

SIMULATION-BASED ANALYSIS OF IMPORT CARGO-HANDLING OPERATIONS ON A CONTAINER TERMINAL

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ABSTRACT

Maritime container terminals are faced with the issue of an increased quantity of cargos that must be handled with limited resources. In this study, a simulation model of a container terminal focused on import cargos was constructed and used to examine handling operation flows. Yard operation data recorded by a terminal operating system were processed using Visual Basic Application (VBA) and analyzed to capture the system working features and to obtain model input parameters. Then, a special purpose data generator was developed to create experimental data to execute the simulation to compare and evaluate the performance of the cargo handling equipment under various workloads. The proposed procedure for processing system data and creating input parameters represents a potential method for forecasting and evaluating port operation.

1 INTRODUCTION

Due to the advantages of low cost, reduced package, convenience and efficient handling, the international containerization market is undergoing large growth with the increased international trade in recent years. Accordingly, an increasing number of container shipments has induced a higher demands for maritime container terminals, container logistics and management and technical equipment (Steenken, Voß, and Stahlbock 2004). Container terminals are required to handle the changeable quantity of containers with limited resources, including berths, yard stocks, and cargo-handling equipment.

Maritime container terminals are complex systems characterized by highly dynamic interactions among the various handling, transportation, and storage units and incomplete knowledge of future events (Günther and Kim 2006). Thus, seaport terminals represent a promising topic area for simulations due to their randomness and complexity. Recent studies have focused the design of container terminals or ports (Lee et al. 2008), the dispatching and scheduling of yard cranes or quay cranes (Guo et al. 2008; Clausen and Kaffka 2012), container loading and stacking inside vessels (Zeng et al. 2010), and container transshipments and stacking in a yard (Sgouridis and Angelides 2002; Van Asperen, Borgman, and Dekker 2010).

Information and communication technology (ICT) systems are widely used to assist and support the operations on seaport terminals (Liu and Takakuwa 2011). A terminal operating system is a software application that supports the planning, scheduling and equipment control activities of a container terminal (Boer and Saanen 2008). Terminal operating systems often utilize ICTs, such as the internet, EDI processing, wireless LANs, and radio-frequency identification, etc., to efficiently control the movement and storage of the cargos and support. Real-time tracking data are accumulated as an operational record simultaneously when an operation is completed. These system record data can be extracted and processed

to capture the features of the system and to generate input data for the simulation model.

In this study, a simulation model of the container terminal focusing on the import cargos is constructed and used to examine the handling operation performance. This paper is structured as follows: Section 2 presents a brief description of the container handling processes and the terminal operating system. The process of the data acquisition during terminal operation is clarified. In the Section 3, the detailed data processing procedure of the yard crane operation records using VBA is introduced. Then, a special purpose data generator is developed to create experimental data to execute the simulation in the Section 4. The experimental data to be created include the attributes (size, type) of the containers. Next, a simulation analysis under various levels of activity is performed in Section 5. The performance of the system under various resource arrangement principles is examined. Finally, conclusions are presented in the Section 6.

2 THE ESSENTIAL HANDLING PROCESSES IN THE CONTAINER TERMINAL

2.1 Container Terminal and Essential Handling Processes

The container terminal considered in this study object is located at the Port of Nagoya, Aichi, where Japan’s main automobile industry is located. The terminal primarily serves vessels on the China and South Korea routes operated by regional shipping lines. Imports of fiber products and daily necessities and multi-frequency and small-sum exports of automobile parts and other industrial products comprise the majority of the cargos handled at the terminal.

An overview of the terminal facility layout with two berths is shown in Figure 1. The container handling equipment in the terminal primarily includes gantry cranes (GCs), which are located at the quay side and are used for unloading or loading containers during vessel handling operations, and yard cranes, which are the transfer cranes (TCs) and straddle cranes (SCs) used to move containers to and from trailers or to relocate containers inside the yard. SC are employed to transport and handle hazardous goods or to inspect cargos in the terminal. The majority of the general cargos in the yard are handled by TCs.

