DENIZ TÜRSEL ELIIYI, Ph.D.
E-mail: deniz.eliiyi@ieu.edu.tr
GAMZE MAT, B.Eng.
E-mail: gamzemat@gmail.com
BURCU ÖZMEN, B.Eng.
E-mail: ozmenburcu89@gmail.com
Izmir University of Economics,
Department of Industrial Engineering
Sakarya Cad., No: 156, 35330, Balcova, Izmir, Turkey

STORAGE OPTIMIZATION FOR EXPORT CONTAINERS IN THE PORT OF IZMIR

ABSTRACT

This study considers a real-life export container storage problem at an important container terminal in the Port of Izmir, Turkey. Currently, the container storage decisions at the port are taken by operators manually, which leads to continuous unnecessary re-handling movements of the containers. High transportation costs, waste of time, and inefficient capacity utilization in the container storage area are the consequences of non-optimal decisions. The main goal of this study is to minimize the transportation costs and the number of re-handling moves while storing the export containers at the terminal yard. The problem has been formulated in two stages. While the first stage assigns the containers of the same vessel to a group of yard bays via an optimization model, the second stage decides on the exact location of each container with the help of an efficient heuristic approach. The experimental results with real data are presented and discussed.

KEYWORDS

container storage optimization, export containers, mixed integer programming, heuristic approach

1. INTRODUCTION

Containerized sea-freight transportation is a favoured mode of transportation, as using containers reduces the amount of product packaging and damage, and a container is a standardized load unit that is also suitable for road and rail transportation. Consequently, this mode of transportation has escalated considerably over the last decades. Container terminals are the connection points between different transportation modes; hence, a blockage in terminal operations affects the inbound and outbound traffic. The transhipment can be between ships and land vehicles, such as trains or trucks, in which case the terminal is described as a maritime terminal. Alternatively, the transhipment can be between land vehicles, typically between train and truck, in which case the terminal is described as an inland terminal [1].

The operations research methods have been used extensively to maximize the performance at container terminals, measured by metrics such as waiting time of the vessels at the berths, dwell time of the containers at the terminal, and the amount of congestion at the terminal due to inadequate container handling. There are five major typical decision problems arising in the management of container terminals: berth allocation, quay crane scheduling, yard operations, transfer operations, and ship stowage planning [2]. One of the most important processes of a container terminal, which is also the main focus of this study, is the transfer and storage of containers in the terminal yard. The aim of these operations is to maximize the operational productivity by efficiently utilizing available ground space.

The loading operation of an export container starts as the container arrives at a maritime terminal by rail or road transport. As the container enters the stacking yard for temporary storage, a straddle carrier stores it in one of the stacks. This handling equipment can be used both for transporting and storing containers. As the container vessel arrives at the port, the container is taken off by a straddle carrier and transferred to the quay for loading. A quay crane is used in loading the container onto the vessel. The processes for the import containers follow the reverse order of the ones for the export containers [3]. The transhipment containers are stored in the stacking yard in the time between discharging from a vessel and loading onto another one. The stacking yards are usually divided into export,

import and transit areas, and divided into multiple blocks (lanes), each consisting of a number of rows (bays). A yard bay or bay is composed of several stacks of a certain stack size (tiers), and holds containers of the same size. A container position in the yard is then addressed by its block, bay, row and tier identifiers [4]. These definitions are illustrated in *Figure 1*.
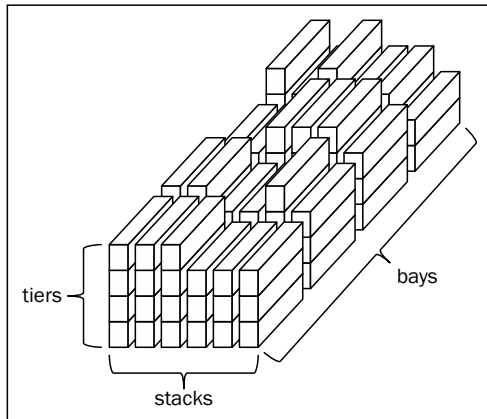

Figure 1 - Illustration of a block in the stacking yard

A stacking decision has to include which block, stack and tier has to be selected for a container to be stored. Not every container is directly accessible in a stack; the topmost containers have to be removed for accessing the containers below. As a result, reshuffling or re-handling may occur, which is defined as removing some containers to gain access to another container and then reinserting them back to their original positions. These are unproductive and costly moves for a container terminal, and have to be minimized. Inefficient storage plans and handling can cause bottlenecks or operational delays in container flow. Therefore, the objective of yard optimization is to minimize the number of reshuffles and to maximize the storage utilization in general [4].

There are many studies in literature on container storage with several considerations. As an example, Gudelj et al. [5] considered the container terminal of the Port of Koper, Slovenia, and used Petri net and genetic algorithm to handle the problems of berth allocation and container loading/unloading. Their preliminary results indicated that the developed algorithms are promising. Lee and Kim [6] studied on the optimal layout of container yards, taking into consideration the storage space requirements and the throughput capacities of yard cranes and transporters. They considered two different types of layout plans. The first one was a layout where blocks are laid out parallel to the quay and the second one included a layout whose blocks are laid out perpendicular to the quay. These layout strategies were compared in terms of various cost factors.

