Effective Rules for Scheduling Landside Operations
of a Container Terminal
[004-0230]

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Abstract

Rising competition among container ports has put tremendous pressure on the ports to develop effective methods to manage their complex and dynamic operations. This paper studies the problem of scheduling trucks and yard cranes in the landside operations of a container terminal to support the discharging and loading of containers in the quayside. Two scheduling objectives, minimizing average vessel tardiness and maximizing average terminal throughput, are considered. As the scheduling problem is very complicated, popular dispatching rules and a fuzzy-logic rule developed by this paper are used to solve the problem. The effectiveness of the rules is evaluated by simulation. The simulation results show that the fuzzy-logic rule performs best with respect to the two objectives considered.

Key words: scheduling, container terminal, rule, fuzzy logic, simulation

1. Introduction

Serving as a hub for transshipment of containers among shipping and landside transportations, container terminal has received great business demand of quick delivery and large turnover. In order to survive the rising competition, ports have to develop effective methods for their complex and dynamic terminal operations. Among various terminal performance measures, vessel berthing time and quayside throughput are key issues. Thus, shortening vessel berthing time and improving quayside throughput have become two main objectives of managing a container terminal.

Generally, handling operations for a vessel, mainly discharging and loading containers, take most of the vessel berthing time. On the other side, quayside throughput largely depends on quay crane handling rate during the operation. Therefore, among all terminal operations, discharging and loading containers are targeted ones for this study.

Containers are loaded and unloaded in quay area from a set of vessels berthing alongside, and are stored in various yard blocks in storage yard. A Typical layout of a container terminal is illustrated in Figure 1. In the quay area, each vessel is served by multiple quay cranes for loading and unloading operations; while in the storage yard, each yard block is served by a set of yard cranes for handling. Containers are moved between the vessels and the yard using internal trucks. Generally, the storage locations of the export containers for a certain vessel and import containers from that vessel are determined a few days before the vessel arrival.

When a vessel arrives, the quay cranes assigned to it unload the containers, from the vessel onto the trucks, for transportation to various predetermined storage locations, and the yard crane serving at the position unloads the container from the truck for storage. In loading operations, the export containers stored in the yard are loaded onto trucks by yard cranes, and are off-loaded in the quay, loaded onto a vessel by quay cranes. In both discharging and loading loops, once handling operation starts on a vessel, handling jobs
of quay cranes will correspondingly produce transportation jobs for trucks and handling jobs for yard cranes. Thus, (1) dispatching transportation jobs, from a quay crane to a truck, and (2) scheduling handling jobs on a yard crane become two key planning problems in the operation.

The first problem concerns a situation in the terminal when there are on one side a set of empty trucks at various locations, and on the other side a set of quay cranes and yard cranes in need of trucks to perform transportation jobs. Dispatching the trucks to the cranes and deciding the sequence of dispatching are two sub-problems to be determined in this situation. Because the container flow in the terminal can be bottlenecked by the scarce resource of trucks or sometimes high truck occupancy by less urgent jobs in the terminal, a good dispatching can increase container flow efficiency and finally increase terminal throughput and decrease vessel berthing time as well.

The second problem considers the handling sequence of jobs on a yard crane, which in a certain time window may includes both loading jobs, firstly unloading containers from arriving trucks and then loading them onto the storage block, and unloading jobs, firstly fetching the required container from a known position within the block and then loading it onto an arriving empty truck. Since the handling rate of a yard crane is generally 2 to 3 times of that of a quay crane, the comparatively slow yard crane operation may produce bottleneck in terminal container flows. Therefore, a good yard crane schedule can also contribute to the two objectives by increasing the container flows to and from the vessel.

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2. Literature Review

Problems associated with scheduling jobs and equipments, dispatching and routing vehicles have been extensively studied in the operation research and management science literature. Unfortunately, to the best of my knowledge, only a few among them are directly applicable to a container terminal due to its unique characteristics. On the other side, most studies on container terminal tend to place concern on a local activity in the container flow, like the truck routing, yard crane scheduling, etc., rather than on the whole flow including multiple equipments and inter-related handling activities, which may take into account the interrelation of various operations in the terminal area and not local, but overall operation objectives for the port container terminal. The lack of studies on this may be due to the complex application environment, which raised hard requirements and constrains on developing algorithms. Another reason could be that, planning multiple activities through the container flow may produce multiple objectives, which may also cause difficulties and make some optimal approaches inapplicable.

