Trip allocation and stacking policies at a container terminal

Ceyhun Güven\textsuperscript{a}, Deniz Türsel Eliyi\textsuperscript{b,*}

\textsuperscript{a}Bimar Information Technology Services S.A., Izmir 35430, Turkey
\textsuperscript{b}Yasar University, Department of Industrial Engineering, Izmir 35100, Turkey

Abstract

There are three crucial resources at container terminals; the yard, cranes and the vehicles. The main objective of the terminal is the efficient use of these resources while performing different operations. The yard is a temporary storage area where containers remain until transported to their next location by truck, train or vessel. Containers are stacked on top of each other in order to utilize the yard space efficiently. However, stacking cranes can only directly access those containers at the top of the stack. As a result, reshuffling/shifting occurs, defined as an unproductive move of a container required to access another container stored underneath. We focus on increasing the efficiency of the yard via consideration of the container stacking optimization problem for transshipment, inbound and outbound containers at a container terminal. The objective of the problem is to minimize container storage and retrieval times through avoidance of reshuffles, resulting in more efficient loading/unloading operations, and in turn minimizing the dwell time of containers. The main inputs are the type, weight, discharge port/location, destined vessel/vehicle of the container, and the expected departure time. Different stacking policies are proposed in this study, and we also investigate the problem of allocating the transit container to outbound vessels to minimize dwell time at the terminal. Transit containers require multiple sea-trips to reach their final destination. Vessels departing from the terminal and destined for the same port may provide exchangeable trips for this type of container, based on their several attributes and capacity restrictions. We consider this problem taking into account several factors that affect container/trip allocation decisions. The solution of this problem also has implications for the stacking problem.

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* Corresponding author. Tel.: +90-232-411-5697; fax: +90-232-374-5474.
E-mail address: deniz.eliyi@yasar.edu.tr
1. Introduction

Maritime transportation is a favored mode of transportation, in which the goods are usually carried by containers. A container is a standardized load unit, which is also suitable for road and rail transportation. Use of containers reduces the amount of product packaging and possibility of damage. Therefore, this mode of transportation has increased remarkably over the last few decades (Steenken et al., 2004).

A container terminal is an interim storage area, where container vessels dock on berths, unload inbound containers and load outbound containers. Terminals include storage yards for temporary storage of the incoming containers. Figure 1 illustrates a schematic representation of typical operations and equipment in container terminals, including quay cranes for loading and unloading of the docked vessels, trucks and trailers for carrying containers within the terminal area, and rubber mounted gantry cranes (RMG) for stacking containers in the storage yard.

![Schematic representation of a container terminal](image)

As a result of a dramatic increase in the usage of containers, the number of and competition between container terminals is increasing. The operations in the leading world container ports cannot be carried out in an efficient manner without the use of appropriate scientific methods. Therefore, the use of operations research tools and techniques became crucial in container ports for sustaining efficient operations and compatibility.

Rashidi and Tsang (2013) categorized the problems in container terminals as in Figure 2. According to their classification, there are five main operations that affect their efficiency.

![Decision problems in container terminals](image)
In this study, we focus on the storage space assignment category and study the problem of determining the stacking positions for import, export and transit containers in the storage yard of a container terminal. In the yard, containers are usually stored in multiple-level stacks for efficient usage of the area. When accessing a target container that is under other containers in the stack, a reshuffling operation of the top containers is needed. A reshuffling move (also called as re-handling or shifting) is therefore defined as an unproductive move of a container during stacking or retrieving operations. These moves have a negative effect on the operational efficiency of the container terminal in terms of cranes and operators’ workloads. Therefore, while determining the stacking positions of the containers, the objective of the problem is defined as to minimize both the total reshuffling and transportation cost of containers.

There are many studies in the literature on different aspects of container terminal operations. Steenken et al. (2004) studied the main logistics operations at container terminals. They provided a wide-ranging review of methods for the optimization of these operations. In this study, the operations at a container terminal were classified as berth allocation, stowage planning, crane scheduling, terminal transport optimization, and storage and stacking logistics by the authors, where storage logistics were examined under two classes: storage (yard) planning and scattered stacking. In the storage planning, the location of each container in the storage yard was allocated and reserved before the vessel arrival. The reservation for containers could be based on discharge port, container type and container weight, depending on the stacking strategy. On the other hand, in scattered stacking, a container’s location was not determined before the vessel’s arrival. Instead, the storage location was determined in real time and after the vessel berthed. In a later study, Stahlbock and Voss (2008) concentrated on container terminal operations as an extension of the earlier review by Steenken et al. (2004).

