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A reward-based algorithm for the stacking of outbound containers

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Abstract

As global trade increases, container transshipment activities increase rapidly. Therefore, high competition among container terminals has emerged. The decision for good stacking positions for containers plays a critical role on the performance of a container terminal, since it influences the productivity of the terminal in a strong sense. In this study, we focus on the minimization of the berthing time of vessels by improving the stacking operations through minimization of non-value-added handling operations of containers, which is called reshuffling, as well as the traveling time of the cranes operating at the storage yard. Most of the containers in the container terminal we focus are outbound, which are transported into the container terminal via external trucks and stored in the stacking yard until they are loaded onto vessels. We propose a reward-based algorithm for the stacking of outbound containers by taking the following four components into consideration; container's distance to the closest RTGC, RTGC's workload, the number of stacked containers at the neighborhood bays, and the current height of the stacks at the storage yard. The inputs of the algorithm include the relevant information of the container to be stacked that are just entered into the terminal gate, current usage information of the storage yard and the current positions of the yard cranes. The proposed stacking strategy is in implementation phase to one of the container terminals in Izmir. The results seem to be promising when compared to the current randomized stacking strategy in the container terminal.

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Keywords: Container terminals; Container stacking; Reshuffling; Reward-based algorithm.

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1. Introduction

With over 80% of world merchandise trade being carried by sea, maritime transport is the backbone of international trade and globalization (UNCTAD, 2015). Containerization, where the transportation of freight is achieved in standardized boxes with high level safety and environmental concerns, is the main driver for global intermodal freight transport. Moreover, container shipping has changed the scale and scope of the global trade by providing transportation of greater quantity of commodity with a similar amount of time at a lower cost by improving the transshipment process (Rodrigue and Notteboom, 2015). Transshipment is the activity of shipping goods to and from certain intermediate points before reaching their final destination and has been playing a significant role in international sea freight transport over the past few decades (Vis and de Koster, 2003). Due to the rapid incline of the global trade, container transshipment activities increase rapidly. Hence, high competition among container terminals has emerged. Container terminals are the nodes where different modalities meet to transport containers. Hence, container terminals are the keys to the performance of sea freight transport, a call for efficient management of port operations is required in order to remain competitive (Tao and Lee, 2015).

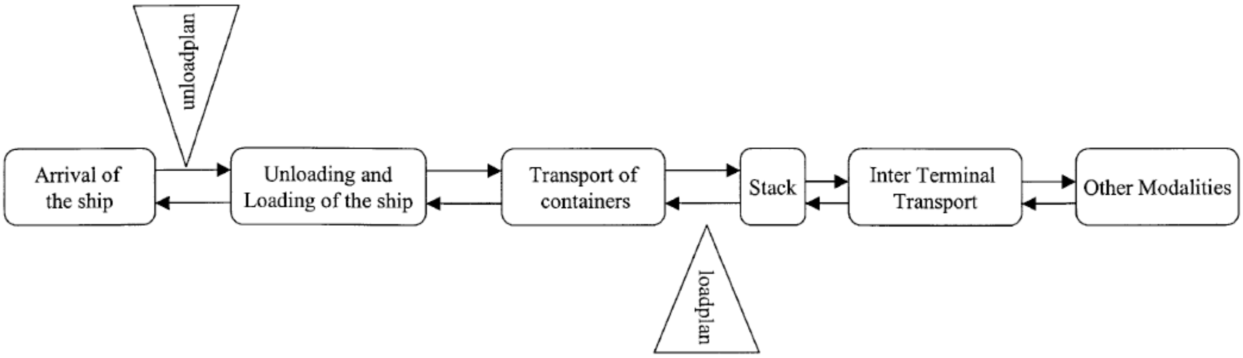

Fig. 1. Processes at a container terminal (Vis and de Koster, 2003).

