Analysis of Combined Productivity of Equipments in Container Terminal

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〈CONTENTS〉

Abstract : The objective of this paper is to analyze the combined productivity of stevedoring system at port container terminal. In general, the productivity of container terminal is evaluated by the productivity of container cranes at apron, but there are other equipments such as transport vehicles and yard cranes. Therefore, a method that can estimate the optimal equipment combination of stevedoring system in container terminal is proposed. From the application of the case study, we demonstrated the savings effect using mean waiting time rates by the equipment combinations. We performed various simulation experiments and estimated the equipment combinations to increase the productivity and to decrease the waiting time between equipments. From the results of the simulation analysis, we demonstrated that bottleneck occurs in TC (Transfer Crane) including TC waiting and waiting of YT(Yard Tractor) in front of TC. In order to improve the combined productivity and decrease savings effect, the equipment should be change from 10 TCs to 12 TCs.

Key Word : combined productivity, stevedoring system, equipment combination, simulation

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Ⅰ. Introduction

The productivity is considered as a viable measure of container terminal performance due to the complexity in finding a solution. The performance of container terminals is determined by a variety of inputs, outputs, actors, intrinsic characteristics and external influences. The method of managing of ports is quite complex and crucial to their efficiency and effectiveness that are increasingly demanded. For the vessel owners it is of paramount importance that the vessel is quickly "turnaround", meaning loaded and discharged as quickly as possible. To shorten the time spent by vessels, terminal operators need to put special emphasis on resource allocation, receipt of information before they come alongside the berth in order to reduce the stay of a containership.[1)]

There are many performance measures for a port container terminal. Watanabe proposed several performance measures to use when designing container terminals.[2)] Yun & Choi used the utilization of equipment for the analysis of container terminals.[3)] Lai & Lam used throughput, utilization, and waiting time as measures for assessing the container yard in Hong Kong.[4)] Ramani provided performance indicators such as berth occupancy, vessel waiting time,

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1) M. Kia, E. Shayan, and F. Ghotb, "The importance of information technology in port terminals operations", *International Journal of Physical Distribution & Logistics Management*, Vol.30, No.3-4, pp.331-344, 2000.

2) I. Watanabe, "Characteristics and analysis method of efficiencies of container terminal-An approach to the optimal loading/unloading method", *Container Age*, March, pp.36-47, 1991.

3) W. Y. Yun & Y. S. Choi, "A simulation model for container-terminal operation analysis using an object-oriented approach", *International Journal of Production Economics*, Vol.59, pp.221-230, 1999.

4) K. K. Lai, & K. Lam, "A study of container yard equipment allocation strategy in Hong Kong", *International Journal of Modeling & Simulation*, Vol.14, No.3, pp.134-138, 1994.

vessel outputs, and vessel turnaround time.[5] Razman & Khalid used performance indicators such as vessel turnaround time, berth occupancy, vessel outputs, and crane utilization to analyze terminal operation[6]). Yun et al. provided various output statistics such as waiting time of vessels and yard tractors, the utilization for container cranes, and the berth occupancy rates.[7] Due to the frequent interaction between equipments, more accurate measures need to be considered.

The methodologies used to develop the measures are based on the analytical queueing model and the simulation model. But complex systems such as port container terminals need more effort and time for modeling and analysis of them considering the high volume of use. It often turns out that it is not possible to develop analytical models for a queueing system. This can be due to the characteristics of the input or service mechanisms, the complexity of the system design, or the nature of the queue principle. In port container terminals, the main objective of their management is to optimize the utilization of the port resources. Optimizing resource utilization encourages trade, improves the competitiveness of the container terminal, and provides efficient and effective services at low cost.

In this paper, it is described to the combined productivity to minimize the sum of waiting times both equipments used in a port container terminal. Using this combined productivity, we find out the optimal strategy to allocate equipments such as container cranes, yard

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5) K. V. Ramani, "An interactive simulation model for the logistics planning of container operations in seaports", *Simulation*, Vol.66, No.5, pp.291-300, 1996.

