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Container Terminal Yard Optimisation: A Case In Turkey

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ABSTRACT: *Due to the ever-changing nature of container terminals, fluctuations in storage capacity, and updates to vessel loading lists, the container yard can often become a hindrance to efficient terminal operations. One specific bottleneck frequently encountered in the stacking yard is referred to as yard clash. This phenomenon results in longer loading times for containers and is caused by the stacking of containers with the same loading time for different vessels within the same limited yard block and the limited availability of yard equipment. To address this issue, a binary integer optimization model was developed and implemented at a major container terminal in Turkey to minimize yard clashes. The results indicated a significant decrease of 92% in yard clashes during the loading of outbound containers, which in turn led to an increase of 2% in the total number of containers handled per vessel per hour.*

KEYWORDS: Container terminal; storage space allocation problem; optimization; binary integer programming; yard clash.

INTRODUCTION

Container yards are among the most dynamic areas in terminal operations due to the movement of incoming and outgoing containers. Inbound containers are unloaded from vessels, and outbound containers are staged in the yards until they leave the terminal. The yard blocks or slots assigned to containers determine their stacking location from arrival to departure (Armas et al., 2019).This requires allocating space for each container in the yard, resulting in a storage space allocation problem (Lin and Chiang, 2017).

The discharge of inbound containers prompts their departure from the port, while the arrival of the vessel triggers the entry of outbound containers into the terminal, thereby reducing yard congestion. However, some outbound containers may arrive at the terminal a few days prior to the arrival of the vessel. As such, the yard planner should allocate container locations in a manner that maximizes yard capacity utilization efficiency.

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The following activities should be considered when allocating storage space: the arrival times of other containers at the container terminal, yard capacity, vessel loading time, port of discharge, and the size and type of container. In some terminals, the container space allocation is done automatically by the terminal operating system's (TOS) modules, while in others, the yard planner allocates the container location manually. When yard congestion is high, the operational efficiency in container terminals may decrease as the arrival times of containers are uncertain. This can be remedied by using advanced tools such as simulation and queuing models to predict the arrival times of vessels and containers at the ports.

When automatic allocation through TOS is unavailable, yard planners manually allocate containers using the vessel loading list submitted by vessel agencies to TOS. With thousands of containers entering the terminal daily, the yard planner faces the challenge of quickly analyzing large amounts of data to allocate containers to the appropriate yard locations. Examining and allocating thousands of containers within a limited time is extremely difficult, making intelligent TOS and optimization models crucial for optimal storage allocation in container terminals.

The inefficiency in storage allocation is the underlying issue that inspired our research. It results in yard bottlenecks, which we define as yard clashes in our study. A yard clash occurs when multiple containers are loaded simultaneously, causing overlap in loading times, particularly in yard blocks where single-yard equipment is utilized. This prolongs the duration of the vessel's stay at the wharf, negatively impacting the average hourly performance of both the yard equipment and the quay crane.

The aim of our research is to address the issue of yard clashes that arise from inefficient storage allocation in a container terminal located in Turkey. Our primary objective is to optimize the allocation of containers into yard blocks in order to minimize the frequency of yard clashes. Additionally, our study intends to provide a yard plan for yard planners, which includes the optimal allocation of outbound containers. The foundation of our research is the binary integer programming optimization model developed by Dursun (2019) in her doctoral thesis. Our study comprises of a thorough review of relevant literature, a detailed explanation of our research methodology, a description of the optimization model, a presentation of our findings, and an evaluation of the results.

We have conducted our study on the issue of container storage space allocation and its impact on container terminal operations. Our research specifically addresses the problem of yard clashes, which frequently hinder terminal efficiency. We applied an optimization model in a container terminal in Turkey and achieved significant results. Our model successfully reduced yard clashes by 92%, leading to an increase of 2% in the total number of containers handled per vessel per hour. Our study provides valuable contributions to both the academic literature and the industry. It serves as a guide for other container terminals facing similar yard clash issues, offering a practical solution to optimize the allocation of containers into yard blocks while minimizing yard clashes of outbound containers.

LITERATURE REVIEW ON CONTAINER STORAGE SPACE ALLOCATION

Numerous research has been conducted on the storage space allocation problem, which proves its importance. We included previous studies to solve container terminals' storage space allocation problem. However, we have not encountered storage allocation problem research focusing on one of the immediate results of inefficient storage allocation: yard clashes. Therefore, our study attempts to fill a gap in the container terminal business and literature by developing an optimization model for storage space allocation to minimize yard clashes.

