Using Truck Appointment System to Improve the Yard Efficiency of the Container Terminal

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ABSTRACT

This paper considers the effectiveness of a truck appointment system in improving the yard efficiency of the container terminal. This research uses truck appointment information to improve the import container retrieval operation and reduce container rehandles by adopting an advanced container location assignment algorithm. By reducing the container rehandles, the terminal could improve yard crane productivity and reduce truck transaction time. A hybrid approach of simulation and queuing model was developed to model the container retrieval operation and estimate the crane productivity and truck turn time. Various configurations of the truck appointment system are modeled to investigate how those factors affect the effectiveness of the truck information. The research results illustrate a clear benefit for terminals utilizing truck appointment system to manage their yard operation if the appointment information is used to reduce rehandling. Reducing the duration of the appointment time window or increasing the appointment lead time could further enhance the system performance. The truck information is still effective for improving system efficiency even if a good portion of trucks miss their appointments.

INTRODUCTION

With global container movement volume forecasted to increase by an average of 7.2 percent annually in the next five years, maritime port congestion could once again become a problem. It is predicted that global container port volumes will rise by 245 million TEUs between 2009 and 2015, an increase of just over 50 percent in this period, while the capacity of the world’s container terminals is forecast to grow by 143 million TEUs during the same time frame, a rise of just under 20 percent (Guido, 2005). As a result, container terminals would be stressed to accommodate the growing container traffic and excessive truck delays could be caused within and around the container terminals.

To deal with truck congestion problems, some US container terminals have, amongst other strategies, deployed gate appointment systems, such as Ports of Los Angeles, Long Beach, and Oakland. Under such systems, truckers can make appointments to pick up or drop off containers during specific time windows. The terminal operator limits the total number of appointments within each time window to even out the truck traffic and avoid congestion during peak periods.

In California, the appointment systems at the San Pedro Ports were first developed in response to Assembly Bill 2650, which was enacted to prevent long truck lines at terminal gates in LA-Long Beach and Oakland. The bill fines terminal operators $250 every time a trucker spends more than 30 minutes waiting to enter a marine terminal. The legislation gives terminals two ways to shield themselves from fines: (a) deploying a gate appointment system; (b) extending gate hours. Truck appointment systems were implemented at many terminals as the least costly option to avoid fines (Lowenthal, 2002). However, because many terminals lacked
strategic commitment to appointment systems and did not streamline terminal operations accordingly, drayage trucking companies perceived the appointment systems as ineffective in reducing truck delays and improving customer services. Figure 1 shows the results of a field survey conducted at the Ports of Los Angeles & Long Beach regarding the effectiveness of gate appointment systems, illustrating that most systems were perceived by trucking firms as less than marginally effective in reducing the truck turn time (Giuliano and O’Brien, 2008).

The gate appointment system provides terminal operators with truck arrival information and provides an opportunity for such information to improve container handling operations. The terminal operators could utilize the truck arrival groups or sequence information by adopting an advanced container location assignment algorithm to reduce container rehandling work during container import retrieval operation (Zhao and Goodchild, 2010a). By reducing container rehandles, the terminal could improve yard crane productivity and reduce truck transaction and delay time.

This paper quantifies the impact of time-window size, appointment lead time and container dwell time on the container yard efficiency. It also quantifies the extent to which the accuracy of the truck information affects yard efficiency. The methodology proposed by Zhao and Goodchild (2010a, 2010b) is adopted in this paper for evaluating the impact of truck arrival information on the crane productivity and truck transaction time. The objective of this paper is to identify the impact of different terminal system configurations and the accuracy of information on the effectiveness of truck information and therefore determine the benefit that could be realized by terminal operators in utilizing truck appointment systems.
The remainder of this paper is organized as follows: the next section provides a literature review of related studies, the third section describes the analysis framework and methodology, the fourth section evaluates the impact of using truck appointment information on the performance of the yard crane service system, and in the fifth section, the impact of the accuracy of information on the effectiveness of truck information is quantified.