Among the limited studies addressing the problem, one study conducted by E.K. Bish (2003) discussed a container terminal logistics system similar to the one presented in this paper. In his study, the problem was decomposed into (i) determining a storage location for each unloaded container, (ii) dispatching vehicles to containers, and (iii) scheduling the unloading and loading operations on each quay crane, so as to minimize the maximum turnaround time of a set of ships. The problem was proved to be NP-hard, and a heuristic algorithm was presented.

As mentioned above, most studies tend to focus on a local activity in the terminal area. Whatever activities are considered though, the objective tends to be the same -- increasing terminal throughput, or in particular, shortening vessel berthing time. With this objective, different strategies are developed for kinds of container terminal operations.

The first category of studies related to this study is on yard crane scheduling. In most cases, scheduling yard cranes is a real-time job and therefore very experience-based. A good schedule on yard cranes may reduce the delay time of outside trucks and finally speed up the service to the vessel. Meersmans and Wagelmans (2001) presented an optimization based beam search heuristic and several dispatching rules for equipment handling in a dynamic environment. In their model, handling time was unknown beforehand and job sequence did not need to be specified completely in advance. Their result was that the beam search heuristic performed best. Kim et al.(2003) studied the problem in both static and dynamic environments. For static environment, they suggested a dynamic programming model; while for dynamic situations, they proposed several heuristic rules as well as a learning-based method for deriving decision rules. Ng and Mak (2005) proposed a branch and bound algorithm for scheduling a yard crane to perform a given set of loading/unloading jobs with different ready times. They concluded with that the algorithm could find the optimal sequence for most problems of realistic sizes.

The second category of studies focuses on the other problem addressed in this paper – dispatching vehicles to jobs. Recently, automated guided vehicle (AGV) joined the terminal vehicles and has attracted special attention. Lim et al.(2003) suggested an
auction algorithm as a method to dispatch AGVs. The dispatching method was different from traditional dispatching rules in that it looked into the future for an efficient assignment of delivery tasks to vehicles and also in that multiple tasks were matched with multiple vehicles. The performance of the method was examined through simulation. Grunow et al. (2004) placed an emphasis on dispatching multi-load AGVs. For practical application within an online logistics control system, they developed a flexible priority rule based approach, making use of an extended concept of the availability of vehicles. The performance of the priority rule based approach was analyzed for different scenarios with respect to total lateness of the AGVs.

3. A Fuzzy Approach

Currently in practice, the operations like scheduling trucks and scheduling yard cranes are executed by human judgment in an experience-based way. Some common simple dispatching or sequencing rules may be used in the process of determination. However, most of these rules are aiming at a particular objective, and consider a single attribute; like the EDD (Earliest Due Date) rule concerning minimizing only individual job tardiness, while MWR (Most Work Remaining) rule considering decreasing total makespan by balancing the workload of several cooperating equipments.

As mentioned above, container terminal operation is a multi-criterion task; there could be more than one objective over the handling operations through the container flow. Therefore, a more complicated rule that can satisfy more objectives is to be developed. This rule should consider more attributes of the candidate job or equipment at the same time, and therefore helps to make a decision in a more balanced way concerning the overall performance other than a local one.

One most common way of combining rules in order to extend their efficiency to several criteria could be the priority-based approach. That is, applying the rules one after another in a rule priority descending order. However, this method is not very effective; because most of the time the tie is broken just after applying the first or second rule, in this case the third or fourth rule are meaningless to the decision. In spite of the disadvantage, the priority-based approach can generate a satisfying result better than single rules for most of the time. Later this paper, this approach will be applied to schedule the two problems presented above, and the result will be used for comparison.

Another way is to construct a decision rule comprising all elementary rules, each of which serves a single criterion. While the rule will benefit from obtaining good performance on nearly all criteria, a compromise among criteria has to be settled. In this paper, the fuzzy-set theory is employed in a multi-objective approach to model compromises among membership functions.