6) M. T. Razman, & H. Khalid, "Simulation and analysis for the Kelang container terminal operations". *Logistics Information Management*, Vol.13, No.1, pp.14-20, 2000.

7) W. Y. Yun, Y. S. Choi, J. Y. Song, C. H. Yang, "A simulation study on efficiency of container crane in container terminal", *IE Interface*, Vol.14, No.1, pp.67-78, 2001.

cranes, and yard tractors.

Ⅱ. Port Productivity

1. Measurement of Port Productivity

According to Thomas Ward, at JWD[8] in USA, one must make the distinction between short-term and long-term productivity, since different categories of measurement are useful in different contexts. Short-term productivity includes stevedoring, gate, intermodal, and yard productivities, while the long-term concerns are overall throughput, terminal throughput density, berth throughput density, and container storage dwell time. For both of these types of productivity, there are a host of relevant measurements that are meaningful only if they are capable of translating across company borders and have some kind of greater relevance in the industry at large. As Thomas Ward explained, this is made possible by clearly defining the units used and doing away with the ambiguity of which elements are included and excluded in making the measurement.

In 1997 Terminal Operation Conference, Asaf Ashar argued that "a meaningful market pricing system should be based on 'productivity-adjusted' charges."[9] His rationale was that the adoption of such a pricing strategy would boost performance as well as make cost structures easier to analyze. However, in order to make a move towards this kind of pricing system, he realized that there would have

8) Jordan, Woodman, & Dobson, "Simulation Analysis Reports", Pusan Newport Container Terminal Planning Study, 1999,

9) A. Ashar, "Dispelling the Myths of Port Performance", 1997 Terminal Operations Conference in Barcelona, 1997.

to be some kind of standardization in place to measure stevedoring productivity.[10] This need became doubly clear when the Port Society of Cartagena in Colombia undertook a study to determine its competitive position in the Caribbean market. It quickly became apparent that making a measurement of stevedoring productivity was not going to be entirely straightforward. Then, as now, there was confusion and inconsistency among different ports concerning their productivity.

In an attempt to do away with the ambiguity surrounding productivity measurements, measurements are defined units and quantities. For example, there are port time, gross berth time(or net berth time), gross gang time(or net gang time), load/unload, rehandle, shifting on-board, and hatch opening/closing.

Watanabe proposed a theory on the measurement of productivity as follows[11]

1) For the means to improve total management for respective container terminals;
2) For statistical analysis. For example if the terminology and its definition for productivity are standardized and followed by respective data such as those in the "Containerization International Yearbook," everybody to analyse and compare;
3) For the planning and designing of container terminals.

Watanabe's theory seems to be concerned solely with the productivity of resource utilization, i.e. land resources, as opposed to the technical productivity of equipment or labour productivity.

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10) Stevedoring productivity is defined as gross work cycles per crane hour and is used as an indicator of operative efficiency.

11) D. Robinson, "Measurements of Port Productivity and Container Terminal Design", Cargo Systems, Cargo Systems Report, 1999.

2. Port Productivity in Busan Port

In general, to measure a port productivity, we used the C/C(Container Crane) productivity like net productivity[12)] and gross productivity.[13)] Using data of 6 container terminals in Busan port, the trend of C/C productivity is analyzed. During 11 years, average 5 lifts/hours was increased respectively in Figure 1.