LITERATURE REVIEW

Gate appointment systems were first introduced at California ports in July 2003 as a result of California Assembly Bill 2650. After the implementation, Giuliano and O’Brien (2008) conducted a survey at the Ports of Los Angeles and Long Beach to evaluate its effectiveness. No evidence was found to suggest that the appointment system reduced queuing at terminal gates. This study revealed that the majority of terminals did not view appointments as an effective operational strategy and few efforts were made to provide priority services for truckers with appointments. Also, trips with appointments made up a small share of all port drayage trips and consequently could not have had a significant impact on queuing even if such trips were granted priority. Gate appointment systems are also in existence at other ports, including Port Metro Vancouver and the Port of Hong Kong. The Transportation Development Centre of Transport Canada published a study in 2006 (Lord and Morais, 2006) to review the programs and strategies used at North American ports to accelerate cargo handling. The study found that the implementation of an appointment system had some effect in reducing truck idling at west coast terminals, although the impacts of its usage will vary depending on the factors that are producing congestion.

Three previous studies have focused on improving gate appointment systems. Huynh and Walton (2008) examined the effect of regulating truck arrivals on truck turn time and crane utilization, and proposed a simulation-optimization methodology for determining the optimal number of trucks a terminal can accept into a yard zone per time window. The methodology is formulated to be robust so that the solution is not sensitive to late and missed appointments. The research results showed that the truck appointment system can be effective if used properly, and the proposed approach could give truckers clear benefits and incentives for using the appointment system.

Namboothiri and Erera (2008) studied how a gate appointment system affects the management of a fleet of trucks providing container pickup and delivery service to a port. They developed a drayage operations planning approach for determining truck pickup and delivery sequences with minimum transportation cost. The research results indicated that the productivity of drayage firms can be significantly affected by minor changes in the characteristics of the gate appointments. It was found that it is critical for terminal operators to provide enough appointment capacity for drayage, since vehicle productivity can be increased by 10-24% when total appointment capacity is increased by 30%. Furthermore, the duration of the appointment windows also affects the ability of drayage firms to provide high levels of customer service. Up
to 4% additional total capacity may be needed to maintain the same level of customer service if the slot duration is reduced by half.

Huynh (2009) investigated how the various scheduling rules of truck appointment systems affect resource utilization and truck turn time in grounded operations. This study considered two appointment-scheduling strategies that were widely used in the health care sector: individual appointment systems (IAS) and block appointment systems. A simulation model of a container terminal was developed to determine the effectiveness of the scheduling strategies. The experimental results showed a clear benefit for a terminal without an appointment system to use the IAS. Such a scheduling system keeps the yard cranes highly utilized, and it improves the internal yard turn time by about 44%.

Different from above studies, this research addresses the effect of the truck appointment system by using the truck arrival information obtained from such a system to improve yard operational efficiency and truck transaction time. Such an understanding could help terminal operators improve their current appointment systems.

ANALYSIS FRAMEWORK AND METHODOLOGY

We consider the retrieval of import containers from a container block by the yard crane and the subsequent processing time for drayage trucks. Some assumptions are made:

1. The yard crane serves the drayage trucks using the first-in-first-out rule;
2. Rehandled containers are relocated to a slot within the same bay;
3. No additional container is added to the block during the container retrieval process;
4. Truck arrivals can be modeled as a Poisson process;
5. The location of the container requested is randomly distributed;
6. The location of each container in the block is known in advance and tracked throughout the pickup process;
7. All the trucks make an appointment and provide information about the requested container at the same time.

These assumptions are consistent with those made in Zhao and Goodchild’s research (2010b). Under the second assumption, container bays are independent of each other; and thus the analysis rehandling work is performed for one bay by one crane, and the result is the same for any bay within the block.

