A Dynamic and Collaborative Truck Appointment Management System in Container Terminals

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Abstract: Given the rising growth in containerized trade, Container Terminals (CTs) are facing truck congestion at the gate and yard. Truck congestion problems not only result in long queues of trucks at the terminal gates and yards but also leads to long turn times of trucks and environmentally harmful emissions. As a result, many terminals are seeking to set strategies and develop new approaches to reduce the congestions in various terminal areas. In this paper, we tackle the truck congestion problem with a new dynamic and collaborative truck appointment system. The collaboration provides shared decision making among the trucking companies and the CT management, while the dynamic features of the proposed system enable both stakeholders to cope with the dynamic nature of the truck scheduling problem. The new Dynamic Collaboration Truck Appointment System (DCTAS) is developed using an integrated simulation-optimization approach. The proposed approach integrates an MIP model with a discrete event simulation model. Results show that the proposed DCTAS could reduce the terminal congestions and flatten the workload peaks in the terminal.

1 INTRODUCTION

In maritime logistics, one of the most important performance measures is the delivery time of a container to a customer. The containerized cargos are transported through the global supply chain, and each chain consumes a part of the total delivery time. Due to that, the decision makers in each phase of the transhipment operations are trying to reduce the total transshipment time taking into consideration the financial, economic, environmental, and even political barriers.

Container terminals are essential nodes in the global supply chain due to the tremendous growth of the containerized cargo trade around the world (figure 1). As a result, the research interests are directed to tackle the CTs' problems and develop robust and reliable solutions for the terminal operators. Figure 2 illustrates the various areas in CTs. Most of CTs can be divided into three main areas: Seaside, yard area, and landside. The seaside is the area where the vessels are berthed, loaded and/or unloaded with the desired containers using quay cranes. Containers are transported by internal transport means like manned trucks or automated guided vehicles to be temporarily stored in the yard blocks. At the yard, handling operations are performed using the yard equipment like yard cranes and straddle carriers. The operations in each yard block depend on vessel's operations and hinterland operations. On the other side of the terminal, the landside comprises the gates, which are provided with X-Ray scanners where an import container is allowed to leave the terminal, and an export container is allowed to enter the yard area.

CT problems were classified by (Bierwirth and Meisel 2010) to operational problems and strategic problems. The operational problems are related to the scheduling of operations and assignment of the resources. Operational problems are solved simultaneously in the short term and solutions and schedules are updated daily. Examples include berth allocation and quay crane assignment (Karam and Eltawil 2015; Karam and Eltawil 2016), and container handling problems (Mohamed Gheitha et al. 2014; Gheith et al. 2016). In this paper, more discussion about landside problems will be introduced mainly for managing the external trucks arrival.

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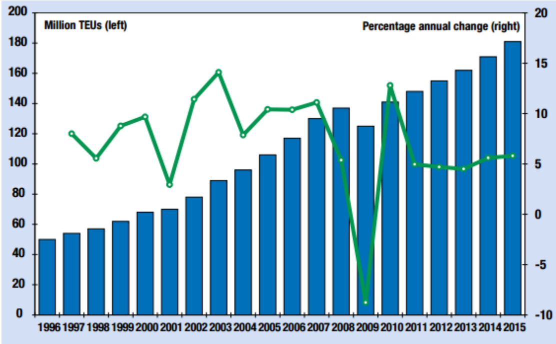

Figure 1: Global containerized trade, 1996–2015 (million TEUs and percentage annual change). (Source: UNCTAD secretariat).

Export/import containers are delivered/picked up from the terminal by external trucks. These trucks are operated by trucking companies to perform the delivery/pick-up operations in minimal time and cost. On the other hand, CTs set the appropriate schedules and rules to reduce the congestion in various terminal areas. To manage the transaction between the terminal and the trucking companies, some CTs adopted a Truck Appointment System (TAS) to control the arrival of external trucks, while some other terminals do not follow an appointment system. The appointment systems can be used to increase the service quality in CTs for all transshipment means; trucks, train, barges and vessels (Zehendner and Feillet 2014). Many terminals have developed Truck Appointment Systems (TAS) to make balance in truck arrivals to alleviate the terminal rush hours. The benefits of the TAS have been reported in literature as will be shown later. In this paper, we propose a dynamic and collaborative appointment management solution to support decision makers in the terminals gain more benefits from applying the appointment systems.