The storage space allocation problem refers to the temporary allocation of the inbound and outbound containers to the storage locations at each time, considering the workload balancing between the yard blocks in order to minimize reshuffling, retrieval times of the container, and maximize yard equipment productivity (Zhang et al., 2003). Storage yard operations consist of yard design, container storage space allocation, dispatching and routing the containers to/from the container yard, and reshuffling (Chang et al., 2019).

While some researchers focused on the storage space allocation phase, others considered storage space allocation together with container dispatching & routing. Hu et al. (2019) integrated the optimal storage allocation, dispatching & routing phases with the three-stage decomposition approach called particle swarm optimization developed in an automated container terminal. On the other hand, Bazzazi et al. (2009) and Wang et al. (2014) presented a different approach. To solve the proposed models, they investigated the effect of the storage space allocation problem on container retrieval time from the yard with the rolling horizon. Although the approaches are different, both contributed to improving service operations quality. On the basis of our study, we touched on the storage space allocation problem of outbound containers. Chen and Lu (2012) handled the outbound storage allocation problem with a two-stage approach similar to our research focus. With the mixed-integer programming model they developed in the first stage, the yards to be allocated to the containers connected to different vessels determined the number of areas in each yard. In the second stage, they applied the hybrid array stacking algorithm to determine the exact location of the container. In another study, Gracia (2021) aimed to improve the posterior loading and retrieval processes in order to enable better use of terminal resources in the storage space allocation of outbound containers.

One of the negative results of inefficient space allocation is reshuffling, in other words, the rehandling problem. Most researchers aimed to minimize reshuffling in their models for storage space allocation. Ozcan and Eliiyi (2017) focused on the container's distance to the closest yard equipment workload and the current height of the stacks at the storage yard to minimize the rehandlings with the reward-based algorithm. Guven and Eliiyi (2019) aimed to reduce reshuffling by assigning inbound and outbound containers with the binary integer optimization model they developed. Another approach raised by Maldonado et al. (2019) was to minimize the reshufflings that occur due to incorrect stacking while providing a decision support system to yard planning with the mixed-integer mathematical model. Zhou et al. (2020) did not solely focus on the mixed-integer model they developed to solve the storage space allocation problem. At the same time, they presented the effect of the developed model on reshufflings with the discrete event simulation model. With a similar study, Zhu et al. (2020) have developed a two-stage integer programming model by dealing with inbound containers' unloading and stacking problems together, helping to reduce container rehandling.

We observed during the literature search that some researchers focused on balancing container-yard allocations with the workload in yard equipment as a holistic approach to storage space allocation problems. An example may be seen in Wu et al. (2014), a mixed-integer programming model that combines yard planning logic with the vehicle and crane scheduling approaches. Similarly, Zheng et al. (2019) indicated the importance of delimiting the joint operation areas between different gantry cranes to increase resource utilization's operational efficiency.

Based on the storage space allocation problems, we understood that challenges arise from the structure of the hinterland and terminal, such as yard space capacity shortage and high yard occupancy. To combat the challenges such as yard capacity shortage, Hu et al. (2021) developed a yard sharing strategy that uses the dry port's surplus storage space solution. The non-dominated sorting genetic algorithm II created optimal storage space allocation ensured in the terminal and dry port areas.

Case Study: Terminal and Current Status

Scope of the Case Study

Our study aims to determine the optimal yard location for storing outbound containers before they are loaded onto a vessel to minimize yard clashes. The objective is to minimize yard clashes and improve the key operational performance indicators of the vessel loading process. We have developed a binary integer programming model that aims to optimize the allocation of yard locations for outbound containers. As a result of the optimized allocation, we expect to observe an increase in the total number of containers handled per hour and a reduction in yard clashes during the loading of outbound containers.

The container terminal, the site of the application part of the study, has been in operation in Turkey for over fifty years and was ranked among the top five container terminals in terms of cargo handled in 2022. In addition to container services, it provides conventional cargo and pilotage services. To maintain confidentiality, the identity of the terminal has been kept confidential in accordance with corporate rules and data agreements. Although the Terminal Operating System (TOS) is utilized for functions such as berth allocation, stowage planning, and container yard allocation, it does not possess advanced algorithms for these operations. As a result, the planning unit assumes the role of key decision-maker in operational matters and implements terminal operations through the TOS.

