3D Simulation Modeling of Yard Operation in a Container Terminal

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ABSTRACT

The yard operation plays an important role in the daily running of a container terminal. Whether the efficiency of a terminal can be improved depends to a significant extent on the operation of its container yard. In order to analyze the yard operation, this paper builds a 3D simulation model to simulate and visualize the yard operation in a container terminal. First, we study the characteristics of yard layout and present the logical model of container yard operation with rubber-tired gantry cranes and trucks. Then, a 3D simulation model of yard operation is implemented, which includes model setup module, container terminal layout module, horizontal transport module, yard operation module, statistics analysis module, and 3D amination module. Finally, the implemented model is applied in practice to examine the impact of reshuffle operation, and the numbers of internal trucks and yard cranes on the efficiency of yard operation. And the results show the proposed simulation model performs well and is helpful for exploring yard operation effectively.

1. INTRODUCTION

Due to the boom in world trade, over 90% of cargo currently transported worldwide is shipped as containerized cargo (Liu et al. 2002). The container yard as a central part of cargo stacking and transport has a significant impact on the whole operation of a container terminal. Therefore, to design and operate a successful container terminal, an effective model is needed to help the planners to evaluate and explore the efficiency of yard operation considering the stochastic characteristics of port system.

Therefore, many researchers have applied computer simulation to study the operation of container terminals. Petering (2009) analyzed the effect of block width and storage yard layout on the performance of a container transshipment terminal. He simulated dozens of yard configurations to determine the optimal block width (Petering 2009). Böse et al. (2000) compared different strategies of trucks dispatching to yard cranes to reduce the time in port for the vessels. Veeke and Ottjes (2002) used computer simulation to provide a decision support for the extension of Rotterdam Port. Gu et al. (2007) applied dynamic simulation in order to provide the operators and designers some advice on the plan and design of a container yard.

The objective of this paper is to establish a 3D simulation model of container yard operation. we focus on the implementation of traffic simulation of horizontal transport and 3D animation of yard operation, which are main contributions of this paper.

2. ANALYSIS OF YARD OPERATION

2.1 Layout of Container Yard

The container yard is composed of storage blocks and driving lanes separating those blocks (see Figure 1). The block structure is determined by equipment type used and, more importantly, by the options for transferring a container between a storage block and a horizontal means of transport. Therefore, the yard layout is defined by the organization of the driving lanes, by the number of driving lanes, by the orientation of the storage blocks, the block structure and the design of the storage blocks (Bish et al. 2001).

