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Dynamic Equipment Deployment at a Container Terminal: Transfer System Based on Real-Time Positioning

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In container terminals, containers are transported from the quay to the storage yard and vice versa by yard trucks (YTs), in which YTs are used for transfer operations. We focus on the operational management of the dynamic transfer equipment deployed between the quay and the container yard, during the container unloading/loading process at a given number of ships according to a previously planned berth schedule. This study discusses how virtue of information technology enhancement activities is provided to raise port competitiveness. Advanced operation systems are actively being made, and determined from the viewpoint of investment effect. These systems are more preferable than infrastructure expansion and additional equipment acquisition. Using a simulation methodology, we have tried to prove that the real-time data collection by using radio frequency identification (RFID) and dynamic operation of YT brings a positive effect on the productivity improvement and resource utilization enhancement. As a result of that, it was found that about 25% of productivity improvement may be realized by simulation study. Computational calculations for validation of simulation models based on real-time data are provided.

Keywords: container terminals, container transport, operational management, simulation, information technology

0 INTRODUCTION

Simulation methodology is widely used for dynamic planning and operation at a container terminal. We present a general framework to support the operational decisions for dynamic transfer system deployment based on real-time positioning.

A container terminal is a complex system with various interrelated components. There are many complicated decisions that operators or planners have to make. The handling operations in container terminals include three types of operations: ship operations associated with ship-berth link, receiving/delivery operations for external trucks, and container handling and storage operations in a yard. Container ships are loaded and unloaded where containers are temporarily stored while awaiting a new journey. Inbound containers arrive by ship and quay cranes (QCs) transfers containers from ship to a yard truck (YT). The YT then delivers the inbound container to a yard crane (YC) which may be a rubber tired gantry crane (RTGC) or rail mounted gantry crane (RMGC). The YC picks it off the YT which moves back to the QC to receive the next unloaded container. For the loading operation, the process is carried out in the opposite direction. This is indirect transfer systems where a YT delivers a container between the apron and the container yard. RTGCs or RMGCs transfer containers between yard trucks and yard stacks in the container yard.

Before we continue, it is important to mention that several alternative handling operations in container terminals are currently being used and planners usually plan them in advance to maximize the efficiency of the operations. In this paper, we assume dynamic YT deployment based on real-time positioning. These resources for the planning operation are usually limited in their capacities and thus priorities among handling activities that require the resources must be determined through the planning operation. The resources include berths, QCs, YTs, YCs, container yard space and other handling equipment.

The rest of this paper is organized as follows. In the next subsection we provide an overview of the literature related to container port simulation

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models. Section 1 discusses YT deployment planning at a container terminal. In Section 2, we present the problem statement. Section 3 describes simulation models and presents a brief description of simulation modeling procedure consisting of model structure, data collection and applied simulation algorithm. In Section 4, computational results are reported to evaluate the efficiency of the models. Finally, we conclude by summarizing the results and contributions of this paper.

0.1 Literature Review

Simulation models have been used extensively in the planning and analysis of operating processes at a container terminal. Many different simulation models regarding terminal operation, especially anchorage-ship-berth link, terminal design, container yard optimization planning, YC deployment, container handling and storage operations in a yard and others, have been developed in papers [1] to [33]. These models are coded in different simulation languages, as it can be seen in Table 1.

It should also be pointed out, as shown in Table 1, that there are a few overview concepts of container port operation literature given by Vis and Koster [34], Steenken et al. [35], Stahlbock and Voß [36], Günther and Kim [37] and Kim [38]. Good surveys of container port operation have been done by these papers.

One can conclude that all of these main port links have been adequately analyzed and modeled by using different simulation approaches. Various operations research models and methods in the field of optimizing main port link planning are applied more and more in world terminals.

All the previous studies assumed that the objective simulation models are developed in different environment, and that optimal solutions can be obtained. However, in container terminals, there are many complicated constraints to be satisfied, and so, finding an optimal solution itself is a difficult problem. This is why simulation models of dynamic transfer operations based on real-time positioning are applied to the YTs deployment problem in container terminals.

