Simulation Study on Dynamic Variable Gate Setting Condition of Container Port

Zijian Guo[(a)], Qi Zhang[(b)], Wenyuan Wang[(c)]

[(a),(b),(c)]Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, Liaoning 116024
[(a),(b),(c)]State Key Laboratory of Costal and offshore Engineering, Dalian University of Technology, Dalian, Liaoning 116024

[(a)]zjguo@dlut.edu.cn, [(b)]zhangqidlut@163.com, [(c)]wangwenyuan@dlut.edu.cn

ABSTRACT
In order to ease the queuing congestion at container terminal gate and improve the service level of gate, we propose a kind of intelligent gate of which the working direction can be adjusted automatically according to queuing length of In/Out gate. A queuing imbalance coefficient between In/Out gate is developed to be applied as the setting and changing condition of variable gate. We build a variable gate operating system simulation model and offer a case study, based on which we try to find how the variable gate impacts on the service status of the gate and then estimate the critical value used to decide the setting of variable gate and the moment of changing the working direction.
Keywords: container terminal; variable-gates; service level; simulation model

1. INTRODUCTION
Container terminal gate is an indispensable areas where the containers transported into or out the port area must pass through. With the globalization of containerized trade and the large size of container ships, the transportation volume of containers is increasing in the recent decades. As a results, the gate of the container terminal has gradually become a bottleneck as the most crowded area. However, for most of the container terminals, total number of the gate ca not be amplified with respect to the restriction of space and economic conditions. The through capacity fails to meet the requirement with the increasing logistics demand day by day. Thus, how to make full use of the existing gates and improve the through capacity is a very important problem for the operational efficiency of container terminal.

In recent years, the researches on the through capacity and the plan of container terminal gate has been emphasized gradually all over the world. Minh (2014) and Guan and Liu (2009) built a multi-server queue model to analyze the congestion situation of container terminal gates and the waiting cost of container trucks. Boile (2013) proposed a method based on simulation to evaluate the effect of queuing congestion on the efficiency of container terminal operation. Huynh (2014) developed a planning tool used to study the layout of container terminal gate. In addition, a method based on stochastic service system has been proposed by Mai (2007). To calculate the optimal lanes number of the container terminal gate and the stop buffer length. Liu (2011) built a mathematical model to study the optimal scale of the container terminal gate. An optimization model based on simulation was set up by Yu (2007) to determine the optimal scale of container terminal gate meanwhile minimize the cost of gate construction. Meanwhile, as environmental issues have become important for the port planning, Longo and Padovano et al (2015) proposed a solution capable of recreating a port terminal and while take into consideration the main factors affecting sustainability of port operations. In order to adopt green port policy, Simpson (2010) proposed 11 components in the 160-acre Pier S Marine Terminal. In addition, a chassis exchange terminal and information technology were proposed to reduce the truck congestion at gates respectively by Dekker et al (2013) and Masaaki (2003). However, all the researches above didn't consider how to improve the service level of the gate when given the total number of certain container terminal gates.

With the help of simulation tool and the new concept of the imbalance coefficient of In/Out gate queuing introduced in this paper, we build a variable-gate operating system simulation model to simulate the service states of container

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terminal gate in a state of disequilibrium of the container trucks arriving. It is a new attempt in the field of port planning and construction that study the feasibility of variable gate applied to improve the service level of gate and the critical value used to decide the moment when changing working direction of variable gate. This research can provide a reference for planning and design of large container terminal gate.

2. RELATED CONCEPTS

2.1. Variable gate

The process from arrival to departure of container trucks is a three-level queuing system, as shown in the Figure 1. The container terminal operating system is a stochastic service system. The arrival or departure of the container trucks has a characteristics of randomness. Meanwhile, considering the difference of the service between in and out, the service time is also different. As a result, there is a probable situation in which the traffic pressure has been beyond the capacity in a certain direction of the gate while there is still great redundancy of the through capacity in the other direction.