The study was conducted on a sample of 920 vessels that berthed at the container terminal between October 2017 and March 2018, encompassing over 800,000 containers. The operational data was obtained through collaboration with the planning and information technologies unit during the modeling and implementation phases. Yard planners at the container terminal were tasked with daily allocation of 1000-2000 containers for vessel loading, as well as assigning containers to designated dry port areas for stuffing and unstuffing operations, x-ray, and inspection, based on customs requirements. These planning processes involved a total of 5000-6000 containers per day. The focus of the study was on the outbound container loading operations.

The study aimed to enhance vessel performance by minimizing container yard clashes. To investigate the correlation between yard clashes and vessel performance, the p-value was computed to test the hypothesis of a meaningful relationship between the two variables. The calculation results showed a $p = 0.000$ ($P<0.05$), indicating a statistically significant relationship between yard clashes and vessel performance, thus making it a noteworthy area for further research.

Yard Clash

In the study, the concept of "yard clash" was defined as the overlap in the loading times of outbound containers onto vessels. The yard clashes were classified into two separate categories, differentiated by their source:

1. Multiple vessels' container yard clash (MVCYC)
2. Container entrance and vessel loading yard clash (CEVLYC)

3.2.1. Multiple vessels' container loading yard clash

MVCYC occurs when the containers' entrances to the yard and the vessel loading times overlap in the same yard block. This type of yard clash arises from the miscoordination between the yard entrance and the vessel loading operations, reducing the terminal's operational efficiency. The main consequences of MVCYC include longer waiting times for containers at the yard entrance, decreased use of yard equipment, and a reduction in the overall performance of the terminal.

We analyzed the relationship between Multiple Vessels' Container Yard Clash (MVCYC) and Vessel Rate by calculating the correlation coefficient (r) as -0.626 and the coefficient of determination (R^2) as 0.3920. The results demonstrate a strong inverse relationship between MVCYC and Vessel Rate, with MVCYC accounting for 39% of the variation in Vessel Rate. As illustrated in Figure 1, overlapping loading times for multiple vessels result in a single vessel being served by the Rubber Tire Gantry Crane (RTG) operating in the yard.

Figure 1. Multiple vessels' container loading from the same yard block

The optimal allocation of containers can result in efficient utilization of yard cranes in the container terminal operations by assigning them to different yard blocks instead of having multiple vessels' containers with the same loading times in a single yard.

Container Entrance & Vessel Loading Yard Clash

The second type of yard clash, CEVLYC, arises when containers entering the terminal and containers destined for loading onto a vessel are assigned to the same yard block. This results in overlapping transfer times within the yard block. If single yard equipment is in use, the yard planner must prioritize the equipment for either terminal entry containers or those destined for loading onto the vessel. This can cause traffic congestion within the yard and decreased yard crane performance if vessel-bound containers are prioritized, or prolonged vessel departure if terminal-entry containers are prioritized.

When we examined the vessel performance and container entrance & vessel loading yard clash relationship, we calculated the correlation coefficient (r) as -0.320 and the determination coefficient as (R^2) 0.1022. We explained that terminal entry-vessel loading time overlaps explained 10% of the changes in vessel performance. Figure 2 shows the container entrance & vessel loading yard clash.

When investigating the relationship between the Container Entrance and Vessel Loading Yard Clash (CEVLYC) and vessel performance, we computed the correlation coefficient (r) as -0.320 and the coefficient of determination (R^2) as 0.1022. Our findings indicate a weak inverse relationship between CEVLYC and vessel performance, with only 10% of the changes in vessel performance explained by CEVLYC. Figure 2 presents a visual representation of the CEVLYC.

