Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Traffic Control of Internal Tractors in Port Container Terminal using Simulation

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Abstract: Tight cooperative control of mobile entities and resources is essential to enhance the efficiency and effectiveness of terminal operation. The paper aims at developing an integrated simulation model which integrates the traffic flow control of internal tractors and the berth operation of a container terminal for evaluation of control policies adopted. Terminal operation is modeled as a discrete event system using the AutoMod simulation tool. The model provides a definitive basis for evaluating the performance of the berth and for determining the potentials for the operation improvements such as to resolve traffic congestion problems of a port container terminal.

1. INTRODUCTION

Terminal operation is highly complex, where sophisticated control strategies are deployed. Different control algorithms of equipment such as Rubber Tyred Gantry Cranes (RTGC) and the stacking mechanism of yard have been studied (Duinkerken, Evers & Ottjes, 2001). Due to the complex and often stochastic nature of terminal operation, mathematical modeling and analysis of traffic control (Stathopoulos & Tsekeris, 2002; Zhang, Bourcerie & Ferrier, 2002) become difficult and sometimes impractical. As such, simulation has emerged as an alternative for the analysis of such systems. A large number of studies of container terminals has been undertaken with various simulation tools. Gunther & Kim (2006) summarised various simulation models and algorithms that contributed in the port industry. In particular, complex transportation models (Duinkerken, Ottjes & Lodewijks, 2002) have been studied and demonstrated the effective communication in a distributed architecture in TOMAS. An object-oriented simulation approach (Yun & Choi, 1999) has been adopted to analyse the operation of the port. However, most of these studies did not demonstrate the traffic and the movement encountered to each entity. This is thus the aim of this study to control and deploy of internal tractors in a container terminal by integrating the vehicle routing and the interaction of the entities. Using a simulation approach, a case study of a berth in Hong Kong is undertaken. In this study, the proposed integrated simulation model is developed with the AutoMod simulation tool version 11.2.

In automated container terminals, Automatic Guided Vehicles (AGV) travel between the berth and yard on predefined paths. The operation of AGV and other automated facilities were modelled by functions and equations (Le-Anh & De Koster, 2005; Vis & Harika, 2004; Liu, Jula & Ioannou, 2002). In Duinkerken & Ittjes (2000), an AGV traffic developed focused on the impact of the capacity of quay crane and the number of AGVs deployed in relation to the performance of the berth operation. In our case study, where a semi-automated port is chosen, a reasonable amount of human decision and intervention is involved such as the decision taken by the truck drivers and the operators in the control tower. Despite such human factor can be formulated mathematically, the complexity will be increased while the flexibility of the system will be reduced. In this respect, simulation is adopted to overcome some of these limitations and to effectively model the stochastic human behaviour in the study of the traffic control problem in the terminal.

1.1 Berth Operation

Loading and discharging of containers are the main operation at the quay side of a typical port container terminal. These two operations occur simultaneously and interactively with the major resources including the quay crane (QC) and internal tractors (IT). Loading operation (PS) is the movement of the outbound container from the quay side to vessel. A container is picked up from the yard and is loaded on a dedicated IT, which then travels to and unloads the container at the quay side. Discharge operation (PL) is the movement of an inbound container from a vessel to the quay side. An empty internal tractor travels to the quay side and stopped at the dedicated location, called a service point (SP), then a container is loaded onto the tractor. Tractors either travel to the service point of the next operation or exit the quay depending on the 'movetype' of the current job and the next job if the operation is completed. In this study, the activities that take place in the yard is not explicitly in the simulation model, they are approximated by a black box process with a processing time that relates to the corresponding yard operation.

1.2 Objectives

Based on the cooperation policy for the berth operation of a typical berth that is adopted by the cooperated terminal operator, the optimal configuration of a berth can be determined based on the investigation of the followings,

- Modelling the control policies of internal tractors with regards to the interactions between ITs and quay cranes (QC).
- Performing the sensitivity analysis on the effect of the quay crane rate and other key performance indicators such as the waiting time of the quay cranes and dwell time of tractors with respect to the changes of the input parameters such as the number of tractors deployed.
- Resolving the traffic problems in the port with different IT control policies such as the deployment of IT Controller and the policy on overtaking.