Most of the studies in literature used simulation to model container storage operations. The study by Woo and Kim [7] is such an example. The authors focused on allocating storage space to groups of export containers in port container terminals. In an attempt to minimize the handling effort for quay cranes and yard equipment at the same time, the authors tried to minimize the number of sets of adjacent stacks, which is allocated to a container group. Simulation was used to model the problem, and several models were compared.

Other studies include analytical and optimization models. As an example, Sauri and Martin [8] described three stacking strategies for improving yard performance. The metrics used were the dwell time in the storage area, the vertical re-handles for a homogeneous stack, the vertical re-handles for a heterogeneous stack, and the total re-handles for each strategy. A mathematical model based on the probabilistic distribution functions was developed to estimate the number of re-handles required at an import container yard. Soriguera et al. [9] analyzed the internal transport subsystem at a marine container terminal and investigated the effect of the type of handling equipment used. Queuing theory was applied and a simulation was conducted to analyze the system. To perform the analysis, measurements of parameters related to the terminal were taken from the container terminal at Barcelona, Spain, and the results were discussed.

Preston and Kozan [10] studied on modelling and determining the optimal storage strategy for various container handling schedules. The problem was formulated and solved by a genetic algorithm so as to minimize the container transfer times. Lee et al. [11] studied the integrated problem of bay allocation and yard crane scheduling problem for the transhipment containers. A mixed integer programming model with the objective of minimizing total costs, including yard crane cost and delay cost was developed. Their study ignored re-handling and the exact location considerations. A simulated annealing heuristic algorithm was developed to obtain the near-optimal solutions, and numerical experiments were conducted to test the efficiency of the proposed algorithm.

Chen and Lu [12] considered an assignment problem for export containers. Their problem was decomposed into two stages. In the first stage, the yard bays and the amount of locations that will be assigned to the containers bounded for different ships were determined by a mixed integer programming model. The exact storage location for each container was determined in the second stage by a hybrid sequence stacking algorithm. The objective was to maintain the ship stability and to minimize the handling effort of quay cranes and yard equipment. Jones and Walton [13] assessed the information needs of storing import containers. Their objective was to assess whether and how accurate and timely information about the departure times of containers can be used to efficiently and effectively

manage import containers in storage. The simulation experiment results indicated that import container handling efforts could be significantly reduced through careful ordering of storage, which would in turn reduce handling and the risk of damaging containers and thus improve the quality of service. The same argument can also be valid for export container traffic at a terminal.

This study involves the optimal storage planning of the export containers for an agency at one of the most important container terminals in Turkey, namely the Port of Izmir. This port is located at the far west of Anatolia at the intersection point of heavy traffic. Due to its strategic location in the Aegean Sea, the port is an ideal node for import/export between Europe and Asia. Currently, the container storage decisions at the export area of the agency are left to the responsibility of the crane operators. The decisions are taken manually, which leads to continuous unnecessary re-handling movements of the containers. High transportation costs, waste of time, and inefficient capacity utilization in the container storage area are the results of these non-optimal decisions in the long term. Keeping track of the storage positions is also stated as a problem in the current situation. Our main goal therefore is to minimize the number of re-handling moves and to reduce transportation costs while systematically storing the export containers at the dedicated terminal yard.

The problem has been formulated in two stages as in Chen and Lu [12], but here the objective and the assumptions regarding the system are different from theirs. While the first stage assigns the containers of the same vessel to a group of yard bays via a mathematical model, the second stage decides on the exact location of each container with the help of an efficient heuristics. Our mathematical model optimally decides the locations of container groups according to their assigned vessels and ports of destination (PODs). The output of the model is fed into the dynamic heuristics to stack each export container in the proper yard bay, as it arrives at the terminal area. Our main focus is on the applicability of the whole approach by the practitioners at the port. For this purpose, we have also developed a simple interface for assisting the decision makers while storing each container and keeping track of the storage positions.

Our problem has been described as well as the mathematical model in the next Section. Our solution procedure is explained in Section 3. Numerical results using real data taken from the Port of Izmir are summarized and discussed in Section 4. The conclusion is made in Section 5 with future research areas.

2. PROBLEM DEFINITION

The containers are standardized re-sealable transportation boxes for unitized freight handling with *stan-dardized* equipment. Generally, the most commonly used container sizes are the 20- and 40-feet ones. For these two types of containers, the terms TEU and FEU are used; they stand for *twenty-feet-equivalent-unit* and *forty-feet-equivalent-unit*, respectively [14]. Alternatively, the terms 1-TEU and 2-TEU are used. At the Port of Izmir, mainly 1-TEU and 2-TEU containers are handled. The following assumptions are in line with the current practice at the port:

- 1-TEU and 2-TEU containers are stored in different stacks due to technical reasons.
- Maximum stack height is four containers, for both 1-TEU and 2-TEU containers.
- Recti-linear (Manhattan-type) distances are assumed throughout the port area.
- The planning horizon is periodic, and the model will be executed for each planning horizon.
- The allocation of berths to the incoming vessels is made after the storage plan. Hence, berth allocation is made according to the stored containers.