1 YARD TRUCK DEPLOYMENT PLANNING

We focus on the operational management of the dynamic YT deployed between the apron and the container yard, during the container unloading/loading process at a given number of

Table 1. Literature overview

Considered problems	Approaches	References
Simulation of ports and container terminals (CT)	PORTSIM Modsim III Object oriented programming, C^{++} ARENA, SLX Visual SLAM AweSim Witness software Taylor II GPSS/H Extend-version 3.2.2 Scenario generator Java Generic simulation model Discrete event simulation	Nevins et al. [5]; Gambradella et al. [6] and [11]; Yun and Choi [8]; Tahar and Hussain [10]; Merkuryev et al. [4] and [9]; Lee et al. [17]; Park et al. [27]; Kozan [30]; Legato and Mazza [12]; Nam et al. [13]; Ng and Wong [28]; Shabayek and Yeung [14]; Martinez et al. [21]; Kia et al. [15]; Pachakis and Kiremidjian [16]; Dragović et al. [24] and [25]; Sgouridis et al. [18]; Hartmann [22]; Bielli et al. [26]; Otjes et al. [29]; Dahal et al. [20];Canonaco et al. [31]; Petering & Murty [32]; Petering et al. [33].
Overview concept and surveys of recent research on CT	Quantitative models for various decision problems in CT; Logistics processes and operations in CT – optimization methods; Operations research at container terminals: a literature update; CT and terminal operations; Models and methods for operations in CT.	Vis and Koster [34]; Steenken et al. [35]; Stahlbock and Voß [36]; Günther and Kim [37]; Kim [38].

ships according to a previously planned berth schedule. This methodology indicates how this approach can be successfully integrated in a simulation model, already available, to support dynamic assignment of YT to allocated QCs. In such a model the resource assignment, in terms of representation, allocation and management of the resources, plays a vital role regarding the efficiency of the whole dynamic YT deployment architecture.

The YT assignment process is the allocation of handling tasks to container-handling equipment. Loading/unloading tasks are assigned to one of the QCs, based on the berth schedule and number of loading/unloading tasks for each ship. Transfer tasks are assigned to YCs dynamically, based on real-time information on waiting tasks and the status of each crane.

There are two types of strategies for assigning delivery tasks to YTs. One is a dedicated strategy and the other is a pooled strategy. In the case of the dedicated strategy, a group of YTs is assigned to a QC and deliver containers only for that QC. In the pooled strategy, all the YTs are shared among different QCs and thus any YT can deliver containers for any QC, which is a more flexible strategy for utilizing YTs. However, when YTs are shared by more than one QC (pooled dispatching) or a QC mixes the unloading and the loading operations alternately (dual cycle QC operation), both of which can be found rarely in practice, empty travels may be significantly reduced [38] and [39].

If the productivity of each area such as a quay, yard, and gate is harmoniously achieved, then the total productivity of a whole terminal can be improved. In particular, the productivity of YT in the container yard has a significant effect upon the overall productivity of a container terminal.

Productivity maximization of YT, minimization of QCs and YCs waiting time by effective fulfillment of work order, and remarkable utility rate improvement by dynamic vehicle assignment – all these are essential technologies for state-of-the-art port stevedoring system. For this reason, in order to increase the efficiency of YT, the development of a dynamic assignment technique (or dynamic operation) based on a real-time location system is much needed.

In this paper, we first discuss the YT deployment system. To attain the highest terminal productivity, it is vitally important that the activities of the YTs must be properly coordinated so the YTs serve QCs effectively. The above mentioned highlights the challenging nature of real-time YT operations control problems at a container terminal. Accordingly, we have considered two types of strategies for assigning delivery tasks to YTs: dedicated strategy and a pooled strategy. Then simulation models for both of them have been performed to measure their quantitative effect. The two YT assignment strategies presented here are directly tied into a detailed simulation models: current model for dedicated strategy and improved model related to pooled strategy. Both models are tested and shown to be viable in a real-time environment. Computational results indicate that one of these models is superior to the other.

