3D SIMULATION MODELING OF APRON OPERATION IN A CONTAINER TERMINAL

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KEYWORDS

Container Terminal; Quay Crane; 3D Simulation Modeling; Operation Efficiency.

ABSTRACT

In response to the phenomenon that some container terminals are excess capacity and some others are overloaded because of the imbalance of transportation development, this paper proposed a 3D simulation model of operation system for the container terminal apron. First, we study the characteristics of operation system for container terminal apron. Second, a 3D simulation model of terminal apron operation is implemented, which includes sub-model of layout, sub-model of setting variables and parameters, sub-model of ship arriving, sub-model of loading and discharging operation, and sub-model of horizontal transport and yard operation, as well as sub-model of 3D animation. Finally, the implemented model is applied in practice to examine the impact of the time of single operation of the quay crane, the number of trucks allocated for each working path and the number of yard cranes equipped for each block on the operation efficiency of terminal apron. And the results show the proposed simulation model performs well that can provide experience and reference for exploring terminal apron effectively.

1. INTRODUCTION

As is known to all, the port enterprise is a service industry with large capital investment. From the early stage of land acquisition to construction and the purchase of large port handling machinery, every stage needs to take economy into consideration. For this reason, the operators make the best use of the equipment in the port to increase the port economic interests. However, for peak hour of ship arrival, the equipment may be inadequate for the ships, and the ships have to wait for idle equipment, which leads to the losses for both the port authority and the ship owners. On the contrary, if the port authority aims at providing a high level of service for the ship, it is inevitable to increase the number of equipment and improve production capacity, which would decrease the waiting time of the ship but increase the idle time of berths and equipment when the arriving ships are fewer. Therefore, to design and operate a successful container terminal, an effective model is needed to help planners to evaluate and explore the operation efficiency and utilization of equipment.

In the recent years, many scholars at home and abroad have made great progress in the modeling and simulation of the container terminal operating system, and developed many new modeling and simulation techniques. The foreign scholars mainly focus on the operational simulation. For example, Sun et al. (2012) introduced a general simulation platform, named MicroPort, which aims to provide an integrated and flexible modeling system for evaluating the operational capability and efficiency of different designs of seaport container terminals. And Bruzzone et al. (2013) presented an advanced high level architecture federation of simulators. The federation of simulators is used for operators' training in terminal containers. The federation includes multiple container handling equipment simulators. In addition, Azab and Eltawil (2016) developed a discrete event simulation model to study the effect of various truck arrival patterns on the truck turn time in container terminals. And the result showed the influence of the arrival patterns on the turn time of external trucks. In China, the development and application of the container terminal simulation system also received much attention and obtained a series of research and application results. Zhang et al. (2016) put forward the idea that the operation efficiency by planning the block length reasonably based on the analysis of the operation of container terminals. They built the container terminal operation simulation model based on the computer simulation technology and research the effect of block length on the operation efficiency of container terminals through simulation experiments. Ren (2011) used the software FlexSim to study the quantitative relations of container ships, cranes, berths, and container trucks Lin (2011) studied the loading and discharging process of super large container ships by using the software WITNESS. And they obtained optimization plan according to the analysis on the parameters of loading and discharging

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process. Ji et al. (2007) developed an optimization model aimed at minimizing the operation time of trucks. And they also designed an algorithm to solve the optimization model and carried on digital simulation experiments to obtain the valid numeric results.

This paper presents a 3D simulation model of operations on the container terminal apron using the software AnyLogic (2017). And the model emphasizes on the analysis on the influencing factors of operation efficiency and utilization of equipment and 3D visual operation process for container terminal apron, which are the main contributions of this paper.

2. CONTAINER TERMINAL APRON OPERATION

The container terminal apron is the seaside of a terminal which involves in the loading and unloading of vessels. On arrival, a vessel docks at a free berth. Most container terminals in China use quay cranes for the (un)loading operations of containers (from) onto vessels. And internal and external trucks for the horizon transport between quay and storage yard, as well as between storage yard and landside interfaces.

As shown in Figure 1, the operation process of container terminal apron includes the ship berthing, loading and discharging, as well as the ship departing. And among these, the container loading and discharging process dominates the operation process of terminal apron. And the scheduling of terminal apron mainly includes the berth allocation and the quay crane assignment, both of which have important influence on the efficiency of the container terminal.