Based on container handling operations, a container terminal can be partitioned into two main areas, the quayside and the storage yard. Operations at the quayside are triggered with the berthing of vessels. Quay cranes (QCs) are used to discharge inbound (I/B) and transit containers from and to load outbound (O/B) and transit containers to the vessels. Simultaneously, various activities at the storage yard take place in order to transfer the containers from/to vessels. In addition to the quayside operations, several complex activities of container terminals take place in container storage yards, where containers are stored temporarily after they are discharged from vessels, or before they are loaded onto vessels. The sub-processes at a container terminal are depicted in Figure 1.

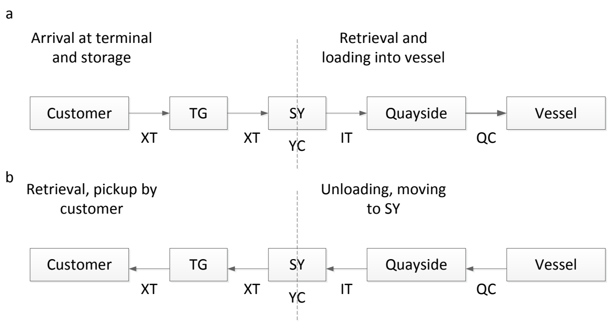

Fig. 2. (a) The flow of outbound containers; (b) The flow of inbound containers (Murty et al., 2005).

Moreover, the flows of O/B and I/B containers are illustrated in Figure 2(a) and 2(b), respectively. O/B containers are carried by the customers' external trucks (XTs) and enter into the terminal through the terminal gatehouse (TG). After being informed about the location at the storage yard (SY) by TG, XT carries the container to there. The container will be stored at that location until the vessel into which it will be loaded arrives. The yard cranes (YC) perform the storage operation, i.e., the YC removes the container from XT and puts it in the storage location. When the vessel into which the container will be loaded arrives, the loading process starts. At that time, YC retrieves the container from its stored position, puts on top of the internal truck (IT) with which the container will be transported to the quayside. Finally, the QCs perform the loading operation of the containers into the vessel. It can be concluded that, the flow of I/B containers are the same operations with the O/B containers, however, the direction of flow is reversed.

Generally, a container terminal is visited by two types of vessels, mother vessels carrying large shipments, and feeder vessels carrying small ones. There are various performance indicators of a container terminal. The two most common indicators that measure the performance are listed as the average vessel berthing time and the (average) throughput of QCs.

The first performance indicator is a measure of the service of container terminal to ship liners (customers). Minimizing berthing time plays a critical role for the newly developing container terminals, and may create an opportunity to enhance the port's customer portfolio. On the other hand, maximizing the throughput of QCs will increase the productivity of a container terminal. These two performance indicators are interrelated with each other. In addition to these common performance indicators, the turnaround times of XTs or the travelling distances of ITs can also be utilized to measure the performance of a container terminal (Zhang et al, 2003).

Although operations at container terminals take place in two main areas, managing the activities performed on these areas should not be underestimated. Every activity performed on either the quayside or the storage yard affect the other activities' performances. On the other hand, optimizing an activity at the container terminal may not become sufficient to improve the performance indicator(s) of the container terminal only. The common problems in container terminals are classified by Rashidi and Tsang, (2013) (see Fig 3).