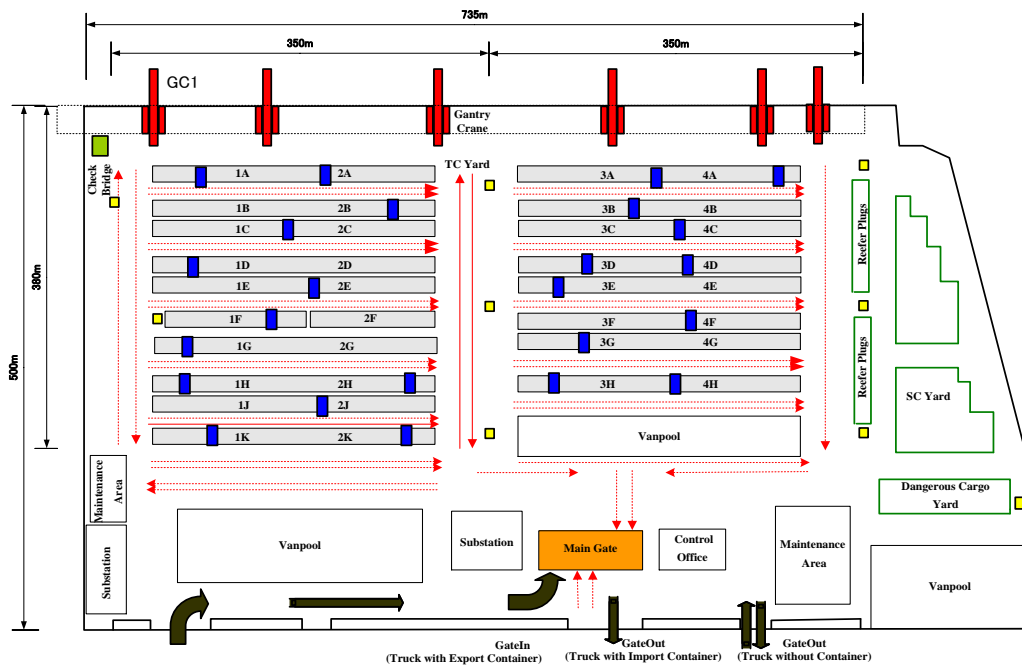


Figure 1: The overview of the terminal facility layout.

Port operations can generally be divided into import and export processes, and these two categories employ opposite operation flows. Import cargos are usually stocked temporarily in a bonded warehouse nearby the container terminal and then sorted and packed into the container at there. Export containers prepared for loading onto a vessel are carried into the yard before the vessel's arrival. Therefore, the logistics department of the Port Corporation could use the available information regarding the containers to gather the same vessel's cargo prior to loading. The export containers waiting to be loaded are generally gathered approximately one day before arrival of the vessel. When the vessel is arriving at the berth, import containers are first unloaded onto trailers. Upon passing an appearance damage checking process, the containers are transferred to the yard storage blocks. After the unloading process completed, the export containers are transferred from the yard to the quay that will be loaded onto the vessel.

TC Yard of the terminal is divided into an export containers area (LD area) and an import containers area (UL area) for efficiently handling cargos. The operations in the LD area include receiving (R), which represents terminal receiving an export container and loading (LD), corresponding to the container handling for loading on the vessel. Conversely, the operations in the UL area include unloading (UL), when the container was unloaded from the vessel, and delivery (D), when the terminal delivers an import container to the cargo owner. Additionally, there are also shift (S) operations in these two areas, which can be primarily divided into: Shift without trailer, which usually refers to re-handling, and shift with trailer, which usually refers to moving the container under the shift plan. The overall operation processes in the terminal are supported by the terminal operating system.

2.2 Terminal Operating System and Data Records

The Nagoya United Terminal System (NUTS) is used as a terminal operating system for all of the container terminals in the Port of Nagoya, supporting the container vessels, container handling equipment and yard stock control. Figure 2 shows the framework of the NUTS and the operation flows in the terminal. The control system in the NUTS performs integrated management of basic information at the terminal and works with three other sub-systems to realize the functions of the yard planning, yard operation and yard control. The operation instructions are given to the container handling equipment during the cargo-handling processes, and the latest container information is updated in the system after the operation completed.