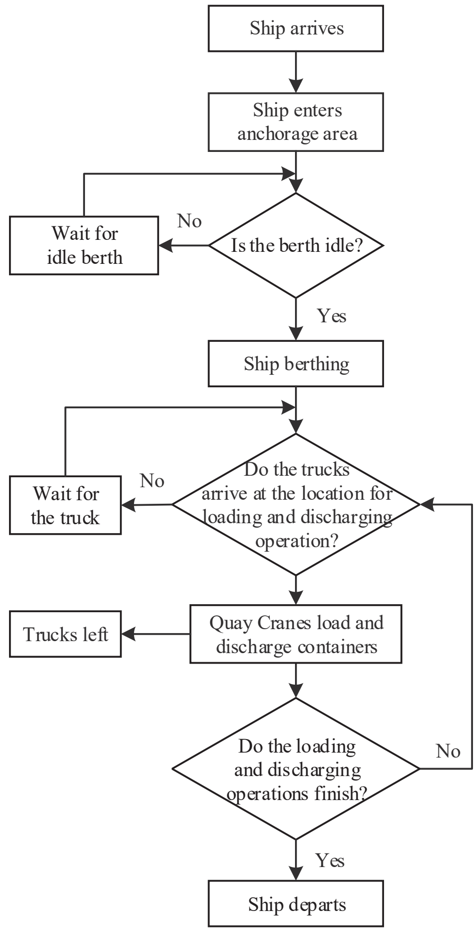

Figure 1: Logical Model of Operation for Container Terminal Apron

3. 3D SIMULATION MODEL OF CONTAINER TERMINAL APRON OPERATION

To evaluate the performance of terminal apron operation, we establish a 3D simulation model to simulate the process of terminal apron operation visually using AnyLogic software (2017).

According to the characteristics of terminal apron operation and interactions with yard operation, the simulation model proposed in this paper includes 6 sub-modules, including terminal layout and setup sub-module, ship behavior sub-module, quay crane operation sub-module, horizontal transport and yard operation sub-module and 3D animation sub-module.

3.1 General Assumptions

(1) Reshuffle operation is not considered in quay crane operation;

(2) The acceleration and deceleration processes of trucks are not implemented in this simulation model.

(3) The yard cranes would return the original location after loading and discharging operation.

3.2 Terminal Layout and Setup Sub-Module

This sub-module is used to visualize the layout of a specific container terminal, and set the working paths and points of container trucks.

(1) Container terminal Layout. To realize the layout of the container terminal, we use the software AutoCAD to draw the masterplan of the terminal layout and then import it to AnyLogic. The plan is consistent with the actual size of the container terminal to facilitate the analysis on the operation process in terminal apron.

(2) The transfer routes and transfer points for yard trucks are set according to the layout plan of the container terminal. In this sub-model, the transfer routes are the paths for horizontal transport, and the transfer points refer to the specific locations for loading and discharging operation.

(3) Entities and service resources. In the simulation system, the entities mainly include containers and ships. And the resources include container trucks, quay cranes and yard cranes. Correspondingly, the parameters for entities are the type and number of containers, the type and number, as well as the arrival regulation of ships. And the parameters of service resources include the

number and speed of trucks, the number and handling time of quay cranes and yard cranes, as well as the yard capacity of the container terminal. This sub-model is also used to setup values of variables and parameters.

3.3 Ship Behavior Sub-Module

This sub-model is used to simulate the process of ship arriving, ship berthing and ship departing.

(1) Ship arriving: The ship arrives at the port according to ship arrival pattern. And the operator of the port makes a berthing plan for the ship according to the arrival information in advance. In this sub-model, the “ShipArrival” module is used to generate the arriving ships in accordance with regulation set in sub-module of set variables and parameters.

(2) Ship berthing: If the assigned berth is occupied by other ships, the ship should wait in anchorage area. And when the assigned berth is idle, the ship starts berthing operation according to the guidance of operators. In this process, the Module “SelectOutput5” is used to evaluated whether is assigned berth is idle. If the assigned berth is occupied with other ships, the Module “Delay” is applied to prevent the ships from berthing. On the contrary, if the berth is idle, the ship starts berthing operation, and the Module “Source” is used to generate containers based on the “Shiptype” function defined in the sub-module of Terminal Layout and Setup sub-module. Then the “SelectOutput5” module is used to allocate quay cranes and call the trucks to move to the terminal apron with the purpose of accomplishing the loading and discharging operation.