The following parameters are needed for the mathematical model:

S – number of ships for which space should be allocated during the planning horizon;

s – index for ships, $1 \leq s \leq S$;

Y – number of yard bays for storing outbound containers;

y – index for yard bays, $1 \leq y \leq Y$;

K – number of types of containers ($K = 2$, corresponding to 1-TEU and 2-TEU containers);

k – index for types of containers, $1 \leq k \leq K$ ($k = 1$: 1-TEU container, $k = 2$: 2-TEU container);

D_s – number of destinations for ship s, $1 \leq s \leq S$;

D – number of destinations in total, $D = \bigcup_s D_s$;

d – index for destinations of ships, $1 \leq d \leq D$;

c_y – storage capacity at yard bay y, $1 \leq y \leq Y$;

V_y^0 – number of containers at yard bay y at the beginning of the planning horizon, $1 \leq y \leq Y$;

N_s – number of containers bound for ship s during the planning horizon, $1 \leq s \leq S$;

M_{y_1,y_2} – distance between yard bays y_1 and y_2 where $y_1 \neq y_2$, $1 \leq y_1 \leq Y$, $1 \leq y_2 \leq Y$;

C_{sd} – number of containers with POD d of ship s, $1 \leq d \leq D$, $1 \leq s \leq S$;

$C_{sd}^{(1)}$ – number of 1-TEU containers with POD d of ship s, $1 \leq d \leq D$, $1 \leq s \leq S$;

$C_{sd}^{(2)}$ – number of 2-TEU containers with POD d of ship s, $1 \leq d \leq D$, $1 \leq s \leq S$.

Our decision variables are as follows:

B_s – total number of yard bays assigned to ship s;

V_y – total number of containers at yard bay y at the end of the planning horizon;

x_{ysdk} – number of type k containers that are bound to ship s and POD d, stacked at yard bay y;

$$\delta_{ysdk} = \begin{cases} 1, & \text{if containers with POD } d\text{, type } k \text{ and ship } s \\ & \text{are assigned to yard bay } y \\ 0, & \text{otherwise} \end{cases}$$

$$\beta_{y_1,y_2,s} = \begin{cases} 1, & \text{if containers for ship } s \text{ are assigned} \\ & \text{to both yard bay } y_1 \text{ and } y_2 \\ 0, & \text{otherwise} \end{cases}$$

With these definitions, our mathematical model for assigning groups of containers to the yard bays is as follows:

$$\text{Minimize} \sum_{s=1}^{S} \sum_{y_1=1}^{Y} \sum_{y_2=1, y_2 \neq y_1}^{Y} M_{y_1,y_2} * \beta_{y_1 y_2, s} \qquad (1)$$

subject to:

$$V_y = \sum_{d=1}^{D} \sum_{k=1}^{K} \sum_{s=1}^{S} x_{ysdk} + V_y^0 \text{ for } y = 1, \dots, Y \qquad (2)$$

$$\sum_{y=1}^{Y} \sum_{d=1}^{D} \sum_{k=1}^{K} x_{ysdk} = N_s \text{ for } s = 1, \dots, S \qquad (3)$$

$$\sum_{y=1}^{Y} \sum_{k=1}^{K} x_{ysdk} = C_{sd} \text{ for } s = 1, \dots, S \text{ and } d = 1, \dots, D \qquad (4)$$

$$\sum_{y=1}^{Y} \sum_{d=1}^{D} x_{ysdk} = C_{sd}^{(1)} \text{ for } s = 1, \dots, S \text{ and } k = 1 \qquad (5)$$

$$\sum_{y=1}^{Y} \sum_{d=1}^{D} x_{ysdk} = C_{sd}^{(2)} \text{ for } s = 1, \dots, S \text{ and } k = 2 \qquad (6)$$

$$x_{ysdk} \leq C_{sd}^{(1)} * \delta_{ysdk} \text{ for } y = 1, \dots, Y, \ d = 1, \dots, D,$$
$$s = 1, \dots, S \text{ and } k = 1 \qquad (7)$$

$$x_{ysdk} \leq C_{sd}^{(2)} * \delta_{ysdk} \text{ for } y = 1, \dots, Y, \ d = 1, \dots, D,$$
$$s = 1, \dots, S \text{ and } k = 2 \qquad (8)$$

$$V_y \leq c_y \text{ for } y = 1, \dots, Y \qquad (9)$$

$$\sum_{s=1}^{S} \sum_{d=1}^{D} \sum_{k=1}^{K} \delta_{ysdk} \leq 1 \text{ for } y = 1, \dots, Y \qquad (10)$$

$$\sum_{s=1}^{S} \sum_{y=1}^{Y} \sum_{d=1}^{D} \sum_{k=1}^{K} x_{ysdk} \leq (Y * c_y) - 3 \qquad (11)$$

$$B_s = \sum_{y=1}^{Y} \sum_{d=1}^{D} \sum_{k=1}^{K} \delta_{ysdk} \text{ for } s = 1, \dots, S \qquad (12)$$

$$\sum_{d=1}^{D} \sum_{k=1}^{K} (\delta_{y_1,sdk} + \delta_{y_2,sdk}) - 1 \leq \beta_{y_1,y_2,s} \text{ for } s = 1, \dots, S,$$
$$y_1, y_2 = 1, \dots, Y, \ y_1 \neq y_2 \qquad (13)$$

$$x_{ysdk} \geq 0, V_y \geq 0, B_s \geq 0 \text{ for } y = 1, \dots, Y, \ s = 1, \dots, S,$$
$$d = 1, \dots, D, \text{ and } k = 1, \dots, K \qquad (14)$$

$$\delta_{ysdk}, \beta_{y_1,y_2,s} \in \{0, 1\} \text{ for } y = 1, \dots, Y, \ s = 1, \dots, S,$$
$$d = 1, \dots, D, \text{ and } k = 1, \dots, K \qquad (15)$$

