figure 4: The Relationship between Different Number of Continuous Berths and Average Throughput Capacity of Marginal Berth with Different Tonnage of Berths

Table 3: Berth Throughput Capacity for Different Number of Continuous Berths with Varying Berth Tonnage

The Number of Continuous Berths	Tonnage of Berths	AWT/AST				
		0.1	0.2	0.3	0.4	0.5
1	10,000/20,000 DWT	10	14	18	22	25
	30,000 DWT	16	22	27	32	36
	50,000/70,000 DWT	23	33	43	51	58
	100,000 DWT	41	62	76	86	93
2	10,000/20,000 DWT	17	25	30	34	36
	30,000 DWT	25	34	40	46	50
	50,000/70,000 DWT	44	61	74	84	91
	100,000 DWT	69	95	114	127	135
3	10,000/20,000 DWT	24	32	37	39	41
	30,000 DWT	36	47	55	60	64
	50,000/70,000 DWT	59	78	91	98	104
	100,000 DWT	92	120	137	148	155
4	10,000/20,000 DWT	30	38	41	42	42
	30,000 DWT	41	53	60	65	68
	50,000/70,000 DWT	70	91	102	108	111
	100,000 DWT	108	137	150	157	160
5	10,000/20,000 DWT	33	40	42	43	43
	30,000 DWT	48	58	64	68	70
	50,000/70,000 DWT	80	100	108	113	114
	100,000 DWT	122	147	157	160	161
6	10,000/20,000 DWT	35	41	43	44	44
	30,000 DWT	52	63	68	70	71
	50,000/70,000 DWT	88	105	112	114	116
	100,000 DWT	129	152	160	163	165

5. CONCLUSIONS

In this paper, we have established a simulation model of the container terminal operation system to obtain the relationship between the port service level and the throughput capacity of container terminals. According to the results of this simulation model, we can draw some conclusions.

(1) The average berth throughput capacity of container terminals increases exponentially with the value of the port service level (AWT/AST) increasing given the same number of berths.

(2) The continuous berth number *n* has great influence on the average berth capacity of container terminals. And the continuous arrangement of 3~5 berths is relatively economical and reasonable.

(3) The recommended terminal throughput capacity in terms of AWT/AST are deduced, which are used to evaluate the terminal capacity and determine the number of new berths.

The simulation model provides technical support for the further systematical research on the throughput capacity of container terminals, and it can also be used as a guide for the planning and operation of container terminals.

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REFERENCES

Arena: Arena http:// www.arenasimulation.com /. (Accessed from January 2017)

Azab A.E, Amr B, Eltawil. 2016. "A Simulation Based Study of the Effect of Truck Arrival Patterns on Truck Turn Time in Container Terminals". *In Proceedings of the 30th European Conference on Modelling and Simulation*, 80-86.

Demirci, E. 2003 Simulation modeling and analysis of a port investment, Simulation, 79, 94-105.

Ding YZ 2010. "Throughput Capacity of a Container Terminal Considering the Combination Patterns of the Types of Arriving Vessels". *Journal of Shanghai Jiaotong University (English Edition)*, Vol 15, No.1, 124-128.

Imai, a., Nishimura, E. and Papadimitrou, S. (2001) The dynamic berth allocation problem for a container port. Transportation Research Part B, 35: 401-417.

Imai, a., Sun, X., Nishimura, E., Papadimitrou, S. (2005) Berth allocation in a container port: using a continuous location space approach. Transportation Research part B, 39: 199-221.

Lee B.K. et al. 2014. “Analysis on Container Port Capacity: A Markovian Modeling Approach.” *OR Spectrum*, Vol 36, No.2, 425–54.

Liu F. 2009. “Study on the Berth Capacity and Related Indexes of Container Terminal”. Dalian Maritime University, Dalian, China.

Ministry of Transport of the People’s Republic of China (MTPRC). (2014) Design code of general layout of sea ports, JTS 165-2013. Beijing: China Communication Press.

Quy, N.M., Vrijling, J.K., and Van Gelder, P.H.A.J.M. (2008). "Risk-and simulation-based optimization of channel depths, entrance channel of Cam Pha Coal Port." Simulation, 84, 41-55.

Tang, G., Guo, Z., Yu, X, Song, X, Du P. (2014) “SPAC to improve port performance for seaports with very long one-way entrance channels.” Journal of Waterway, Port, Coastal, and Ocean Engineering, 140(040140114).

Wang WY. et al. 2008 “System Simulation of Capacity for Container Terminal Based on Stochastic Petri Net”. *In Proceedings of 2008 International Conference on Automation and Logistics*, 2889-2892.

Wang ZM. 2004. “On the Reasonable Throughput Capacity of Container Terminals”. *Port and Waterway Engineering*, No.3, 16-20.

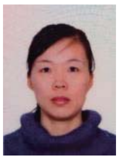
Wanke, P. (2011). Ship-berth link and demurrage costs: evaluating different allocation policies and queue priorities via simulation. Pesquisa Operacional, 31(1), 113-134.

Wu, YZ. Peng, C. 2013. “An Analysis of Capacity and Service level of the Container Terminals of Hong Kong”. *In Proceedings of the 10th International Conference on Service Systems and Service Management,* 404-409

Xie CX. 2008. “Study on Some Problems about the Calculation of the Berth Capacity of Container Terminal”. Dalian Maritime University, Dalian, China.

Zhang LN. 2013. “The Influence of Container Arrival Distribution on the Throughout Capacity”. Dalian Maritime University, Dalian, China.

AUTHOR BIOGRAPHIES



NINGNING LI studied in Shandong University from 2001 to 2005, and got the Bachelor’s Degree. Then she went to Dalian University of Technology and obtained the Master’s Degree in 2008. And now, she as an associate professor is working in Dalian Neusoft University of Information, focusing on data mining and mobile application.

JINGJING YU was born in Chaoyang City, Liaoning Province, China, and went to Dalian University of Technology, where she majored in port and waterway engineering and obtained the Bachelor’s Degree in 2015. Now, she is studying for a Doctor’s Degree in the field of simulation for port and waterway engineering analysis. Her e-mail address is: yigaoyujingjing@mail.dlut.edu.cn, and her Webpage can be found at http://port .dlut.edu.cn.

DA LI was born in Weifang City, Shandong Province, China, and went to Harbin Engineering University to study port and waterway engineering. In 2016, he obtained the Bachelor’s Degree. Now, he is studying for a Master’s Degree in the field of simulation for port and waterway engineering analysis in Dalian University of Technology. His e-mail address is: dlutllida@mail.dlut.edu.cn, and his Webpage can be found at http://port.dlut.edu.cn.

YONG ZHANG was born in Zaozhuang City, Shandong province, China, and went to Dalian University of Technology. Where he majored in port and waterway engineering and obtained the Bachelor’s Degree in 2016. Now he is studying for a master‘s Degree in the field of simulation for port and waterway engineering analysis. His e-mail address is horizon@mail.dlut.edu.cn and his Webpage can be found at http://port.dlut.edu.cn

GUOLEI TANG went to Dalian University of Technology, where he obtained the Doctor’s Degree in Hydrology and Water Resources in 2009. He worked for a couple of years for the simulation modeling in engineering, and now, he is leading a large research group in the field of simulation for port and waterway engineering. His e-mail address is: tangguolei@dlut.edu.cn, and his Webpage can be found at http://port.dlut.edu.cn.