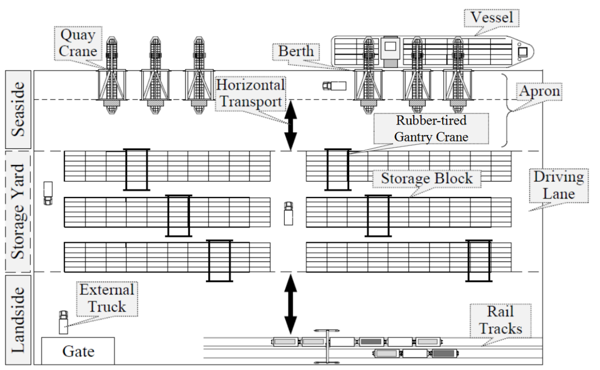

Figure 1: Schematic Structure of a Typical Container Terminal

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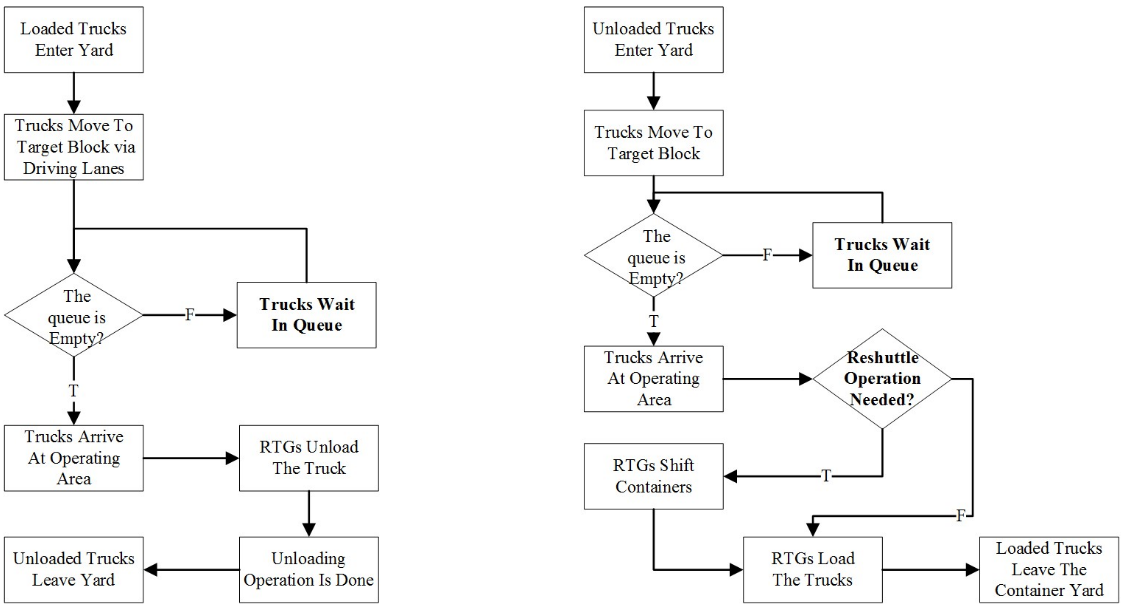
As shown in Figure 1, in most container terminals in China, the orientation of the storage blocks is parallel to the quay (in the case of a single straight quay wall). And rubber-tired gantry cranes (RTGs) are widely used for the yard operations (e.g., loading/unloading, stocking and reshuffle operation), 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).

2.2 Logical Model of Container Yard Operation

Figure 2 shows the logic model of yard operations with RTGs and internal and external trucks. The trucks loaded containers travel through driving lanes into the yard, where the container is stacked into a block. As illustrated in Figure 2 (a), when the truck arrives at transfer lane of target block, the RTGs in this block unload the container from the truck, and stack it into a block, if the queue of transfer lane is empty.

The container remains in the block until it is collected by another carrier (e.g., vessel, truck). In this case the container will be retrieved from the block and passed to an internal or external truck which conveys the container to its destination at the quay or the landside. However, a container might be requested from a stack in which other containers are stored upon the requested container. In this case the containers on top of the requested container have to be repositioned within the block, as shown in Figure 2 (b). The repositioning moves of containers within a block to retrieve another container are called reshuffle operation. Therefore, the main processes in the yard are thus the loading and unloading of container trucks, the stacking of containers and the retrieval of containers.



(a) Unloading and Stocking Operation (b) Loading and Retrieval Operation

Figure 2: The Logical Model of Container Yard Operation with RTGs and Trucks

3. 3D SIMULATION MODELING OF YARD OPERATION IN A CONTAINER TERMINAL

This paper implements a 3D simulation model of container yard operation by using AnyLogic simulation software (AnyLogic 2016). According to the characteristics of yard operation and the relationship with other terminal operations, the model consists of six sub-models, including model setup module, container terminal layout module, horizontal transport module, yard operation module, statistics analysis module, and 3D amination module.

3.1 Model Setup Sub-Model

In this sub-module, we define a series of variables and parameters (listed in Table 1), to describe the characteristics of entities and resources in the simulation model. So it makes the simulation model flexible as it can be applied to different settings by properly tuning the several variables and parameters in the model.

Table 1: Variables/Parameters of Entities

Entities/Resources	Variables/Parameters
Rubber-Tired Crane	number, size, action
Quay Crane	number, size, action
Container	size, color, number
Internal Truck	size, speed, number
External Truck	arrivalPattern, speed
Storage Yard	type, size, height, number
Seaside	berth, length
Landside	parkingLots, location, number
Driving Lanes	nodes, lines, direction

3.2 ContainerTerminal Layout Sub-Model

This sub-model is used to visualize the layout of a specific container terminal, including the seaside, the storage yard (e.g., storage blocks and transfer lanes), the landside (parking lots) and driving lanes network.