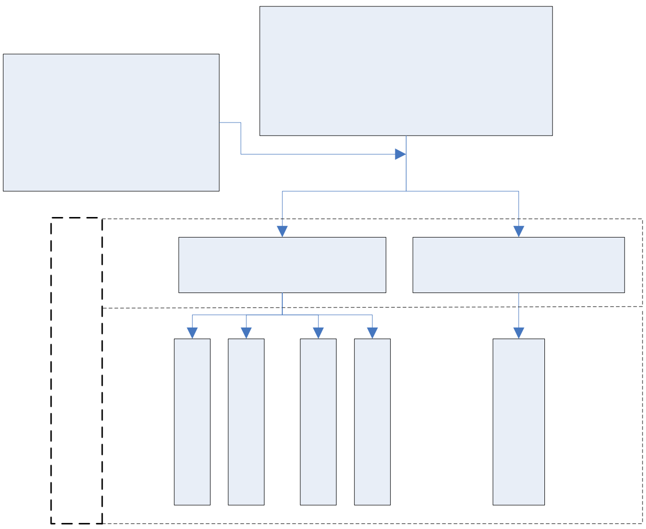

Fig. 1. Architecture of the proposed traffic model

In our study, a detail analysis of the system based on the integrated model is undertaken and the investigation of traffic problems with a view to resolve these problems based on the results of simulation study.

2. CONTROL LOGICS

Four main algorithms are developed in the simulation model with respect to the operation of internal tractors as shown in Fig. 1 that highlights the scheduling (loading and discharging) and the routing of the tractors. As the focus of this paper is on the traffic control of IT, although the validation of the model and other algorithms, such as the QC movements form part of the integrated model, they will not be addressed in this paper. Detail description of the model can be referred to (Lau & Lee, 2007).

2.1 Job Assignment

A new job is defined for every tractor which completed the current job either at the yard or in the quayside. The heuristics for QC selection is as follows:

Step 1: The number of unassigned jobs of QCi, denoted as J_{QCi} - Define the search space by listing all QCi whose $J_{QCi} >$ 0 for i = 1, 2… n, which is the number of deployed QCs defined by the user.

Step 2: The number of ITs has been assigned to QCi, denoted as M_{QCi}, where select the QCi whose $M_{QCi} < DMax_{QCi}$ where $DMax_{QCi}$ is the predefined maximum number of tractors assigned to each QC.

Step 3: The number of ITs is coming back from yard to berth, denoted as MB_{QCi}, which is composed of four parameters described by various kinds of tractors at the quayside, is defined as

$$MB_{QC_i} = MB_{QCi(PS,PL)} + MB_{QCi(PS,PS)} + MB_{QCi(PL,PS)} + MB_{QCi(PL,PL)} \quad (1)$$

The categories of tractors are classified based on the movement (either Loading (PS) or Discharging (PL) of the current job as well as the next job. For instance, the first term of equation (1), $MB_{QCi(PS,PL)}$, represents the tractor whose the current and next operation are loading (PS) and discharging (PL), respectively. After calculating MB_{QCi} for each QC, the QCi whose MB_{QCi} is the smallest is selected.

Step 4: Waiting time since the last assignment of QCi (WTi) - Select the QCi whose WTi is the longest among the selected QCs in Step 3.

Step 5: Job search function (J_y) - After QCi has been defined, another search algorithm will be triggered. The iteration terminates when $J_y = 0$ (if J_y has been assigned to dedicated tractor, $J_y = 1$).

2.2 Out-of-Sequence

A job (either loading or discharging operation) is out-of-sequence when it is not in the predefined sequence as in the Container Work Program (CWP). A virtual operator called Checker that performs specific control actions is deployed to maintain the sequence by comparing the attributes (e.g. job number carried by each container of an incoming tractor (JT_x) and the corresponding QC at the entrance of the berth (JT_y)). The tractor is allowed to pass when all the four criteria listed below are met even though both job numbers (i.e. JT_x and JT_y) are not matched.

1. Bay number (BayNo): location of the container in the vessel.
2. Weight class: a specified weight class will be assigned to the container whose weight (in kilograms) is in the specific limits.
3. Port of discharge (POD): the port where is the destination of the container for discharging
4. Container size: container size is classified into the container size into two main groups: (1) 20-foot and (2) 40-foot

As a result of swapping both jobs, the sequence will be changed. However, those disqualified internal tractors, which violate the requirement mentioned above, will be sent to the parking area until they are in sequence.

2.3 IT Controller

The role of IT Controller aims at limiting the number of ITs entering the berth, which has a role different from the Checker. As such, the action of IT Controller limits the number of ITs queuing up at the corresponding QC. ITs that are waiting will be released if an IT completed its job at the quay side and is ready to move to the next job.