The objective function in (1) minimizes the distance between the allocated containers of the same ship at the yard bays. Constraint (2) calculates the total number of containers at each yard bay at the end of the planning horizon as the summation of the containers at the beginning and the allocated number of containers during the planning horizon. Constraint (3) ensures that the number of allocated containers of a ship over all bays is equal to the total number of containers bound for that ship. Constraints (4) through (6) guarantee that all containers bound for each ship and each destination are stored at the yard bays. Constraints (7) and (8) relate the x and δ variables for 1- and 2-TEU containers, respectively. Constraint (9) limits the storage capacity of each yard bay, while constraint (10) confirms that only containers of one ship can be assigned to a single yard bay. Containers bound for different ships cannot be mixed within a yard bay. Constraint (11) is developed due to technical reasons stated by the planning authorities. For ease of accessibility, three container slots of a tier have to be empty at each container block. The reason for this requirement can be exemplified as follows: consider a block that is entirely filled with containers and a container which is located at the first (bottom) tier of a stack of this block has to be handled next. This means that there are currently three containers above the target container that need to be carried temporarily to an empty stack. Since the block is full, there is no room for moving these three containers. Thus, constraint (11) calculates the total number of stacked containers at each yard bay as the total block capacity less the three slack slots. Constraint (12) calculates the total number of yard bays that are allocated to each ship at the end of the planning horizon. Constraint (13) ensures that if there is an allocation for both yard bay y_1 and y_2, the corresponding β variable takes the value of 1. The last two constraints, constraint (14) and constraint (15) guarantee non-negativity and integrity of the decision variables.

With this mathematical model, attempts are made to cluster the containers bound for the same destination and the same ships. Since berth allocation is assumed to be made accordingly, this objective helps in minimizing the transportation cost. A yard bay is assigned for each container group of the same type with the same destination-ship pair, and thus the number of reshuffles is minimized. If one yard bay is not enough for storing the containers, efforts are made to minimize the distance between the assigned yard bays, which in turn minimizes the transportation cost.

The capacity of a yard bay (c_y) is a matter of layout design, and it is to be determined by the decision-maker. If the yard bay capacities are small, the number of yard bays will be larger. Note that the size of the model grows considerably with the number of yard bays; hence the size of a yard bay greatly affects the run-time of the model. On the other hand, as one yard bay is occupied by a single container group regardless of its size, the utilization of the yard bays, and in turn of the whole storage area, will definitely increase with

smaller yard bay designs. This trade-off is investigated through analyzing past data, and the yard bay capacities are determined as $c_y = 20$, $\forall y$, by the decision-makers of our problem.

3. THE SOLUTION PROCEDURE

The highly combinatorial structure of the model presented in the previous section does not allow fast solutions on a standard PC. ILOG OPL 6.3 is used for formulating the mathematical model and IBM ILOG CPLEX 12.1 is used as a state-of-the-art solver for the exact solution. Preliminary experimentation using real examples of several sizes on a Core 2 Duo 2.8 GHz Win7 PC with 4-GB memory reveals that the solution times are either too long (more than 24 hours of run-time for the smallest example of two-week data, having 9 vessels and around 960 containers), or even a feasible solution cannot be obtained. For this reason, a two-stage solution procedure has been designed that will make use of the developed mathematical model while having tolerable computation times for practical purposes. In addition, this solution procedure provides the exact locations of each container in the yard bay considering taking into account some technical constraints that cannot be handled by the model. These are explained below.

The first stage of our heuristic approach starts with sorting all vessels in the planning horizon in decreasing order of their number of containers. This is done in an attempt to prioritize the space allocation for vessels with larger numbers of outbound containers. Then, the mathematical model in the previous section is executed for each individual vessel in this order. The output of the mathematical model yields the assignments of groups of containers in each vessel to the yard bays. With this approach, the available yard bays for storage are updated every time and the assignment is made or the vessel departs. Namely, when the model is run for a vessel, a number of yard bays are allocated to the vessel, and these cannot be used for the next vessel. As a vessel departs from the port, all of its assigned yard bays become available for further storage. After the model is run for all vessels, the container groups are assigned according to their types and destinations, and the containers that will leave with the same vessel are kept together in the storage area. At this point, the stack and tier of an individual container at the stacking area is not determined.

The second stage is involved with identifying the exact position of each incoming container that enters the port area. The flowchart of the heuristic algorithm developed for this purpose can be seen in *Figure 2*. The heuristics is coded in MS Excel Visual Basic for ease of access and increased usability for practitioners. A user-friendly interface is designed for the same purpose.

The heuristic is executed when a new container arrives at the container terminal gate by truck, train or other vehicles. That is, it is run for each incoming container separately. As the container ID of the incoming container is entered into the system, reading the results of the mathematical model, the algorithm accesses the assigned yard bay and opens the related excel sheet. Each sheet contains information of all container IDs, ports of destinations (PODs), weight, stack IDs and tier IDs of a yard bay, updated each time a container is stacked in that yard bay.

While assigning a container to a stack in the yard bay, the algorithm takes into account the weight differences of containers in the same stack. To maintain the balance of a vessel and to avoid unwanted damages, the containers are stacked onto the vessel according to the 3-ton rule, as stated by the port authorities. This rule suggests that the range of weight of the containers in the same stack must be less than 3 tons. The rule is implemented in the yard bay for reducing re-handling operations and ease of vessel loading. Hence, if the weight difference between the incoming container and each container of an available stack in the assigned yard bay is less than or equal to 3 tons, the incoming container is assigned to that stack and all related information is stored. If no such stack is found, the container is placed in an empty stack of the same yard bay.