3.3 Horizontal Transport Sub-Model

This sub-model is used for trucks scheduling, which chooses the optimal path according to the traffic of driving lanes between the apron and storage yard as well as between storage yard and landside interfaces.

3.4 Yard Operation Sub-Model

(1) Queue of Trucks in Storage Blocks

The queue is used to store the trucks waiting for a RTG for loading/unloading containers.

(2) Unloading Operation Module

When a truck with containers arrives at the target transfer lane, it first seizes an idle RTG by "Seize" module in AnyLogic, which unloads the container from the truck, and steps to "Stacking Operation Module".

(3) Stacking Operation Module

The seized RTG stacks the container into the specified block according to the attribute of container entity. Once the container is stacked, the RTG is released via "Release" module in AnyLogic, and this model updates the states of storage blocks, and the location of the container. Finally, the RTG goes back to the original location and serves the next truck.

(4) Retrieval Operation Module

When a truck arrives at the specific transfer lane to collect a container, it first seizes an idle RTG by "Seize" module in AnyLogic. Then the RTG determines whether the reshuffle operation is needed according to the location of the target container. If the reshuffles are not needed, the RTG retrieves the target container. Otherwise, the RTG moves containers within a block to retrieve the target container, according to implemented function. The function is used to determine the number and locations of containers that need reshuffles, and the sequence of reshuffles moves. Finally, the RTG steps "Loading Operation Module".

(5) Loading Operation Module

The RTG loads the target container on the truck, and is released via "Release" module in AnyLogic. Once the container is loaded, the RTG goes back to the original location and serves the next truck. And this module updates the state of storage blocks synchronously.

3.5 Statistics Analysis Sub-Model

This sub-model records the real-time information, including the locations of the target containers, the number and locations of containers in each storage block, etc. And the values of indicators for yard operation performance are also analyzed, such as the utilization ratio of yard cranes.

3.6 3D Amination Sub-Model

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

(1) Horizontal Transport Animation

Figure 3 shows the 3D animation of horizontal transport traffic of driving lanes between storage yards and the seaside or gates. In this way, it is easy for the planner to check traffic congestion that might occur in the container terminal operation. Note that, in this animation, the traffic simulation is also included, so the simulated times of horizontal transport are more accurate as the effect of traffic congestion in transfer lanes is considered. Therefore, traffic simulation implementation is one contribution of this paper.

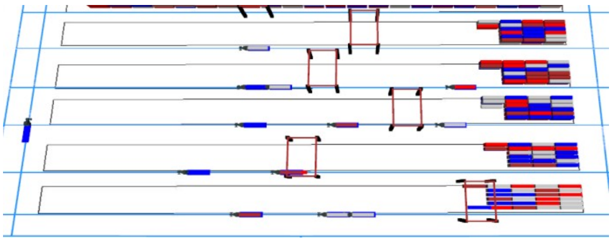


Figure 3: Horizontal Transport Animation

(2) Yard Operation Animation

The 3D animations of yard operation including loading/unloading operation (seen in Figure 4 and 5), stacking and retrieval operation (seen in Figure 6 and 7), are implemented according to the processes discussed in the Section 3.4.

In the yard operation animation, a series of operations, including lifting, translation and dropping are accomplished in order with the speeds set by the model setup sub-model, which is another contribution of this paper.