Castilho and Daganzo (1993) focused on import container operations at marine terminals. Stack heights and stacking strategy were influential in the efficient retrieval of containers from stacks. They considered two strategies: the first aimed to keep all stacks at an equal height, while the second segregated containers according to arrival times. The height and the width of a bay were the significant variables that influenced the expected number of reshuffles needed to retrieve a container. Kim (1997) studied different stack configurations and estimated the expected number of reshuffles needed to retrieve a random container from the stack, and the total expected number of reshuffles to retrieve all the containers from the bay. Kim and Kim (1998) developed a cost model to determine the optimal amount of storage space and the optimal number of transfer cranes for import containers. The space cost, the fixed cost of transfer cranes, the variable cost of transfer cranes and outside truck costs were considered in their model. A later study by Kim and Kim (1999) concentrated on the allocation of storage space for import containers using a segregation strategy. Stacking newly arrived containers on the top of containers that arrived earlier was not allowed in the segregation strategy. Storage locations were allocated for each arriving vessel in order to minimize the expected number of re-handles. Vessel arrivals, i.e. the arrivals of the import containers were assumed to be constant, cyclic, or dynamic. Each case was analyzed and appropriate solution methods were suggested.

Chen et al. (2000) provided an empirical study on yard operations at a Taiwanese container terminal. They quantified unproductive movements of containers undertaken in quay transfer operations for both discharge and loading operations. The number of shift moves was examined for each factor, i.e., the storage density, the volume of containers loaded and the volume of containers discharged. Decision rules for the location of export containers based on weight were derived by Kim et al. (2000). The weight distribution of containers was assumed to be known, and dynamic programming was used to determine the storage location of export containers in order to minimize the expected number of relocation movements for the loading operation of containers.

Stacking policies for containers in automated container terminals were simulated by Dekker et al. (2006). Different category stacking policies for containers were simulated and compared with a base case, in which the containers were stacked randomly. In category stacking, containers of the same category (e.g., weight class, destination, type of containers) were assumed to be interchangeable, and could be stacked on top of each other. Category stacking was found to have a much better performance than random stacking. They also took into account extra factors such as considering the workload of each automated stacking crane, horizontal distance travelled in the terminal, preference for ground locations, in order to increase the performance of the system. Similarly, Duinkerken et al. (2001) developed simulation model on stacking policies for automated container terminals. The model of a quay transport system using automated guided vehicles (AGVs) was integrated into the container stacking area. During simulation, re-stacking or re-handling was necessary if one or more container was on the top of the desired
Two methods of restacking were considered: In proactive stacking, operation occurred when the stacking crane was idle, which in turn could reduce the stack response time. On the other hand, in reactive re-stacking, the operation occurred at the time that the lower container is needed to be retrieved. Four different stacking policies were developed in the simulation model, these were named as follows: random, leveling, closest position, and maximum remaining stack capacity (RSC). Saanen and Dekker (2006a, b) aimed to identify a set of rules to use stacking space more efficiently without incurring an increase in costs per move or a decrease in performance. For this purpose, a reference case was set and alternative cases were suggested. They considered a container terminal with Rubber-Tyred Gantry (RTG) Cranes, and by simulating each movement of the trucks and RTGs. They developed a simulation model based on stacking algorithms and were able to make comparisons between stacking strategies.

The rest of this paper is organized as follows. Section 2 defines the problem and Section 3 presents our dynamic container stacking strategies. In Section 4, we discuss our results and conclusions.

2. Problem Definition

Container terminals are places where containers are temporarily stored and transshipped. When a vessel arrives at the container terminal, it moors to the berth and quay cranes (QCs) are allocated to the berths to unload import containers and loading export containers. Then, containers are transported from berths to the storage area by trucks or other vehicles. If the container is stacked as close to as possible the transfer point, the traveled distance and time of the truck is minimized, which in turn decreases the turnaround time of a vessel, which is an important performance measure for container terminals. Once a container arrives at its stacking lane in the storage area, the stacking crane lifts the container from the truck and stacks it to the storage position. When necessary, these cranes are used to re-stack the containers. Containers are temporarily stored at their storage positions until their departure time. As a result of the rapid increase in the number of containers and the container traffic around the world, expectations on the efficient usage of the storage space, which has become a scarce resource, have increased considerably.