If no tier of any stack of the assigned yard bay is available for placing the incoming container, the algorithm searches for the nearest yard bay of the same vessel and the same type of containers to place the container. In rare cases where no yard bay of the same vessel is available for stacking the current container, the nearest yard bay of a different vessel is searched. The algorithm therefore allows containers with different PODs in the same yard bay in order to satisfy the 3-ton constraint, which is in line with the requirements stated by the decision-makers. The algorithm ends when the current container is placed in an empty position.

The developed solution procedure and the user interface also allow the users to see the current layout of the whole yard, observe a yard bay current status and make manual changes, and delete containers from the yard bay when their vessel departs from the port.

4. NUMERICAL RESULTS AND DISCUSSION

Three sets of real data are gathered from an agency in Port of Izmir to obtain numerical results, corresponding to two weeks, one month and two months of export traffic. The data include container IDs and weights, PODs, outbound vessel information and times of arrival at the port. The agency has a dedicated export container storage area in the port.
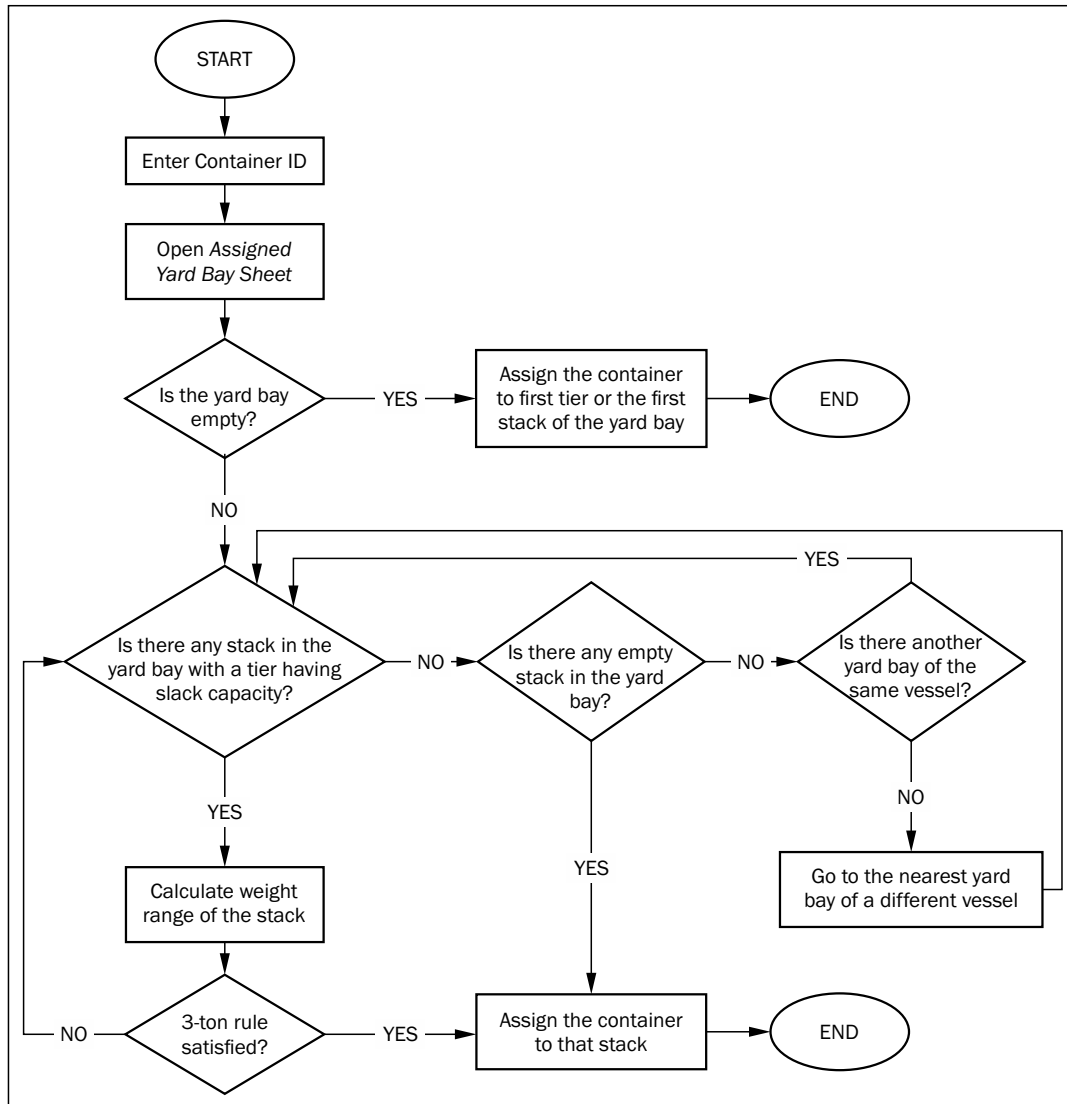
Figure 2 - Flowchart of the stacking heuristics

The small data set (Data 1) of the agency contains two-week data that has 9 vessels and 964 containers in total that will depart onboard these vessels with different types and PODs, with a maximum of 12 PODs per vessel. The shape of the storage area that will hold these containers is a rectangle formed by 5 by 16 yard bays, each having a capacity of 20 containers (5 stacks with 4 tiers). The model is run for each vessel, and the groups of containers having the same vessel, the same POD and the same type are organized as can be seen in *Figure 3*(a) (taken from the corresponding Excel sheet) for an example vessel. There are nine groups of containers for this vessel, each of which should occupy at least one yard bay. For example, the 1-TEU containers with POD 2 will occupy two yard bays, as the number of containers in this group is 23. It can be easily calculated from the organized data that the containers for this vessel should occupy at least 15 yard bays.