2.4 Routing of IT

Routing of the internal tractors is governed by the operation of the current job and the next job according to the classification stated in Equation (1). They are routed on the predefined guide path depicted in Fig. 2. Tractors are coming in the quay side via the entrance of the quay side on the left of the figure. After the operation is completed, tractors leave the quay side by either one of the exit points provided (squared by the dotted lines as the figure shown below).

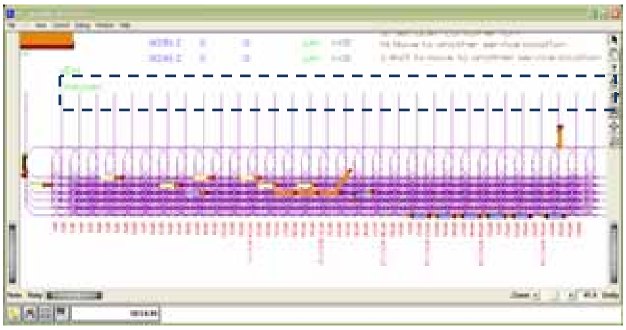

Fig. 2. Predefined guided path modelled in AutoMod

In general, after a job is completed at the quay side, the movement of the IT is governed by the following heuristics.

Step 1: Execute job assignment (as mentioned in Section 2.1)

Step 2: Travel to the nearest exit of the quay side

Step 3: Perform a yard operation (which is excluded in this study, however, a black box represented for this operation is adopted) – wait for *x* min.

Step 4: Arrive at the entrance of the quay side and update the current job and go back to job assignment as in Step 1.

Step 5: Travel to the service point of the current job.

3. EXPERIMENT DESIGN

An experiment is designed to investigate the performance of the berth with respect to the observable traffic problems and the changes of the QC Rate when different control policies are deployed. The configuration of the quay is listed in the following table, can be varied according to the set up of terminal. For simplicity, the number of deployed ITs and number of lanes closed (Lc) will be varied, are two major resources found in the berth. The deployed IT will provide the service to the dedicated vessel until all jobs are executed with the lanes provided (which means some of the lanes will be closed for other purposes). The number of QCs deployed and number of ITs assigned per QC are fixed variables in this study. The former specified number of QC used until the jobs are processed and the latter limits the number of tractors (but not the dedicated tractors) servicing for each QC.

Table 1. Configuration of the quay

Scenario	**1**	**2**	**3**
No. of ITs deployed for a vessel	35	40	42
No. of QCs Deployed		6	
No. of Traffic Lanes closed (Lc)		0-3	
No. of ITs assigned per QC ($DMax_{QCi}$)		7	

There is the number of performance indicators often adopted to quantify the efficiency and productivity of the berth in a port container terminal. Amongst these indicators, the major performance indicator adopted in this study is the Quay Crane Rate (QC Rate), which is defined as the number of boxes (containers) handled per hour by each QC. Average QC Rate is defined by:

$$QC\ Rate_{Avg} = \sum_{i=1}^{n} (B_{QCi}) / \sum_{i=1}^{n} (T_{QCi}) \qquad (2)$$

Where

B_{QCi}: Number of containers of the vessel handled by QCj

T_{QCi}: Total time required to handle B_{QCj} containers

As the objective of the study is the influence of the control policies of the traffic of the berth, in particular, the deployment of IT Controller, overtaking (routing of IT) and rearrangement of CWP under the influence of human factor and intervention, four experiments are designed and undertaken:

(E1) No human intervention (without the deployment of either policies) – there is no limitation of the number of internal tractors going into the berth and a simple routing heuristic is applied as mentioned in the last section.

(E2) Deployment of an IT Controller – IT Controller limits the number of internal tractors queuing up at corresponding QC (v_ITControl).

(E3) Overtaking – a simple overtaking algorithm is applied to the particular type of internal tractors (PL/PS) that can directly travel to the next destination without exiting the berth.

(E4) Rearranged Container Work Program (CWP) – this is a control policy on berth operation instead of the policy for managing internal tractors at the quay side. It indirectly influences the travel pattern of the internal tractors. The rearranged CWP causes QCs to move in a single direction that reduces QC conflict.

4. RESULTS

When no human intervention is involved, the QC Rate is depicted in Fig. 3. QC Rate is increased when the number of ITs increases, and this rate saturates when the number of ITs deployed is approaching its maximum used of internal tractors which is the product of the number of QCs deployed and number of internal tractors assigned per QC ($DMax_{QCi}$), forty-two tractors in this case. In general, an extra box is added to the QC Rate if two additional tractors are used.