A container’s position in the yard is then denoted by its lane, bay, stack and tier identifiers. A lane is defined by its bays (length) and stacks (width). Stacking yards are usually divided into multiple lanes, each consisting of a number of bays. A bay is composed of several stacks of a certain size which called tier, and holds containers of the same size. A bay is composed of several stacks of a certain size, which are called tiers which hold container of equal size. These definitions are illustrated in Figure 3. A storage position should be assigned to each container arriving at the container terminal, and the minimum number of reshuffles is aimed while getting the container from its assigned location at its departure time. The assignment decision is based on various parameters like the container’s destination, its arrival and departure time, as well as the owner of the container and the transporting company. This problem is called as the Container Stacking Problem (CSP), which is one of the most common and important problems at container terminals.

Fig. 3. Illustration of a lane in the stacking yard (Source: Kim and Günther, 2006).
A schematic overview of the container terminal considered in this study is provided in Figure 4. There are 24 lanes, each equipped with a single automated stacking crane (ASC). Automated Stacking Crane is used for stacking and removing containers at the storage yard. As it can be seen from the figure, lanes can be either horizontal or vertical to the waterfront. One bay of a lane consists of 7 stacks, and each lane consists of 20 bays. Maximum stacking height is assumed as 4 containers. Thus, the theoretical container capacity of the yard is 24 x 20 x 7 x 4 = 13,440 TEUs (twenty-feet-equivalent units), which correspond to 13,440 standard 20-feet containers. Import, export and transit containers are not separated into different lanes to increase yard utilization. We propose stacking strategies for import, export and transit containers in the following section.

![Fig. 4. Schematic overview of the container terminal.](image)

### 3. Dynamic Container Stacking Strategies

Dynamic container strategies with a number of stacking rules are presented in this section. Container stacking strategies are solution algorithms used to determine the storage position of each individual container, considering several operational constraints. In other words, stacking strategies are used to decide where to store newly arrived containers. We assume that the incoming containers belong to one of two types, namely 20-feet and 40-feet. A 20-feet container occupies 1 TEU in the storage area, while a 40-feet container occupies 2 TEUs. Containers of different sizes cannot be stacked on top of each other and cannot be stacked in the same bay due to physical restrictions and to prevent possible damage. Yard Terminal Trucks (YTTs) transport the containers from the berths and land transfer points to the lanes and vice versa. The number of YTTs is assumed to be sufficient for transportation of containers in the terminal area. The number of YTTs is assumed to be sufficient to cope with the transportation of the containers in the terminal area.

#### 3.1. Strategy 1

In this strategy, we present a simplistic random stacking algorithm to be used as a benchmark. The algorithm finds a position for an arriving container by randomly selecting a new lane, bay and stack. If the stack is not full, and the containers in the stack are of the same type as the arriving container, then an acceptable position has been found and the container can be placed in this stack. Else, a new random stack is considered.
The steps of the random stacking algorithm are:

1. Select a random position (lane, bay, and stack)
2. Check whether or not the selected bay type is the same as the arriving container’s type (20 or 40 feet).
   a. If selected bay type ≠ type of the arriving container, it cannot be placed in this stack. Return to Step 1.
   b. If selected bay type = type of the arriving container, check whether or not the selected stack is full.
      i. If full, return to Step 1.
      ii. If not full, stack the arriving container in this position.

3.2. Strategy 2

In this strategy, we consider several attributes of the containers while determining a stacking position. The first attribute is the expected departure time (EDT), which is defined as the time when a container will be removed from the stack to leave the terminal by a vessel, truck or train. Secondly, the category of each container is considered. Categories differ depending on the type of container. While the category of a transit container or an export container is defined as its destined vessel, for import containers it is defined as the owner company of the container. The port of destination (POD) sequence is also considered while stacking transit or export containers of the same vessel, as it affects the order in which the containers are loaded onto the vessel. A container that will be discharged in the first POD of the sequence needs to be loaded last onto the vessel. We also consider the weight of the containers as another attribute, and define an operational constraint that allows stacking containers on top of each other only if the weight range of the stack remains below 3 tons. This constraint is dictated by the port authorities.