In order to improve the reliability of each simulation model, we have collected the operation data of Hanjin Gamman Container Terminal (HGCT) located in Busan for one year [27]. We have used Arena as a simulation language [40] and a visual basic for a linkage to event handling.

2 PROBLEM STATEMENT

The crucial terminal management problem is to optimize the balance between the shipowners who request quick service of their ships and economic use of allocated resources. Since both the container ships and the container port facilities are very expensive, it is desirable to utilize them as intensively as possible. Simulation modeling is better than the analytical one in representing random and complex environment of container terminal. The different types of simulation languages that have been used for modeling the main container terminal link processes include PORTSIM, Modsim III, AweSim, Arena, Extend, Witness, GPSS/H and other. One of the problems is, also, the process of choosing the simulation tool to develop the model. There are two options in which the model of container terminal can be developed by general purpose programming language and simulation package or language.

2.1 Operational Situation

In an effort to make a survey of utilization for real-time data, we have visited HGCT a few times from October to December 2006. In order to find out current operational problems, we have been established requirements for transfer process improvement. Managers of HGCT informed us about the necessity of real-time data and also provided the needed data for simulations. Consequently, operational problems and the requirements for advancement of HGCT are defined.

In most cases, the bottlenecks in the operational process are usually caused by YT more than QCs or YCs. Furthermore, certain ports [27] included a pooling system or a dual cycle system for improved YT efficiency. But because of inaccurate location recognition and scanty wireless communication infrastructure, these systems ended up in failure.

In many Korean ports, the final job location of a crane can be checked by crane operator's input, consequently lowering the accuracy of input data. As for YT, it is almost impossible to conduct location tracking.

2.2 Requirements for Improvement

According to the realized interview, we address problem at HGCT, where YTs are assigned to specific QC until the work is completed. A more efficient YT assignment method called pooled strategy will be proposed. In this process, YTs return to any QC after delivering the containers and YTs can be dynamically assigned to the QC. Dynamic approach may be more advantageous, such as: when a YT arrives at a container stack point in the yard after receiving a container from a QC under unloading operation, instead of going back to the QC which is situated far from the present location, it proceeds to the next stack point which is close to the present location, to receive a container for export, and then proceeds to another QC under loading operation.

3 SIMULATION MODELS

Simulation of the logistics activities related to the arrival, loading/unloading, transfer and departure processes of YTs in container terminal can be carried out for different usages such as design of storage yard, increase productivity and efficiency of terminal equipment (YTs, QCs and YCs), analysis and planning of terminal transfer operations from the quay to the storage yard, etc. These logistics activities are particularly complex and very costly since they require the combined use of expensive infrastructure capacities especially berths and storage yard. Terminal transfer operations are required to serve containers as quickly as possible. Thus, in order to successfully design and develop terminal transfer operations and utilize it as efficiently as possible, it is necessary to develop a simulation model that will support decision making processes of terminal managers. The results, analysis and conclusions given here are intended to provide guidance on achieving time efficiency, raise productivity of YT and accuracy in the modeling and calibration of simulation models for HGCT.

Simulation model development is required to test the efficacy of dynamic operation based on RTLS. We need to analyze the current business process and then to design an improved business process. A current model YTs operation method is based on group of YTs, that is, a certain number of YTs per QCs, thus performing the job of loading and unloading for QC. At this time each YT group can be distinguished by their flag. Fig. 1 shows current YT operation concept of the dedicated strategy where a group of YTs is assigned to a QC and deliver containers only for that QC.

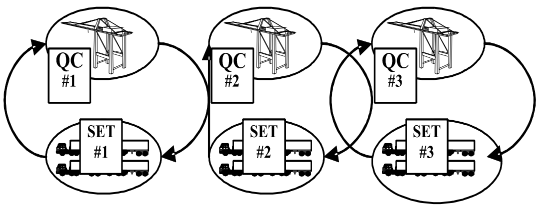

Fig. 1. *An illustration of current YT operation concept* (*dedicated strategy*)

Considering the dedicated strategy, YTs can be assigned per QCs orderly, which offers positive results. On the other side, it makes it impossible to exchange mutual cooperation with YTs belonging to the other groups. Consequently, job flexibility lowering and the availability of equipment are also expressed here.