Bellman and Zadeh (1970) observed that in a fuzzy environment, a fuzzy decision is basically a choice or a set of choices drawn from the available alternatives resulting from the combined effect of the goals and constraints. They further stated that, given a set of alternatives \( X = \{x\} \), a decision \( D \) can be defined as the confluence of a fuzzy goal \( G \) and a fuzzy constraint \( C \):
\[ D = G \cap C \]  
where \( G \) and \( C \) are both given fuzzy sets in \( X \). More generally, if there are \( n \) goals and \( m \) constraints, that is:

\[
D = \left( \bigcap_{i=1}^{n} G_i \right) \cap \left( \bigcap_{j=1}^{m} C_j \right)
\]  

When the goals and constraints are of different importance, \( D \) is expressed as a convex combination of the goals and the constraints with weighting coefficients. The membership function is given by:

\[
\mu_D(x) = \sum_{i=1}^{n} \alpha_i(x) \mu_{G_i}(x) + \sum_{j=1}^{m} \beta_j(x) \mu_{C_j}(x)
\]  

where

\[
\sum_{i=1}^{n} \alpha_i(x) + \sum_{j=1}^{m} \beta_j(x) \equiv 1
\]  

Since in this study, only objectives are concerned and no constraints are considered in the two problems, the equation (3) and (4) can be reduced to:

\[
\mu_D(x) = \sum_{j=1}^{m} \beta_j(x) \mu_{C_j}(x)
\]  

and

\[
\sum_{j=1}^{m} \beta_j(x) = 1
\]

Based on (5) and (6), the equation below is derived:

\[
\mu_{Fj}(k) = \sum_{j=1}^{m} \left( w_j \times \mu_j(k) \right) \times S(k)
\]

where

\begin{align*}
  k & = 1, 2, \ldots, n \text{ alternative operations: selecting job } k \text{ from all candidate jobs} \\
  j & = 1, 2, \ldots, m \text{ objectives} \\
  \mu_j(k) & = \text{membership effect of selecting job } k \text{ to objective } j \\
  \mu_{Fj}(k) & = \text{membership effect of selecting job } k \text{ to all objectives} \\
  w_j & = \text{weight (normalized) of objective } j \\
  S(k) & = \begin{cases} 
      0 & \text{if } \mu_j(k) < 0 \\
      1 & \text{if } \mu_j(k) \geq 0
   \end{cases}
\end{align*}

The remaining this section will explain how this fuzzy approach is applied to schedule the two problems presented in the beginning part of this paper.

As mentioned in the introduction, once the handling jobs start on the quay cranes, the corresponding transportation jobs for trucks and handling jobs for yard cranes are automatically generated. Thus, empty trucks in the system are to be dispatched to transportation jobs which are to be released soon from various cranes in the terminal. To any available truck, dispatching it to any candidate job is an alternative operation. To determine which operation to be finally implemented, the contributions of all the alternative operations to the objectives are evaluated, using the function expressed in equation (7). Actually, \( \mu_{Fj}(k) \) is the integrated contribution of dispatching the available
truck to transportation job $k$ to all objectives considered. After all alternative operations are evaluated, the one with the largest contribution will win the bid.

Similarly in yard crane scheduling, all loading and unloading jobs arrived at the yard crane will be evaluated concerning their contribution to all the objectives. The yard crane is to handle the job highest scored.

As long as transportation jobs or handling jobs exist in the job queue, whenever a newly released truck reports to the system, or a yard crane just completes the handling job, all job attributes are updated and a new dispatching evaluation loop is triggered.

The method suggested here is a multi-criteria approach which makes it possible to combine membership functions in order to extend their efficiency to several objectives. Making the approach efficient still requires (1) well-defined membership functions to be consistent with one or more objectives in the objective set; and (2) well-determined weight set properly balancing the compromises among the objectives.

The following section will discuss in detail the membership functions of the fuzzy approaches for scheduling the two problems. The efficiency of the fuzzy approach is examined through the simulation way, and a satisfying weight set for membership functions can also be obtained this way – these will be discussed in Section 5 and 6.