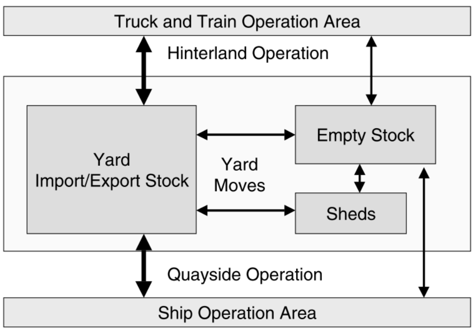

Figure 2: Operation areas of a seaport container terminal and flow of transports (Steenken et al. 2005).

The remaining of the paper is organized as follows. Section 2 discusses related literature. The proposed system is explained in section 3. Section 4 presents the numerical experiment. Section 5 shows the results, and section 6 illustrates the conclusion.

2 PREVIOUS WORK

Landside operations affect the whole terminal performance and therefore, decision problems related to landside operations received an increasing interest in literature. Scheduling the arrival of external trucks is considered one of the most important landside problems addressed in the literature. One of the earliest case studies is conducted by Murty et al. (2005) at HongKong International Terminal (HIT) , which resulted in the reduction of terminal congestion using the truck appointment system. Authors developed a decision support system based on an information system to help in making the terminal operational decisions efficiently. A comprehensive study by Morais and Lord (2006) is developed to review the appointment system implemented in terminals across North America. They adopted various strategies to reduce the idling of truck, congestion at gates and emissions related to CT drayage operations. Namboothiri and Erera, (2008) used a planning strategy for pickup and delivery operations in CTs based on an integer programming heuristic. The sequence of the drayage operations is determined by minimizing the transportation cost. An improvement in productivity and capacity utilization is obtained with some sensitivity to poor selection of the appointment time.

Huynh and Walton (2008) and Huynh (2009) investigated limiting the arrivals and individual appointments versus the block appointments. In addition, they introduced combined mathematical model and DES model. Guan and Liu (2009) stated that the TAS is one of the most viable strategies to avoid the terminal congestion and improve the system efficiency. To achieve that, authors formulated a nonlinear optimization model and applied a multi-server queuing model. Chen and Yang (2010) studied the export container's drayage operations in Chinese CT. They proposed an integer programming model in order to reduce the transportation cost through time window management. They indicated that the peak arrivals are smoothed by solving the problem using a genetic algorithm (GA). Zhao and Goodchild (2010) studied the impact of using the arrival information of external trucks on the yard operations. They concluded that prior knowledge about the arrival time of external trucks reduces the queue lengths at gates and re-handling frequency at the yard. Chen et al. (2011) introduced a stationary time-dependent queueing model providing a supporting tool to improve demand management at CTs.

Simulation was used in many studies for developing and testing truck appointment systems. Sharif et al., (2011) developed an agent-based simulation model to achieve a steady arrival of external trucks at container terminals. The results showed that the congestion at CTs can be minimized by using gate congestion information and estimating the truck idling times. Karafa (2012) conducted a case study using a dynamic traffic simulation model to investigate the congestions and related emissions. They concluded that extending the gate working hours increases the terminal productivity and reduces the emissions especially at peak hours. Based on a previous work, Van Asperen et al., (2013) used a DES model to investigate the effect of truck announcement system on the yard operations performance, and a significant reduction in yard crane moves is obtained using the proposed algorithms.

Zhang et al., (2013) developed an optimization approach for truck appointments to reduce the heavy truck congestions in CTs. A method based on Genetic Algorithms (GA) and Point Wise Stationary Fluid Flow Approximation (PSFFA) was designed to solve the problem that resulted in reducing truck turn times. In a series of papers, Chen, Govindan, Yang, et al. (2013), Chen, Govindan and Yang (2013) and Chen, Govindan and Golias (2013) studied various strategies and approaches to optimize the appointments of external trucks in the terminal. Various performance measures and objective are examined such as transportation cost, fuel consumption, shifted arrivals, and truck waiting times. A new concept of chassis exchange introduced by Dekker et al., (2013) to reduce the CT congestion using simulation as a calculation tool. Zhao and Goodchild (2013) used a hybrid approach of simulation and queuing models to examine the impact of the TAS on the performance of yard crane operations. The results showed a significant improvement in system performance and efficiency. Zehendner and Feillet (2014) formulated a mixed integer programming model to get the optimum number of appointments considering the CT workload. Results are validated using DES to ensure the improvements of service quality for both the trucks and also for all terminal resources.