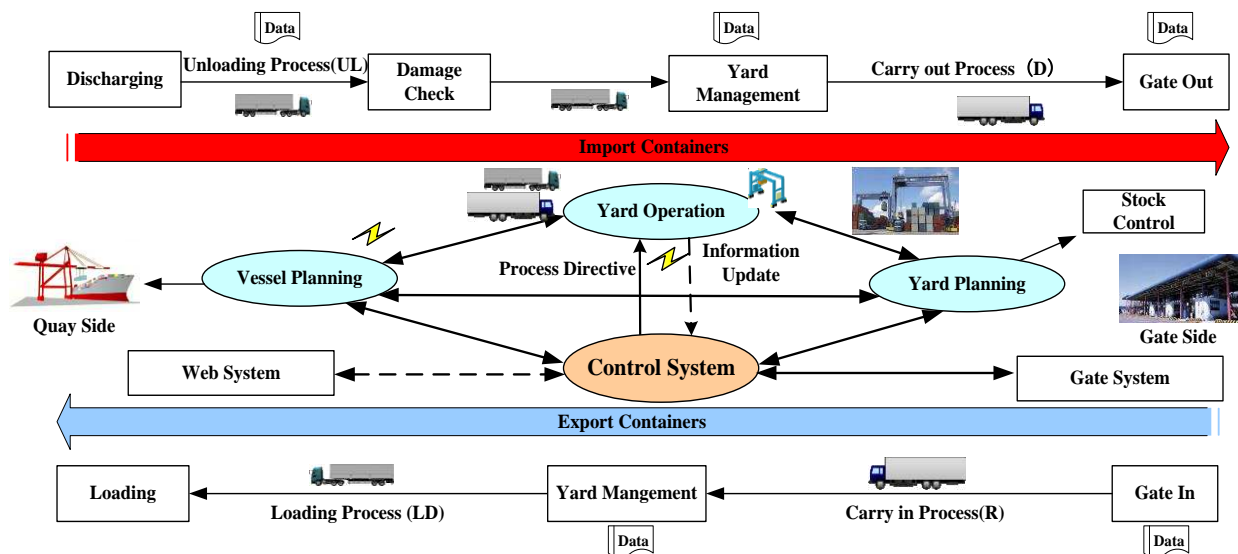


Figure 2: Framework of the NUTS and operation flows.

When a vessel arrives at berth, containers are unloaded by a gantry crane onto trailers that transfer them to the yard storage blocks. Once a container is unloaded onto the trailer, information indicating unloading completion is transferred to the NUTS. Shortly thereafter, handling instructions for containers-storage spots are sent to the yard cranes. However, instructions from the NUTS allow the driver of the yard cranes to choose the next job in real-time. Concurrently, the NUTS records the time of the handling completion. Other operations inside the yard (S/D/R/LD) and the basic information of the container and vessel are also recorded in the NUTS. These data records are used to analyze and improve the system, which are divided into vessel information data, yard operation data, and container inventory data.

3 PRELIMINARY ANALYSIS OF THE OPERATION DATA

3.1 Data Processing Procedure

Daily operation records of the TCs and SCs are stored in the yard operation data file. There are 112 items contained in the total information regarding the port operations recorded in the raw data. They are required to be processed to clarify the system working features and to obtain the input parameters.

For the yard operation data, only the system instruction time (reception time) and completion time of the operation is recorded. The operation start time is unknown, and hence the actual operation processing time is unclear. To calculate operation start time, procedures for processing and integrating system data file records (TC yard) are implemented according to the following steps, and the program is written in Excel VBA. The data of an entire working day is used for the analysis.

1. Extract the necessary data from the historical data file. The items listed below are selected for further analyses:
 - (a) Operation No.
 - (b) Container attributes: Container No., Size (20 Ft./40 Ft.), Type (Dry/Others);
 - (c) Vessel information: Vessel Code, Unloading Time (in the UL processing);
 - (d) Yard crane information: TC No., Operation Area;
 - (e) Operation information: Operation Code, Operation Instruction Time, Operation Completion Time, Original Coordinates, Destination Coordinates;
2. Change the Area Code to the standard form.
 - (a) Change the yard column number A, B, C...(omitted)...H, J, K to 01, 02, 03...(omitted) ...08, 09, 10, respectively.
 - (b) The identification number of the yard blocks are modified to include up to the hundreds digit.
3. Change the time to the difference from 8:00 am (unit: second)

The primary purpose of steps 2 and 3 is to facilitate the calculations. A part of the data example of the system processed after step 3 is shown in Table 1. TC may be transferred to various blocks between two adjacent operations. Steps 4 to 6 are performed to calculate the TC transfer distance and the operation start time.

4. Calculate the TC transfer distance between the two adjacent operations.
 - (a) Clarify the container stacking arrangement in the TC yard and move the patterns of the TC. Figure 3 shows the detailed arrangement of the containers in the yard blocks and the TC movement patterns. There are two TC movement patterns: horizontal movement (moving in a row) and vertical movement (moving across the row). Additionally, five types of possible calculation situations are also shown in Figure 3.
 - (b) Calculate the TC transfer distance under the each possible situation. The method is shown in Figure 4.

- (c) Calculate the TC transfer time based on the distance. The transfer time is calculated by transferring the distance and TC travel speed. The method is also shown in Figure 4, there is a 90-second safety confirmation time in the vertical transfer.