〈Figure-1〉 **Trend of C/C Productivity**

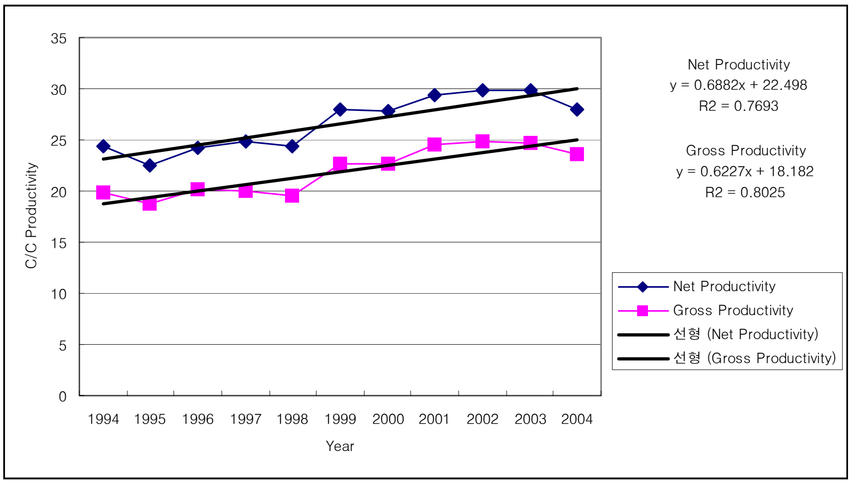


Table 1 shows the combination of stevedoring system and C/C productivity for each container terminals. Especially, Gamman container terminal was recorded higher C/C productivity because it

12) Net productivity is based on a ship productivity measure. The number of containers moved per net hour. Net time is the elapsed time minus time unable to work the ship due to award shift breaks, ship's fault, weather, awaiting cargo, industrial disputes, closed holidays, or shifts not worked at the ship operator's request.

13) Gross productivity is based on a crane productivity measure. The number of containers moved per net crane hour. In theory, dividing the net rate by the crane rate provides a measure of crane intensity.

has more TC(Transfer Crane) per C/C and over average YT(Yard Truck). We know that the number of equipment is an important factor in C/C productivity in terms of the combination of equipments. Because TC and YT support C/C work, it need to be found the feasible number of equipment.

〈Table-1〉 **Stevedoring system and CC productivity in Busan port**

Items	Stevedoring system			C/C Productivity(year)			
	# of C/C	# of YT per C/C	# of TC per C/C	2001	2002	2003	2004
HBCT	13	4.8	2.4	22.7	19.6	21.1	21.9
PECT	12	7.6*	2.6	22.4	21.1	22.5	23.6
UTC	5	4.0	2.6	21.1	19.3	19.4	19.8
Gamman	14*	5.7	2.8*	26.4**	25.1**	24.6	25.5**
Gamcheon	4	4.8	2.5	24.3	22.9	21.9	21.9
New Gamman	7	5.1	2.3	-	21.8	25.4**	23.5
Average		5.3	2.5	23.4	21.6	22.5	22.7

* : respectively maximum equipment rate
** : maximum value among C/C productivities

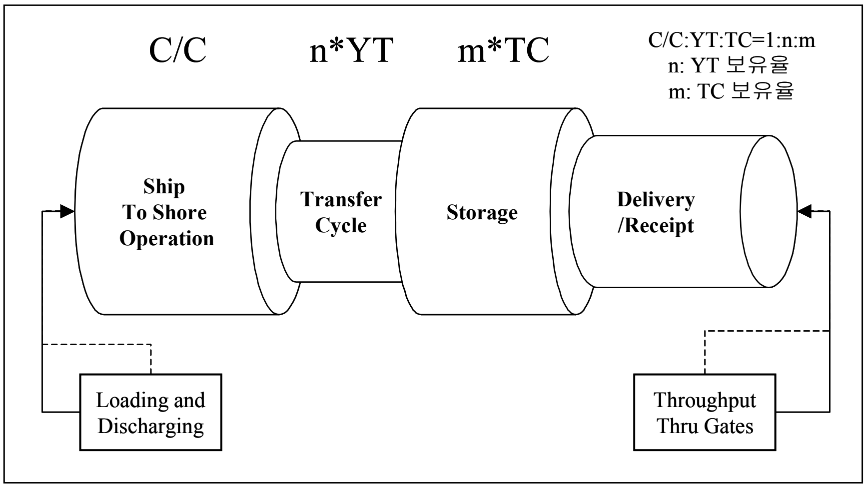
Ⅲ. System Operations and Evaluation Model

1. System Operation

We assume that the container terminal consists of three subsystems: gate, yard, and berth. Container handling equipments in this system are C/C(Container Crane), TC(Transfer Crane), YT(Yard Tractor), and trailers.