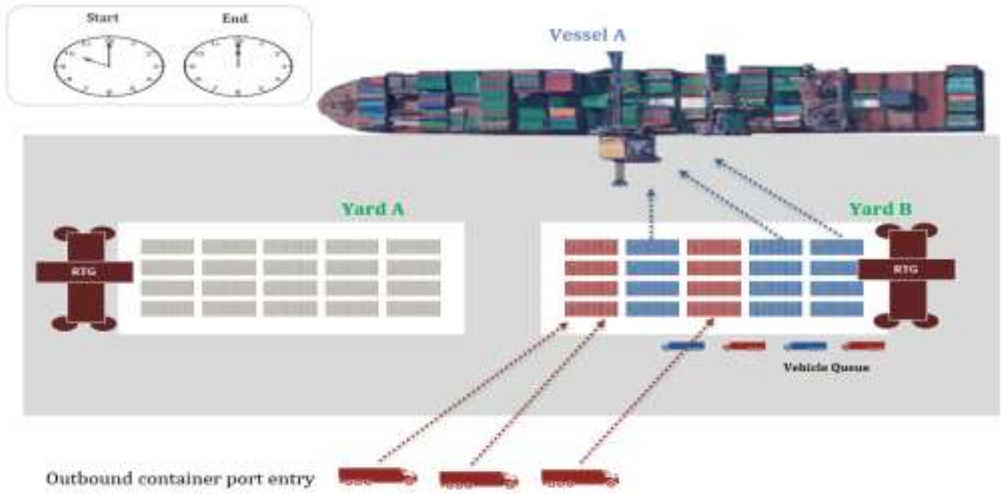

Figure 2. Container entrance & vessel loading yard clash

RESEARCH METHODOLOGY

Mathematical Programming Model

The mathematical model is built on the principle of assigning containers to yard locations by grouping them based on common criteria, such as the vessel to be loaded, voyage, port of discharge, weight classification, container type, and vessel service name.Grouping containers based on criteria such as the vessel to be loaded, voyage, port of discharge, weight classification, container type, and vessel service name forms the foundation of our mathematical model. The grouping of containers is automatically performed upon submitting outbound container information into the Terminal Operating System (TOS). All vessel loading lists are stored in the database for later use. To allocate containers to yard locations, information such as the current yard capacity status, yard occupancy status, instant and historical Twenty-foot Equivalent Units (TEUs) handled per crane per vessel, information about containers being transferred from the gate entrance to the vessel, and the current yard equipment needed was required. This information was obtained from the vessel loading lists and real-time data stored in the database, which was processed using Structured Query Language (SQL) to handle the large volume of data. The meaningful information was then transferred to CPLEX Optimization Studio for further analysis, making the data analysis step a crucial part of our study.

In our model, S=$\{1,2,\ldots,n\}$ is a set of yard container capacities to define 20 and 40-foot containers. y=$\{1,2,\ldots,n\}$ $\forall y \in Y$ is the index of the yard number where the set of where container clusters C are allocated to yard set Y. c=$\{1,2,\ldots,n\}$ $\forall c \in C$ defines the container cluster index. V=$\{1,2,\ldots,n\}$ is a set of vessel where v=$\{1,2,\ldots,n\}$ vessel index belongs. T=$\{1,2,\ldots,n\}$ represents a set of time and t=$\{1,2,\ldots,n\}$ is the index of T. VL=$\{1,2,\ldots,n\}$ defines the set of yard clashes regarding the MVCYC where VP=$\{1,2,\ldots,n\}$ is the set of CEVLYC.

The parameters are introduced below:

S20	Subset of 20-foot container cluster belongs to the set $\boldsymbol{S} = \{\mathbf{0}, \mathbf{1}, \mathbf{2}, \dots, \boldsymbol{n}\}$
s20	Index of the vehicle number belonging to the subset *S20*=$\{0,1,2, \dots, n\}$
S20Max	Maximum 20-foot container cluster belonging to *S20*
$S20\_PeriodN_{s20}$	Period belonging to *s20*
$S20\_BlockID_{s20}$	Yard information belonging to *s20*
$S20\_Teu_{s20}$	TEU of container cluster belonging to *s20*
S20_DummyNs20	The dummy yard indicator belonging to s20
S20_Capacitys20	Container capacity of yard blocks belonging to s20
S40	Subset of 40-foot container cluster belongs to the set $S = \{0,1,2, \dots, n\}$
s40	Index of the vehicle number belonging to the subset *S40*=$\{0,1,2, \dots, n\}$
S40Max	Maximum 40-foot container cluster belonging to *S40*
$S40\_PeriodN_{s40}$	Period belonging to *s40*
$S40\_BlockID_{s40}$	Yard information belonging to *s40*
$S40\_Teu_{s40}$	TEU of container cluster belonging to *s40*
S40_Capacitys40	Container capacity of yard blocks belonging to s40
Y	Yard location set
y	Index of the yard number belonging to *Y*
YMax	Maximum number of yard belonging to *Y*
$BlockID_y$	Yard information belonging to *y*
$DummyN_m$	The dummy yard indicator belonging to *y*
C	Container cluster set
c	Index of the container cluster belonging to *C*
CMax	Maximum number of container cluster belonging to *C*
VVC_c	Vessel & voyage index of container cluster belonging to c
$PeriodIn_c$	Port entrance period of container cluster belonging to c
$PeriodOut_c$	Port exit period of container cluster belonging to *c*
$CntrOpsTeu_c$	TEU of container cluster belonging to *c*
$InYard_c$	Container cluster of index c presence in yard blocks $InYard_c = \{(0,1)\}$
$CntrBlockID_c$	Yard block information of the container cluster belonging to *c*
$TotalBox_c$	Total number of containers belonging to *c*
$TotalTeu_c$	Total TEU of containers belonging to *c*
V	Vessel set
v	Index of the vessel belonging to *V*
VMax	Maximum number of vessels belonging to *v*
$GVVC_v$	Vessel & voyage information belonging to *v*
VL	Set of yard clashes of *MVCYC*
vl	Index of container clusters belonging to *VL*
VLMax	Maximum index number of *vl*
VP	Set of CEVLYC
vp	Index of the vessel belonging to *VP*
VPMax	Maximum index number of *vp*
T	Set of time
t	Index of the loading time belonging to *T*

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Our primary objective is to minimize yard clashes per vessel service, thereby maximizing the occurrence of non-yard clashes. To achieve this goal, we formulate our algorithm based on the non-yard clash conditions of outbound containers.

Model Formulation:

Decision variable:

$$X_{cy} = \begin{cases} 1 & if\ c\ number\ in\ group\ C\ is\ assigned\ to\ number\ y\ in\ set\ Y \\ 0 & Other \end{cases} \tag{1}$$

$\forall c \in C;\ \forall y \in Y$

Objective Function:

$$\begin{aligned} Max\ Z = \Bigg(& \left(\sum_{y1=1}^{YMax} \sum_{c1=1;\ \boldsymbol{a1}}^{CMax} \left(X_{c1y1} * TotalTeu_{c1} \right) \right) * (-M) \\ & + \sum_{y2=1}^{YMax} \sum_{vl2=1}^{VLMax} \left| \left(\sum_{c2=1;\ \boldsymbol{a2}}^{CMax} TotalBox_{c2} + \sum_{c3=1;\ \boldsymbol{a3}}^{CMax} X_{c3y2} * TotalBox_{c3} \right) \right. \\ & \left. - \left(\sum_{c4=1;\ \boldsymbol{a4}}^{CMax} TotalBox_{c4} + \sum_{c5=1;\ \boldsymbol{a5}}^{CMax} X_{c5y2} * TotalBox_{c5} \right) \right| \\ & + \sum_{y3=1}^{YMax} \sum_{vp2=1}^{VPMax} \left| \left(\sum_{c6=1;\ \boldsymbol{a6}}^{CMax} TotalBox_{c6} + \sum_{c7=1;\ \boldsymbol{a7}}^{CMax} X_{c7y3} * TotalBox_{c7} \right) \right. \\ & \left. - \left(\sum_{c8=1;\ \boldsymbol{a8}}^{CMax} TotalBox_{c8} + \sum_{c9=1;\ \boldsymbol{a9}}^{CMax} X_{c9y3} * TotalBox_{c9} \right) \right| \Bigg) \end{aligned} \tag{2}$$