Table 1: An example of the yard operation data.

Operation No.	Operation Completion Time	Operation Instruction Time	Operation Code	Container No.	Vessel Code
$i-1$	3189	2986	D	TEMU2226XXX	HPRN
i	3471	3298	UL	SKHU9101XXX	DSAC
$i+1$	3734	3550	UL	SKHU9005XXX	DSAC

(1)

Container Size	Container Type	Unloading Time	GC No.	Handling Equipment No.	Operation Block No.	Operation Bay No.
20	DC	Null	Null	15	104	14
40	DC	3268	6	15	204	1
40	DC	3519	6	15	204	3

(2)

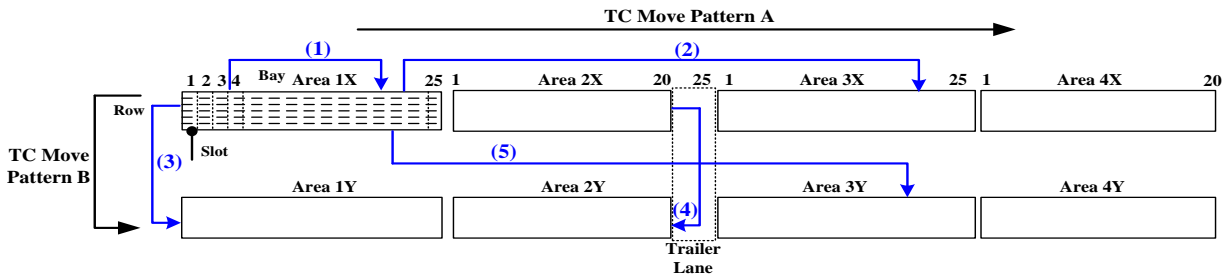


Figure 3: Arrangements of yard blocks and TC move patterns.

- Calculate the earliest operation start time. There are two cases for operation time: the system may give a new instruction (a) before the latest task is completed (b) or after the all tasks are completed. The two cases are shown in Figure 5.
 - Operation (i+1) Start Time = Operation (i) Completion Time + TC Transfer Time
 - Operation (i+1) Start Time = Operation (i+1) Reception Time + TC Transfer Time
- Calculate the yard crane processing time and the operation window:
 - TC Processing Time (i) = Operation (i) Completion Time – Operation (i) Start Time
 - TC Operating Window(i) = TC Processing Time (i) + TC Transfer Time (i)
- Move the processed data to a new sheet.

The programs were written in VBA for implementing. The processed data are used for the analysis.

3.2 Data Analysis and the Feature of System

There are many statistics that can be acquired from the processed data. There are two main objectives for analyzing the processed data. The first is to capture the system features, and the second is to generate the model input data.

If TC moves from Operation i to Operation i+1,

Set

HD = Horizontal Distance (unit: slot), VD = Vertical Distance (unit: slot) ;

ABS = Absolute Value, a = Area No.(1~4), b = Bay No.(1~25), r = Yard Row No. (A~K; 1~10)

Set the Area No. Large one to a_m , its Bay No. to b_m ; Area No. Small one to a_n , its Bay No. to b_n .

Transfer Distance:

Move Pattern A (Only HD):

(1) TC moves inside the same area,

$$HD = ABS[b(i+1) - b(i)]$$

(2) TC moves among the different areas,

$$HD = [(a_m - a_n) - 1 * 25] + [ABS(25 - b_n) + b_m]$$

Move Pattern B (VD and HD): $VD = ABS[r(i+1) - r(i)]$

(3) $a(i+1) = a(i) = 1$ or 3

$$HD = b(i+1) + b(i)$$

(4) $a(i+1) = a(i) = 2$ or 4

$$HD = 20 - b(i+1) + 20 - b(i)$$

(5) $a(i+1) \neq a(i) = 2$ or 4

$$HD = [(a_m - a_n) - 1 * 25] + [ABS(25 - b_n) + b_m]$$

Transfer Time:

TC Transfer Time = Horizontal Transfer Time + Vertical Transfer Time

TC Transfer Speed = 2.25 m/s, Length of 1 Slot = 6.5 m

Horizontal Transfer Time = $(HD * 6.5) / 2.25$ (second)

Vertical Transfer Time = $90 + VD * 15$ (second)

Figure 4: The method for calculating the TC transfer distance and transfer time.