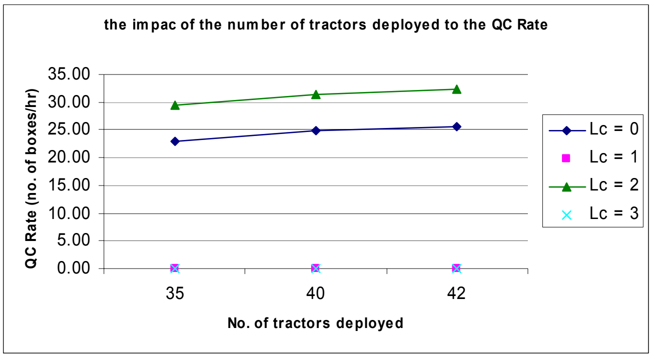

Fig. 3. The impact of the change of the number of internal tractors to the QC Rate

When all lanes are opened (Lc = 0), the QC Rate rises with an increase in the number of internal tractors deployed.

When 20% of internal tractors are added to the same configuration, other performance indicators considered include:

- Waiting time of QC (min.): the time waiting for the movement of other QCs is recorded before the movement of QC. It is reduced by approximately 12% when an increase in the number of internal tractors deployed for a vessel.
- Queue length (no. of vehicle): the number of internal tractors waiting at the quay side for loading and discharge is decreased by 4%.
- Dwell time of internal tractor (min.): the time incurred after leaving the service point of current job and the completion time of the next job is recorded and slightly reduced by 4%.

However, a traffic problem is observed when a number of traffic lane(s) is closed. For instance, the accumulation of internal tractors at the quay side may be induced by:

- QC Conflict – this happens when two QCs are moving in opposite direction and the working location is either occupied or blocked by other QC.
- Inter-blockage – internal tractors are accumulated at the quay side as depicted in Fig. 4. Such phenomenon represents a deadlock situation and consequently the movement of tractors and QC are halted.

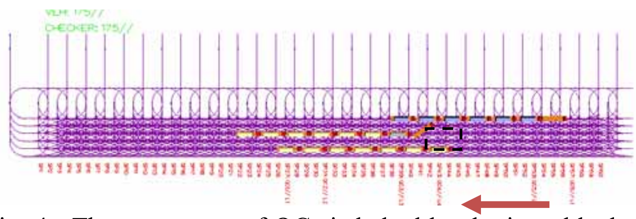

Fig. 4. The movement of QCs is halted by the inter-blockage of tractors

QC conflict and inter-blockage are interrelated. In Fig. 4, a long queue of IT for QC6 (tractors carrying blue containers) is found at the first lane, blocked the movement of an orange tractor (squared by the dotted lines) located on Lane 3. QC3 could not handle the blue container carried by a tractor located behind that orange tractor. As a result, QC5 could not move to its destination (as the arrow indicates the direction and the distance required) due to the non productive QC3.

In the following sections, the simulation study considers the deployment of the proposed control policies which are (1) IT Controller, (2) Overtaking and (3) Rearranged CWP.

4.1 Deployment of IT Controller

The traffic problem observed in the Experiment (E1) cannot be solved after the deployment of IT Controller. In other words, inter-block of internal tractors and QC conflict are still found in some cases.

When six lanes are used (Lc = 0), the obtained QC Rates increases, as depicted in Fig. 5. The productivity of QC is similar to the results from human intervention do not involved in Experiment (E1). However, a dramatical improvement on other performance indicators with respect to the change of number of internal tractors is summarized in Fig. 6. Amongst the indicators investigated in this study, waiting time of QC is greatly reduced whereas the queue length is minor to the increment of the QC Rate.

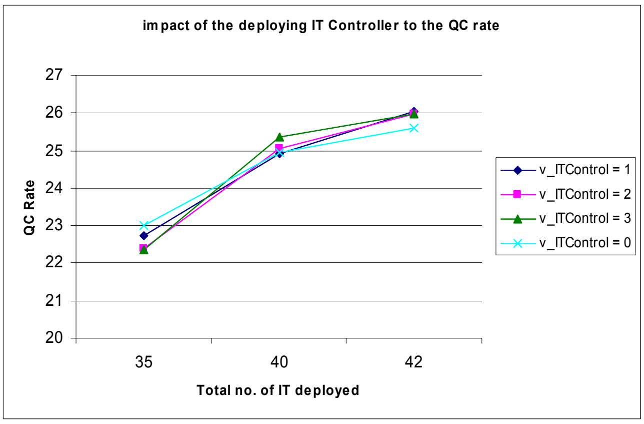

Fig. 5. Impact to the QC Rate after deploying the IT Controller when no lane is closed (Lc = 0)