According to the above considerations, for avoiding any reshuffling, note that an arriving container should be placed on top of a non-empty stack if it is of the same category, its POD order is less than the POD order of the containers already in the stack, and its weight does not violate the 3-ton constraint for the stack. Based on this idea, we define the following algorithm to determine the storage position of each arriving export, transit or import container.

Algorithm for determining storage position of containers:

1. Get the relevant information of the container: Container type (20 or 40 feet, export, transit or import), category (vessel), weight, EDT, and POD (if export or transit).
2. Check each bay of matching container type in order, in ascending order and check whether selected bay is empty or not.
   a. If empty, place the arriving container to the first tier of the first stack in ascending order.
   b. If not empty, check each stack in order in ascending order of the selected bay for empty positions.
      i. If stack empty, place the arriving container in this stack.
      ii. If not empty, check whether category of the arriving container is the same as the category of the containers in the stack, or not.
         1. If category is same, check if the POD order of the topmost container of the stack is greater than or equal to the POD order of the container, if available (in case the container is transit or export).
            a. If yes, or if POD is not available (if the container is import), check for the 3-ton constraint.
               i. If satisfied, place the container in this stack.
               ii. If violated, return Step 2.b to check another stack of the selected bay.
            b. If no, return Step 2.b.
         2. If category is not same, check whether EDT of the newly arrived container is before than or equal to EDT of the topmost container of the stack or not.
            a. If yes, check for the 3-ton constraint.
               i. If satisfied, place the container in this stack.
               ii. If violated, return Step 2.b to check another stack of the selected bay.
            b. If no, return Step 2.b.
4. Results

As a pilot study, a simulation model with the above scenarios has been executed for approximately one thousand containers’ arrival and departure data. The data include container ID, arrival time, weight and type, vessel, EDT, and POD information of the container (if export or transit), owner company of the container (if import).

To be used in the pilot study, real data is gathered for the Port of Izmir, Turkey, from Bimar Information Technology Services S.A. The data set, as summarized in Table 1, contains 6 vessels and 1109 (included 227 warm-up period containers) containers that will arrive and depart from the terminal by a vessel, truck or train, corresponding to approximately three weeks duration. The simulation model is run for all incoming containers. The storage position of each container can only be determined after it arrives at the terminal. A warm-up period is also used to build up the initial conditions of the storage yard by assuming 227 containers’ arrival. These containers are assumed to be stacked on the storage area and remain until their departure time.

The model is coded with the C# programming language on a Microsoft Visual Studio 2013 platform. The developed program has a user-friendly interface that indicates information about the stored container by visually illustrating the storage yard. The pilot simulation is executed on a Core 2 Duo 3.4 GHz Win7 PC with 8-GB memory.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Port of Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
</tr>
</tbody>
</table>

The results of the pilot study are summarized in Table 2, comparing the two strategies in terms of four performance measures. First of all, the number of ground locations used for containers to be stacked is considered. Both strategy 1 and strategy 2 use same number of ground locations to place the containers, although the exact storage places may be different.

<table>
<thead>
<tr>
<th></th>
<th>Strategy 1</th>
<th>Strategy 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used Ground Locations</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Number of reshuffles</td>
<td>745</td>
<td>39</td>
</tr>
<tr>
<td>Number of reshuffle occasions</td>
<td>484</td>
<td>21</td>
</tr>
<tr>
<td>Can add new container?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

As expected, Policy 2 outperforms random stacking in terms of the number of reshuffles performed. The average number of reshuffling moves decreases by approximately 95% when policy 2 is performed. This result is expected as policy 2 seeks to minimize the number of reshuffles. In the simulation model, reshuffling moves are defined as unproductive moves when a container is to be removed from the stack. For instance, if the crane should reach container A, above which there is another container (B) in the stack, first container B is removed and temporarily put on another stack, then A is removed from the stack, and then B is put back to the top of its original stack. In this example, 2 reshuffling moves are made for handling container A. Obviously, the number of reshuffling increases if there are more containers on top of container A.
The next measure counts the events of reshuffling rather than moves. A reshuffle occasion is said to happen when one or more reshuffling moves are required to retrieve a container from the stack. Note that for the above example, number of reshuffling occasions is counted as 1, disregarding how many containers are on top of container A. It can be observed from the tables that Policy 2 performs better than random stacking in terms of the total number of reshuffle occasions, as this measure drops by approximately 95% on average when policy 2 is used.