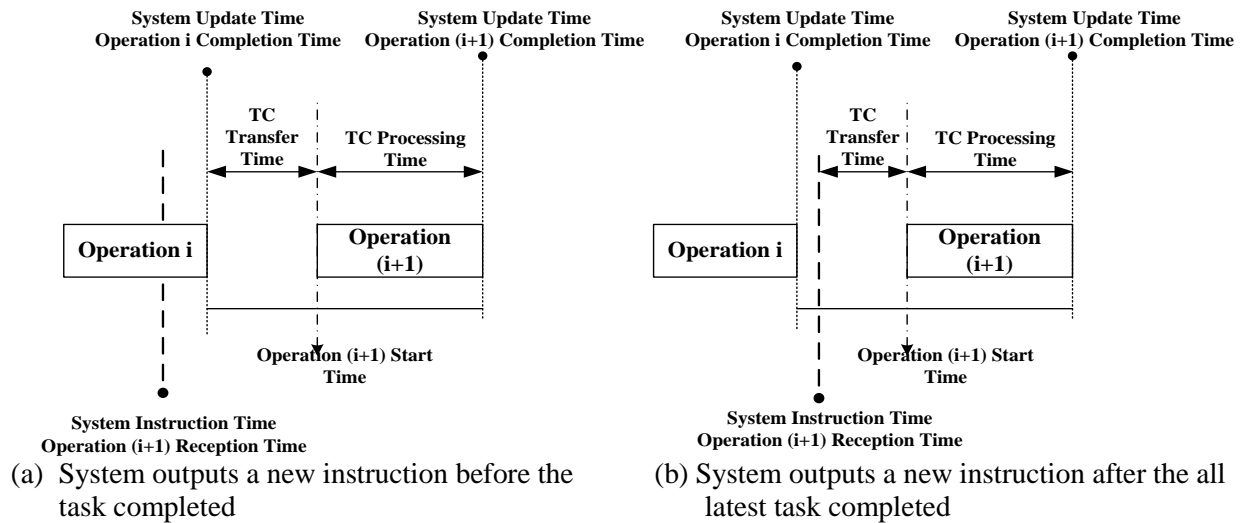


Figure 5: Two cases of the operation start time.

Based on the statistical analysis, we found that there is only a 0.5% TC vertical movement in the daily operation. In addition, the average horizontal transfer distance is 5 slots, which indicates that the average TC transfer time is 14.4 seconds. The proportions of operation types in the each area are shown in Figure 6. The UL area and LD area can be divided through the statistics.

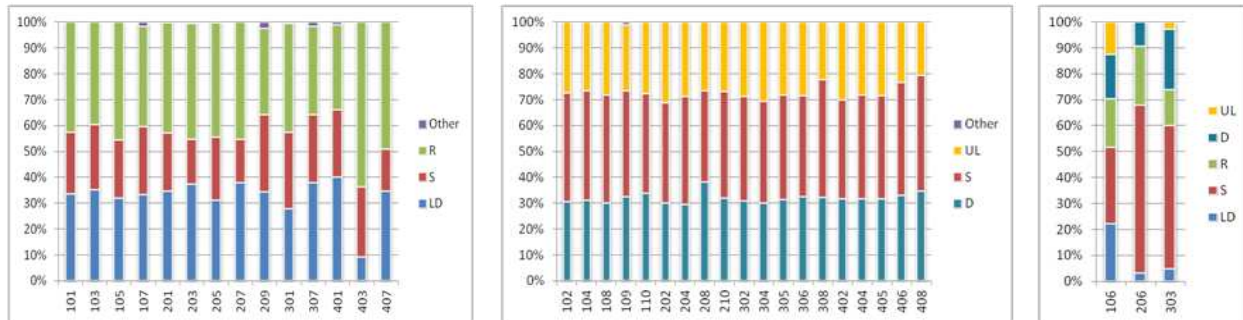


Figure 6: Proportions of operation types in the each area.

4 DATA GENERATOR FOR SIMULATION

The number of the containers that must be handled in a terminal can change based on factors such as the seasonal variation of cargo, fluctuations in the exchange rates, etc. As previously described, the information on export containers that are prepared for loading onto a vessel is mastered by the logistics department of the Port Corporation, and the export containers for each vessel are gathered the day before the arrival of the vessel. A specialized yard crane usually serves the associated area. However, for import containers, cargos should be distributed to different areas to improve the unloading speed. If more import containers are processed in the system, it is difficult to estimate whether the current handling equipment and yard space are busy or occupied for increasing the volume of import containers.

Because it would be prohibitively costly and difficult to perform the experiment with an actual port system, a simulation model was constructed in this study to test solutions to the problem described above. The handling flow of the import containers is shown in Figure 7. A container is unloaded by the GC and temporarily stocked in the yard. The experimental parameters of the terminal and handling equipment obtained from the processed data are shown in Table 2.