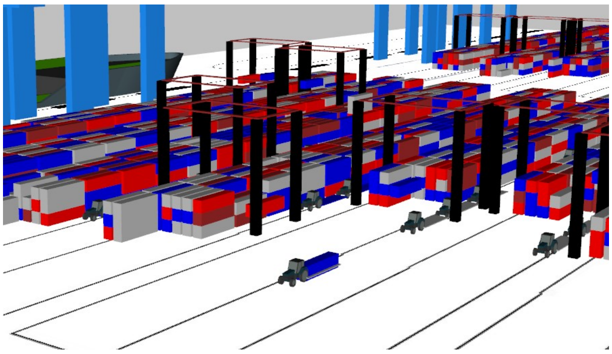


Figure 4: Loading Operation Animation

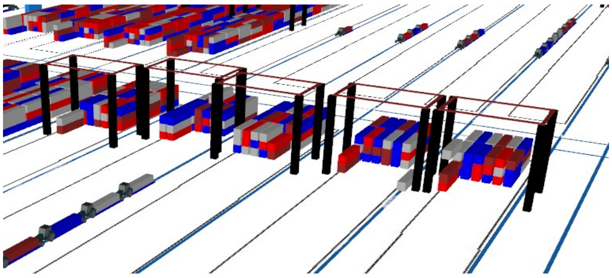


Figure 5: Unloading Operation Animation

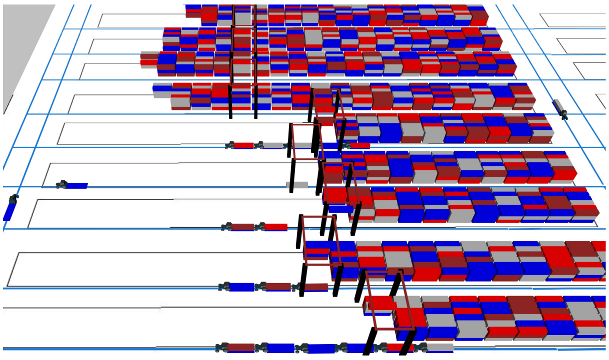


Figure 6: Stacking Operation Animation

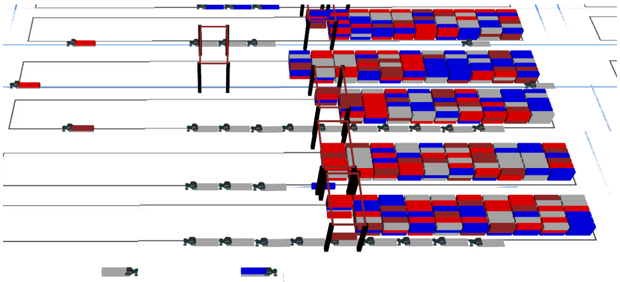


Figure 7: Retrieval Operation Animation

(3) 3D Model of Entities and Resources

The containers established in the model are standard 40-foot containers, and the external dimensions are 2.9m (height) * 2.44m (width) * 12.2m (length). The trucks in the model can transport a 40-foot container, and the length of trailers is 12.5m. 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.

3.7 Model Verification and Validation

This model is verified to confirm that it is correctly implemented with respect to the process of yard operation. First, we implement the model through sub-models and each sub-model is individually examined by a subject-matter expert. Secondly, we use tracing approach in AnyLogic throughout the development of simulation model to check if the logic implemented in the model is as intended. Finally, we use 3D animation to observe traffic flows, operation processes and the queues in yard, and verify simulation model logically.

The average time of trucks from the apron to the locations for loading/unloading and the average time of quay cranes to operate on single container are used to verify the simulation model. Therefore, we compare the simulation results with manual calculations as shown in Table 2. Since the discrepancies between the manual calculations and the simulation results are very small, the simulation model proposed in this paper can be used to reflect the impact of reshuffle operation, and the numbers of internal trucks and yard cranes on the efficiency of yard operation.

Table 2 Comparison between Manual Calculations and Simulation Results

Items	Average time of trucks (min)	Average time of gantry cranes(min)
Manual calculations	1.516	4.56
Simulation results	1.515	4.57
Errors (%)	0.065	0.219

4. CASE STUDY

The case study considers a container terminal with 2 70000-DWT berths. As shown in Figure 8, the container yard includes four rows of export blocks and five rows of import blocks. The rubber-tired gantry cranes are used for the yard operations, and internal and external trucks for the horizon transport between storage yard and seaside and gate. To explore the impact of reshuffle operation, and the numbers of internal trucks and yard cranes on the efficiency of yard operation, we implement a 3D simulation model to simulate the yard operation in this terminal.