3.4 Quay Crane Operation Sub-Module

This sub-module is used to realize the loading and discharging operations. Figure 2 shows the logic model of loading and discharging operations on container terminal apron.

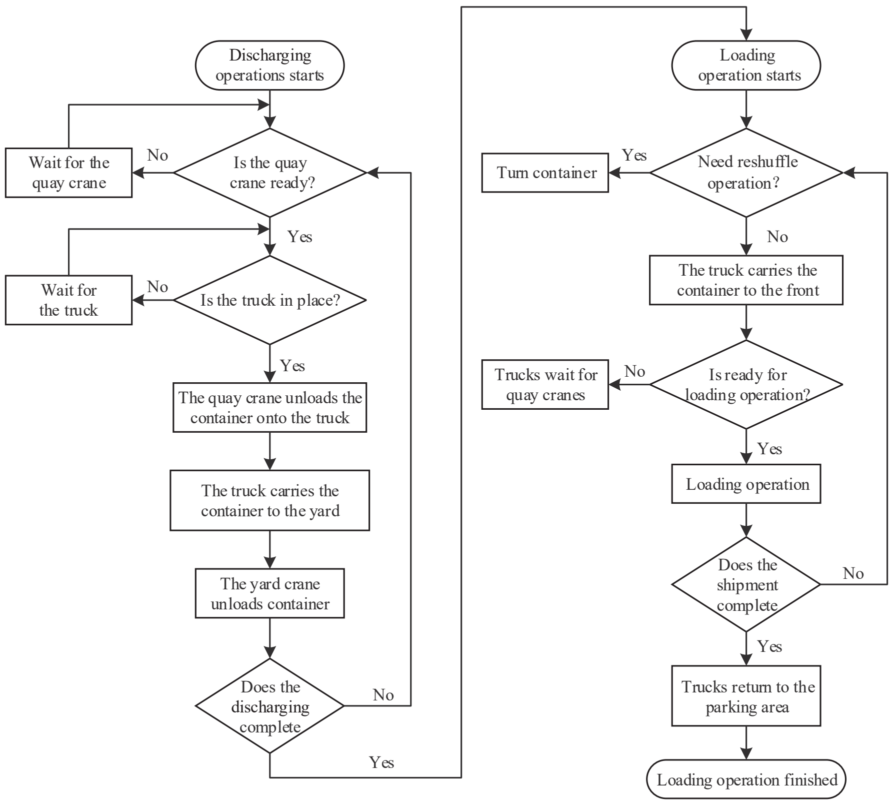

Figure 2: Flow Chart of Loading and Unloading Ship

(1) Discharging Operation: we use the "Seize" module to realize the request of container trucks and quay cranes. And the “Lifting-Translation-Dropping” module is used to simulate the operating animation and record operating time of quay cranes. The "Queue" module is applied to simulate the queue of container trucks, and after unloading the container on to the truck, the quay crane will be released by “Release” module. In addition, the "combine" module is used to output loaded container trucks, which enter the yard operation system by “SelectOutput5” module.

(2) Loading Operation: in this system, we focus on the process that the trucks retrieve containers from different blocks and transport them to the terminal apron where the containers are loaded on to ships by quay cranes. And when the loading and discharging tasks are finished, the quay cranes are released and the ship deberths, then the berth will be released.

3.5 Horizontal Transport and Yard Operation Sub-Module

The horizontal transport studied in this paper includes horizontal transport for loading operation and discharging operation. The movements of trucks in horizontal transports are realized by "MoveTo" module. In the horizontal transport for discharging operation, the loaded trucks from "Combine" module enter the yard by "SelectOutput5" module, carry the containers unloaded from the ship by quay cranes, and move to the specified blocks to start yard operation by "MoveTo" module.

In the horizontal transport for loading operation, the trucks transport the containers from the yard to the terminal apron by "SelectOutput5", and then the containers are loaded on the ship by quay cranes.

3.6 3D Animation Sub-Module

This sub-module is used to realize a 3D animation of container terminal apron operation, which helps the planners to identify the bottleneck that may be encountered during the operation of container terminals.

(1) Animation of ship waiting for berth and berthing: When the ship arrives, the system can evaluate whether the assigned berth is idle according to the current state of the berth. If it is idle, the ship will berth at the assigned berth, as shown as in Figure 3. If not, the ship will wait in anchorage area until the berth is idle, as shown in Figure 4.