Parameters inside the objective function:

a1: $Dummy_{y1} = 1$ (3)

a2: $InYard_{c2} = 1 \wedge BlockID_{y2} = CntrBlockID_{c2} \wedge VL\_D1_{vl2} = VVC_{c2}$ (4)

a3: $InYard_{c3} = 0 \wedge VL\_D1_{vl2} = VVC_{c3}$ (5)

a4: $InYard_{c4} = 1 \wedge BlockID_{y2} = CntrBlockID_{c4} \wedge VL\_D2_{vl2} = VVC_{c4}$ (6)

a5. $InYard_{c5} = 0 \wedge VL\_D2_{vl2} = VVC_{c5}$ (7)

a6. $InYard_{c6} = 1 \wedge BlockID_{y3} = CntrBlockID_{c6} \wedge VL\_P1_{vp2} = VVC_{c6}$ (8)

a7. $InYard_{c7} = 0 \wedge VP\_D1_{vp2} = VVC_{c7}$ (9)

a8. $InYard_{c8} = 1 \wedge BlockID_{y3} = CntrBlockID_{c8} \wedge VP\_D2_{vp2} = VVC_{c8}$ (10)

a9. $InYard_{c9} = 0 \wedge VP\_D2_{vp2} = VVC_{c9}$ (11)

Constraints:

$$\sum_{y=1}^{YMax} X_{cy} = 0 \quad \forall c = 1,..,CMax \ni \quad InYard_c = 1 \tag{12}$$

$$\sum_{y=1}^{YMax} X_{cy} = 1 \quad \forall c = 1,..,CMax \ni \quad InYard_c = 0 \tag{13}$$

$$\sum_{c=1}^{CMax} (X_{cy} * TotalTeu_c) \leq \sum_{s20=1}^{S20Max} (S20\_Teu_{s20}) \quad \forall y = 1,..,YMax; \quad \forall s20 = 1,..,S20Max, \quad \forall c = 1,..,CMax \ni BlockID_y = S20_{\_BlockID_{s20}} \wedge PeriodOut_c \geq S20_{\_PeriodN_{s20}} \wedge InYard_c = 0 \wedge \boldsymbol{CntrOpsTeu_c = 1} \tag{14}$$

$$\sum_{c=1}^{CMax} (X_{cy} * TotalTeu_c) \leq \sum_{s40=1}^{S40Max} (S40\_Teu_{s40}) \quad \forall y = 1,..,YMax; \quad \forall s40 = 1,..,S40Max, \quad \forall c = 1,..,CMax \ni BlockID_y = S40_{\_BlockID_{s40}} \wedge PeriodOut_c \geq S40_{\_PeriodN_{s40}} \wedge InYard_c = 0 \wedge \boldsymbol{CntrOpsTeu_c = 2} \tag{15}$$

The aim is to assign containers in container group C to yard blocks. As a result of the model's resolution of the specified decision variable, the relevant container group will take the value 1 if assigned to the yard block and 0 if not. (2) We defined the non-overlapping condition in the model, thereby maximizing the non-overlapping of the containers to be allocated in the yard block is the objective function. (3) gives the number of containers assigned to the dummy yard. We described a dummy yard to assign containers that are not allocated due to yard capacity constraints. We generated (4), (5), and (6) to minimize yard clash type 1, multiple vessel loading times overlapping. (4) shows the total number of containers present in the yard based on the vessel and yard block, whereby brings the "VL_D1" vessel information, which shows the container yard clash based on binary vessel loading yard clash. (5) is the total number of containers to be planned based on the vessel and yard breakdown, whereby brings the vessel information attached to "VL_D1" (6) shows the total number of containers present in the yard based on the vessel and yard block, whereby brings the "VL_D2" vessel information which shows the container yard clash based on binary vessel loading yard clash. (7) is the total number of containers to be planned based on the vessel and yard breakdown, which brings the vessel information "VL_D2". (8), (9), (10), and (11) are created to minimize the yard clash type 2, vessel loading & terminal entrance time yard clash. (8) shows the total number of containers present in the yard based on the vessel and yard block, whereby brings the "VP_D1" vessel information, which shows the container yard clash based on the binary terminal entrance and vessel loading time. (9) is created for the containers to be planned based on vessel and yard breakdown, which brings the vessel information attached to "VP_D1". (10) shows the total number of containers present in the yard which brings the "VP_D2" vessel information of the binary terminal entrance & vessel loading time yard clash. (11) brings the total number of containers to be planned, attached to "VP_D2" vessel information of the binary terminal entrance & vessel loading time yard clash. (12) If a container cluster is assigned in the yard block, another cluster cannot be assigned to that yard block. (13) is created to assign a container cluster to the yard block if the yard block is empty. (14) defines the cluster attached to a 20-foot dry container (DC) type. Total 20-foot DC TEU information is given if period $(PeriodN_t)$ is in between the entrance and exit periods. For assignments to be made on a period-based 20' DC container, the TEU information of the container cluster to be assigned must be less than the existing yard capacity. (15) applies the same logic for the 40-foot DC cluster.