4. Membership Functions

4.1 Sub-objectives

A fuzzy membership function is to be built to evaluate the contribution of an alternative operation – in this study, dispatching a truck to a transportation job or selecting a yard crane job for next handling – to an objective. As presented in the introduction, shortening vessel berthing time and improving quayside throughput are the two key objectives in this study. Generally, each berthing vessel has a due date concerning the required completion time of all loading and unloading jobs, so the first objective can be conveniently transferred to decreasing vessel tardiness, that is, the vessel completion time minus the vessel due date. In this way, the avg. vessel tardiness can be used as a criterion to measure the performance on this objective. Similarly, avg. quay crane handling rate can be used as a measure for the objective of quayside throughput. However, these are still high-level objectives and are not convenient for constructing membership functions which are to evaluate the specific, localized operations. Therefore, we have to divide them into several sub-objectives:

1. Balancing the vessel process
2. Balancing the QC process on one vessel
3. Minimizing QC job lateness
4. Keeping a low risk of shortage of available trucks in the system
5. Minimizing total waiting time of trucks in the queue.
6. Minimizing truck travel time
Some of the above sub-objectives serve a single overall objective, like (2), keeping the working process of the QCs handling the same vessel at a balanced level, not to leave a QC processing too fast or too slow, would effectively shorten the makespan and avoid vessel tardiness. Some sub-objectives may be consistent with both two overall objectives, like (3), decreasing QC job lateness will also decrease vessel tardiness; on the other side, decreasing late QC jobs will improve the avg. QC handling rate and finally improve quayside throughput.

4.2 Constructing membership functions

Membership function is to be built one by one according to the sub-objectives. In the following part, the yard crane scheduling problem is discussed first.

Considering objective(1). Choosing job $x$ from the YC job queue for next handling is an alternative operation. If the job is an export job, the membership function to express the contribution can be built as:

$$
\mu_1(x) = \frac{\text{Jobs remain}_{\text{Vessel}(job_x)} / \text{Jobs total}_{\text{Vessel}(job_x)}}{(DD_{\text{Vessel}(job_x)} - T_0) / (DD_{\text{Vessel}(job_x)} - T_{\text{arr}})}
$$

$Vessel(job_x)$ denotes the vessel which job $x$ belongs to. The numerator is, at the current time $T_0$, the remaining jobs of the vessel divided by the total vessel jobs. In the denominator, $T_0$ represents the current time, $T_{\text{arr}}$ represents the vessel arrival time and $DD$ represents the vessel due date. $\mu_1(x)$ actually indicates the comparative vessel process at time $T_0$, concerning it should complete all jobs at $DD_{Vessel(job_x)}$. If the vessel keeps a steady handling rate as the plan, the value of $\mu_1(x)$ should be 1 at any time during the handling. However, if the vessel process is slower than the plan, the remaining jobs take a larger proportion in total jobs than the remaining time in total time, so the value of $\mu_1(x)$ is higher than 1 which indicates the job should be handled soon in order to speed up the vessel process.

For import jobs, whichever job is chosen, no contribution will be made to the vessel process, so the function is a constant:

$$
\mu_1(x) = 0
$$

When objective (2) is considered, the membership function can be built as:

For export jobs: $\mu_2(x) = \left( JQL_{\text{QC}(job_x), x=T_0} - \text{AvgJQL}_{\text{QC}(Vessel(job_x), x=T_0)} \right) / \text{MaxJQL}_{\text{QC}}$  (10)

For import jobs: $\mu_2(x) = 0$  (11)

$JQL_{\text{QC}(job_x)}$ denotes the job queue length of the QC which the job is sent to; $\text{AvgJQL}_{\text{QC}(Vessel(job_x), x=T_0)}$ denotes at time $T_0$, the average job queue length of all the QCs serving the vessel which the job belongs to. $\text{MaxJQL}_{\text{QC}}$ is max QC job queue length which is set to be a constant. If the QC’s process is faster than other QCs serving the same vessel, that is, the QC’s current job queue length is shorter than the average value, the value of $\mu_2(x)$ is low which means this job should be considered with a lower priority.
When objective (3) is considered, the membership function can be built as:

For export jobs: \( \mu_j(x) = \frac{T_0 - DD_{job_x}}{MaxJL} \)  \( (12) \)

For import jobs: \( \mu_j(x) = 0 \)  \( (13) \)

where \( DD_{job_x} \) is the due date of job \( x \) and \( MaxJL \), max job lateness, is a constant which is set to be 20 min, determined according to the average value from simulation data.