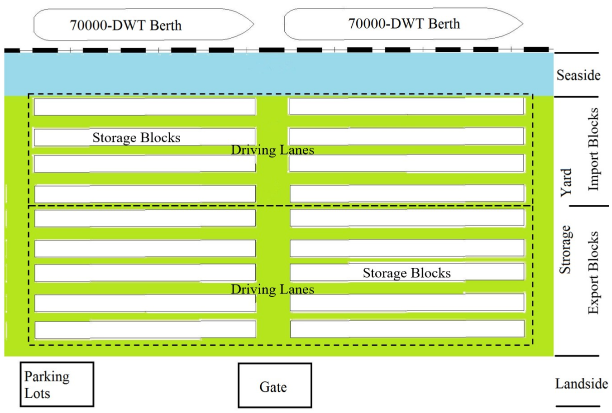


Figure 8: Schematic Structure of the Container Yard

4.1 Model Parameters

According to MTPRC (Ministry of Transport of the People's Republic of China, 2014), the empty trucks and the loaded trucks move at speeds of 35km/h and 25km/h respectively. And the containers loaded and unloaded of a 70000-DWT container ship range from 2000 TEUs to 2250 TEUs. The specifications of container, trucks and RTGs refer to the Section of "3D Amination Sub-Model".

4.2 Simulation Experiments

We change some parameters (e.g., the number of internal trucks serving a quay crane, the number of yard cranes in the yard, and whether reshuffle operation is considered), and establish five simulation experiments to explore their impacts as shown in the Table 3.

4.3 Analysis and Discussion

The simulation model for this terminal has been verified and validated logically as described in Section 3.7 "Model Verification and Validation". For each scenario, similar simulations are performed 10 times for a period of a week. Then the average utilization ratio of yard cranes and the average number of vessels served in a week can be obtained by running the simulation model as shown in the Table 4.

Table 3: The Parameters Setting of Simulation Experiments

No.	The Number of Quay Cranes Per Berth	The Number of Trucks Per Quay Crane	The Number of Yard Cranes Per Berth	Whether Reshuffle Operation is considered
1	4	5	9	YES
2	4	5	9	NO
3	4	5	18	YES
4	4	4	9	YES
5	4	6	9	YES

Table 4: Simulation Results of Different Simulation Experiments

No.	The Utilization Ratio of Yard Crane (%)	The Number of Vessels Served
1	72.3	8
2	70.0	11
3	62.0	14
4	64.7	8
5	71.0	9

(1) The Impact of the Reshuffle Operation on the Efficiency of Yard Operation

Based on the simulation results of Experiments 1 and 2, we can know that reshuffle operation can result in the lower utilization of yard cranes due to the longer occupied time. So that the vessels will spend more time in the port, and the number of vessels served at unit time is less, then it will lead to less competitiveness of the container terminal. Therefore, these reshuffle moves should be avoided as far as possible, as they slow down the retrieval of the requested container.

(2) The Impact of the Number of Trucks Per Quay Crane on the Efficiency of Yard Operation

Based on the simulation results of Experiments 1, 4 and 5, we conclude that with more trucks, the utilization ratios of yard cranes and the number of ships serviced are stable. Therefore, more trucks per quay crane can partly improve the efficiency of yard operation.

(3) The Impact of the Number of Yard Cranes on the Efficiency of Yard Operation

Based on the simulation results of Experiments 1 and 3, we can know that when we increase the number of gantry cranes, the average utilization will decrease and the number of vessels that have finished loading and discharging process will increase. Therefore, more gantry cranes can shorten the queue of trucks and improve the efficiency of yard operation.

Therefore, the model can be used to investigate the impact of reshuffle operation, and the numbers of internal trucks and gantry cranes on the efficiency of yard operation.

5. CONCLUSIONS

The main contribution of this paper is to provide a 3D simulation model of container yard operation. And the proposed simulation model can simulate the real situation of container yard operation by controlling the exact coordinates of various processes, including stacking, moving, as well as lifting and dropping, etc. Based on the 3D simulation model, a good reference for operation planning of a container yard can be provided.

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