In building a model of the container terminal, a set of operations is taken from the various subsystems that exist within the terminal domain. In Figure 2, the four main operations in a container terminal are illustrated: (1) ship-to-shore, (2) transfer cycle, (3) storage, and (4) delivery/receipt area.

〈Figure-2〉 **Concept model for analysis of combined productivity**



1) Ship-to-shore operation

The loading/discharging of a vessel requires a feasible number of cranes. Ship-to-shore area where terminal operators are experiencing problems is reducing the unproductive and expensive container moves in a container terminal. The number of cranes used varies between 2-4 on containerships with about 5-10 transfer cranes serving them. The vessel planning program will work with the load sequence list provided by the ship line.

2) Transfer cycle

Containers are moved from apron to the storage area to be stacked or placed in an area for dispatch. Depending on the operations, yard tractors are usually employed in this operation. Transfer cranes are further employed in stacking or moving containers around the storage area.

3) Storage

Transfer cranes are employed in the sorting and handling of containers in the container terminal. A yard-planning program is employed in this operation that will use stacking algorithms in assigning a space for the container till it is loaded or dispatched /picked-up.

4) Delivery and Receipt

The interface to other modes of transport lies in this operation. The managing of the gate is to obtain information of containers coming into the container terminal so as to be properly physically handled till loading. Controlling this access to the container terminal is important in that it affects other parts of the container terminal operation. The data collected; container number, weight, port of destination, hazmat, reefer, shipper, ship line, and seal number are used in deciding where to place containers for storage and later for loading.

2. Equipment Operation

The equipment operation in container terminal was formulated as a queueing system where the CC and TC are classified as servers and the vessels, YTs, and trucks are classified as customer. In fact, the system consists of two queueing networks as follows.

1) A close queueing network

The equipment involved in this network is CC, TC, and YT as customers. The YTs are alternatively served by the CC and the TC. That is, the YTs transport containers between these two servers until the loading and unloading process is completed. As the YTs are bound by the container terminal, this is a close queueing network.

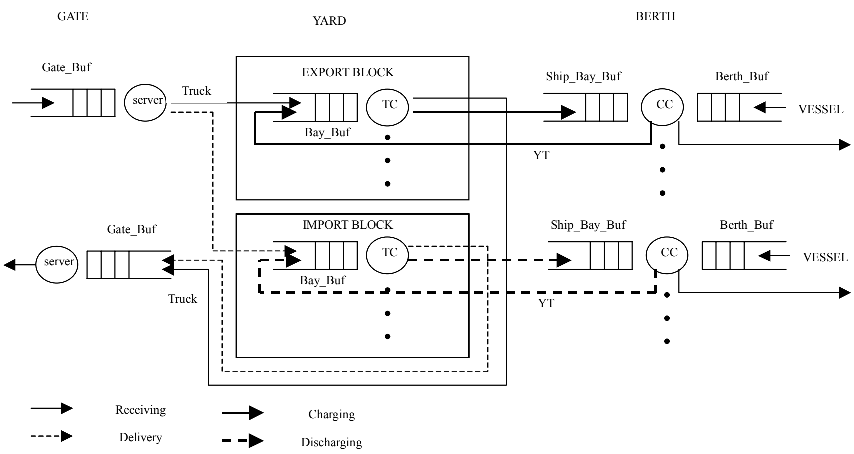
2) An open queueing network

The trucks and vessels are involved in this network. Every truck comes through the gate from outside the container terminal and is then served by one of the TCs. Because the trucks are not bound by the container terminal, this is an open queueing network component. Similarly the vessel is not bound by the container terminal. They come from outside the port and is then served by several container cranes. So vessels are a component of an open queueing network.