The output of the mathematical model for Data 1 can be seen in *Figure 3*(b). Note that Vessel 6 occupies

exactly 15 yard bays. Also note that the yard bays allocated to the same vessel are as close to each other as possible (which is the main objective stated by the decision-makers) and some yard bays remain empty. When the heuristic algorithm is run for each incoming container considering the arrival times, the exact positions of each container are determined.

Figure 3(c) (taken from the Excel sheet of Data 1 for Vessel 6) illustrates the resulting layout by the heuristics for yard bays 1 through 15, which are allocated to Vessel 6. The number in each position represents the ID for the POD of that container and the darker cells represent 2-TEU containers. For example, yard bay 1 holds fourteen 2-TEU containers all of which will leave for port 2. On the other hand, yard bay 11 holds three 1-TEU and one 2-TEU containers destined for port 2. As can be seen from the figure, attempts are made to keep 1-TEU and 2-TEU containers in separate yard bays as much as possible, and the yard bays belonging to the same POD are clustered. For this example,
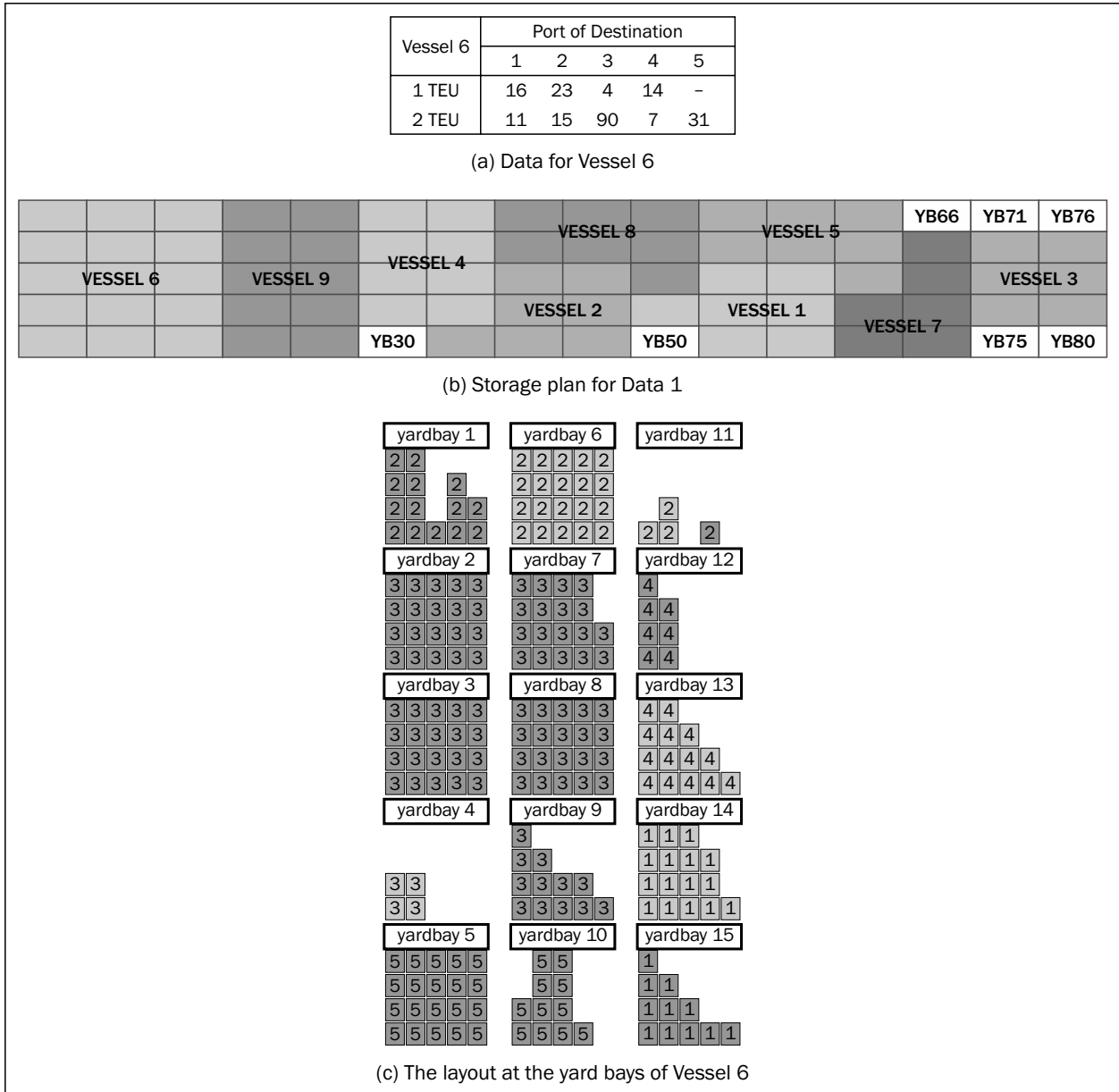
Vessel 6	Port of Destination				
	1	2	3	4	5
1 TEU	16	23	4	14	–
2 TEU	11	15	90	7	31