Solution Process

We ran the optimization model on IBM CPLEX Optimization Studio 12.6.3 and a 64-bit Windows 10 computer with a 3.6 GHz i7 processor, 4 cores (8 logical processors), and 16 GB of RAM. We used Optimization Programming Language (OPL) to code the developed model within the IBM CPLEX Solver. In addition, SQL (Structured Query Language) was used to transfer the vessel loading list, yard occupancy status, yard equipment information, data of related parameters, and model output from the TOS database.

The mathematical model encoded in the IBM CPLEX solver is run on CPLEX. It solves the model subject to the application for 2 minutes. We showed the model's data processing and solution process in Figure 3.

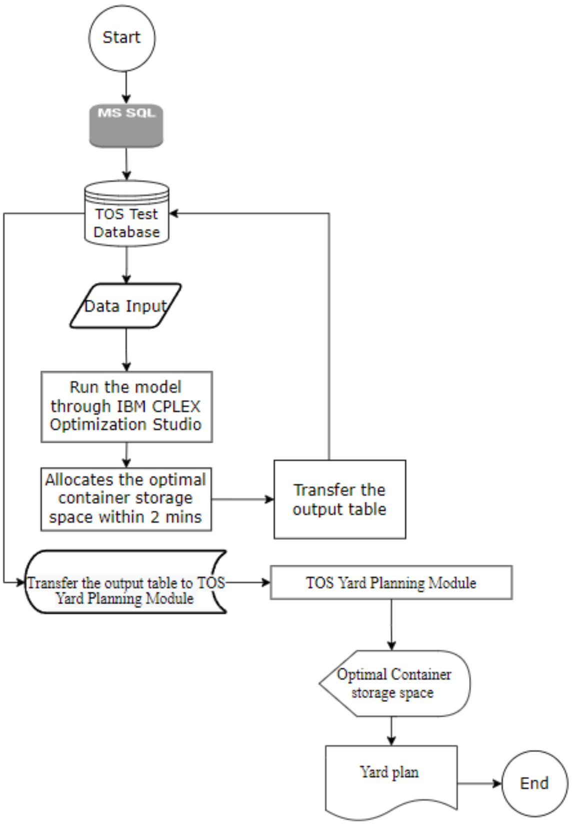


Figure 3: Model processing and solution process

FINDINGS

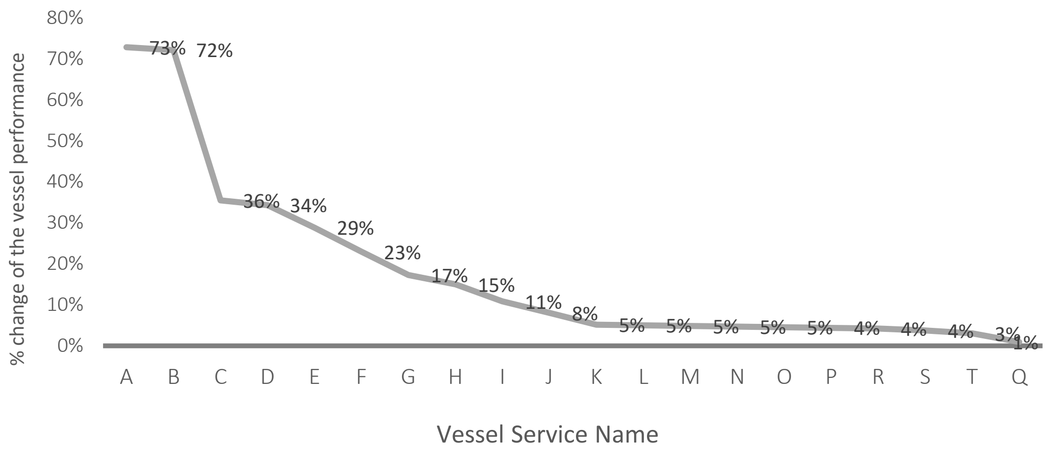
We started to test the model output from March to September 2018 at the twelve outbound container yard blocks. We applied the model to vessel services, which refer to regular calls of a particular vessel operator along a certain route. In other words, we aimed to maximize the non-overlapping situation to minimize the container yard clashes of overlapped loading times. Eventually, reduced yard clashes per vessel call will increase hourly vessel performance. Therefore, we showed the number of container yard clashes before the implementation (October 2017 - March 2018) and after the implementation (March-September 2018) according to the yard clash types to measure the model's success. Table 1 shows the number of containers separated by yard clash types