3) State transition network

The flow of containers is composed of import and export flows. For the import flows, containers are discharged by the cranes from vessels, and transported by the YTs to the import block, then they are stacked in the pre-assigned bay. At the import block, the YTs queue for the TC(Transfer Crane) to stack the containers in the pre-assigned block. For the export containers, the reverse process can be applied. The operational system for the port is depicted in Figure 3.

〈Figure-3〉 **Terminal Operations with Queueing System**



Source : Choi, Y. S., "Simulation Study for Performance Measures of Resources in a Port Container Terminal", *International Journal of Navigation and Port Research*, Vol.28, No.7, 2004.

The process begins when a vessel arrives at the berth and joins a "Berth_Buf". The first-come-first-served strategy is usually employed. If a berth is free, then the vessel can enter the berth. A delay occurs for the vessel until a berth is available. After the vessel enters the berth, it counts an average delay of about one hour before the discharging operation takes place. Several CC(Container Crane) per vessel are assigned to start the discharging and charging the containers. When these activities are complete, the vessel may have to wait for one hour before it can leave the port. Figure 3 shows all the equipment and buffers used to transport the import and export containers.

The state transition network presented in this paper has been implemented and solved by Visual Basic, a general-purpose programming language, in order to capture all of the details of the resource management policy.

The arrival-service(travel)-departure process followed by truck has been represented in terms of a state transition network, to make evident the congestion points along the process evident.

The work-move-wait-idle process followed by cranes such as CCs and TCs has been represented as a state transition network, to change the state along the process under work condition. Similarly, The YTs has the travel-wait-idle process. The state transition network of cranes and YTs is a closed network model to work continuously until all tasks are completed.

3. Evaluation Model of Productivity

In container handling operation, a YT is a vehicle that is loaded and unloaded by both a C/C and TC, but a vehicle that can also travel from the loading point to its destination under its speed. In this study, the control assigns an idle YT to respond to the needs of loading/unloading equipment such as the C/C or the TC, which load the YT. Then the crane activates the YT, which moves to the destination with a user-determined speed. At the destination, the YT activates the crane and waits until unloading is completed. Then the YT is empty again and the empty YT is sent to a destination unloaded.

Therefore, we can derive the inference based on the interaction between equipments such as C/C, YT, and TC. Table 2 shows that the cause and the occurrence point of bottleneck process in container handling operation. In Table 2, bottlenecks by equipment interaction mean an obstacle of productivity. Through the remove of obstacles, the bottleneck elements are minimize. In other word, that is to improve the productivity in terms of combined productivity.

〈Table-2〉 **Inference for cause and occurrence point of bottleneck process**

Occurrence point / Elements of bottleneck	Berth		Yard	
	C/C	YT	YT	TC
C/C waiting	Bottleneck	Lack of Equip.		Lack of Equip.
TC waiting	Lack of Equip.	Lack of Equip.		Bottleneck
YT waiting in C/C buffer	Lack of Equip.	Bottleneck		
YT waiting in TC buffer			Bottleneck	Lack of Equip.

* gray area : occurrence points of bottleneck process
** Lack of Equip. : the causes of bottleneck are the lack of each equipment

We discover the measure to find the waiting times using elements of bottleneck. Using the simulation results, the notations are defined as follows:

$W_{r(CC)}$: average waiting time rate of YT for C/C ······················ (1)
$W_{r(TC)}$: average waiting time rate of YT for TC ························ (2)
$W_{r(YT+CC)}$: average waiting time rate of YT in C/C buffer ······ (3)
$W_{r(YT+TC)}$: average waiting time rate of YT in TC buffer ······· (4)
A_w: average waiting value of C/C and YT in apron ················· (5)
Y_w: average waiting value of TC and YT in yard ····················· (6)
w_1: weight of waiting in apron(>+M) ··· (7)
w_2: weight of waiting in yard(>0) ··· (8)
P : evaluation function of combined productivity

Using the defined notations, the evaluation equation, P are defined as follows.