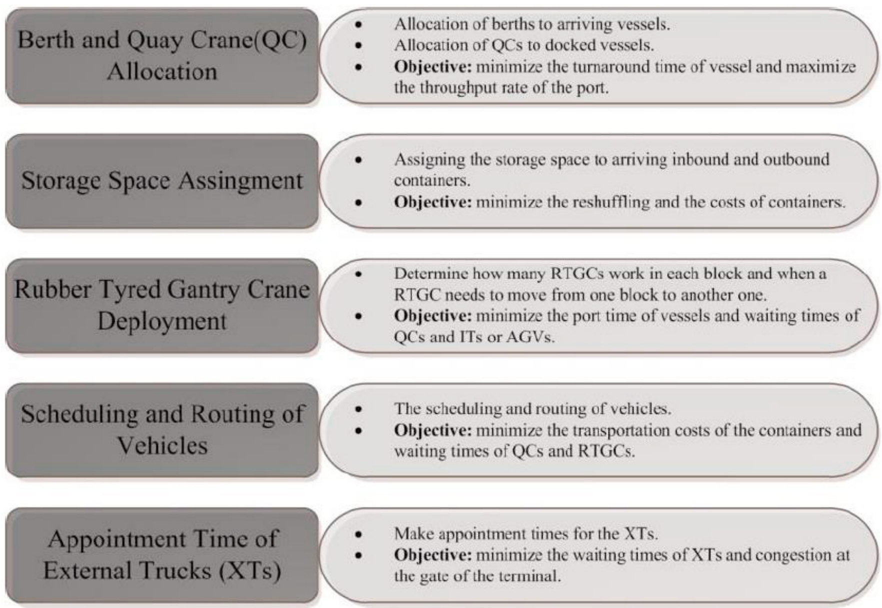

Fig. 3. Decision problems in container terminals (Rashidi and Tsang, 2013).

These five core problems reflect the main operations at a container terminal. Each problem has an independent objective, and one problem is the predecessor(s) of the other problem(s), i.e., all of them are interrelated (Zhang et al, 2003). Although there are minor examples that try to consider combinations these problems as integrated, every problem stated above is hard to optimize even by itself, due to its complex nature. For many years, several activities at the container terminals are studied in the literature. Vis and de Koster (2003), Steenken et al. (2004) and Stahlbock and Voß (2008) provide comprehensive literature reviews related with the operations at the container terminals.

In this study, we concentrate on the storage space allocation problem at the storage yard, and our aim is to find the best stacking position for containers using a reward-based algorithm. There are studies in the literature concentrated on the storage space allocation problems at container terminals. For instance, several studies focus on shortening the transportation distances of ITs between the yard and the berth by deciding storage space locations for the containers (MK Li, 2015). On the other hand, Kim (1997) works on different strategies for storage space allocation, and focus on minimizing the number of rehandles of the bay.

Güven and Türsel Eliiyi (2014) propose two dynamic stacking strategies for O/B, I/B and transit containers, and conduct their experimentation using the real data of a container terminal through simulation. They test the performances of their stacking strategies under various scenarios, and conclude that transit containers should be stacked as close to the transfer point quayside as possible, whereas I/B containers should be placed as close to the transfer point landside as possible.

Park et al. (2011) work on the stacking problem by determining the stacking positions of the containers transported to the storage yard of an automated container terminal (ACT). They notice that the optimal stacking policies for the conventional terminals cannot be applied to the ACT, since the operational characteristics of ACTs are quite different. They propose an online search algorithm for the purpose. In their work, the stacking position is determined in two hierarchical steps. In the first step, a block is selected, and then a stack is selected to locate the container on its top. During the selection, the efficiency of the stacking crane and the space utilization are considered.

Zhang et al. (2003) study the storage space allocation problem where I/B, O/B and transit containers are mixed in the blocks in the storage yard. They propose a rolling-horizon approach and a two-level solution method to solve this problem. For each planning horizon, the problem is decomposed into two levels, and each level is formulated as a mathematical programming model. Furthermore, each level has a different objective. At the first level, the aim is to balance the workloads among blocks in each period. The second level addresses to minimize the total distance to transport the containers between their blocks and the quayside.

Wan et al. (2009) consider the storage space allocation problem, and formulate it as an integer program. Furthermore, they extend the three heuristics used in the literature that were formerly used for the static version of the problem. With the heuristic they come up with, they try to minimize the total number of reshuffles. Their computational results indicate that the developed heuristic achieve the best performance, and outperform the heuristics used in the literature.