In additional, YT's loaded travel and an empty travel are alternately repeated (called single cycle operation) between a QC and YCs. It happens because YTs are usually assigned to a single QC (dedicated assignment) and QCs start the loading operations only after all the unloading operations are completed.

Different from the above-mentioned is pooled dispatching strategy. In the pooled strategy, all the YTs are shared among different QCs and thus any YT can deliver containers for any QC as illustrated in Fig. 2. This strategy can be composed for a ship or for a whole container terminal.

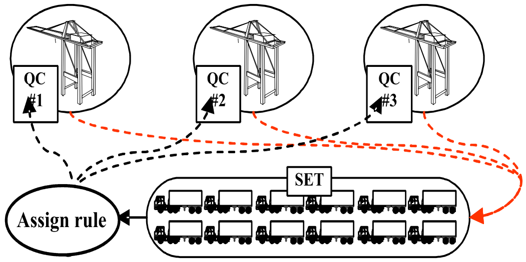

Fig. 2. *An illustration of improved YT operation concept (pooled strategy)*

As this method is FIFO-based assignment of YT, it can coordinate the YT imbalances utility rate. Referring to the job situation including the moving distance from the current job place, YTs can be dynamically assigned to the QC and YC, thus considerably reducing empty movement.

3.1 Initial Environment Setup for Simulation

This study has assumed that one berth has three QCs, one QC has one group organization composed of five YTs, and each group works for 10 hours. Transfer distance has been counted according to the required time of each movement lines for YTs as illustrated in Fig. 3 (environment setup for a current model). On the other side, the improved model based on 15 YTs has been dynamically assigned to 3 QCs. The environment setup provides another powerful advantage for improving the YT assignment processes at the HGCT.

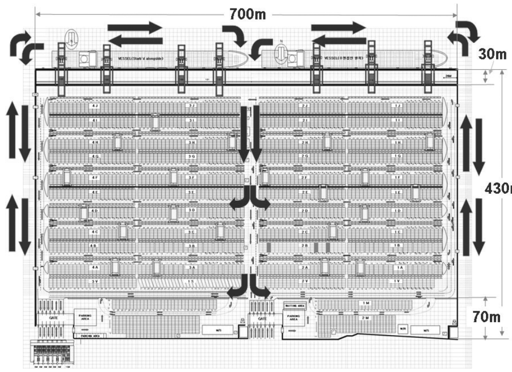

Fig. 3. *Terminal layout and movement lines of YTs*

An important part of the models implementation is the correct choice of the values of the simulation parameters. The input data of the mother ships are collected for one year (2005) [27]. Related to statistical analysis obtained data comes from the HGCT and includes the following values: arrival and departure time of mother ship, work time, number of assigned QCs, number of YTs, number of YCs, and storage position at the container yard. The average of each values and probability distributions were calculated by input analysis with Arena. YT’s waiting time for YC, working hours, YT’s travel speed and transfer distance have been calculated based on real data. Table 2 and Fig. 4 show the values of major input variables.

Table 2. The major simulation input variables

Variable	Type	Value
Service time distribution of ships	Distribution	1+GAMM (2.58, 5.48) hrs
Number of QC	Average value	3
Loading time for QC	Distribution	TRIA (20, 30, 40) sec
Number of YT	Average value	5 YTs per QC
Travel speed of YT	Average value	115 meters/minute
Waiting time distribution of YC	Distribution	TRIA (0.4, 1, 1.5) minute
YC working hours	Distribution	NORM (3, 0.2) minute
YT’s transfer distance	Considering the port layout and movement lines which are converted into meters.	

In addition, we have developed simulation models where service times were calculated by using a particular distribution. To obtain accurate data, we have first fitted the empirical distribution of service times to the appropriate theoretical distribution for serviced ship. Service time distribution is given in Fig. 4.