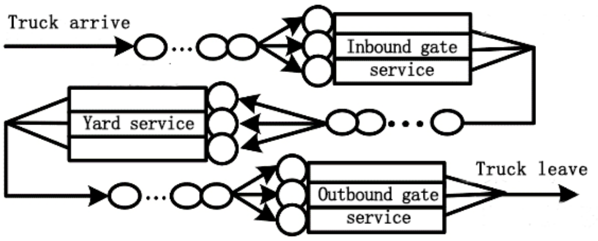

Figure1: Schematic diagram of container truck queuing system

To alleviate the congestion in one direction and improve the service level of the gate on the premise of a certain number of container terminal gates, we propose the concept of variable gate of which the working direction can be changed according to the dynamic requirement of traffic status, referring to the thought of tide lane (Li et al., 2009; Dai et al., 2012) in the field of road traffic. Changing the working direction of some gates, according to the queuing indicators about the truckers entering and leaving the port, can maximizing the through capacity of container terminal gate.

2.2. Imbalance coefficient of In/Out-gate queuing

The queuing status at container terminal gate in the two directions is the decision basis for changing the working direction of the variable gates. To quantitatively describe this condition, we introduce the imbalance coefficient of In/Out-gate queuing which is defined as the ratio of the inbound gate average queuing length and outbound gate average queuing length, denoted by τ.

$$\tau = \frac{\text{In gate average queuing length}}{\text{Out gate average queuing length}}$$

2.3. Critical value of τ used to change direction of the gate

A critical value of τ (denoted as τ^*) is set to determine whether to change the direction of gate. Here is an example. It is assumed that the initial direction of the variable gate is entrance direction. The working mechanism of variable gate is as follows: when $\tau > \tau^*$ which means the queue length at the entrance gate is greater than the one at the exit gate, the variable gate should still be the entrance gate until the queuing congestion of entrance gate is eased and the value τ decreases gradually; when $\tau < \frac{1}{\tau^*}$, which means the queue length at the exit gate is τ^* times greater than that at the entrance gate, the variable gate should be adjusted as an exit gate in order to ease the queuing congestion of the exit gate. The operation is similar to the example to adjust the passage direction of the variable gate dynamically.

If the value of τ^* is too small, the passage direction of the variable gate will be changed frequently, while if the value is defined too large, the sensitivity of the variable gate operation will significantly reduce, which can not fully reflect the role of a variable gate . Therefore, it is necessary to find a reasonable critical value to change the direction of the variable gate.

3. SIMULATION MODEL CONSTRUCTION

3.1. Operation Process of Container terminal gate

The operation process of the container terminal gate which is not variable is as follows: if the entrance gate is idle, the arriving truck will accept service, else it need to wait until it is idle. Then it drives to the yard waiting to load and unload. After that, the container truck will drive to exit gate. If the exit gate is idle, the truck will accept service and leave the port, else, it will wait until it is idle.

The operation process of the variable gate is similar to the ordinary operation process of the container terminal

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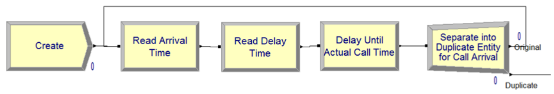
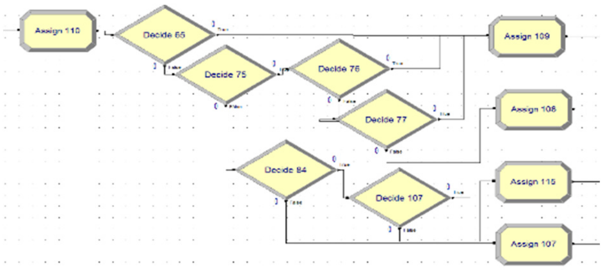
entrance， excerpt the numbers of entrances or exits are decided by the direction of variable gate at present.