Preston and Kozan (2001) formulate a MILP container location model to determine the optimal container storage strategy for the I/B, O/B and transit containers with the objective of the minimization of the vessel's berthing time. Moreover, they propose a Genetic Algorithm (GA) and test the performances of their algorithm for different schedules of container handling (random, first-come-first-served, last-come-first-served). They claim that the type of schedule has no effect on transfer time if a good storage layout is used. Kim and Park (2003) construct a basic MIP-model and a dynamic space allocation method to place the export containers with the aim of increasing the storage space and loading operations' efficiency.

MK Li (2015) focus on planning the storage yard. Hence, by placing the export containers to the appropriate locations, they target to decrease the container handling time as well as increase yard space utilization. They introduce a hierarchical solution procedure and decompose the problem into two stages. Every stage is formulated as an IP. At the first stage, the IP model optimizes the workload distribution in the storage yard. On the next stage, effective yard templates are formulated.

Zhao et al. (2015) present a simulation-based optimization algorithm for the storage allocation of the O/B containers in the automated container terminals. They utilize Timed-Colored-Petri-Net method in order to get the average QC waiting time. Moreover, GA and Particle Swarm Optimization (PSO) are presented. The performances of these two algorithms are reported. They conclude that PSO performs better than GA with respect to solution quality; however, GA converges faster than PSO.

The rest of this paper is organized as follows. Section 2 defines the problem and Section 3 presents our container stacking strategies. Section 4 includes conclusions and future research directions.

2. Problem Definition

In this study, we concentrate on the storage space allocation problem at the yard, and our aim is to find the best stacking position for containers using a reward-based algorithm. The storage yard of a container terminal is divided into large areas called blocks. The smallest storage unit is a slot for one container, slots of containers are stacked one on top of another to form a column, and columns are put together to form stacks. A block is generated when a number of stacks are put together. Slots of the same level in a block form a tier. Columns tailing one another in a block form a lane. In general, the triplet (lane, stack, tier) defines the (x,y,z) coordinates of a container (Wan et al, 2009) (see Fig. 4). Rubber tire gantry cranes (RTGCs) are used as the YCs in each block. In this study, the main assumption is that an RTGC serves for one block only, however, there are more than one RTGCs used in some blocks. Figure 5 visualizes a storage yard where there are more than one RTGCs serving in each block.

In many container terminals, the storage units of the containers are well defined, and the real-time status of every slot is recorded and monitored in the information management system of the container terminal. In order to optimize the storage decisions of the containers, this up-to-date status information is required as input (Wan et al, 2009).

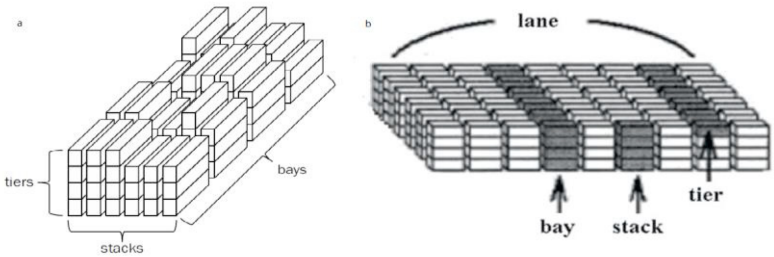

Fig. 4. (a) Illustration of a block in the storage yard; (b) Illustration of a lane in the storage yard (Güven and Eliiyi, 2013)