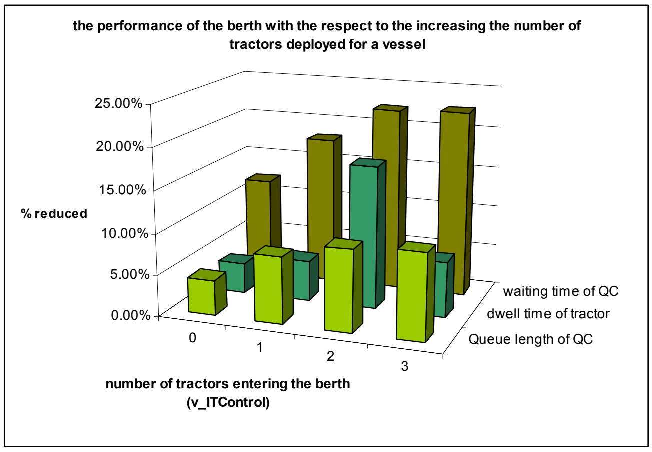

Fig. 6. The performance of the berth when the number of internal tractors increased when no lane is closed (Lc = 0)

4.2 Overtaking

A simple routing policy has been discussed in Section 2.4. However, decision made by the tractor drivers is not considered. Drivers make their judgement based on the current traffic condition and decide to overtake or travel via other shortest paths. The latter can be formulated with a simple algorithm to find the shortest path and reach the nearest exit point of the quay side. In this study, overtaking is activated for particular type of internal tractor (PL/PS). Aforementioned, ITs are allowed to travel from one point to another without exiting the berth, sometimes, tractors travel across traffic lanes in order to reach other destination.

Comparing the results obtained in Fig. 3 and 7 (with overtaking), the difference in QC Rate is less than a box per hour, which does not represent a significant achievement in improving the QC Rate. Thus, overtaking may not be a good solution to deal with the accumulation of internal tractors at the quay side.

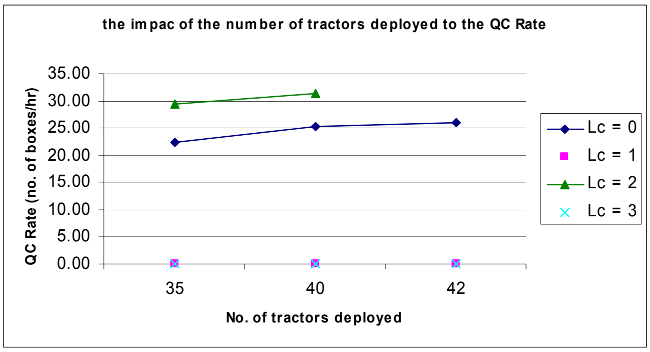

Fig. 7. The impact of changing the number of the internal tractors to the QC Rate (overtaking)

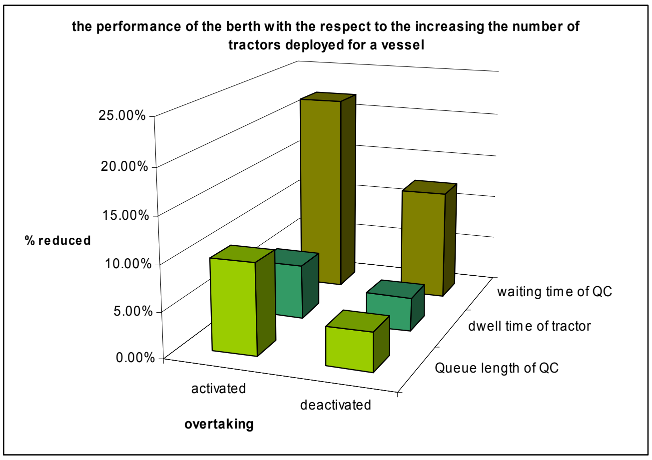

Fig. 8. The performance of the berth when increasing the number of internal tractors for a vessel when Lc = 0 (overtaking)

Though there is no significant improvement in QC Rate, better utilization of internal tractors and shorter waiting time of QC are observed when overtaking is implemented, as depicted in Fig. 8.