(2) Animation of quay cranes operation: Figure 5 shows the 3D animation of containers being lifted by spreader of the quay crane. The containers are moved on to ships from trucks by quay cranes according to the steps of "Lifting-Translation-Dropping" in loading process. And in discharging process, following the same steps, the containers are moved on to trucks from ships by quay cranes by quay cranes. With the handling process of quay cranes, the number of containers on ships would change.

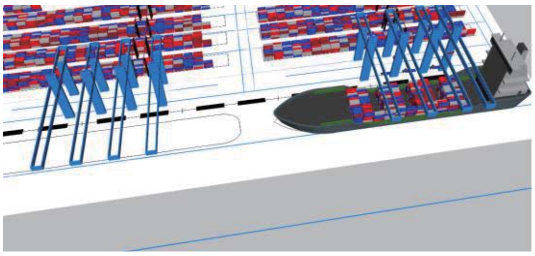

Figure 3: Ship at Berth

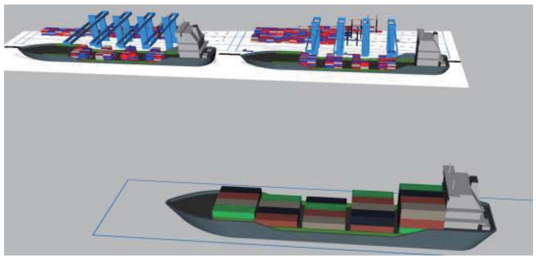

Figure 4: Ship Waiting for Berth

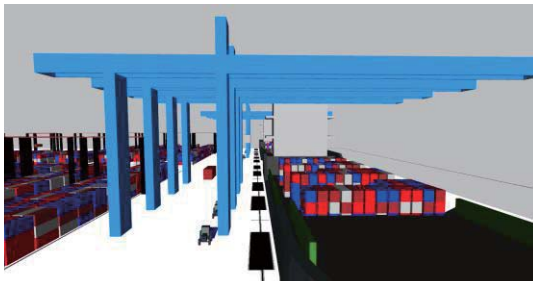

Figure 5: Loading and Discharging Process by Quay Cranes

3.7 Model Verification and Validation

This model is verified and validated to confirm that it is correctly implemented with respect to the process of terminal apron operation. We consider the design ship is 70000-DWT, the number of quay cranes is 4 for each berth, the number of yard cranes is 18, and the number of trucks allocated for one quay crane is 5. After the model is performed for one week, we get the average utilization of quay cranes. The output result from this model is 64%, and the actual utilization of quay cranes is within 62%~77%. Therefore, the simulation model proposed in this paper can be used to simulate the processes of terminal apron operations.

4 CASE STUDY

The case study considers a container terminal with two 70000-DWT berths in the north of China. As shown in Figure 6, the berths are arranged along the shore, and the length of the two berths is 680m. The quay cranes are used to loading and discharging operation in the terminal apron, and the rubber-tired gantry cranes (RTGs) are used for yard operation. And the internal and external trucks are for horizon transport between quay and storage yard, as well as between storage yard and landside interfaces.

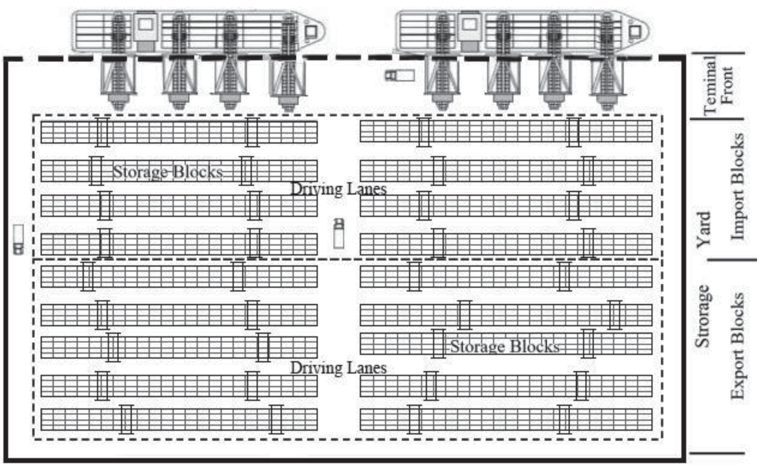

Figure 6: The Layout of Container Terminal in This Case Study

4.1 Model Parameters

(1) Ship arrival: the interval of ship arrival follows the negative exponential distribution with $\lambda = 4$, and the numbers of containers handled in this terminal obey the uniform distribution within 2000 ~ 2250TEU.