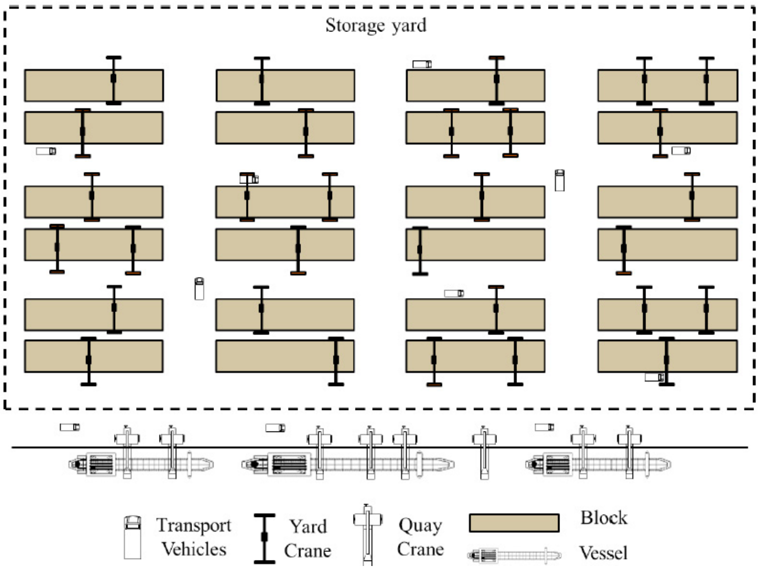

Fig. 5. General picture of a storage yard (Zen et al., 2013).

We concentrate on the storage space allocation problem, and try to determine the stacking positions for O/B containers in the storage yard of a container terminal in Izmir. The number of stacks put together is determined by the layout of the storage yard and it is assumed to be at most 35. The container terminal examined in this study is export-oriented and the containers are monitored in real-time. Hence, its storage yard is mostly used by the outbound and transit containers. As explained in the previous section in general, the flow of an outbound and a transit container within the terminal differs. The outbound containers are usually carried by XTs to the terminal, and then they are stored at suitable slots in the storage yard. For outbound containers of the same destination and of similar weight and size, storage locations on vessels are interchangeable. Transit containers are firstly unloaded from a vessel, transported to the storage yard via ITs. Afterwards, they are located into the storage yard. When a vessel arrives, the loading activity is triggered. According to the stowage plan, the container loading activity is performed. Similar to the outbound containers, for the transit containers of the same destination, similar weight, size, and type their storage locations on vessels are interchangeable. On the other hand, whenever a stack becomes empty, it may be used to store any type of containers. There is no buffer area before the entrance gate of the container terminal.

When an XT arrives, the outbound container is located directly to the storage yard in an available location. Likewise, transit containers are placed without considering their Expected Departure Times (EDTs), Port of Destinations (PODs) or estimated workloads at RTGCs. When accessing a target container that is below some other containers in the stack, the top containers should be rehandled; this non-value-added operation is called as reshuffling. Hence, the number of reshuffling activity influences the performance of the container terminal negatively, yielding a decline of the terminal's productivity. Therefore, while determining the stacking positions of the outbound and transit containers, the objective of the problem is defined as to minimize both the total time spent for reshuffling and transportation of the containers and decrease the vessel berthing time implicitly. Determining the stacking position of each container is called as the Container Stacking Problem (CSP) and should be handled properly. The next section defines the proposed reward-based stacking algorithm for the O/B containers.

3. Reward-based Stacking Algorithm

Container stacking policies are the solution algorithms that used to determine the storage location of each individual container, with the consideration of several operational limitations.

The proposed reward-based algorithm measures the total score of a stacking position by calculating the weighted sum of the evaluation values of these criteria. The four main criteria are listed as:

1. Container's distance to the closest RTGC
2. RTGC's workload, considering the weights of the containers handled (within the last operating hour)
3. Number of stacked containers at the neighborhood bays
4. Current height of the stacks

The pseudocode of the algorithm is as follows:

<u>Step 0:</u> The inputs of the algorithm should be entered into the system.

- The relevant information of container i to be stacked that enters into the TG.
  - Type: 20 or 40 feet, dry
  - Weight: Heavy, Medium or Light
  - Vessel to be loaded
  - EDT information
  - POD information
- Current usage information of the storage yard.
- Current positions of the RTGCs on each block.
- Estimated unit handling and movement times of the RTGCs.
- Estimated reshuffling times of each container stacked below.