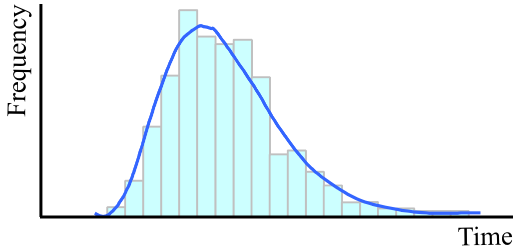

Fig. 4. *Service time distribution of ships* (1+GAMM (2.58, 5.48) hrs)

We have carried out the extensive numerical work for the high/low values of the HGCT models characteristics. For purposes of validation of the simulation model and verification of the simulation computer program, the results of simulation model were compared with the actual measurement. Our output computational calculation are based on different parameters of various HGCT characteristics such as: total handling volume at the same hours, handling volume per YT and delayed working hours owing to YT's waiting. And then the research on correlationship between handling volume and YT's working hour delay has been made.

3.2 Simulation Modeling

Storage yards at container terminals serve as temporary buffers for inbound and outbound containers. YTs are the most frequently used equipment at terminal for transfer operations. The efficiency of transfer operations heavily depends on the productivity of these YTs. As the workload distribution in the terminal changes over time, dynamic deployment of YTs between quay and container storage areas is an important issue of terminal operations management. These models addresses the YT deployment problem. Given the forecasted workload of each YT in each period of a day, the objective is to find the assignment strategy and routes of YT movements between quay and storage yard so that the productivity at terminal is improved and average delay time of QC is minimized. The problem is solved by simulation model. To improve the performance of this approach, we augment the new model and modify the solution procedure accordingly. Computational calculation shows that the modified model generates better results.

In particular, simulation modeling is suitable for the complex environment of a container terminal, which requires various criteria and scenarios. Most container terminal systems are sufficiently complex to warrant simulation analysis to determine systems performance.

We now present simulation models of dynamic transfer operations based on RTLS. These models, based on the authors experience and on extended discussions with managers and staff members at HGCT, are designed to show dependence of assigning strategies for YTs in real time.

Let's assume that we conduct modeling based on one ship. The modeling can be divided into three parts. Firstly, if containers come, it needs to be checked whether there are YTs available or not. If available, YTs will be assigned to QC, and if not, QC is to wait YTs. In the same time, the QC's waiting time for YT is counted. This procedure is explained in Fig. 5. Group of 5 YTs has been assigned by using the transporter module for QC referring to Table 3.

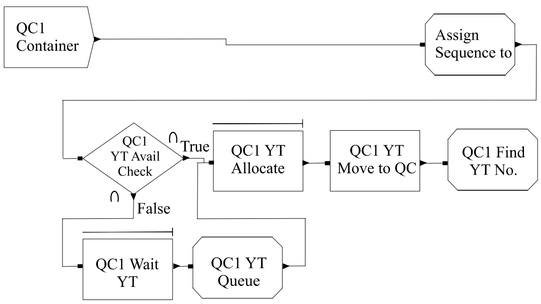

Fig. 5. *Sub-model for YT available after job completion of QC*

Secondly, if YTs are assigned, the corresponding containers will be loaded on the YTs, and move to the YCs. In the same time, the YT moving distance becomes the movement lines to the destination. If YC is under work, YT has to wait related to Fig. 6. At this point, the moving distance of YT is measured by a distance module displayed in Table 4.

Table 3. *Transporter module*

	Name	No. of YTs	Type	Distance Set	Travel speed (m/h)	Initial Position
1	QC1 YT	5	Free Path	QC1 YT Distance	10	QC1 Station
2	QC2 YT	5	Free Path	QC2 YT Distance	10	QC2 Station
3	QC3 YT	5	Free Path	QC3 YT Distance	10	QC3 Station

Table 4. *Distance module*

	Distance Module Name	Beginning Station	Ending Station	Distance (Meters)
1	QC1 Yard Truck Distance	QC1 Station	YC1 Station	378
2		YC1 Station	QC1 Exit	621
3	QC2 Yard Truck Distance	QC2 Station	YC2 Station	351
4		YC2 Station	QC2 Exit	486
5	QC3 Yard Truck Distance	QC3 Station	YC3 Station	621
6		YC3 Station	QC3 Exit	297