The revised difference heuristic algorithm (Zhao and Goodchild, 2010a) is adopted for utilizing truck arrival information to improve the container retrieval operation. This method determines the optimal storage location of rehandled containers in order to minimize future rehandles. In current practice, the containers are usually relocated to the nearest available stack, limiting the distance traveled by the crane to finish one rehandle operation. This nearest relocation strategy will be used in a base scenario without any truck information for comparison.
To evaluate the impact of using truck arrival information on crane productivity and truck transaction time, we use a hybrid approach of simulation and queue modeling. As illustrated in Figure 2, a computer based simulation is first developed to model the container retrieval operation for a bay of containers under different container location assignment algorithms, including the revised difference heuristic and nearest relocation strategy, and keeps track of the container location and the number of container movements. It takes the container block design and truck appointment system configurations as inputs, and outputs the expectation and variance of number of rehandles under different scenarios. This information serves as input for the truck queuing model. An \(M/G/1\) queuing model is formulated by considering the yard crane as the single server and the drayage trucks as customers whose arrivals can be modeled as a Poisson process. The server’s parameters are determined by decomposing the crane service time into inter-bay travel time, container rehandling time and handling time and estimating the variance and expectation of each component. This queuing model takes the truck arrival rate as another input and outputs the crane productivity and truck turn time. A detailed explanation of the queuing model can be found in Zhao and Goodchild (2010b). A detailed explanation of the simulation model will be provided as follows.

**FIGURE 2 A hybrid approach of simulation and queuing model**

Parameters used to model terminal system configuration and information accuracy are described in Tables 1 and 2.
### TABLE 1 Modeled terminal system configurations

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameter settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum dwell time of containers</td>
<td>Within the range (1, 14) in days</td>
</tr>
<tr>
<td>Appointment lead time</td>
<td>1 day, 2 days</td>
</tr>
<tr>
<td>Duration of truck appointment window</td>
<td>0, 0.5 hour, 1 hour, 2 hours, 4 hours</td>
</tr>
</tbody>
</table>

Three parameters are used to describe the characteristics of container terminal system (Table 1). Maximum dwell time of containers refers to the number of days that a block of import containers sit at the container yard before the last container is retrieved for a drayage truck. In this paper, the dwell time is calculated from the day that the last import container was stored into a block. After that no more containers are added to this block. The second parameter, appointment lead time, refers to how early appointments are made before truck arrivals. Two cases are considered: the appointments are made 1 day in advance, and 2 days in advance. It is assumed that appointments are always made at the end of the day. The third parameter, duration of truck appointment window, is the length of time window assigned to trucks for container pickup. Four parameter values are considered for the time window duration: 0 (an exact arrival time is assigned and its duration is zero), 0.5 hour, 1 hour, 2 hours, and 4 hours. Exact arrival time is not realistic but represents the best-level information that could ever be achieved and is used to provide an upper bound on the benefit achieved.

In practice, container terminals need to deal with inaccurate information about truck arrivals, since drayage trucks may miss their appointments. Truck arrival information is considered accurate if the trucks arrive within their appointment time window or at their expected arrival time. Otherwise the information is considered inaccurate. Two measures used to define the accuracy of arrival information are: deviation from appointment time and missed appointment rate (Table 2). Deviation from appointment time is the absolute difference between the actual arrival time of a truck and the lower limit or upper limit of its appointment window. This measure is used to capture the degree of deviation of the actual arrival time from the appointment window. Missed appointment rate refers to the frequency with which drayage trucks miss their appointments. It is assumed that all the trucks will arrive within the complete time horizon. The considered parameter values are provided in Table 2.

### TABLE 2 Information accuracy measurements

<table>
<thead>
<tr>
<th>Measures</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation from appointment time</td>
<td>(0, 0.5 hour], (0, 1 hour], (0, 2 hours], (0, 4 hours], (0, 8 hours], (0, 16 hours], (0, 24 hours], (0, 32 hours], (0, 48 hours]</td>
</tr>
<tr>
<td>Missed appointment rate</td>
<td>5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%</td>
</tr>
</tbody>
</table>

The computer simulation was developed in Matlab to model the container retrieval process within a bay and takes all the parameters described in Tables 1 and 2 as inputs. It is assumed in the program that the terminal is open eight hours a day, and truck arrivals are modeled as a Poisson distribution. Therefore, the total number of truck arrivals within the
complete time horizon is set to the total number of containers in the bay, and the exact arrival times of trucks are generated by a homogeneous Poisson process. One day is evenly divided into several time windows based on time-window duration, and then the arrival time window for each truck is identified by comparing the generated arrival time with the starting and ending time of the time windows.