A special purpose data generator is designed and developed to create experimental data in the study. The data generator is written in Excel VBA. The experimental data created contain the load factor, the vessel number, the container type, and the size.

The overall flow of the data generator proposed in this study can be summarized as follows:

1. Specify a percentage of container or increase compared with the baseline condition (50%~200%);
2. Specify the headings of A1 through D1;
3. Number the container in column A;
4. Specify the no. of the vessel in column B;
5. Specify the size of the container in column C;
6. Specify the type of the container in column D.

A similar idea for the data generator for simulation experiments appears in simulations of warehousing at the distribution centers, international-departure flights at airports, and emergency departments at general hospitals (Takakuwa et al. 2000; Oyama and Takakuwa 2003; Takakuwa and Shiozaki 2004). The required input parameters are percentages that correspond to increases or decreases compared to the baseline condition on the 100 containers/ship that are being unloaded and a percentage of

each size and type of containers. The interface of the data generator is shown in Figure 8. By inputting these parameters, the corresponding container handling list is created. Table 3 shows a sample output created by the proposed data generator. The generated data includes the ship number and the size and the type of the container. The other types of containers included refer to the container, i.e., a tank container, a reefer container, etc. These are usually stocking at the SC yard and in specified areas, which are omitted in this study. By utilizing these generated data as an input file for the simulation model, experiments can be conducted under any specified condition.

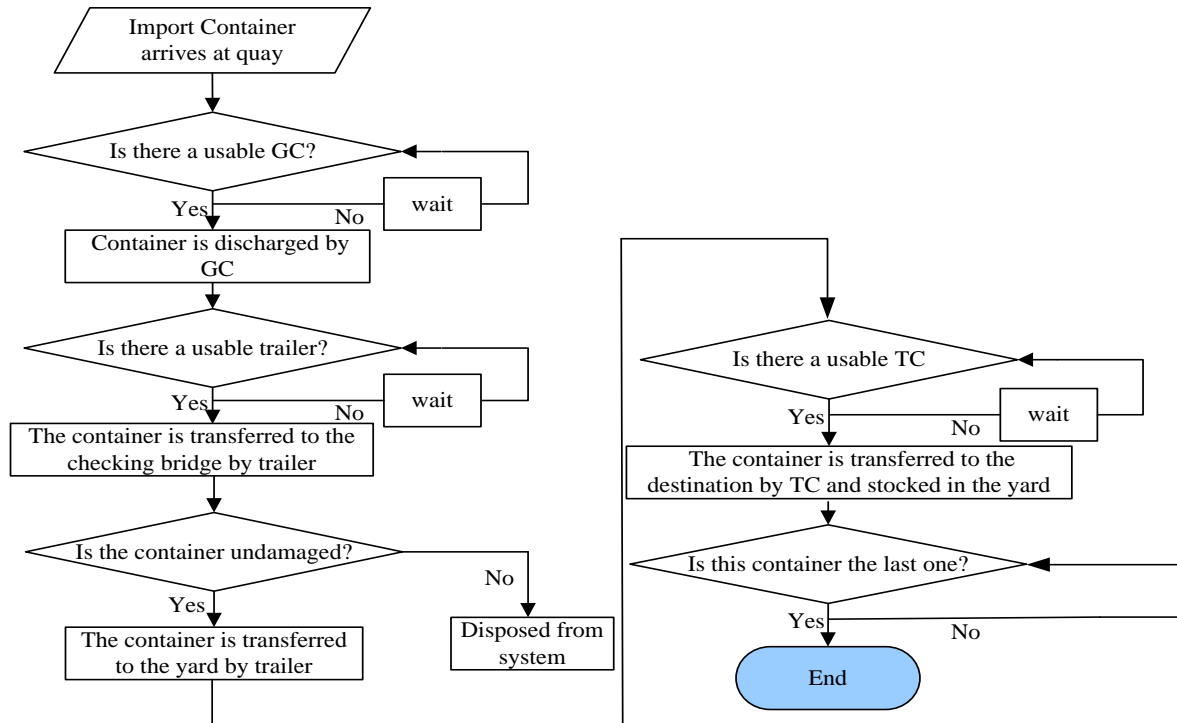


Figure 7: Handling flows of the import container.