As a last measure, we check whether the arriving container can be stacked in the storage yard, without the need of adding extra temporary stacking positions. The last row of the table indicates that there are no problems in finding a suitable position for the incoming containers for both of the strategies, i.e. there is an empty position in the yard whenever a container arrives. In the further stages of the experiment, as the problem size grows, there may be some problems in finding a space for an arriving container. In such a case, new temporary stacking spaces are formed by the model in appropriate areas of the yard, which is in line with the current practice of the port.

5. Assignment of Transit Containers to Trips

In addition to determining the storage positions of the import, export and transit containers, we investigate the problem of allocating the transit containers to outbound vessels in order to minimize dwell time, which is the time that a container remains at the container terminal. Transit containers require multiple sea-trips to reach their final destination. Vessels departing from the terminal and destined for the same port may provide exchangeable trips for this type of containers, based on their various attributes and capacity restrictions.

The problem tries to assign the containers that are temporarily stored at the transit container terminal to trips that will transport them to their final destinations. A trip denotes a combination of a ship and its routing with a port of destination sequence. A transit booking indicates the amount of goods (or container groups) that must be shipped together from an initial point to a destination. The expected times of arrival to different points on the route of the given trip are assumed to be known. We assume that the containers belong to one of two types, namely 20-feet and 40-feet. A 20-feet container occupies 1 TEU space in the vessel, while a 40-feet container occupies 2 TEU spaces. Physical capacities of the vessels with respect to types of containers are known, as containers with special characteristics (i.e., reefer containers) should be loaded to specific locations (i.e., they must be connected to the reefer platforms) in the vessel.

We consider this problem taking into account four factors that can affect container/trip allocation decisions:
1. The time taken for the booking to reach to its destination including the time spent in the port. (the transit duration),
2. Whether or not the booking has priority shipment privileges,
3. Whether the shipper company and the ship owner are the same; as such assignments are preferable,
4. The physical properties of the containers (reefers, hazmat containers, etc.); priority is given to the shipment of such containers.

The objective of the problem aims to consider the above criteria that affect the assignment of the transit containers to the most appropriate trips departing from the terminal. A mathematical programming model for maximizing a combined measure of the multiple criteria of assignments is currently under progress.

6. Conclusion and Future Work

We have proposed two dynamic strategies for stacking containers in an automated container terminal. Real data is obtained from a container terminal, and used as an input for the initial experimentation of the developed simulation model. Three types of containers, namely, import, export and transit are included in simulation. The port of destination (POD) sequence is also considered while stacking transit or export containers of the same vessel, as it affects the order in which the containers are loaded onto the vessel. We also consider the weight of the containers as another attribute, and define an operational constraint that allows stacking containers on top of each other only if the weight range of the stack remains below 3 tons. This constraint is dictated by the port authorities.

The results are tabulated and discussed. Random stacking is used as a base case for comparison. The results indicate that the number of reshuffles can be reduced by 95% when policy 2 is used. We can thereby conclude that,
when reshuffling is the single most important criterion, it is best to use the second policy. In the same way, policy 2 performs better than the policy 1 in terms of reshuffle occasions.

A number of strategies with different stacking rules will be developed as a next step in the study, including several additional attributes. Such an attribute is the expected departure time (EDT) of a container, which is defined as the time when the container will be removed from the stack to leave the terminal by a vessel, truck or train. Another attribute may be the closest transfer point, which requires selecting an empty position closest to the transfer points from which the container will leave the stack. For instance, transit containers should be stacked as close to the transfer point quayside as possible, because they both arrive and leave the lane there. Similarly, export containers are stacked as close to the transfer point quayside as possible in order to minimize the horizontal distance traveled by the yard trucks. On the other hand, import containers should be stacked as close to the transfer point landside as possible to decrease the traffic caused by external trucks.

Usage of multiple stacking cranes in each lane is another scenario worth investigating in order to improve handling operations. In this case, newly arrived containers should be assigned to storage positions taking into account the usage of multiple cranes. The size and capacity of the yard will be another experimental parameter.

Future steps of the study include the evaluation of the effects of several strategies and experimental parameters through extensive experimentation. The advantages and disadvantages of each strategy, and the performances in terms of several criteria will be analyzed.

References