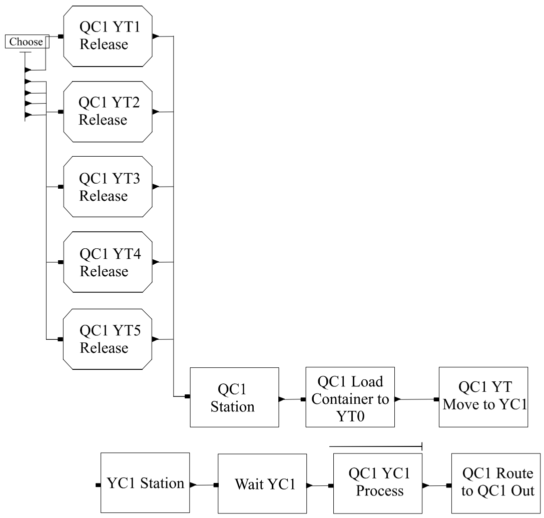

Fig. 6. *Sub-model for YT moves to QC*

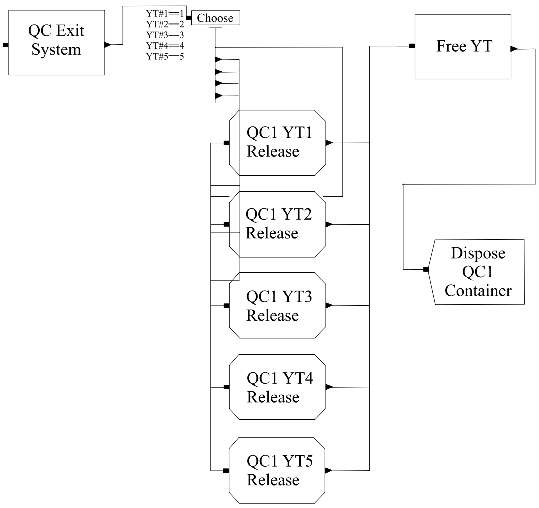

Fig. 7. *Sub-model for YC's storage work is over, YT is released*

Finally, if YC's storage work is over, YTs will be released, and containers handling will also be ended. This procedure is shown in Fig. 7.

One of the productivity terms is the time of YTs for one container, which is incurred by the travel of trucks in the yard. The travel time is proportional to the travel distance of YTs and availability of YC at time. YTs travel from the quay to the storage yard and then return to the quay.

The model developed here can be used to obtain results that can be important to the terminal management.

If the above-mentioned modules are connected, the modeling for one berth is completed. And this modeling is used for the three berth container terminal programming. A new improved model is similar to the current model, but the difference is that YT is not assigned to a specific QC. Besides, if YTs are free, they are to be assigned to the nearest QC. Fig. 8 illustrates the difference between the two models.

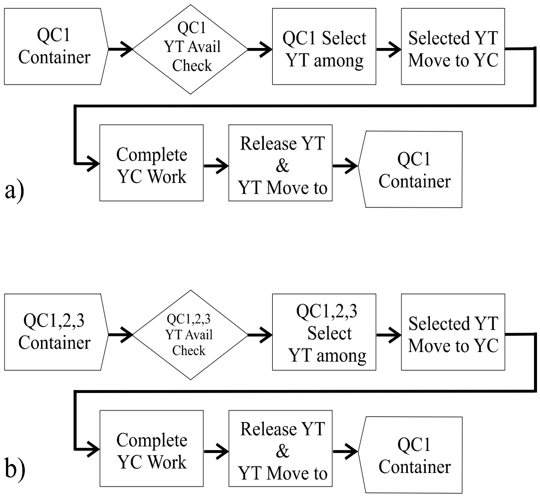

Fig. 8. *Difference between the current model* (a) *and the improved model* (b)

4 COMPUTATIONAL RESULTS

This section presents some simulation results. The Arena software has been used for solution procedure.