The simulation model first generates the bay configuration and truck arrival time windows, and then translates the time window information into arrival group information. Next, the computer program simulates the container pickup operation under two different strategies (Revised Difference Heuristic algorithm (RDH) and nearest relocation strategy) by calling the corresponding function when a container is required to be rehandled and updating its storage location in the bay. When the simulation time reaches the end of each day, the program obtains new information about truck arrival time windows and updates the truck group information. The program keeps track of the total number of rehandles under each strategy occurred, and calculates the expectation and variance of number of rehandles for 3000 iterations.

THE IMPACT OF TRUCK TIME WINDOW INFORMATION ON THE PERFORMANCE OF YARD CRANE SERVICE SYSTEM

This section quantifies improvements in crane productivity and truck transaction time when the terminal utilizes the arrival time window information of trucks to reduce container rehandling work. This will quantify how the truck appointment system configurations and terminal design affect the efficiency of truck-container terminal interface. The impact of several system design factors on drayage truck-yard crane system will be evaluated, including the maximum dwell time of containers, the duration of the appointment window and the appointment lead time. The crane parameter values introduced in Zhao and Goodchild (2010b) are applied in this analysis. In these experiments a terminal system with a fixed container block configuration is considered, for which the number of container bays is ten, the number of stacks is six, and each stack has four containers.

Performance analysis under different combinations of truck time window duration and container dwell time

Consider a truck appointment system with one day’s lead time. The dwell time of containers, truck arrival rate and block configuration have the following relationship:

\[
\text{average truck arrival rate} = \frac{\text{number of stacks} \times \text{number of containers in each stack} \times \text{number of bays}}{\text{maximum container dwell time}}
\]

When the block configuration and maximum dwell time of containers is known, the average truck arrival rate is determined. The impact of duration of truck time window and
container dwell time (truck arrival rate) on the performance of the yard crane service system is shown in Figures 3, and 4.

FIGURE 3 (a) Rehandle reductions under various container dwell times and time window scenarios, (b) improvements in productivity under various container dwell times and time window durations

Figure 3(a) indicates that under most scenarios, the improvement in crane productivity decreases gradually with the maximum dwell time of containers. That is because the amount of known
truck information is affected by the container dwell time. Since it is assumed that truck appointments are made one day in advance, the number of trucks with a known arrival time window equals the number of containers picked up each day. When the average dwell time of containers increases, the number of trucks known for their arrival time windows decreases. That results in less amount of known truck information being utilized to reduce container rehandling work and improve container retrieval operation. Figure 3(a) also indicates that as the container dwell time increases, the difference in productivity improvement between the exact arrival time scenario and other scenarios diminishes gradually. The benefit curves for all the scenarios start overlapping while the container dwell time increases to six days. Therefore, if the containers have a long dwell time on the yard, knowing and utilizing the truck arrival time window information could generate the same magnitude of benefit as having the exact truck arrival time information, and the amount of benefit is not sensitive to the duration of time window.

Since the truck arrival rate equals the quotient of the total number of containers in the block and the container dwell time, the benefit curve can be redrawn by replacing the x axis in Figure 3(a) with truck arrival rate. As shown in Figure 3(b), this indicates that the improvement in crane productivity increases gradually with truck arrival rate under most scenarios.