(2) Quay cranes: each berth is equipped with 4 quay cranes, considering the instability of practical operation, the time for the single operation of the quay crane (T) follows the uniform distribution of 80~120s and 120~160s respectively for two parallel experiments.

(3) Yard cranes: the yard cranes are RTGs of SRTG5223S, with the dimensions of 26.5m long, 26.5m high and 15.2m wide, and the maximum lifting height of 18.2m. In each block, the number of RTGs (*Nyc*) is 1 and 2 respectively for two parallel experiments.

(4) The containers in the case are standard 40-foot containers, and the external dimensions are 2.9m (height) * 2.44m (width) * 12.2m (length).

(5) There are 20 internal trucks, and according to MTPRC (Ministry of Transport of the People's Republic of China, 2014), the speed limit is 35km/h for empty trucks, and 25km/h for loaded truck. Based on the number of trucks (N_t) from 4 to 8 allocated for each working path, 5 parallel experiments are conducted.

4.2 Simulation Experiments

This experiment mainly changes the following three parameters: the time for the single operation of the quay crane (T), the number of trucks allocated for each quay crane (*Nt*) and the number of yard cranes equipped for each block (*Nyc*). And according to these parameters, 20 simulation schemes are evaluated to estimate the apron performance. For each scheme, similar simulations are performed 10 times for a period of a week.

4.3 Results and Discussion

Running the 20 simulation schemes, we can obtain the average utilization ratio of yard cranes and the average handling efficiency of quay cranes. As shown in Figure 7 and 8, we can draw the following conclusions:

(1) The utilization of quay cranes

Figure 7 compares the utilization of quay cranes of different T, N_t and N_{yc}. And the results show that the three variables are the important factors for the utilization of quay cranes. For the condition with the same T and N_{yc}, with the increase of N_t, the utilization of the quay crane increases at first and then decreases. And for the condition with the same N_t and $N_{yc,}$, with the increase of T, the utilization of the quay crane increases; And for the condition with the same N_t and T, with the increase of $N_{yc,}$, the utilization of the quay crane increases.

Taking the combination of T=140s, $N_{yc,}$=2 as an example, we can find that when N_t =5, the utilization of quay cranes is 60%. If the N_t increases to 6, the utilization of quay cranes would increase to 70%. However, if the N_t increases to 7, the utilization of quay cranes would decrease to 65%. Therefore, when T and $N_{yc,}$ are determined, the N_t is not the more the better for a container terminal. In each scenario, there is an optimal N_t for getting the maximum utilization of quay cranes.

From the view point of T, we take the combination of N_t =6, $N_{yc,}$ =2 as the example. For T =100s, the utilization of quay cranes is 52%, and for T =140s, the utilization of quay cranes is 70%. This result can be explained that the completed time of loading and discharging the same ship would become less with the operation level improved, and there would no need to equip more quay cranes in the port. Therefore, if the workers with high operation level are employed, the cost of purchasing the machines can be saved.

Moreover, from the view point of N_{yc},, taking the combination of N_t =6, T =100s as the example, we can find that when $N_{yc,}$ =1, the utilization of quay cranes is 40%, and when $N_{yc,}$ =2, the utilization of quay cranes is 60%. It is concluded that the efficiency of the yard has an important effect on the utilization of quay cranes. If the efficiency of the yard is neglected, the yard operation would become the bottleneck of improving the utilization of quay cranes.

(2) The efficiency of quay cranes

Figure 8 shows the efficiency of quay cranes of different T, N_t and N_{yc}. And the results demonstrate that the three variables are the important factors for the efficiency of quay cranes. For the condition with the same T and N_{yc}, with the increase of N_t, the efficiency of the quay crane increases at first and then decreases. And for the condition with the same N_t and N_{yc},, with the increase of T, the efficiency of quay cranes decreases; And for the condition with the same N_t and T, with the increase of N_{yc},, the efficiency of quay cranes increases.

Taking the combination of T=140s, $N_{yc,}$=2 as an example, we can find that when N_t =5, 6 and 7, the efficiency of quay cranes is 50, 54, 52 TEU/h respectively. Therefore, with the similar conclusion of the utilization of quay cranes, when T and $N_{yc,}$ are determined, the N_t is not the more the better for a container terminal. In each scenario, there is an optimal N_t for getting the maximum efficiency of quay cranes.