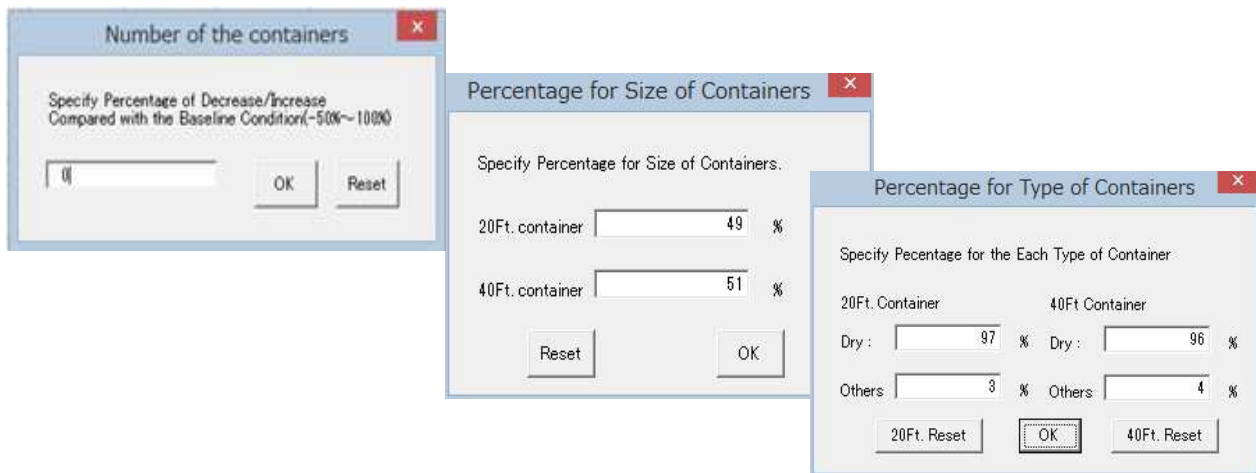


Figure 8: Interface of the data generator.

Table 2: Experimental conditions and parameters.

Items	Descriptions	Parameters	Unit
Gantry Crane	Number of units held	1	(units)
	Processing Time	27 + Erlang(28.4, 3)	(second)
Check Bridge	Number of units held	1	(units)
	Processing Time	Triangular(26, 30, 32)	(second)
UL Block	Number of units held	No.2 (1B, 2B), No.4 (1D, 2D), No.8 (1H, 2H), No. 9 (1J, 2J), No.10 (1K, 2K), No.12 (3B, 4B), No.14 (3D, 4D), No.15 (3E, 4E), No.16 (3F, 4F), No.18 (3H, 4H)	
Transfer Crane	Number of units held	1	(unit/block)
	Processing Time	20 ft.	30 + Erlang(26.3, 3) (second)
		40 ft.	36 + Erlang(27.7, 3) (second)
Inbound Trailer	Number of units held	4	(units/GC)
	Travel speed	20	(km/h)

Table 3: Sample of the generated data.

No.	Ship No.	Size	Type
1	1	0	1
2	1	0	1
3	1	0	1
4	1	0	1
5	1	1	1
6	1	1	2
7	1	0	1
8	1	1	1
9	1	1	1
10	1	0	1
omitted			

5 SIMULATION ANALYSIS

In this section, the above-mentioned procedure of preparing simulation data explain the process of obtaining the ship discharging times using numerical examples. Consider a case of 100 containers/ship, 20 F:40 F=1:1, dry container 100% as a typical case in the discharging processes. In this case, the associated area including apron (GC1 in Figure 1) and the UL blocks were included in the simulation model used to examine the discharging flows and to collect the ship discharging statistics. A simulation model in this study was conducted using the modeling software Simio (Kelton, Smith, and Sturrock 2013). The 3D animation provides an efficient mechanism assist in the model verification.

The evaluation indicators of trailer travel time and ship discharging time are included. Trailer travel time is defined as the time interval required for the trailer to take the container from the GC to the yard block where the container is unloaded. Ship discharging time is defined as the time interval required from the first container unloaded onto the trailer to when the last container enters the yard block.

As the experimental conditions of the experiment, the numbers of the import containers are specified as 1.00, 1.20, 1.40, 1.60, 1.80, and 2.00 times the baseline. The defined-operation blocks are divided into

5 groups: 1 block (No. 2), left 5 blocks (No. 2, 4, 8, 9, 10), front 5 blocks (No. 2, 4, 12, 14, 15), right 5 blocks (No. 12, 14, 15, 16, 18), and the total 10 blocks. Thus, twenty replications of the simulation model are performed.