[calculation equation of waiting time rate]

$A_w = W_{r(CC)} + W_{r(YT+CC)}$ ·· (9)

$Y_w = W_{r(TC)} + W_{r(YT+TC)}$ ·· (10)

$P = w_1 * A_w + w_2 * Y_w$ ·· (11)

In equation (9), A_w indicates the waiting effects of C/C and YT in apron. In equation (10), we let Y_w denote the waiting effects of TC and YT in yard. Let $w_1 * A_w + w_2 * Y_w$ denote the evaluation function of waiting rates between equipments. By using P, it is a simple calculation to derive an expression for the effect of waiting time between equipments. Therefore, the objective function is to minimize the evaluation function P.

Let S(NCC, NTC, NYT) be the scenarios defiend by the values of the parameters NCC, NTC, and NYT. For example, S(4, 10, 4) denotes the four C/Cs per berth, ten TCs, and four YTs per C/C are employed during simulation run.

Ⅳ. Simulation and Analysis

The simulation system[14)] was programmed in the general-purpose language Visual C++ based on object-oriented programming. The object-oriented modeling methodology for object-oriented simulations was used. This approach can support to build state transition models easily, and is easily modified.

14) Y. S. Choi & T. Y. Ha, "Simulation Application for Container Terminal Using an Object Oriented Simulation", *Ocean Policy Research*, Vol.19, No.2, pp.211-238, 2004.

1. Experiment Design

We used the Korea Express Gamman container terminal with one berth located in Busan as the model system in this simulation. The scope of our experiment model is as follows. The gate has three entrances and two exits. The container yard has 22 blocks (13 export blocks and 9 import blocks) and 10 TCs. Each block includes 20 bays and each bay consists of 6 rows by 5 tiers. A quay has one berth and four C/Cs. The container types include 20 foot and 40 foot containers.

This model considers the values of the various parameters of facility operations and the same criteria are used to evaluate the system effectiveness. Table 3 shows throughput by cargo composition in the year of 2004 and applied 1.53 as TEU/VAN ratio.

〈Table-3〉 **Throughput figure in the Korea Express Gamman Terminal**

Cargo Composition	Berth (TEU)	Yard (TEU)	Gate (TEU)	Gate (Truck)
Import volume	247,172		247,172	161,550
Export volume	214,828		214,828	140,410
T/S discharging	132,472			
T/S (to other terminal)	61,751	874,825	61,751	40,360
T/S loading	132,473			
T/S (to this terminal)	53,673		53,673	35,080
Coastal	32,457			
Annual throughput	874,825	874,825	577,424	377,401

This model uses the TC system as yard side equipment and the same operation flows. Therefore, as operation policies, the same parameters as input in this experiment are used.

- Receiving operation: permission during 24 hours
- Storage dwell time: import (3 days), export (4 days), transshipment(7 days)
- Vessel time: berthing (40 minutes), deberthing (20 minutes)
- Vessel interarrival time: average 2 hours

The equipment characteristics are summarized in Table 4. We assumed that operation times of C/C and TC has a normal distribution.[15)]

〈Table-4〉 **Equipment characteristics**

Characteristics \ Equipment	C/C	TC	YT	Truck
Number of equipment	4	10	24	-
Operation time(second)	N(112.8, 31.2)	N(87, 19.3)	-	-
Speed(km/h)	3	8	20	20

2. Result Analysis

In simulation experiment, the results of S(NCC, NTC, NYT) are analysed by changing the number of TC and YT under fixed 4 C/C. The weight between apron and yard is assumed equivalent as w_1=1 and w_2 =1.

A simulation analysis is performed to estimate the performance of equipment deployment strategies under different scenarios.

Table 5 shows that $W_{r(CC)}$ decrease as the allocated number of YT

15) Choi, Y. S., "Simulation Study for Performance Measures of Resources in a Port Container Terminal", *International Journal of Navigation and Port Research*, Vol.28, No.7, 2004.

per C/Cs and the number of TCs is increased.