Table 1. Total number of container yard clashes per vessel

Clash Type	Before application	After application	Δ%
MVCYC	921	73	-92%
CEVLYC	465	57	-88%

We analyzed the vessel rate (total number of containers handled on a vessel per hour) of 37 vessel services to measure the impact on the operations performance. We saw that the vessel rate of 20 services among 37 has increased. These 20 vessel services covered 36% of the total handling volume. We did not observe any increase in vessel performance among the remaining 17 services. 80% of the 17 vessel services performed the same before the implementation, whereas 20% of vessel services' performance decreased slightly due to reasons independent of the model. After examining the vessels belonging to all services, we finalized an increase of 2% in the overall vessel rate after the model implementation. As a result of the confidentiality agreement signed with the company, the service information is kept confidential. Figure 4 shows the vessel rate change for service-based vessels compared to pre-implementation.

Figure 4. Vessel rate change per vessel service name



The implementation result shows that the optimization model successfully minimizes multiple vessel container yard clashes and outbound container entrance & vessel loading container yard clashes. Another essential point to be considered is integrating the developed model with the TOS. The primary purpose of the integration is to ensure the sustainability of the study whereby proof of concept has been completed to enable the yard planners to reach the optimal storage space allocation and allow them to plan the container blocks by considering the model results.

CONCLUSION

The dynamic and complex structure seen in terminal yard operations, the difficulty of instantaneous analysis of big data by yard planners, and the availability to update data before the cutoff time dampens the possibility of allocating outbound containers to an optimal container storage location. Therefore, using various mathematical models to perform the optimal container storage space allocation becomes inevitable.

In this paper, we focused on the optimal allocation of containers within a container group that is clustered based on standard criteria such as vessel service name, container size, container weight, container type, port of discharge, and vessel name to improve the operational performance of a container terminal located in Turkey. As a result of outbound container allocation, the container terminal faced time overlaps that we call yard clashes, which negatively affected the overall vessel performance. We meant that yard clashes overlap the loading times of the containers that need to be loaded onto the vessel from the same yard block and/or the terminal entry times of the outbound containers simultaneously. In our research, we analyzed the yard clashes in two categories: the multiple vessels' container loading time overlap at the same yard block (multiple vessel container yard clash), and the terminal entry time and vessel loading time overlap of the outbound containers at the same yard block (container entrance & vessel loading yard clash). In response to this overlap problem experienced by the container terminal, we developed a binary integer optimization model to maximize the condition of non-overlapping of containers' vessel loading time within the same yard block.

We implemented the optimization model from March to September 2018 in the yard planning unit to observe the model's success. The model provided a 92% improvement in the overlapping loading times of the containers of multiple ships in the same yard block, which is the first yard clash type. In the second type, the model reduced the total number of container yard clashes by 88%.

The ultimate goal of the study was to increase vessel performance by minimizing yard clashes. We expressed the vessel performance as the total number of containers (discharged and loaded) handled per hour on a vessel. When we examined the results, we saw that the model improved the vessel performance by 2%. We noticed that the vessel rate reached 73%, especially in some vessel services.

We explained the variation in vessel rate by 49% of the change in yard clashes. Therefore, terminals aiming to improve their leading performance indicators should consider other bottleneck factors as well as yard clashes. With a holistic approach, the model has the potential to improve vessel performance further. For this reason, we will expand our studies by exploring the relationship between other factors and vessel performance in future studies. When we evaluate the model in terms of sustainability, we recommend that the model be integrated with the terminal operating system to make yard planners more flexible and embody the proof of concept.

Our study fills a research gap in the literature by unveiling the operational bottlenecks arising from different container yard clash types and finally proposing a novel binary integer mathematical model to minimize container yard clashes tested and implemented in one of the major container terminals in Turkey.

In the future, we will consider inbound and outbound containers as integral parts of the model. Another research direction is to consider factors such as the uncertain entry times for containers, data-related errors, and vessel renominations that contribute to container yard clashes to reinforce the model.

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