(a) Data for Vessel 6

(b) Storage plan for Data 1

(c) The layout at the yard bays of Vessel 6

Figure 3 - Results for Data 1
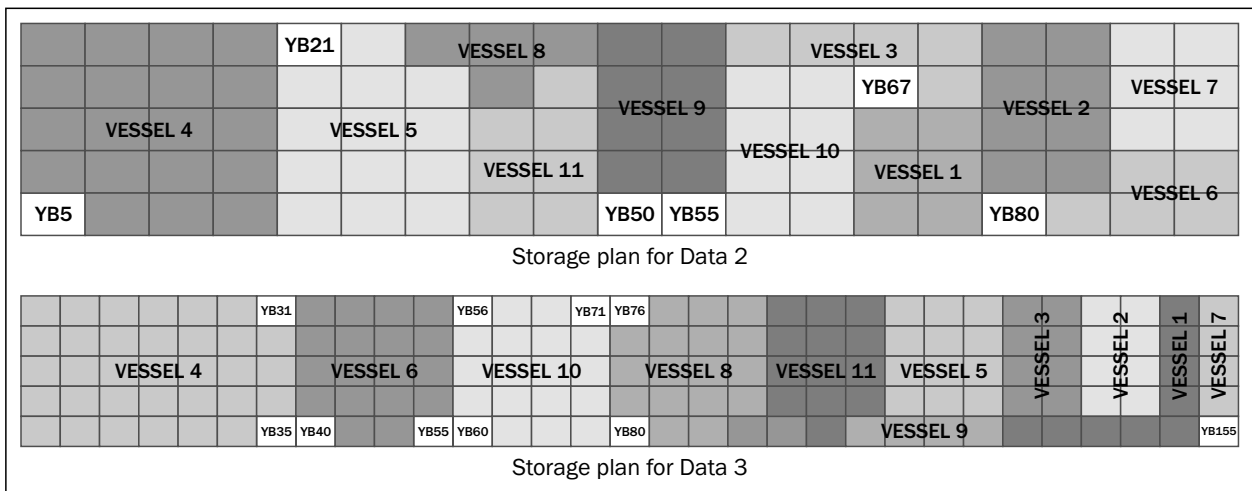

Storage plan for Data 2

Storage plan for Data 3

Figure 4 - Results for Data 2 and Data 3

the containers for different ports or different ships are not mixed in the same yard bay, but yard bays contain some single container stacks, which is a result of the 3-ton rule applied by the algorithm. The allocation of the yard bays to different PODs is done dynamically, as each container arrives at the port. The total number of containers in all yard bays is 211, which can also be checked from *Figure 3*(a). The users can modify the resulting layout manually.

Figure 4 illustrates the results of the model for one-month and two-month data sets (Data 2 and Data 3, respectively). Data 2 includes 1,232 export containers in total, which will be loaded onto 11 vessels through this period. There are 11 different PODs of concern. The runtimes of the model for Data 2 are all under three seconds. Data 3 has 2,250 containers and 11 ships with at most 18 PODs. The runtimes are very small again for this data, but for two large vessels with 18 PODs the runtimes go up to 300 seconds. As can be seen from the layouts, a 5 by 19 grid of yard bays are used for the medium-size data while a 5 by 31 grid is required for the large-size data.

It can be seen in *Figure 4*(b) that the yard bays of Vessel 9 do not form a nice cluster. This is due to the fact that Vessel 9 has the smallest number of outbound containers, and therefore, has the least priority and it is the last one considered while running the model. Consequently, two of its yard bays came out to be non-adjacent to the other four. The user interface allows manual adjustments in such cases.

5. CONCLUSION

This study has considered a real-life container storage problem at a container terminal. The problem has been defined and a practical two-stage solution approach proposed. The first stage, which assigns yard bays to container groups, involves usage of a developed mathematical model, whereas a heuristic approach is used in the second stage, which identifies the exact position of the containers.

The results of this study and contacts with the authorities reveal that the developed solution approach can be applied practically by the agency at the port. The simple interface designed for assisting the decision makers for storing each container and keeping track of the storage positions proves very helpful and practical. The current efforts are on pilot implementation of the results.

As the next step, improvement to the allocations in the first stage may be considered. The heuristic procedure that includes repeated solutions of the mathematical model yields suboptimal solutions, as it was discussed in the previous section. Packing-based approaches with time dimension can prove useful for this stage. One advantage of the developed system is that it allows for such modifications after the implementation.

Although manual changes are facilitated through the developed methodology, simple improvement heuristics may be employed at both stages for enhanced solutions. These will assist in proposing better allocations to the decision makers.

The problem considered in this study is a static problem. As all parameters of the outbound containers are predetermined; once a container is stored in the yard, it remains in the same position until it leaves with a vessel. Future research may take into account the dynamic nature of the problem; namely, that some containers may not remain permanently in their storage positions. Due to uncertainties or unexpected situations, a container can be reclaimed or moved to another storage position, and its place in the yard may become available for further storage.