3.2. A Simulation Model of Gate Operation System for Container Terminals with Variable Gate

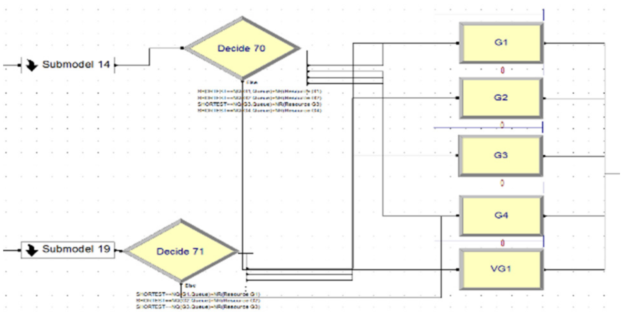
The simulation model mainly includes five sub-models, which are truck entity creation, variable gate working direction decision, entrance gate selection, yard service and exit gate selection. The sub-models are shown in Figure 2.



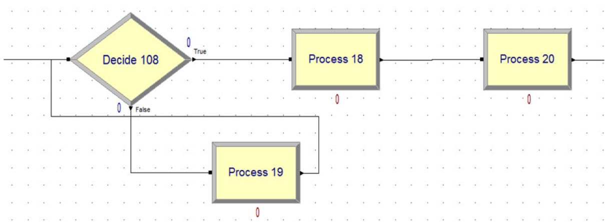
a) sub-model of truck entity creation



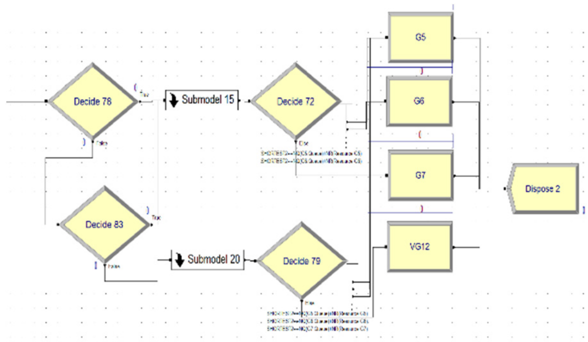
b) sub-model of variable gate working direction decision



c) sub-model of entrance gate selection



d) sub-model of yard service



d) sub-model of exit gate selection

Figure2: Simulation Model of Gate Operation System for Container Terminals

1) Sub-model of truck entity creation. The Create module generates truck entities, reads and inputs values of the interval to port from truck data file, and enters the *Read Arrival Time* module, and then reads the data with the *Read Delay Time* module. At last it arrives to the *Delay Until Actual Call Time* module. This ensures that each truck has one-to-one correspondence with its time parameters. On the one hand, the truck entity can sent back to the *Read Arrival Time* module through the Original exit point, and then obtain the time interval for the next truck from the data file. On the other hand, the module generates a copy truck entity, which can be passed to the model by the *Duplicate* module, completing all remaining model logic.

2) Sub-model of variable gate working direction decision: at first, the current passage direction of the variable gate is judged by *Decide* module and then assigned by the *Assign* module to determine direction of the variable gate after comparing τ with τ^* or comparing τ τ and $\frac{1}{\tau^*}$.

3) Sub-model of entrance gate selection: the truck entity is prepared to enter the port operation through the gate channel. Sub-model is adopted to select the most suitable gate channel. A Nonpooled queuing system is used to decide whether the entrance channel is idle by the *Decided* module. If the entrance channel is idle, then the truck entity chooses to accept the service, else, the truck chooses the entrance channel with the shortest queue length. After then, the truck entity enters to the port through entrance channel, enters yard and accepts yard service.

4) Sub-model of yard service: The truck entity enters the container terminal yard, and then examines whether the loading and unloading machinery is idle by the *Decide* module. After that, the truck entity goes to loading and unloading operation in the yard. Then the truck entity leaves the yard and prepares to enter the exit gate channel.

5) Sub-model of exit gate selection: The main process is the same as the entrance channel selection module of the gate.