Step 1: Initialize the values of MAXSCORE as 0 and MAXPOSITION as 0.

Step 2: For every available location j of the container i, calculate the total weighted score where weights are $w_1, w_2, w_3,$ and w_4. The weighted score is denoted by $\mathrm{SCORE}(i,j)$:

$$\mathrm{SCORE}(i,j) = w_1 \mathrm{RTGC\_DIST\_SCORE}(i,j) + w_2 \mathrm{RTGC\_WORKLOAD\_SCORE}(i,j) + w_3 \mathrm{NEIGHBORHOOD\_STACK\_SCORE}(i,j) + w_4 \mathrm{STACK\_HEIGHT\_SCORE}(i,j) \quad (1)$$

$\mathrm{RTGDist} \doteq$ the distance between the current position of RTGC and the candidate location j

Hence, $$\mathrm{RTGC\_DIST\_SCORE}(i,j) = 100 - (2 \bullet \mathrm{RTGDist}) \quad (2)$$

$C_h \doteq$ the number of heavy containers handled by the corresponding RTGC within last one hour.
$C_m \doteq$ the number of medium-weighted containers handled by the corresponding RTGC within last one hour.
$C_l \doteq$ the number of light containers handled by the corresponding RTGC within last one hour.

$$\mathrm{RTGC\_WORKLOAD\_SCORE}(i,j) = (q^1 C_h) + (q^2 C_m) + q^3 C_l \quad (3)$$

$$\mathrm{NEIGHBOR\_ROW}(j) = \begin{cases} 1, & \text{if there is at least one fully loaded stack in the next row of position } j \\ 0, & \text{otherwise.} \end{cases}$$

$$\mathrm{NEIGHBOR\_BAY}(j) = \begin{cases} 1, & \text{if there is at least one fully loaded stack in the next bay of position } j \\ 0, & \text{otherwise.} \end{cases}$$

$$\mathrm{NEIGHBORHOOD\_STACK\_SCORE}(i,j) = s_1 \text{ if, } \mathrm{NEIGHBOR\_ROW}(j) = \mathrm{NEIGHBOR\_BAY}(j) = 1. \quad (4)$$

$$\mathrm{NEIGHBORHOOD\_STACK\_SCORE}(i,j) = s_2 \text{ if, } \mathrm{NEIGHBOR\_ROW}(j) = 0, \text{ and } \mathrm{NEIGHBOR\_BAY}(j) = 1. \quad (5)$$

$$\mathrm{NEIGHBORHOOD\_STACK\_SCORE}(i,j) = s_3 \text{ if, } \mathrm{NEIGHBOR\_ROW}(j) = \mathrm{NEIGHBOR\_BAY}(j) = 0. \quad (6)$$

$H(j) \doteq$ the current number of containers stacked at position j.

$$\mathrm{STACK\_HEIGHT\_SCORE}(i,j) = 25(S - H(j)) \quad (7)$$

The first component in equation (1) is $\mathrm{RTGC\_DIST\_SCORE}(i,j)$, and as shown in (2), it calculates container $i's$ distance to the closest RTGC. The parameter $\mathrm{RTGDist}$ is defined to indicate the distance between the current position of RTGC and candidate location j. A perfect score of 100 is obtained when RTGC's current position is the same as candidate location j, since the corresponding $\mathrm{RTGDist}$ is then zero. If the distance between the RTGC's current position and the candidate location is one bay, the $\mathrm{RTGC\_DIST\_SCORE}(i,j)$ equals to 98. The scores for other distance values are similarly calculated. This criterion tries to minimize the transportation time of the container.

The second component in (1) defines the current workload of the RTGC within the last working hour, and focuses on balancing the workload of the RTGCs, as shown in equation (3). A queue may occur at a block if the requests for retrieving containers to the blocks are distributed in an imbalanced manner. An imbalanced load distribution on the RTGCs causes delays at the overloaded blocks, thus decreasing the productivity of both the storage yard and the container terminal (Park et al., 2011).