In objective(4), the risk of truck shortage can be demonstrated as total truck demand in the system divided by total truck supply. If, on a certain time in the terminal, many equipments are ordering empty trucks while only a few trucks are available, the yard crane should consider handle an import job first because this action, unloading a container from a truck, can immediately release a truck to the system. On the contrast, loading a container on a waiting empty truck would do no contribution:

For export jobs: \( \mu_i(x) = 0 \)  \( (14) \)

For import jobs:
\[
\mu_i(x) = 1 - \frac{Truck_{demand}}{Truck_{supply}}
\]  \( (15) \)

Jobs in a YC job queue are of different processing time, which are related to the in-block position of the container. Therefore, objective(5) will support those with shorter processing time to be handled first, thus the membership function can be built as:

\[
\mu_s(x) = \frac{MaxPT - PT_{job_x}}{MaxPT - MinPT}
\]  \( (16) \)

where \( PT_{job_x} \) denotes the processing time of job \( x \).

Since a YC schedule would not affect the truck travel time, objective(6) is irrelevant to YC scheduling.

After the membership functions are constructed, they need to be normalized with a function value between [0,1]. Suppose this is done, now there are in all 5 normalized membership functions for scheduling YC jobs. Suppose the 5 sub-objectives considered in YC scheduling are weighted by \( \{w_j\} \) \( (j = 1, 2, \ldots, 5) \), then the contribution of selecting job \( x \) for next handling to all objectives can be calculated by:

\[
\mu_F(x) = \sum_{j=1}^{5} \left( w_j \times \mu_j(x) \right) \times S(x)
\]  \( (17) \)

Let \( \lambda_j(k) \) be the membership of sub-objectives in the operation of scheduling trucks. When an available truck is to be dispatched, dispatching it to any coming transportation jobs from a QC or YC in the terminal is an alternative operation.

When objective(1) is considered, the function can be built as:

\[
\lambda_i(x) = \frac{Jobs_{remain}_{Vesl_{job_x}}}{Jobs_{total}_{Vesl_{job_x}}} \times \frac{DD_{Vesl_{job_x}} - T_0}{(DD_{Vesl_{job_x}} - T_{ariv})}
\]  \( (18) \)

The equation indicates that, the empty truck should be dispatched to the job which would do the biggest contribution in speeding up the handling process of the vessel with least process.
The function considering objective (2) is built as:
\[ \lambda_2(x) = \left( JQL_{QC(job, x = T_0)} - AvgJQL_{QC(Val(job, x = T_0))} \right) / \text{MaxJQL}_{QC} \]  \tag{19} 

When objective (3) is considered, for import jobs the function can be built as:
\[ \lambda_3(x) = -\frac{DD_{job} - T_0}{\text{MaxJL}} \]  \tag{20} 
where \( \text{MaxJL} \) denotes the max job lateness, which is a constant according to the average level from simulation data. \( DD_{job} \) is the due date of job \( x \), which can be calculated through the QC job sequence and a normal QC rate. For export jobs, the function is built as:
\[ \lambda_3(x) = -\frac{(DD_{job} - T_0) - \text{YCPT}_{job} - \text{TranspT}_{job}}{\text{MaxJL}} \]  \tag{21} 
As in (19), \( (DD_{job} - T_0) \) represents the time remaining for job \( x \) before its due date. In this period of time, the export job \( x \), if not to be late, has to be loaded on a truck in the yard with a YC processing time \( \text{YCPT}_{job} \) and transported to the quay with a transportation time \( \text{TranspT}_{job} \).

Objective (4) and (5) are irrelevant to the operation of truck scheduling. The membership function considering objective (6) can be built as:
\[ \lambda_4(x) = \left( \text{MaxTrvlT} - \text{TrvlT}_{job} \right) / \text{MaxTrvlT} \]  \tag{22} 
where \( \text{TrvlT}_{job} \) is the travel time of the truck from its current location to the pick-up location of job \( x \); \( \text{MaxTrvlT} \) represents the max possible truck travel time in the terminal.