4. CASE STUDY

4.1. Overview of the port in the case

There are 10 container berths in the container terminal, of which the design capacity is 8,900 thousands TEU in this case.

4.2. Simulation parameters

1) Arrival time of container trucks

The time when the trucks arriving at the gate of terminal is gotten by practical investigation and taken as the original data. Due to the irregularity of the arrival time in this case, we select the data in one year as the inputs of the model.

2) Service time

The service time of a truck through the In/Out the gate follows a normal distribution. The average service time of a truck through entrance gate is 1.024 minutes, the standard deviation is 0.28. And the average service time of a truck through the exit gate is 0.871 minutes, the standard deviation is 0.16.

3) Number of gates

According to the layout of the terminal, the number of the gates is 10

4.3. Determination of critical value

In order to determine the value of τ^* ($\tau^* > 1$) used to decide whether to change the working direction of the gate, we need to find a reasonable value of τ^* to optimize the queuing indexes, including maximum queuing time, average queuing time, maximum queue length and average queue length. In this study, we simulate the service status of the gate with only one variable gate in the situation in which the value range of τ^* is 1.1~2.3. We obtain the data of the aforementioned indexes. The results of the simulation are shown in Fig. 3.

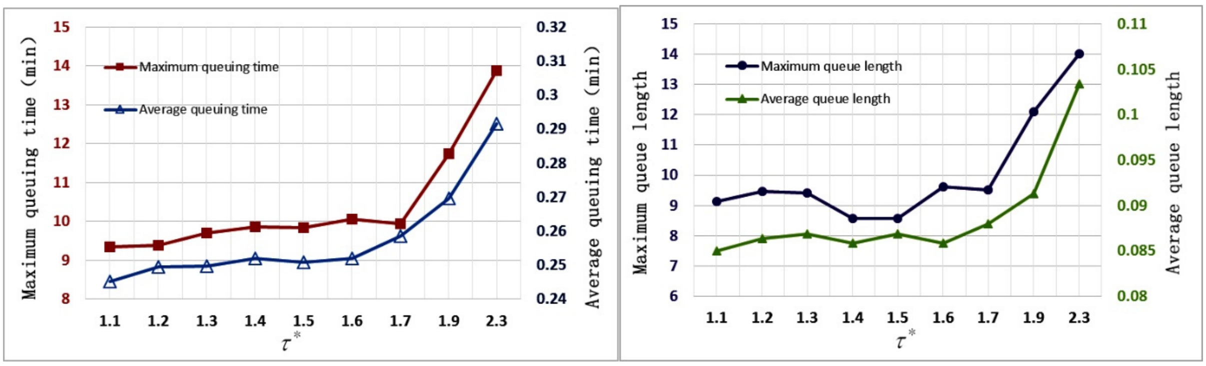


Figure 3: The results of the simulation

As shown in the Fig.3, with the increasing of τ^*, all the queuing indexes of the container trucks in the gate follow the same trend. And it should be noted that τ^* has little effect on the queuing indexes before its value reaches 1.7. It means that, on the premise that the values of maximum queuing length and time change little, we should take the value of τ^* as much as possible when the range is (1/1.7, 1.7), so that the direction change of the variable-gate won't be too frequent. After the value of τ^* reaching 1.7, the queuing indexes increased rapidly. Obviously, when the value of τ^* is sufficiently large, the critical value of the variable gate will never be able to reach in the model. And the variable gate won't change working direction.

Hence, the critical value in this case should be 1.7, which means that we should set variable gates when $\tau < 1/1.7$ or $\tau > 1.7$. In this situation, the judging condition of direction changing from In gate to Out gate is $\tau < 1/1.7$, and the judging condition of changing from Out gate to In gate is $\tau > 1.7$. When the interval of τ is (1/1.7, 1.7), it will keep the previous working direction.