〈Table-5〉 **Mean waiting time rate of CC($W_{r(CC)}$)**

YT \ TC	6	8	10	12	14
2	68.14	63.78	60.07	59.81	59.02
3	58.86	50.24	43.53	42.31	39.83
4	52.95	38.90	29.72	26.71	23.80
5	50.26	33.50	19.25	13.99	10.31
6	46.00	29.57	12.10	5.76	1.31*

<Table-6> shows that $W_{r(TC)}$ decrease as the allocated number of YT per C/C is increased but it increases as the number of TC is increased.

〈Table-6〉 **Mean waiting time rate of TC($W_{r(TC)}$)**

YT \ TC	6	8	10	12	14
2	19.67	27.85	35.31	40.59	44.28
3	15.24	23.38	31.99	37.59	45.41
4	11.57	19.31	26.91	34.54	41.32
5	9.73	14.53	22.15	30.39	37.06
6	6.76*	11.65	18.53	26.44	36.70

Table 7 shows that $W_{r(YT+CC)}$ is significantly increased when the condition of equipment employment is more than 5 YTs and 10 TCs.

〈Table-7〉 **Mean waiting time rate of YT in front of CC($W_{r(YT+CC)}$)**

YT \ TC	6	8	10	12	14
2	1.05*	1.30	1.61	1.62	1.60
3	1.81	2.62	3.41	3.51	3.59
4	2.26	3.97	5.45	5.81	6.00
5	2.37	4.73	7.79	8.81	9.50
6	2.63	5.38	10.78	13.61	17.51

Table 8 shows that $W_{r(YT+TC)}$ is significantly decreased as the number of YT and TC is increased. Minimum mean waiting time rate, $W_{r(YT+TC)}$ is 6.85 in 14 TCs and 2 YTs.

〈Table-8〉 **Mean waiting time rate of YT in front of TC($W_{r(YT+TC)}$)**

YT \ TC	6	8	10	12	14
2	27.47	17.88	12.24	8.74	6.85*
3	36.68	23.34	15.39	11.49	7.37
4	44.94	28.04	18.73	12.74	8.79
5	52.97	35.91	22.51	14.66	10.04
6	56.98	42.21	25.95	16.61	9.19

Table 9 shows that A_w is significantly decrease as the number of YT and TC is increased. Minimum waiting value of apron, A_w is 18.83 in 14 TCs and 6 YTs. A_w is stabilized over 5 YTs and 12 TCs.

〈Table-9〉 **Waiting value of apron(A_w)**

YT \ TC	6	8	10	12	14
2	69.19	65.08	61.69	61.43	60.61
3	60.68	52.86	46.94	45.82	43.42
4	55.21	42.87	35.17	32.53	29.80
5	52.63	38.23	27.05	22.81	19.76
6	48.64	34.95	22.88	19.38	18.83*

Table 10 shows that Y_w is not specific pattern as the number of YTs and TCs. Minimum waiting value of yard, Y_w is 43.05 in 12 TCs and 6 YTs.

〈Table-10〉 **Waiting value of yard(Y_w)**

YT \ TC	6	8	10	12	14
2	47.14	45.73	47.55	49.33	51.13
3	51.93	46.72	47.39	49.09	52.79
4	56.51	47.35	45.64	47.29	50.11
5	62.70	50.44	44.65	45.05	47.10
6	63.73	53.87	44.48	43.05*	45.90

Minimum value of evaluation function can be found out when equipment combination is 12 TCs and 6 YTs in Table 11.