![Figure 3](image-url)

**FIGURE 3** Percentage savings in truck transaction time under various truck arrival rates and time window durations

Figure 4 indicates that the truck time saving resulting from any time window information increases exponentially with truck arrival rates. The truck time window information is therefore more valuable for a yard crane system operating near its capacity for truck delay reduction. The benefit curves for different scenarios almost overlap with each other, illustrating that four-hour time window information is almost as effective as the exact arrival time information in reducing truck transaction time. Therefore, the exact arrival time information of trucks is not required to
significantly improve system performance of yard crane service system if the arrival time window information is available.

**Performance analysis under different combinations of appointment lead times and container dwell time**

The impacts of appointment lead time and average dwell time of containers on the performance of yard crane service system are presented in Figure 5.

Figure 5(a) demonstrates that implementing an appointment system with two-day lead time could generate greater improvements in crane productivity compared to a system with one-day lead time. The efficiency gain in crane productivity for an appointment system with a two-day lead time first stays constant and then gradually decreases as the container dwell time reaches five days. For the system with a one-day lead time, the productivity improvement decreases steadily as the container dwell time increases. Two-day lead time also generates more improvements in crane productivity compared with one-day lead time, and this incremental benefit gradually increases as the container dwell time increases.

Figure 5(b) illustrates that truck time savings decrease steadily as container dwell time increases under different appointment lead times. Knowing the truck arrival information two days in advance generates more reductions in truck transaction time compared with knowing the truck arrival information one day in advance.
Therefore, increasing the lead time of the truck appointment system can thus further enhance the performance of yard crane service system. The additional benefit of a longer lead time gradually diminishes when the average dwell time of containers increases.

**IMPACT OF INFORMATION ACCURACY ON THE EFFECTIVENESS OF TRUCK INFORMATION**

This section estimates the improvement in crane productivity and truck transaction time if a terminal utilizes inaccurate truck arrival information to reduce rehandling work. The impact of missed appointment rate and deviation from appointment time on the performance of yard crane service system is evaluated to identify the effectiveness of truck time window information under different levels of information accuracy. In these experiments a terminal system with a fixed container block configuration is considered, for which the number of container bays is ten, the number of stacks is six, and each stack has four containers. The maximum container dwell time is assumed to be three days, the average arrival rate of trucks is ten vehicles per hour, and the appointment lead time of trucks is assumed to be one day. Again, the crane parameter values introduced in Zhao and Goodchild (2010b) are applied in this analysis.

**Performance analysis under various deviations from appointment time**

Assume a gate appointment system for which the missed appointment rate of trucks is 50%. That is, half of the trucks kept their appointments while the other half did not. The impacts of
deviation from appointment time on the performance of yard crane service system are shown in Figure 6.

FIGURE 6 (a) improvements in crane productivity under various maximum deviations from appointment time, (b) reductions in truck transaction time under various maximum deviations from appointment time
Figure 6 indicates that change in maximum deviation from appointment time has a similar effect on crane productivity and truck transaction time. Two other observations from Figure 6 are as follows:

First, the crane productivity improvement and truck time saving decrease gradually as the deviation from appointment time increases under all the scenarios. However, knowing the expected arrival time of trucks or their appointment time windows could still guarantee 6% improvement in crane productivity and 11% reduction in truck transaction time even if half of the trucks missed their appointments and their lateness/earliness is as long as four hours. This indicates that inaccurate information is still useful in improving the performance of the yard crane service system. That is because the container location assignment algorithm employed for using truck information, the revised difference heuristic (RDH), is superior to the nearest relocation strategy, which is adopted for the no information scenario. RDH is designed to relocate containers to a location to avoid future rehandles, and would store the rehandled container in an empty stack if possible. The nearest relocation strategy is intended to minimize the travel distance of the yard crane and always relocate rehandled containers to the nearest available stack without considering the rehandling effort being incurred. Our simulation results demonstrate that RDH outperforms the nearest relocation strategy in terms of reducing rehandling work and improving operational efficiency even if the utilized truck information is inaccurate.