Azab and Eltawil (2016) studied the effect various arrival patterns of external trucks on truck turn times in CTs through a simulation-based study. Their results show that arrival patterns have a significant effect on the terminal performance in such a way that makes it important to consider the arrival pattern effects during the design of the truck appointment system. Li et al., (2016) proposed some response strategies that help in solving the problem of truck arrivals' deviation from its appointments. Results showed that the greenness of operations is significantly affected by the use of truck appointments. Chen and Jiang (2016) introduced some strategies to manage the truck arrivals within the time windows based on truck-vessel service relationship to reduce the terminal congestion.

To sum up, an increasing attention is paid to the TAS in literature. However, only two studies (Phan and Kim (2015) and Phan and Kim (2016)) investigated the TAS with considering the collaboration among trucking companies and the container terminal. In these two papers, an iterative approach is used to model the collaboration among trucking companies and the terminal operator. The iterative approach consists of two levels which are interconnected by a feedback loop. The first level is a mathematical model which includes a sub-problem for each trucking company to minimize the total waiting cost of trucks at the yard. On the other hand, the second level is a procedure to estimate the expected times at the yard of trucks based on the solution of first level. This iterative approach enables the collaboration process.

By careful investigation of the approaches proposed in Phan and Kim (2015) and Phan and Kim (2016), we notice three gaps that are needed to be covered to improve the existing approaches. The first gap is related to the second level where a simple procedure is typically used to estimate the truck turn times. This simple procedure lacks real world aspects such as the waiting times of trucks at gate. The second gap is that the existing approach did not consider the randomness of the terminal operations. The third gap is related to the number of times the trucking companies and terminal operator send their decisions to each other. According to Phan and Kim (2016) , their iterative approach needs about nine iterations on average to terminate and produce the final solution. In contrast, the proposed system in this paper requires only 2 iterations between trucking companies and the container terminal. From a practical point of view, large number of iterations may cause some of trucking companies not to submit their appointment applications for some reasons such as not having time to reschedule their truck operation or forgetting to resubmit their applications. In this case, the quality of the solution may be impaired.

Based on the above understandings, we propose a new approach for dynamic and collaborative truck appointment scheduling in container terminals. The proposed approach considers the collaboration among trucking companies and terminal operators by a pre-processing integration of a mixed integer programming model and a discrete event simulation (DES) model. The contributions of the proposed approach are as follows:

1) The turn times of trucks are estimated based on a simulation model which enables capturing several real world aspects as well as the stochastic nature of the terminal operations.
2) By employing the pre-processing integration, the trucking companies send their rescheduled appointments to the terminal two times only. Thus, this improves the applicability of the proposed new appointment system.

3 THE PROPOSED DYNAMIC AND COLLABORATIVE TRUCK APPOINTMENT SYSTEM

In this section, the proposed Dynamic Collaborative Truck Appointment System is introduced (DCTAS) based on the collaboration concepts. The paper introduces an integrated simulation optimization approach to achieve the collaboration goal considering both the dynamic and stochastic nature of the problem. The proposed DCTAS (figure 3) can be illustrated in five operational steps as follows:

Step (1): each trucking company submits an arrival proposal to the terminal. This proposal contains the preferable arrival time of their external trucks based on some factors such as; ship arrival, container dwell time, ship departure, available trucks, etc.

Step (2): once the terminal operators receive the submitted proposal, the terminal working load is updated and the performance measures are determined. To do this, a DES model of the terminal is introduced to help the terminal operator to estimate the total truck turn time for the trucking company and evaluate the terminal congestion at each yard block (YB) during each working hour (time window). It is assumed that the workload of the CT contains the set of confirmed appointments that are already reserved before the terminal appointment application's deadline for each time window (Tw) and the ship tasks assigned to each yard block.

Step (3): The terminal operators publishes the schedule information online with the expected turn times for all submitted requests. Each trucking company is then capable of knowing how much time they are supposed to spend in the terminal (turn time) to achieve their delivery/pick up tasks.

Step (4): To avoid going to the terminal in congestion times, the trucking company will use the mixed integer programming (MIP) model available as a scheduling tool for their trucks. The MIP model is solved to reduce the transportation cost in the CT considering the previous preferable arrival time (step 1) and the terminal performance measures (step 2), and a new arrival request will be issued.

Step (5): the new schedule will be submitted as a confirmed appointment request and the terminal workload will be updated waiting the new requests to be submitted and confirmed.