We assume that the time spent on an RTGC differs based on the weight of the container. Hence, the time for retrieving a heavy or a light container using an RTGC are not the same. We take the retrieval time for the light containers as a base q^3, and estimate the durations for the medium-weighted and heavy containers by assuming that it takes more than the light containers. The parameters q^1, q^2 and q^3 represent the weighted durations for the containers and we assume $q^3 < q^2 < q^1$. In addition, to calculate the total score due to RTGC workload, we define parameters C_h, C_m, and C_l as the number of heavy, medium-weighted and light containers that the corresponding RTGC handled within the last hour, and multiply them with their estimated weighted durations. The corresponding equation is shown in (3).

The third criterion serves for both the minimization of the total time spent for reshuffling, and for transportation distance of the RTGC. The parameters $\text{NEIGHBOR\_ROW}(j)$ and $\text{NEIGHBOR\_BAY}(j)$ are defined to indicate whether the neighbor rows and bays of the candidate position j are fully stacked or not. As indicated in equations (4), (5) and (6), the third criterion can take three alternative values based on the corresponding values of $\text{NEIGHBOR\_ROW}(j)$ and $\text{NEIGHBOR\_BAY}(j)$: If there is at least one fully stacked row and bay, the best score is achieved, as s_1. If $\text{NEIGHBOR\_ROW}(j) = 0$ but $\text{NEIGHBOR\_BAY}(j) = 1$, the score gathered is s_2. If both of the parameter values are zero, the total score will be s_3, and we assume $s_3 = 0$, and $s_3 < s_2 < s_1$. As a result of this score, the positioning of the incoming containers will be as closely packed as possible, yielding minimum transportation distance for the RTGC. As fully empty stacks will not be preferred, close packing of containers will also lead to the minimization of reshuffling. In this study, the maximum number of stacked container is stated as $S = 5$.

Reshuffling is also minimized with the last criterion stated in equation (7). With this criterion, the height of the stack at position j is taken into consideration. For example, if there is no container on a stack, i.e. $H(j) = 0$, then locating a container to that slot is highly preferred. Conversely, if there are already stacked containers, placing the container on top of that stack may yield reshuffling during the retrieval of a container located at the rows below, hence, this situation is least preferred.

Using the main inputs as the size, weight, type, ship liner, EDT and POD of a container, and considering the current layout of the storage yard and the current coordinates of the RTGCs; the reward of each candidate location is calculated and then, the incoming container i is placed into location j having the maximum reward. Note that, determining the weights of each component is highly crucial and affects the performance of the algorithm.

Due to unexpected delays on the implementation phase of the algorithm to the container terminal, we cannot report the performance of the proposed algorithm. However, initial runs indicate that the results are very promising when compared to the current stacking strategy in the container terminal, i.e., random stacking. In this strategy, the container terminal finds a position for a container that enters into the TG in a random manner. In this case, a candidate position is found when a selected random stack is not full, and the containers in that stack are of the same type as the candidate container. Otherwise, a new random stack is considered.

4. Conclusion and Future Work

We propose a reward-based algorithm to determine the best location for each outbound container. In this algorithm, we measure the reward by taking the weighted sum of these four criteria; container's distance to the closest RTGC, RTGC's workload, number of stacked containers at the neighborhood bays, and current height of the stacks at the storage yard. We believe that our proposed algorithm will minimize the reshuffling and the total travel time of the RTGCs, which lead to significant reductions on the berthing time of vessels. Furthermore, as the complexity of our proposed algorithm is very low, the initial runs indicate that the run time performance is very high, which greatly increases the applicability of the proposed algorithm.

As a future work, we plan to develop various strategies for the inbound and transit containers, as well. Another research area is to define additional components for the algorithm to include the movements of the internal trucks and traffic congestion within the terminal.

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