〈Table-11〉 **Values of evaluation function(P)**

TC / YT	6	8	10	12	14
2	116.33	110.82	109.24	110.76	111.75
3	112.61	99.59	94.32	94.91	96.21
4	111.72	90.22	80.81	79.82	79.92
5	115.33	88.67	71.70	67.85	66.87
6	112.37	88.82	67.36	62.43*	64.73

In Figure 4, we know that the decrease pattern can be found over 10 TCs. Especially, minimum value of P occur in 12 TCs and 6 YTs

〈Figure-4〉 **Graph of evaluation function(P)**

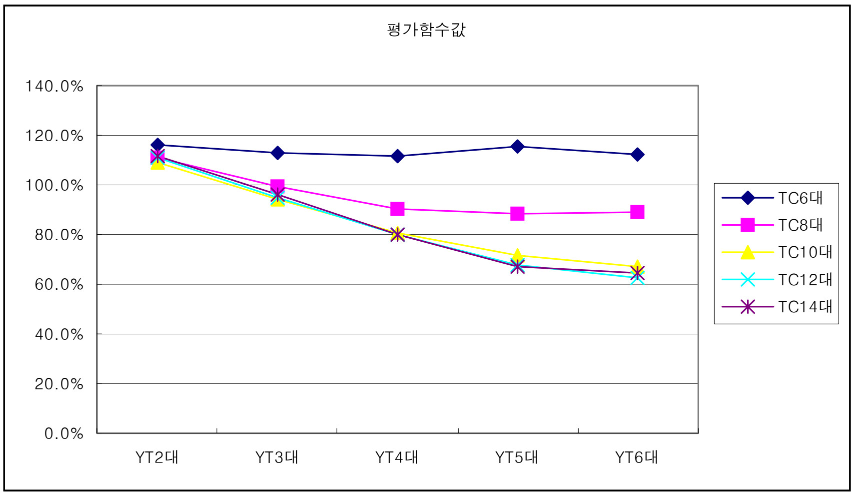


Table 12 shows that relative savings effect significantly decrease when the number of equipment is more than 10 TCs and 5 YTs. Therefore, the best equipment combination to reduce waiting time both equipments are 12 TCs and 6 YTs.

〈Table-12〉 **Relative savings effect**

YT \ TC	6	8	10	12	14
2	0.54	0.48	0.47	0.48	0.49
3	0.50	0.37	0.32	0.32	0.34
4	0.49	0.28	0.18	0.17	0.17
5	0.53	0.26	0.09	0.05	0.04
6	0.50	0.26	0.05	0.00*	0.02

In various scenarios for equipment deployment, an alternative S(4, 12, 6) to minimize the waiting time both equipments are 12 TCs and 6 YTs in terms of zero savings effect.

Therefore, if the existing 10 TCs are changed to 12 TCs, the evaluation function of combined productivity is minimized in minimizing waiting situations.

As for the results, in Table 12, we demonstrated that bottleneck occurs in TC including TC waiting and waiting of YT in front of TC. In addition, we know that there are savings effects by changing from 10 TCs to 12 TCs.

〈Table-13〉 **Bottleneck and improvement in case study**

Stevedoring System		Bottleneck	Improvement
Equipment	Number		
C/C	4		
TC	10	TC waiting	10 TCs -> 12 TCs
		waiting of YT in front of TC	
YT	24		

Ⅴ. Conclusions

This paper aims to finding out the combined productivity to improve the productivity in container terminal. In order to measure the combined productivity, evaluation function for waiting times of both equipment was established. Using the simulation model developed for a container terminal, we analyzed the waiting time with various deployment for equipment, and obtained the required number of equipments and a savings effect by evaluation functions. This measure can analyze the bottleneck equipment and find the improvement point of stevedoring system. From the results of the simulation analysis, we demonstrated that bottleneck occurs in TC(Transfer Crane) including TC waiting and waiting of YT(Yard Tractor) in front of TC. In order to improve the combined productivity and decrease savings effect, equipment should be change from 10 TCs to 12 TCs.

Presently, container handling operations at the Korean container terminal have expanded considerably. Consequently, there will be an increased need for new equipment and extended container terminal facilities. In order to solve this problem and obtain a good alternative, the combination of equipment to minimize the savings effect will be useful.

For further study, we are trying to find the relationship between waiting value of apron and waiting value of yard and the relationship can support the efficient operation strategy for equipment allocation.

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