4.4. Study of the effect on capacity of variable gate

In order to study the effect on capacity of variable gate of, we make three stimulations. Two of them is without variable gate and considers two combinations of numbers of In gates and Out gates, which are 4 in and 4 out, and 5 in and 3 out. In the other one simulation, the direction of the variable gate is dynamically adjusted according to the queuing index at the entrance and exit gate and the value of τ^* is from 1.1 to 2.3 with variable gate. In the three simulations, we obtain the values of the indexes including maximum queue time, maximum queue length, average queue time and the average queue length of the truck are gained. The results are shown in Fig 4.

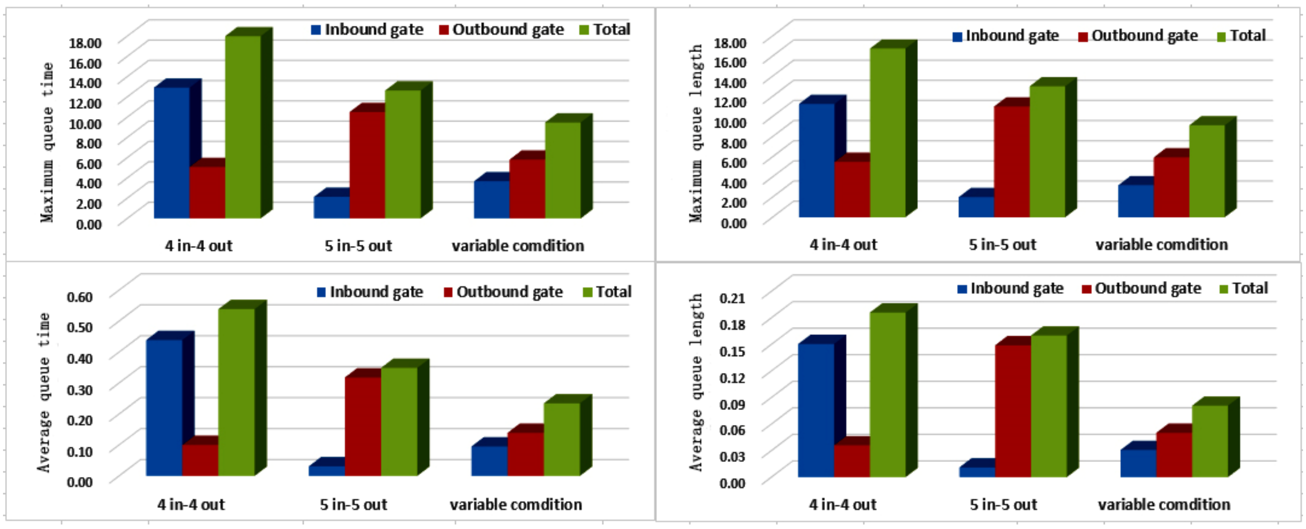


Figure 4: Comparison of the queue index of the port gate

Figure 4 shows that there is a great imbalance between the values of the indexes at entrance and exit gates in the simulations without variable gate. When the variable gate is set, the queuing imbalance is obviously relieved, and the overall queuing index is also significantly decreased, which indicates that the variable gate has a significant effect on easing the queuing phenomenon at the gate channel.

5. CONCLUSION

The research on the efficient and intelligent gate operation and making full use of existing gate resources can not only avoid the wastage caused by the blind expansion of gate, but also can greatly improve the terminal operating efficiency. According to the simulation model of the container terminal gate operating system, the variable gate is proposed as a method of improving the service level of the container gate.

Based on the simulation model with different values of imbalance coefficient, the effect of the variable gate on service status is measured. The critical values τ^* used to determine whether to set variable gates and to change the direction of variable gates is measured. The conclusions are as follows:

1） Setting variable gate has a significant effect on easing the queuing congestion at the entrance and exit gate.

2） The simulation model can be used to determine the critical values of τ used to determine whether to set the variable gate and changing its direction.

3) The application of simulation method can provide an effective tool for ports to scientifically plan and operate the wharf, which has great randomness and uncertainty. The results of this paper can provide a reference for the planning and design of large-scale container terminal gates.

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