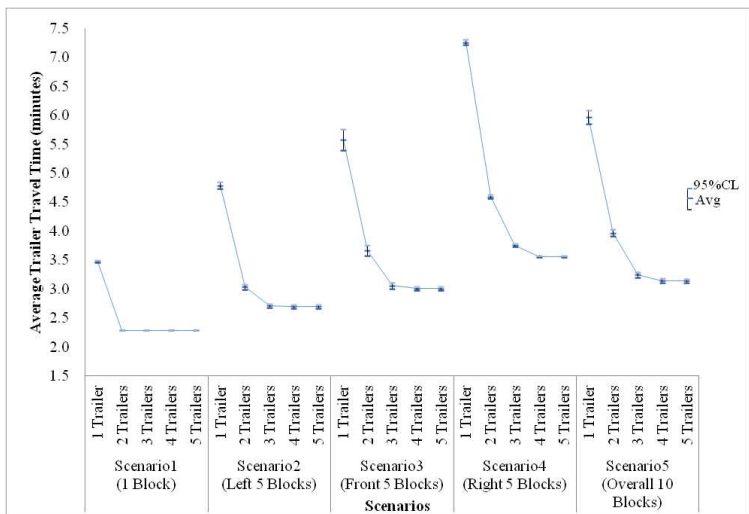


Figure 9: The trailer travel time.

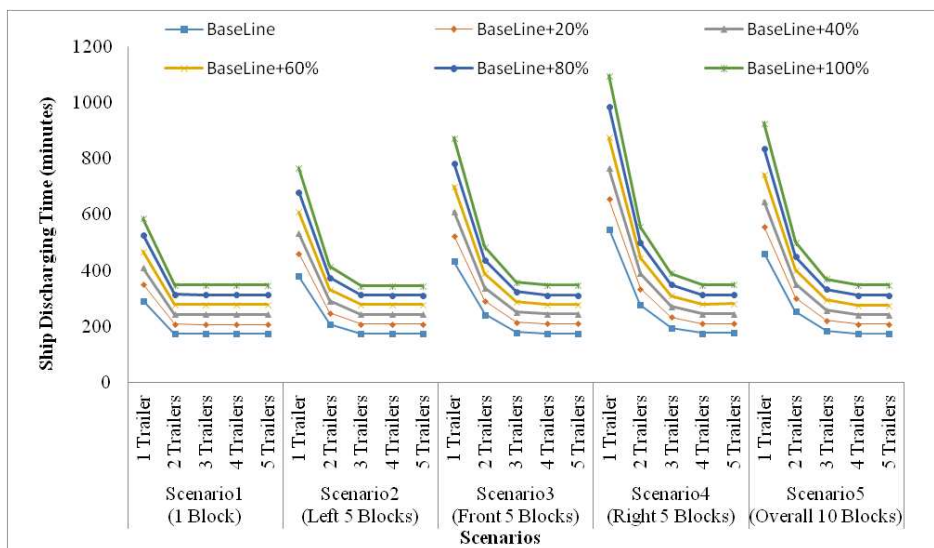


Figure 10: The ship discharging time.

After twenty replications of the simulation experiments under the specified conditions are executed, the 95% confidence interval for the average trailer travel time is obtained, as shown in Figure 9. The time is shortened effectively by increasing the trailer number to 3 units, except for Scenario 1. In addition, when the trailer number is up to 4 units, only the time in the Scenario 4 is significantly shortened. There is almost no difference among the scenarios when the trailer number is increased to 5 units. Therefore, four trailer units to a GC can be confirmed as the appropriate number to ensure the ship service. Furthermore, the average ship discharging time is shown in Figure 10. The ship discharging time changes very little between scenarios 2 and 3 when the number of trailers is increased from three to four units. The ship discharging time assumes that three trailers can complete the tasks in the shortest time if the import

container can be unloaded in the blocks among the left area and front area. In this case, rest of the trailers can be arranged to serve other GCs.

6 CONCLUSIONS

In this study, a simulation model of a container terminal is constructed and used to examine the flows of the import containers under the various levels of activity. The yard operation data recorded in the terminal operating system is processed using a VBA program, which was developed in this study, to capture the system working features and to obtain the simulation input parameters. Then, a special purpose data generator is developed to create experimental data to execute the simulation experiments under various activity levels. The system performance is compared by implementing the simulation model. Consequently, the proposed procedure for processing system data and creating input parameters for the model can be used as a model to forecasting and evaluate port operation.

Future studies should consider the influence of the loading containers flows and other types operations on the yard. Furthermore, the berth allocation problem to determine the number of GCs dispatched to the vessel should studied under the various activity levels.

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