From the view point of T, taking the combination of N_t =5, $N_{yc,}$ =2, we can find that when T =100s, the efficiency of quay cranes is 60 TEU/h, and when T =140s, the efficiency of quay cranes is 50 TEU/h. This result can be explained that as the operation level is improved, the efficiency of loading and discharging operation can be improved naturally. In addition, from Figure 8, we can also find that if $N_{yc,}$ =1, the optimal efficiency of quay cranes for T =100s and T =140s could be obtained when N_t = 6 and 5 respectively. And if $N_{yc,}$ =2, the optimal efficiency of quay cranes for T =100s and T =140s could be obtained when N_t = 7 and 6 respectively. For this reason, with the improvement of operation level of the workers, the container trucks allocated for the quay cranes should be increased appropriately according to the actual condition of the container terminal.

Furthermore, from the view point of N_{yc}, we take the combination of N_t =7, T =100s as the example. And we can find that when N_{yc} =1, the efficiency of quay cranes is 42%, and when N_{yc} =2, the efficiency of quay cranes is 62%. Therefore, in order to increase the efficiency of operation in the terminal front, the efficiency of yard operation should be taken into consideration, as the operation system of a container terminal is an integrated system, of which all the sub-systems are interrelated and mutual restraint.

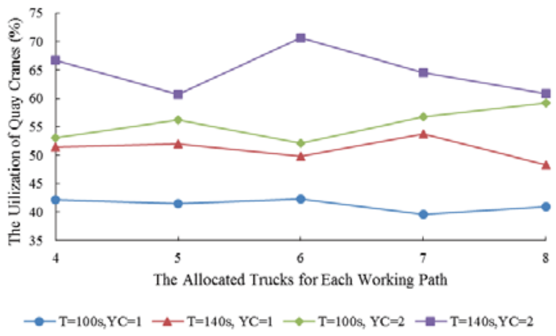

Figure 7: The Simulation Results of the Utilization of Quay Cranes

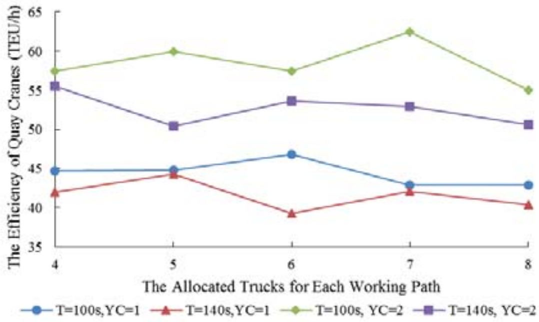

Figure 8: The Simulation Results of the Efficiency of Quay Cranes

5. CONCLUSIONS

The main contribution of this paper is to provide a 3D simulation model of container terminal apron operation. By controlling the exact coordinates of various processes, the proposed simulation model can simulate the real situation of container terminal apron, including ships arriving, berthing, as well as loading and discharging, etc. Based on this 3D simulation model, a good reference for operation planning of a container terminal apron can be provided.

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REFERENCES

AnyLogic: AnyLogic. http:// www.anylogic.com (Accessed from April 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.

Bruzzone A.G; Longo F. 2013. "3D Simulation as Training Tool in Container Terminals". *The Transports Simulator Journal of Manufacturing Systems*, Vol 32, No.1, 85-98.

Ji MJ, Jin ZH. 2007. “The Integrated Optimization Model for Berth Allocation and Container Truck Assignment”. *Journal of Fudan University (Natural Science)*, Vol 46, No.4, 476-480+488.

Lin W. 2011. “The Research on Optimization Model on Traffic Organization of Loading and Discharging Process for Super Large Container Ships”. *China Water Transport*, Vol 11, No.1, 41-42+45.

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.

Ren S. 2011. “The Research on the Optimized Simulation of the Container Terminal Key Operation Equipment”. Dalian Maritime University, Dalian, China.

Sun Z et al. 2012. “A General Simulation Platform for Seaport Container Terminals”. *Advanced Engineering Informatics*, Vol 26, No.1, 80-89

Zhang YH et al. 2016. “Effect of Block Length on Operation Efficiency of Container Terminal”. *Port & Waterway Engineering*, No.11 (Nov), 94-98.

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