Second, as the maximum deviation from appointment time increases, the benefit achieved from using time window information decreases at a slower rate compared to the benefit curve under exact arrival time scenario. When the maximum deviation from appointment time is over four hours, using the time window information could generate some additional benefit of the system improvement compared with using expected arrival time information. Therefore, the magnitude of benefit obtained from a system with wider appointment windows is less sensitive to inaccurate information. With regard to the case with exact arrival time of trucks, the earliness/lateness of truck arrivals could change the truck arrival sequence greatly. With regard to cases with truck appointment windows, since such time window information is translated into group information for usage, earliness/lateness of truck arrivals only affects the number of trucks in the groups, and such impact is limited by the maximum deviation from appointment window. Take the four-hour time window scenario as an example, if the time deviation is within four hours, those trucks that missed their appointments would only arrive in the preceding or the next time window. Thus the expected arrival time information is less accurate and useful than the time window information if the deviation of trucks from their expected arrival time or appointment window is large.

**Performance analysis under various missed appointment rates**

The previous section considered a 50% missed appointment rate. We now consider the sensitivity of performance to the percent of missed appointments. Consider a terminal gate
appointment system for which the deviation of truck’s actual arrival time from appointment time is within four hours. The impacts of missed appointment rates on the performance of yard crane service system are shown in Figure 7.

Figure 7 (a) improvements in crane productivity under various missed appointment rates and durations of time window, (b) reductions in truck transaction time under various missed appointment rates and durations of time window.
Note the similarity between Figure 7(a) and Figure 7(b), indicating that the change in missed appointment rates has similar impacts on crane productivity and truck turn time. The amount of benefit is much greater for drayage trucks than the yard crane, given the same level of information quality and accuracy. Two other observations from Figure 7 are as follows:

First, in the scenario with expected arrival time information, the benefit of system improvement decreases gradually as the missed appointment rate increases. That is because a higher missed appointment rate could incur more changes to the truck arrival sequence.

Second, benefit curves corresponding to time window scenarios almost stay flat as missed appointment rate increases. It indicates that the system performance is robust to missed appointments if the earliness or lateness of truck arrivals is less than four hours. That can be explained by how the information quality affects the implementation of RDH algorithm in the container relocation process. Firstly, 100% missed appointment rate doesn’t mean that the time window information is useless. Trucks could either arrive earlier or later than their appointment time, but those late arrivals do not have an impact on the effectiveness of RDH algorithm because RDH is designed to minimize future rehandles and a decision made to relocate a container on top of containers with delayed pickups won’t incur additional future rehandles. Secondly, as discussed in the previous subsection, the impact of missed appointments on the information quality is limited by the maximum deviation from appointment time and it only changes the number of trucks in the neighboring groups. Our simulation results demonstrate that such information quality has little impact on the usefulness of RDH algorithm.

CONCLUSION

This paper quantifies the impact of using a truck appointment system on the yard efficiency of container terminals. An advanced container location assignment algorithm was adopted for using the truck appointment information to reduce the container rehandling work and improve yard efficiency. A hybrid approach of simulation and queuing model was developed to model the interaction between the yard crane and arriving trucks during the container retrieval process. This hybrid model is designed to evaluate how strategic factors such as truck appointment system configuration and container dwell time affect the crane productivity and truck transaction time.

The research results demonstrate that utilizing truck appointment system information can generate significant improvements for the terminal and for drayage trucks. Reducing the duration of appointment window could further enhance the yard efficiency if the container dwell time on yard is short. However, as the container dwell time becomes longer, the size of time window has no impact on the yard efficiency, and utilizing any time window information could generate the same amount of benefit. Also, increasing the appointment lead time of trucks could improve the system performance, and such an additional benefit gradually increases with the container dwell time. In addition, the performance of yard crane service system is robust to the usage of
inaccurate truck information. Missed appointments have no effect on the system performance if the earliness or lateness of truck arrivals does not exceed four hours.

The work can help terminal operators to understand the magnitude of benefit they could obtain from implementing an appointment system, and also shed light on how to improve their current appointment systems for more benefits.

REFERENCE