4.2 Rearranged Container Work Program

In the previous experiments, the performance indicators reflect a great improvement on waiting time, queue length and dwell time although traffic problem has not been tackled. With regards to the advent of traffic problems, the CWP is rearranged so that the jobs are handled from bay to bay and QC moves in a single direction instead of taking a bi-directional movement. As such, the occurrence of inter-blockage of internal tractors will be minimized. The proposed CWP may not optimize the productivity of QCs but the traffic at the quay side will be eased. The results show that most of the congestion problems are eliminated. The obtained QC Rate is presented in Fig. 9. The efficiency of the berth is enhanced by 25% when a lane is closed (Lc = 1). However, the QC Rate is insensitive to the change of number of traffic lanes deployed with respect to the QC Rate obtained in Experiment (E1) (Fig. 3.), where at least 5 more boxes can be handled hourly if two of the lanes are closed. If more traffic lanes are closed (Lc > 3), the traffic problem can no longer be resolved.

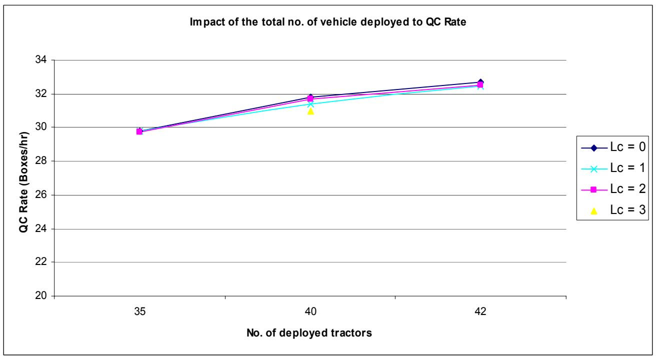

Fig. 9. Impact of the total number of internal tractors to the QC Rate (Rearranged CWP)

This study also reveals that a significant improvement on waiting time of QC and internal tractors as well as the queue length of QC. By comparing the waiting time of QC, it is greatly reduced by approx. 75%, there is about fifty per-cents more than the other two control policies. The performance of other indicators is depicted in Fig. 10.

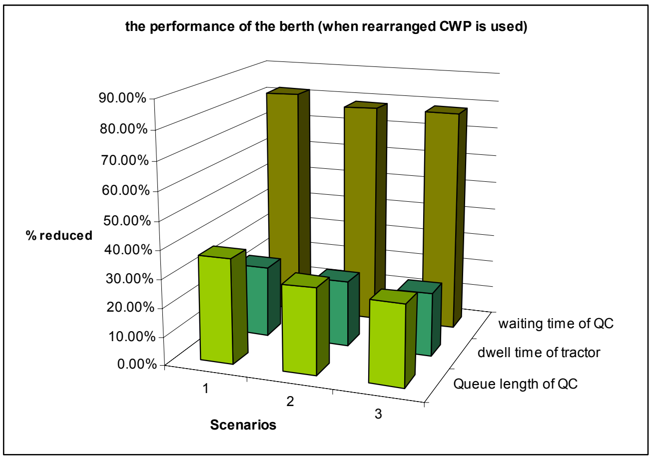

Fig. 10. The performance of the berth when a set of rearranged CWP is used (Lc = 0)

The traffic problem can be minimized by rearranging the CWP rather than controlling the total number of internal tractors deployed and number of internal tractors queuing up at the QC. Moreover, the efficiency of the berth operation is higher than using the original CWP.

6. CONCLUSIONS

In this study, the performance of the quayside operation with respect to different control policies of the IT in a container terminal is studied through simulation. An integrated model for quayside operation is developed and implemented under a simulated environment. Simulation studies reveal that the number of internal tractors deployed has a positive influence to the productivity of the quay crane. Other performance indicators also show a tremendous improvement on the utilization of resources. On the other hand, the number of traffic lanes deployed induces a number of traffic problems that are mainly caused by the queuing of IT on the traffic lanes and conflicting between QCs. With the change in IT control policies as suggested by the simulation results, near optimal productivity can be achieved. However, with regards to conflicts between QCs, the problem cannot be solved by simply changing the control policy of IT such as the deployment of IT Controller.

According to the QC Rate and other performance indicators, Scenario 3 showed the optimal configuration under the given constraints, where the maximum number of internal tractors is used. When six lanes are used, the optimal QC Rate with approximately 25-26 boxes/hr is obtained. If the CWP is arranged, additional 25% of boxes can be handled even other control policies are not adopted. Traffic lanes can be closed so long as the number of lanes in operation should be more than half of the total number of QCs deployed.

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