Since this study is intended as an initial effort on container storage in the port, the berth allocation is assumed to be made according to the storage plans, which is in line with the current system. A more comprehensive study could be to investigate the relationship between the berth allocation and quayside operations and the efficiency of the container storage. Transportation costs within the terminal could be reduced through such an integrated approach. In addition, only export containers are considered in this study. The storage plans could be extended to include import, transit and empty containers at the port.

Dr. **DENIZ TÜRSEL ELIIYI**
E-mail: deniz.eliiyi@ieu.edu.tr
GAMZE MAT, B.Eng.
E-mail: gamzemat@gmail.com
BURCU ÖZMEN, B.Eng.
E-mail: ozmenburcu89@gmail.com
Izmir Ekonomi Üniversitesi, Endüstri Mühendisligi Bölümü
Sakarya Cad., No: 156, 35330, Balcova, Izmir, Türkiye

ÖZET

IZMIR LIMANI'NDA EXPORT KONTEYNERLER IÇIN DEPOLAMA OPTIMIZASYONU

Bu çalişmada Türkiye'nin önemli limanlarindan olan Izmir Konteyner Limani'ndaki gerçek bir export konteyner depolama problemi ele alinmiştir. Mevcut sistemde depolama kararlari operatörler tarafindan sezgisel olarak yapilmakta, bu durum konteynerlerin tekrar elleçlenmelerine sebep olabilmektedir. Bu optimal olmayan kararlarin sonucu olarak yüksek taşima maliyetleri, zaman kaybi ve verimsiz kapasite kullanimi ortaya çikmaktadir. Çalişmanin

ana amaci export konteynerlerin liman sahasinda depolan-masi sirasindaki taşima ve tekrar elleçleme maliyetlerini minimize etmektir. Problem iki aşamada formüle edilmiştir. Birinci aşamada ayni gemiyle taşinacak konteyner gruplari liman sahasindaki belirli bölmelere bir optimizasyon modeli kullanilarak atanmakta, ikinci aşamada gruplardaki her bir konteynerin bölme içindeki yeri tam olarak etkin bir sezgisel yöntem vasitasiyla belirlenmektedir. Gerçek veri kullanila-rak gerçekleştirilen sayisal deneyin sonuçlari sunulmuş ve tartişilmiştir.

ANAHTAR SÖZCÜKLER

Konteyner Depolama Optimizasyonu, Export Konteynerler, Karma Tamsayili Programlama, Sezgisel Yöntem

REFERENCES

[1] **Günther, H-O.**, **Kim, K.H.**: *Container Terminals and Automated Transport Systems*. Springer, Berlin, 2005

[2] **Vacca, I.**, **Bierlaire, M.**, **Salani, M.**: *Optimization at Container Terminals: Status, Trends and Perspectives*, Technical report TRANSP-OR 071204, Transport and Mobility Laboratory, EPFL, 2007

[3] **Daganzo, C.F.**: *The crane scheduling problem*, Transportation Research Part B: Methodological, Vol. 23, No. 3, 1989, pp. 159-175

[4] **Gambardella, L.M.**, **Rizzoli, A. Zaffalon, M.**: *Simulation and Planning of an Intermodal Container Terminal*, Simulation, Vol. 71, No. 2, 1998, pp. 107-116

[5] **Gudelj, A.**, **Krčum, M.**, **Twrdy, E.**: *Models and Methods for Operations in Port Container Terminals*, Promet – Traffic&Transportation, Vol. 22, No. 1, 2010, pp. 43-51

[6] **Lee, B.K.**, **Kim, K.H.**: *Optimizing the yard layout in container terminals*. OR Spectrum, 2012, DOI: 10.1007/s00291-012-0298-z

[7] **Woo, Y.J.**, **Kim, K.H.**: *Estimating the space requirement for outbound container inventories in port container terminals*, International Journal of Production Economics, Vol. 133, No. 1, 2011, pp. 293–301

[8] **Sauri, S.**, **Martin, E.**: *Space Allocating Strategies For Improving Import Yard Performance At Marine Terminals*, Transportation Research Part E: Logistics and Transportation Review, Vol. 47, No. 6, 2011, pp. 1038–1057

[9] **Soriguera, F.**, **Robuste, F.**, **Juanola, R.**, **Lopez-Pita, A.**: *Optimization of Handling Equipment in the Container Terminal of the Port of Barcelona*, Spain, Transportation Research Record: Journal of the Transportation Research Board, No. 1963, 2006, pp. 44–51

[10] **Kozan, E.**, **Preston, P.**: *Genetic algorithms to schedule container transfers at multimodal terminals*. International Transactions in Operational Research, Vol. 6, No. 3, 1999, pp.311-329

[11] **Lee, D-H.**, **Jin, J.G.**, **Chen, J.H.**: *Integrated Bay Allocation and Yard Crane Scheduling Problem for Transshipment Containers*, Transportation Research Record: Journal of the Transportation Research Board, No. 2222, 2011, pp. 63–71

[12] **Chen, L.**, **Lu, Z.**: *The storage location assignment problem for outbound containers in a maritime terminal*, International Journal of Production Economics, Vol. 135, No. 1, 2012, pp. 73–80

[13] **Jones, E.G.**, **Walton, C.M.**: *Managing Containers in a Marine Terminal: Assessing Information Needs*, Transportation Research Record: Journal of the Transportation Research Board, No. 1782, 2002, pp 92-99

[14] **Böse, J.W.**: *Handbook of Terminal Planning: Operations Research Computer Science Interfaces Series* Vol. 49, Springer, Heidelberg, 2011