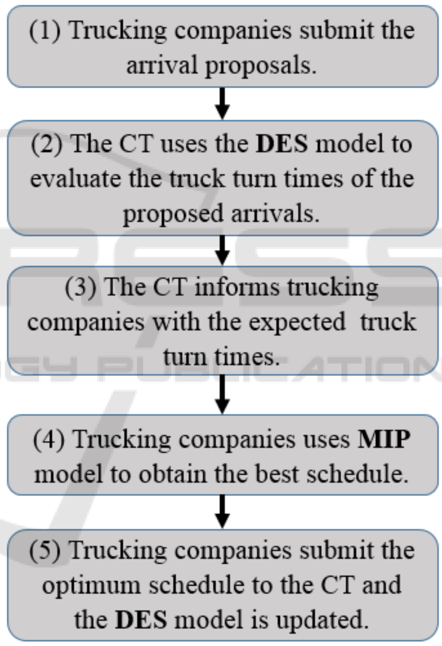

Figure 3: The operational steps of the proposed DCTAS.

As illustrated, the DCTAS provides an interactive management strategy between the stakeholders to cope with the dynamic nature of the appointment process in CTs. Interacting communication among stakeholders can be implemented easily using an online collaboration platform. In a previous work, (Azab et al. 2016) adopted a design thinking strategy to design and synthesize an online information system for transportation logistics. Whenever a trucking company is ready to submit the preferable arrival times, the system receives the appointments and deals with the workload updates and changes hourly.

Moreover, using the DES model is expected to enhance the solution and to accommodate the system's actual variability and randomness. This randomness results from the stochastic operations and events such as the gate service rate, inter-terminal traveling times, yard crane handling rates, quay crane handling rate, and the failure of equipment. The proposed simulation optimization approach integrates the MIP model with the DES model in a pre-processing way (Bierwirth and Meisel 2015) in which the problem under particular circumstances is solved to produce the input data for the other problem. The DES model provide the input to the MIP model. After solving the MIP model, the optimum truck appointment schedule is evaluated using the simulation model to get the turn time of trucks after optimization.

3.1 The DES Model

The DES model is built using "Flexsim CT®" package, which is a special software for simulating container terminal operations. The basic elements of the model are shown in figure 4. The 3D DES model includes five yard blocks, five yard cranes, four gates, and a single shared gate queue. When the external truck arrives at the gate according to the predetermined schedule (Tables 2-3), the truck joins a single queue shared among the four gates. Trucks will leave the gate queue to the first available gate and will be processed according to an Erlang distribution (0.65,4) (Guan and Liu 2009). Once the truck completes processing at the gate, the trucks are directed to the yard block that contains a container to be picked up or to the location of the container where it will be dropped off. Yard cranes are the equipment that handles the container within the blocks to/from the external trucks. The external trucks leave the terminal after finishing the pickup/drop off operation. On the seaside of the terminal, the arriving vessels are berthed, and there is a truck gang that serves each quay crane assigned to the vessel. The internal trucks deliver the containers between the seaside and yard area. At the yard block, the highest priority is given to shipside operations, next to gate side operations and lastly to internal yard operations.

There are some assumptions that are used in this simulation model. At the gates, it is assumed that all arriving trucks will share the same queue before going to the first available gate, and external trucks travel time within the terminal is neglected. As a result, the truck turn time will be the sum of the gate queue waiting time, the gate service time, the yard waiting time, and the yard service time. To obtain more accurate results, each time window is divided into four time intervals, and the average truck turn time is calculated per each time interval. Moreover, the collision of trucks traveling through the internal transportation network of the terminal is not considered. Because the problem is regarded as a design problem for a new appointment system, the input parameters are driven from literature and based on some experience. Berth and yard cranes service rates are represented by the average net moves/hr calculated form the busy time and truck throughput for each crane. Table 1 illustrates the input parameters to the DES model.