Similar to YC scheduling, suppose the four membership functions are already normalized and are weighted by \( \{ \omega_j \} \) \( (j = 1, 2, 3, 4) \), the integrated contribution of dispatching the truck to job \( x \) to all sub-objectives can be calculated by:
\[ \lambda_F(x) = \sum_{j=1}^{4} (\omega_j \times \lambda_j(x)) \times S(x) \]  \tag{23} 

So far the fuzzy approach for scheduling the two problems is obtained. The effectiveness of the developed method will be evaluated through a simulation approach.

5. A Simulation Model

In the dynamic and complex terminal environment, setting up a real system to examine the operation strategies could be very time-consuming and money-consuming and is almost impossible. Running simulations based on computational approaches, however, can avoid such disadvantages and can be very convenient for a large scale of testing. In all, the benefits of using the simulation methodology to model the container terminal system for evaluating various scheduling methods can be reduced to 6 points:

1. Reduction of capital cost
(2) Reduction of experiment time
(3) Reduction of experiment risk
(4) More flexibility on various scenarios
(5) Better understanding for the research
(6) Easier implementation

In the light of the above statement, a model has been developed to simulate a common port container terminal, the layout of which is shown in figure 2.

![Figure 2. Layout of the container terminal for simulation](image)

This is a typical layout of a port container terminal with 4 berths in the quay area and in the yard 16 yard zones each includes 3 yard blocks. On each block a yard crane is responsible of all handling operations. According to the vessel of fourth generation, the number of quay cranes assigned to the berth serving one vessel is set to be 4. Then in the terminal, the ratio of QC to YC is 1:3, which is consistent to the normal level. According to the practical data, the ratio of QC to truck is 1:5, then the number of trucks in the simulation is set to be 80.

According to the practical data, the QC handling time of a single job is set to be 1.5min, and the YC handling time to be 2-6min. The truck travel time from any location in the terminal to another is calculated based on the travel distance and a normal truck speed of 4m/s.
The amount of vessel jobs is randomly generated and the number is between [1000, 2000], according to the fourth generation vessel data. The discharging batch and the loading batch go alternatively with a normal batch size of [10, 20].

In the simulation, the vessels arrive at the port continuously and are led into the berth in a FCFS way if there are vacant berths; otherwise the vessels will stay in the waiting list for berths to be available. Once the vessel is in berth, the four QCs at the berth immediately start the handling. The vessel will leave the berth when all jobs are completed. The berth will become available again after 30 minutes.

The vessel inter-arrival time was set to follow the negative exponential distribution with a mean value. The experiment considers five scenarios respectively with a mean vessel inter-arrival time of 8hr, 12hr, 16hr, 20hr and 24hr. This design is to better analyze the effectiveness of scheduling methods under different workload levels.

Besides the fuzzy approach, various dispatching and sequencing rules currently used in practice are also evaluated through the simulation. Using these rules, the two problems are scheduled either by a single rule or by multi-rule combined with a priority-based approach. For each method, 20 replicas of the simulation were run with different random number streams and in each round, the data are collected from the steady period of the simulation. The studied period of the simulation time was around 3 months, which should be long enough to represent the normal operation level of the terminal.

It should be noted here that the weight set for membership functions in the fuzzy approach needs to be decided before the simulation experiment. A satisfying weight set can be obtained through the simulation method, too. In this study, the scenario with the mid-value of 16 hr was chosen for weight set testing. All possible combinations of the weights for membership functions were tested, and the combination of the weight set \( \{ w_1 = 0.1, w_2 = 0.2, w_3 = 0.55, w_4 = 0.1, w_5 = 0.05 \} \) for YC scheduling and the weight set \( \{ \omega_2 = 0.05, \omega_3 = 0.85, \omega_4 = 0.1 \} \) for truck scheduling is proved to be satisfying and is finally used in the simulation experiment. It can be noticed that the number of membership functions for scheduling trucks were reduced to 3; this is because the tested weight for \( \lambda \) stays at a level below 5% through all the best 200 combinations and was therefore considered to be discarded from the memberships.