The results of both simulation models include total handling volume, handling volume per YT, average delay time of QC in YT waiting time and the relationship between delay time and throughput. The strategy assignment, based on real-time positioning, is introduced next in order to improve the performance parameters of the terminal transfer operations. Priority is therefore assigned pooled strategy of YTs to each YT and the output is considered in order to help port management establish the best service strategy. To achieve accuracy, we first evaluate the queue properties, and then we deal with productivity of YTs. In order to enhance the readability of simulation, animation has been made. Also, for easy understanding of YT's flow, the animation has been expressed as shown in the Fig. 9.

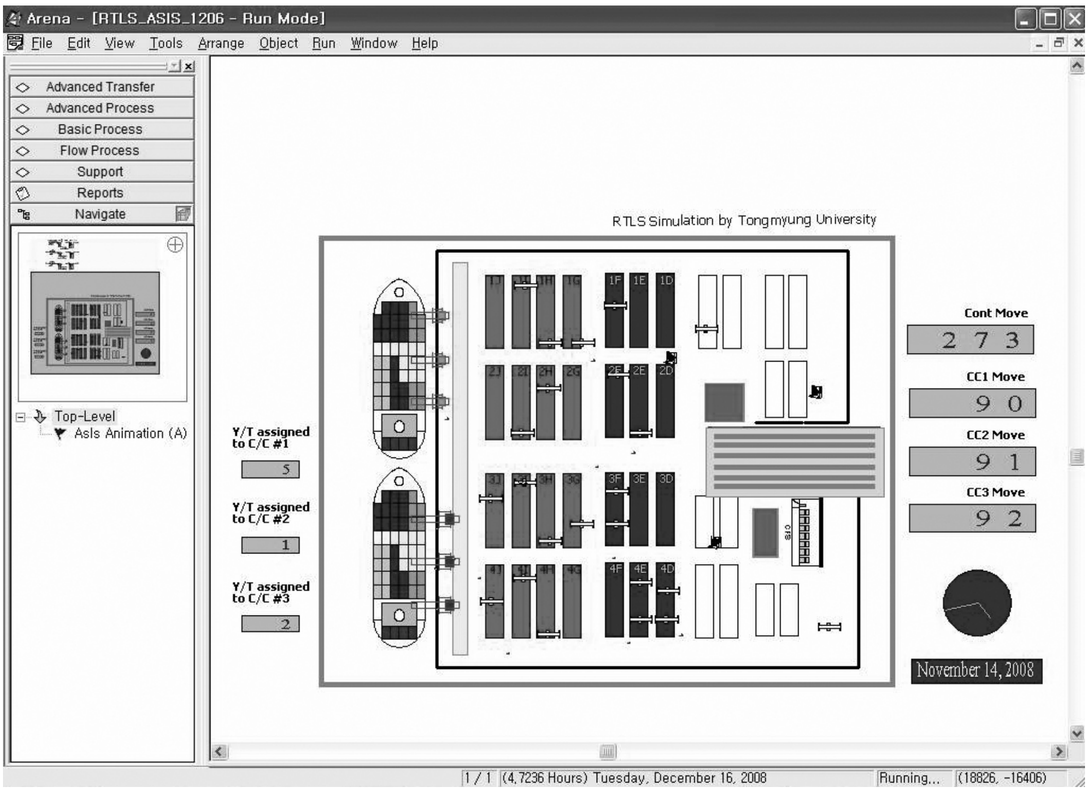

Fig. 9. *Simulation animation*

Table 5. The major output values

Output values	Unit	Current model	Improved model
Total handling volume	TEU	870	1,100
Handling volume per YT	TEU	58	73
Average delay time of QC in YT waiting	Minutes	1.6	0.8

The F simulation models were run for 100 statistically independent replications. The average results were recorded and used in comparisons. Two different models were simulated referring to Fig. 8. The two models had 5 and 15 YTs, and their delivery orders, respectively. Group of 5 YTs has been assigned to QC for current model. The improved model based on 15 YTs has been dynamically assigned to 3 QCs according to resource conditions and shortest distances.

Table 5 shows the experimental results for major output values for the current and improved model. These results presented support the argument that the total handling volume and handling volume per YT could be increased by pooled strategy of YTs. At the same time, the objective is to minimize the average delay time of QC in YT waiting time, and hence the average time that YTs spend in quay area. Our results show that YTs arrivals over time are needed as input data for the optimization of the considered problem. In addition to the arrival date and YTs time in quay area, it also generates the number of lifts per ship (i.e. the number of containers to be served per ship). On the basis on YT and QC productivity, this number of lifts per ship can easily be converted into the average service time of YT needed at the quay area.

Fig. 10 shows the status of throughput according to time progress, while Fig. 11 gives the relationship between delay time and throughput. Figure 10 compares the status of throughput according to time progress of different models at a terminal. They graphically show the sensitivity of throughput. Figure 11 presents how delay time of YTs reduce the throughput for each model. The obtained results shown here support the argument that the throughput could be decreased by increasing delay time of YTs.

In this paper we have presented a new approach that combines the advantages of simulation models and the dynamic transfer operations based on real-time positioning. We have shown that our improved model is able to generate competitive solutions quickly, even compared with traditional planning approaches that are much more time consuming.

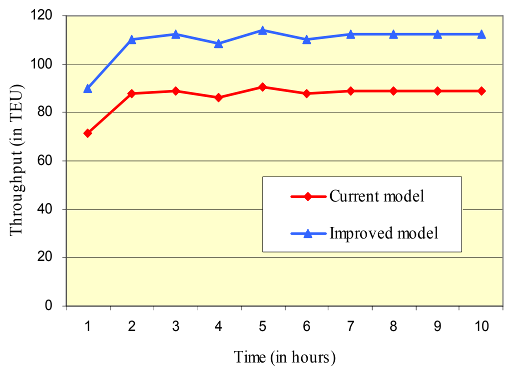

Fig. 10. *The status of throughput according to time progress*

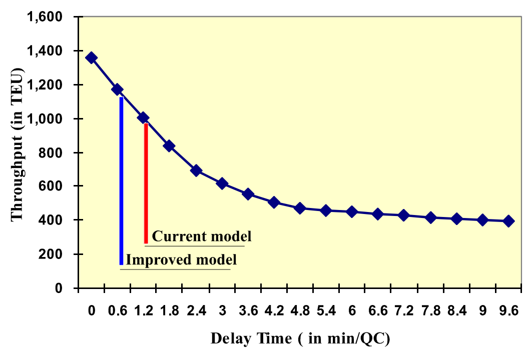

Fig. 11. *The relationship between delay time and throughput*

5 CONCLUSIONS

This paper gives the results of the simulation models for dynamic resources assignment of YT based on real-time positioning. The YT performance for two alternative strategies has been evaluated, and system behavior observed. The results have revealed that simulation modeling is a very effective method to examine the impact of introducing improved strategy. Improved simulation model and pooled strategy of YT assignment would lead to an improvement of the main operational parameters.

As a result of our research, it has been found out that the dynamic resources assignment of YT based on real-time locating data can raise productivity by more than 25% over the dedicated assignment method. If an error range is reduced by using RFID technology, and also if RTLS is applied not only to the YT, but also to the YCs and containers, than higher productivity improvement is expected.

Recently, port operation systems of many advanced countries are becoming more intelligent and object-oriented, and also tremendous efforts are being made to actively and speedily respond to the rapidly changing environments. To the end, RTLS technology is coming to the fore. In this respect, this study is expected to make a contribution to the introduction of RTLS.

Our contribution is twofold: simulation models development and analysis of dynamic transfer operations based on real-time positioning for HGCT (Korea), and an iterative combination of simulation and animation models validation based on real-time data are provided.

Finally, these models address the issues such as the performance criteria and the model parameters to propose an operational method of YTs assigned to a QC based on real-time positioning and increases the terminal efficiency. Also, we are developing alternative simulation based approaches to current and improved models. Improved model based on real-time positioning transfer system looks as the most promising practical technique to support decisions for the YTs deployment problem. This model can be used by the port management to improve the various operations involved in the process of YTs assignment to QC. In addition, the satisfaction or dissatisfaction of HGCT managers with respect to priority assignment is another important consideration that needs to be taken into account in future research.

6 ACKNOWLEDGEMENT

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