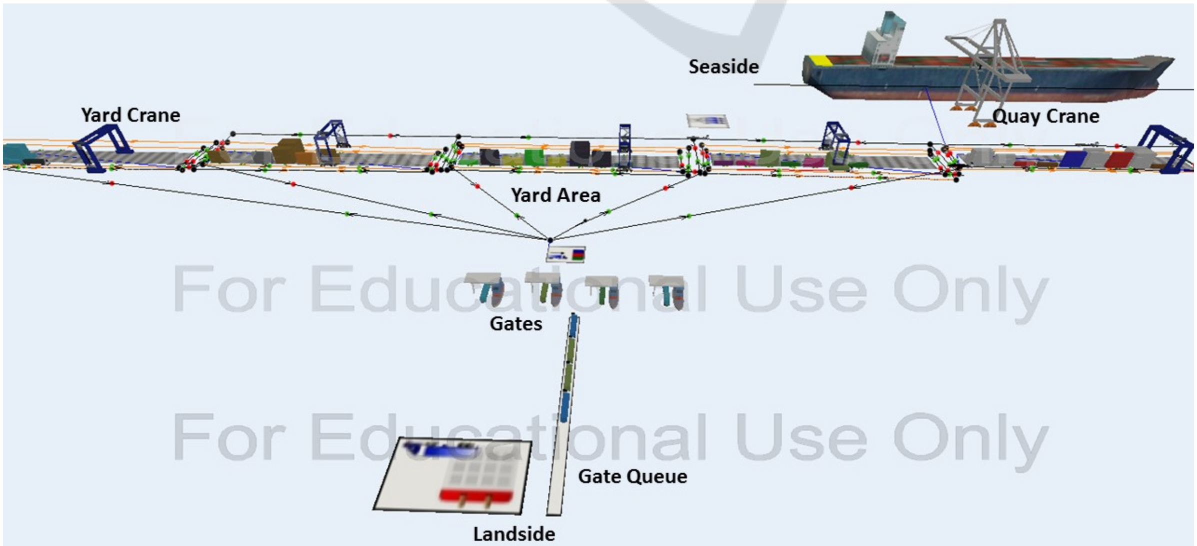

Figure 4: 3D discrete event simulation model.

Table 1: the input parameters to DES model.

General parameters	
Working hours (Tws)	8:00 am- 12 pm
Truck speed (max)	300 m/min (18 km/hour)
Container dwell time	Exponential(0.3) [days]
Gate Parameters	
Process time (min)	Erlang (0.65, 4)
Gate capacity	1 truck/one gate
Yard parameters	
Crane speed (max)	90 m/min (empty/loaded)
Block capacity (max)	24 containers
Crane net moves	27.7 move/hr (average)
Quayside parameters	
crane speed (max)	120 m/min (empty/loaded)
Crane net moves	12.3 move/hr (average)

3.2 The Scheduling Problem: MIP Model

In most container Terminals, the arrival of external trucks from the hinterland is a random process that is affected by the preferable arrival times of trucking companies. These preferable arrival times are not known by the terminal operators to be considered in planning and scheduling operations. As a result, a truck may arrive during a congestion time where the waiting time is costly and the emissions are high. On the other hand, if these trucks are forced to come at certain times that are specified by the terminal operators, it may be inconvenient for some trucking companies due to the trucks availability and other operations outside the terminal. To tackle this problem, the following mathematical model considers both, the convenience of trucking companies to arrive at their preferable times and the total time spent in the terminal which is influenced by the terminal congestion.

Based on the mathematical models formulated by (Phan and Kim 2015), we modified the model to consider the truck turn time (TT_{jt}) of trucks which is derived from the DES model. The proposed DCTAS assumes that each trucking company develops its preferable schedule considering the available number of trucks at each time window ($s_{k\tau}$). The trucking company's operator defines all tasks to be performed, which represents a pick up or a delivery operation for one container using one truck. Tasks that are assigned in the same preferable arrival hour (time window) are grouped together in one task group. For a certain task group, Containers can be delivered or picked up from the same yard block or from several yard blocks (table 2). The used parameters and indices in MIP model are defined as follows:

i index for a task group
j index for a yard block
k index for a trucking company
τ index of a time window
t index of a time interval. Note that multiple time intervals exist in a time window
b_i^l earliest possible (lower) bound of the time window for task group i
b_i^u latest possible (upper) bound of the time window for task group i
d_i number of tasks to be done for task group i
$S_{k\tau}$ number of available trucks of company k during time window τ
p_i most preferable time window at which containers of task group i to be stored or retrieved
σ number of time intervals per each time window
a_{ij} maximum number of containers of task i that can be allocated to yard block j
w_i^+ cost of late arrival by a unit time compared with the preferable time window of task i
w_i^- cost of early arrival by a unit time compared with the preferable time window of task i
w_k truck waiting cost in the terminal of truck company k per time interval
P congestion penalty in \$, a strategic parameter determined by the terminal manager.
TT_{jt} average truck turn time for a truck arriving at yard block j at time interval t derived variables from the DES model

Sets
I set of task groups.
K set of trucking companies.
T set of time intervals.
J set of yard blocks j
W set of time windows.

Decision variables:
$X_{ij\tau}$ number of trucks for task group i which are deployed to yard block j at time window τ

Derived variables from the MIP model:
λ_{ijt} average arrival rate of trucks for task group i at yard block j at time interval t

Minimize:

$$\sum_{i\in I}\sum_{j\in J}\left[w_i^{+}\sum_{\tau\in W}X_{ij\tau}(\tau-p_i)^{+}+\ w_i^{-}\sum_{\tau\in W}X_{ij\tau}(p_i-\tau)^{+}+\sum_{t\in T}(w_k+p)TT_{jt}\lambda_{ijt}\right] \tag{1}$$

Subjected to:

$$\sum_{j\in J}\sum_{\tau\in W}X_{ij\tau}\geq d_i \quad \forall i\in \mathrm{I} \tag{2}$$

$$\sum_{i\in I}\sum_{j\in J}X_{ij\tau}\leq S_{k\tau} \quad \forall k\in \mathrm{K},\tau\in \mathrm{W} \tag{3}$$

$$\sum_{\tau\in W}X_{ij\tau}\leq a_{ij} \quad \forall i\in \mathrm{I},j\in \mathrm{J} \tag{4}$$

$$b_i^l\sum_{j}X_{ij\tau}\leq \tau\sum_{j}X_{ij\tau}\leq b_i^u\sum_{j}X_{ij\tau} \quad \forall i\in \mathrm{I},\tau\in \mathrm{W} \tag{5}$$

$$\lambda_{ijt}=\frac{X_{ij\tau}}{\sigma} \quad \forall i\in \mathrm{I},j\in \mathrm{J},\tau\in \mathrm{W} \tag{6}$$

$$\lambda_{ijt}\geq 0\,,X_{ij\tau}\ integer \quad \forall i\in \mathrm{I},j\in \mathrm{J},\tau\in \mathrm{W},t\in T \tag{7}$$

The objective function (1) is to minimize the cost of shifting (delaying or advancing) the appointment and the truck turn time (TT_{jt}) cost within the terminal. The total number of scheduled trucks must satisfy the number of containers to be delivered or picked up (2). Constraint (3) states that the number of trucks to be assigned to task i cannot be larger than the resource level of the trucking company. The capacity constraint of each yard block is described in (4) to ensure that the number of containers for each task group have to be smaller than or equal to the available spaces in yard blocks. There is an earliest and latest feasible time window for each container (5). To calculate the arrival rate for each task group, constraint (6) is used. Constraint (7) illustrates the domain of each variable in the problem.

4 NUMERICAL EXPERIMENTS

In this section, a numerical example is solved to illustrate the operational scenario and performance of the proposed DCTAS. Table 2 shows a proposed appointment application for 4 trucking companies. Each trucking company is assumed to have a specific number of containers (d_i) in the terminal. The task group is a set of tasks that will be submitted by the same trucking company at the same preferred arrival time (p_i). It is assumed also that each trucking company knows which yard block (j) holds its containers. To create a workload in the terminal, the externally confirmed applications and inter-terminal tasks are developed in order to investigate the response of the proposed system to the heavy-loaded time windows. The proposed system (DCTAS) is expected to shift the proposed arrival appointments to the time windows where the turn time cost will be minimized with consideration of the preferred arrival times. Table 3 illustrates the tasks that are assumed to be already reserved and confirmed.

To start working with the DCTAS, all tasks are loaded to the simulation model input. Each task has a corresponding arrival time, the number of containers, and yard block location. By running the DES model, the external trucks arrive to the terminal model according to the predetermined scheduled times and released out of the system as the task is completed. The average truck turn times at each yard block are recorded for each time window to be used in the MIP model input. Other performance measures can be derived from the simulation model such as the queue length at gates, waiting times at gates and yard, service rate at gates and yard, cranes' utilization, etc.

Table 2: Proposed appointment applications for four trucking companies.

Truck. Company	Task group	*di*	*Pi*	*j*
TC1	1	5	2	1
	2	3	4	2
	3	1	3	1
		2		2
TC2	4	3	4	4
	5	4	3	2
	6	4	1	3
TC3	7	4	2	1
		2		3
	8	2	1	2
		3		4
TC4	9	3	2	4
	10	1	3	3
		5		5

Table 3: the reserved tasks in the CT.

Confirmed tasks	*Di*	*Tw*	*j*
11	30	2	1
12	30	3	2
13	30	2	3
14	30	2	4
15	30	3	5
16	10 (to ship)	3-4	1

To get statistically reliable results, the simulation model is run for 35 replications which are used to determine the 95% confidence intervals of the targeted mean performance measures. After obtaining the results from the simulation model, the derived variables are sent to the MIP model. The MIP model is solved using a personal computer with Intel® Core i7 CPU and 4 GB RAM. IBM Ilog CPLEX Optimization Studio version 12.2 is used to code the problem and get the optimum solution. The cost parameters in the objective function are assumed to be \$1, \$4, \$5, and \$2 per each time for w_i^+, w_i^-, w_k, and *P* respectively. Table 4 shows the available number of trucks ($s_{k\tau}$) for each trucking company per each time window. In Constraint 3, the number of available trucks is used to guarantee that the new assigned tasks do not exceed the trucking company's available trucks per each time window.

5 RESULTS AND ANALYSIS

Table 5 shows the MIP model optimum solution of the provided instance. In Table 4, *di* represents the number of containers submitted before solving the problem. After solving the DCTAS problem, the X_{ijt} describes the new scheduled tasks proposed for the trucking company to reduce the total cost of delivering a container to the terminal. There are three possibilities noticed from the results to occur after the solution to the input schedule of the DCTAS. The first possibility, there will be no change in the schedule such as task group 8. The second possibility, the task group preferred time window will be advanced or delayed resulting in an advancing and/or delaying cost without any change in the number of containers per task. For example, the arrival time of task group 5 is shifted from Tw3 to Tw2. This seems reasonable because, at yard block 2, the workload in Tw3 was the highest among the other three time windows in the same block before the solution. The third possibility is that the task group will be decomposed to smaller mini-task groups. It is evident that the second and third possibility may occur together like in task groups 1, 2, 7, and 10.

Table 4: the available number ($S_{k\tau}$) of trucks for each trucking company per each time widow.

Truck. Company	Tw1	Tw2	Tw3	Tw4
TC1	3	5	6	4
TC2	7	4	1	5
TC3	6	1	2	4
TC4	3	4	3	4

Table 5: The DCTAS solution.

Truck. Company	Obj. value (\$)	Task group	*di*	*Xijt*	*Tw*	*j*
TC1	137.8	1	5	2	1	1
				3	4	
		2	3	1	1	2
				2	2	
		3	1	1	4	1
			2	2	2	2
TC2	114.7	4	3	3	4	4
		5	4	4	2	2
		6	4	4	1	3
TC3	101.75	7	4	4	4	1
			2	1	2	3
				1	3	
		8	2	2	1	2
			3	3	1	4
TC4	130.31	9	3	3	4	4
		10	1	1	4	3
			5	4	2	5
				1	3	

To investigate the solution performance, the simulation model is used to test the performance of the output schedule from the MIP model and compare it with simulation results before solving the MIP model. In other words, we need to see how the proposed schedule differs from the optimum schedule after applying the DCTAS. The average truck turn times at each block *j* per each time window τ ($TT_{j\tau}$) are recorded for the proposed (preferred) appointments and the optimum appointments. Figures (5-9) show a comparison between the $TT_{j\tau}$ values for the proposed (preferred) appointments by the trucking companies versus the optimum appointments after applying the DCTAS.

Figure 5: Average $TT_{1\tau}$.

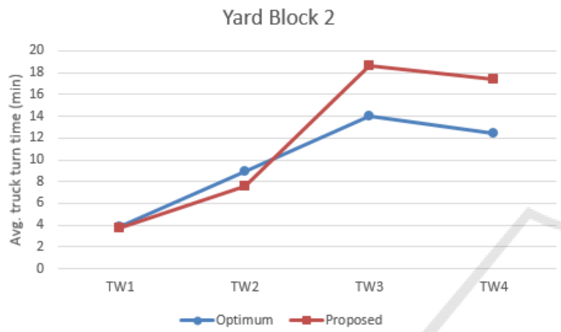

Figure 6: Average $TT_{2\tau}$.

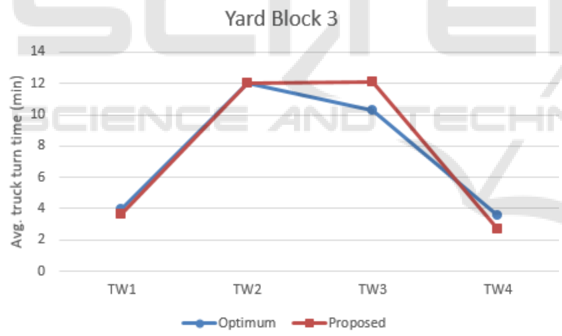

Figure 7: Average $TT_{3\tau}$.

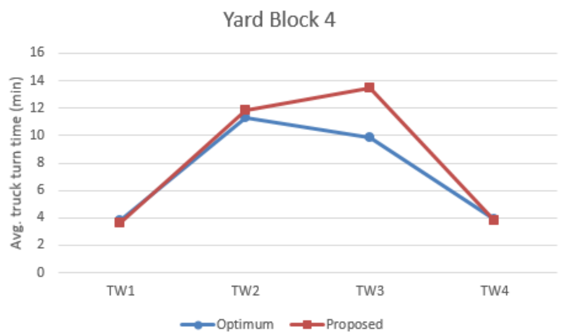

Figure 8: Average $TT_{4\tau}$.

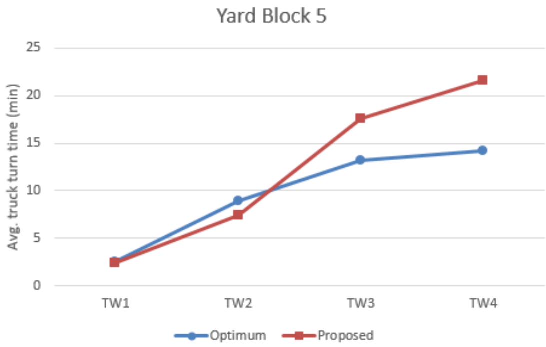

Figure 9: Average $TT_{5\tau}$.

Results show that there is a difference between the $TT_{j\tau}$ values before and after applying the proposed appointment management system. To confirm this difference, a t-test is conducted for $TT_{j\tau}$ values with a 95% confidence interval using Minitab 17 statistical software to test the 35 samples (replications) of $TT_{j\tau}$. The statistical results show that there is a significant difference between the average $TT_{j\tau}$ values before and after solution for most points such as Tw3 at YB1, Tw4 at YB2, Tw4 at YB3, Tw3 at YB4, and Tw4 at YB. While, some points did not depict significant differences in average $TT_{j\tau}$ such as Tw1 at YB2, Tw2 at YB3, Tw2 at YB4, Tw4 at YB4. It is noticed that the number of proposed tasks within some task groups increased after solution because some task groups are decomposed to two or three tasks. However, this reduces the turn time cost for the external trucks, some trucking companies may be inconvenient due to shifting their preferable arrival times. For the CT, distributing the arrival appointments over the terminal working hours is good to avoid congestion in certain times windows. From another side, reducing congestion and decreasing waiting time will result in less emissions and less fuel cost as well increased efficiency for the trucking companies. The results showed also that the average queue length at gates is reduced by 21% and the average truck turn time is reduced by 22.6% after applying the proposed system.

6 CONCLUSIONS

This paper proposed an integrated appointment system by which both the CT and trucking companies collaborate in determining the arrival schedule of external trucks. The proposed Dynamic Collaboration Truck Appointment System (DCTAS) integrates a discrete event simulation model with an MIP model using pre-processing integration. In the proposed DCTAS, the terminal operator firstly uses the simulation model to evaluate the turn times of the trucks considering their preferred arrival times. Then, the trucking companies solve the MIP model to reduce the total stay cost in the terminal. Finally, the terminal operator uses the rescheduled appointments of the trucking companies as inputs to the simulation model to produce the final appointment times and container schedule.

The results showed that the DCTAS could reduce truck congestion at the time windows where the terminal workloads are high. Moreover, the DCTAS could smooth the terminal workload and balance the arrival processes of external trucks. Thus, both stakeholders can benefit from applying the proposed appointment strategy. In addition, the rescheduling frequency is reduced compared to the existing literature approaches.

For future work, the proposed system will be implemented to a real case study and the effect of applying the proposed DCTAS on landside operations, yard operations and seaside operations will be investigated. Also, it is important to examine the emissions from trucks and terminal equipment after applying the DCTAS. One more issue that is expected to increase the appointment system performance is to consider truck sharing and collaboration between the trucking companies to reduce the empty truck trips. For instance, a trucking company may have a truck with an empty trip during a pickup task, which can be utilized by another trucking company to deliver a container to the terminal. This truck sharing process can be considered also in the appointment process.

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