6. Simulation Results

The fuzzy approach and 20 combinations of traditional rules were examined through the simulation. Figure 3 – 6 shows the simulation result of the fuzzy approach and four best combinations of traditional rules, listed in Table 1 for detail.
Figure 3. the Avg. vessel tardiness

Figure 4. the Sdv. Of the Avg. vessel tardiness

Figure 5. the Avg. QC handling rate

Figure 6. the Sdv. Of the Avg. QC handling rate
Table 1: Methods with good performance in the simulation

<table>
<thead>
<tr>
<th>Scheduling methods</th>
<th>For scheduling trucks</th>
<th>For scheduling YCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuzzy approach</td>
<td>$\lambda_2$ $\lambda_3$ $\lambda_4$</td>
<td>$\mu_1$ $\mu_2$ $\mu_3$ $\mu_4$ $\mu_5$</td>
</tr>
<tr>
<td></td>
<td>$\omega_2=0.05$ $\omega_3=0.85$ $\omega_4=0.1$</td>
<td>$w_f=0.1$ $w_f=0.2$ $w_f=0.55$ $w_f=0.1$ $w_f=0.05$</td>
</tr>
<tr>
<td>Rule cmb. 1</td>
<td>EDD</td>
<td>EDD</td>
</tr>
<tr>
<td>Rule cmb. 2</td>
<td>1st Priority: EDD</td>
<td>1st Priority: MWR</td>
</tr>
<tr>
<td></td>
<td>2nd Priority: MWR</td>
<td></td>
</tr>
<tr>
<td>Rule cmb. 3</td>
<td>FCFS</td>
<td></td>
</tr>
<tr>
<td>Rule cmb. 4</td>
<td>FCFS</td>
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</tbody>
</table>

The performance measures considered are the average vessel tardiness and the average QC handling rate, concerning the two overall objectives of shortening vessel berthing time and improving quayside throughput respectively. The vessel tardiness is defined as the lateness of vessel completion time compared with the vessel due date, and the vessel due date is calculated by the vessel arrival time plus total handling time which equals the job amount timed by the normal QC rate.

Figure 3 shows the average level of the vessel tardiness under the 5 scenarios, and Figure 4 shows its standard deviation. The results indicate that, the fuzzy approach can keep producing a low tardiness level under all scenarios, even when the terminal workload is heavy. This is observed from the 1st and 2nd scenarios, when vessels arrive frequently, the fuzzy approach shows a much better performance compared with the traditional rule combinations. However, when the terminal is not busy, the fuzzy approach does not over-perform the traditional rules too much. From the standard deviation data, the fuzzy approach proved to be a comparatively steady scheduling method, compared with the traditional rules.

Figure 5 shows the average QC handling rate during the operation using the rules, and figure 6 shows its standard deviation. Again, the fuzzy approach operates a faster QC handling than the other four rules under all scenarios. However, the gap is small and all the methods seem to be sensitive to the workload level. When the terminal is busy with continuously arriving vessels, both the fuzzy approach and the traditional rules produced a low QC handling rate, which means the QCs were blocked from time to time by late jobs or lack of empty trucks. From the simulation data, in most of the case the QCs were blocked because it could not be dispatched with an empty truck for long time; so the inefficiency may be relative to the scarce resource of terminal facilities. At this point, further research may be conducted on testing different level of terminal facilities.
Figure 7 gives the computational time for running the simulation of 100 terminal work days. The figure implies that the fuzzy approach has a much higher computational complexity than the simple rules, but its absolute computational time is still considerably short and can satisfy the practical use very well. Besides, the figure shows the computational time level of the traditional rules is comparatively steady under various scenarios, while the fuzzy approach produced a sharp increase on computational time when the terminal tends to be busy. This is because when the total job amount increased in a unit time, the handling equipments may get considerably long job queues which substantially increased the calculation amount.

![Graph showing computational time for different scenarios](image)

**Figure 7. The computational time of the simulation**

### 7. Conclusion

The study tries to address an effective method in the problem of scheduling trucks and yard cranes in the landside operations of a container terminal to support the discharging and loading operations in the quayside. Through the simulation experiment, various methods are tested and the performances are evaluated with respect to the two scheduling objectives, minimizing average vessel tardiness and maximizing average terminal throughput. These methods include several combinations of traditional dispatching rules currently used in practice as well as a fuzzy approach proposed in this paper. The fuzzy approach proved to have the best performance on achieving both objectives at all terminal workload levels. To better evaluate the scheduling methods, future work may include more scenario changes on terminal facility resource level.
Reference:


