Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 22, Sayı 3, 1157-1164, 2018

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 22, Issue 3, 1157-1164, 2018

DOI: 10.19113/sdufenbed.444748

# A Simulation Based Approach for Efficient Yard Planning in a Container Port

**Murat ÇOLAK[1], Gülşen AYDIN KESKİN[*2], Hatice ESEN[3], Canan BEKTAŞ[4]**

[1,2,3,4]Kocaeli University, Engineering Faculty, Department of Industrial Engineering, 41380, Kocaeli

(Alınış / Received: 17.07.2018, Kabul / Accepted: 01.10.2018, Online Yayınlanma / Published Online: 11.10.2018)

**Keywords**
Maritime transport,
Simulation,
ARENA,
Stack planning,
Container yard planning

**Abstract:** Maritime transport is the most significant one among several transportation modes. Containers are transported at international level as a part of maritime transport. Seaports have critical role for efficiency of container stacking process. It is necessary to complete operations of arriving vessels at the shortest time in order to provide high customer satisfaction. At this point, simulation is effectively utilized as a decision support system in order to improve port processes. In this study, current situation and two alternative scenarios are compared to each other through simulation so as to realize the most suitable stack planning by removing bottlenecks in a container port. It is aimed to determine the most suitable yard layout to provide minimization of discharging times for arriving vessels, decreasing waiting times of carriers under quay and yard cranes and fair usage of all equipment. Thus, it is planned to reduce energy and workforce costs.

# Bir Konteyner Limanında Etkin Saha Planlaması için Simülasyon Tabanlı Bir Yaklaşım

**Anahtar Kelimeler**
Liman taşımacılığı,
Simülasyon,
ARENA,
İstif planlama,
Konteyner saha planlaması

**Özet:** Deniz taşımacılığı, çeşitli ulaşım çeşitleri arasında en önemli olanıdır. Konteynerler, deniz taşımacılığının bir parçası olarak uluslararası düzeyde nakledilmektedir. Limanlar, konteyner istifleme sürecinin verimliliği açısından kritik bir role sahiptir. Müşteri memnuniyetini en üst düzeyde sağlamak için en kısa sürede gelen gemilerin operasyonlarını tamamlamak gerekmektedir. Bu noktada, liman süreçlerini iyileştirmek için simülasyon bir karar destek sistemi olarak etkin bir şekilde kullanılmaktadır. Bu çalışmada, bir konteyner limanındaki darboğazları gidererek en uygun istif planlamasını gerçekleştirebilmek için mevcut durum ve iki alternatif senaryo benzetim yoluyla birbirleriyle karşılaştırılmıştır. Gelen gemiler için boşaltma zamanının en aza indirgenmesi, taşıyıcıların vinçlerin altındaki bekleme sürelerinin kısaltılması ve tüm ekipmanların adil kullanımı için en uygun saha düzeninin belirlenmesi amaçlanmıştır. Böylece, enerji ve işgücü maliyetlerinin azaltılması planlanmaktadır.

## 1. Introduction

The importance of maritime transport is increasing as the world becomes global. Ports have to improve the quality of their service and customer satisfaction in order to keep up with the world and compete with the ports in the same hinterland. Container transport is preferred more than the other transports as it is a low cost and more trustworthy transport. As container transport becomes more important day by day, it becomes inevitable for container ports to operate continuously and efficiently.

Increase in container transport has also increased the competition among container ports. The way to survive in this competitive environment for container ports will only be possible by providing quality service and high customer satisfaction. The growth of maritime transport has also made development of ports necessary. This development has made operations of ports more complex. Port managements, in this complex and large system, have difficulty to decide on the issues related to ports productivity and optimization. At this point, simulation can be seen as a useful decision support system. It helps to determine the most suitable system by comparing different scenarios.

The aim of this study is to identify the most appropriate yards that import containers are going to be stacked in a container port. Two scenarios have been determined in order to designate appropriate

*Corresponding author: gaydin@kocaeli.edu.tr

yards in blocks for the import containers coming from the vessels which belong to the services stopping by port and to distribute the work load in a balanced way. By comparing the current operation and these scenarios, it is aimed to have a layout model that reduces the total discharging time, balances the work load with the least lead times and minimize the number of bottlenecks.

The rest of paper is organized as follows: In section two, the concept of "warehousing and stack logistics" has been introduced and a literature review for related studies has been given. A case study that carried out within the scope of this study, has been presented in the third section. The study has been concluded with the results in the fourth section.

## 2. Material and Method

### 2.1. Warehousing and stack logistics

Container terminals are generally divided into three main parts as the quayside, the landside and the container yard. Besides, a container yard includes several blocks and each block consists of several bays [1]. In this context, warehousing and stack logistics which is the most important subject that affects the productivity of container ports, became more complicated due to the increase in container traffic. Due to the fact that having fixed size stowage, stack logistics concept became prominent. Warehouses which are separated into blocks in the ports, are used as couple of floors up from the ground for stacking. Location of containers is indicated with the stack block, row, column and floor information. Depending on the operational needs, containers are placed in different yards based on their type, damage conditions, hazardous materials that they include and import or export status. The location of containers is determined based on the stack planning. As it is difficult to reach directly one of the stacked containers which is on top of the other, the containers above the one that needs to be reached, are required to be transferred first. For a good stacking, there has to be accurate and complete information of vessel, discharging port and weight. Otherwise, it leads to material re-handling operation.

The common strategy for export containers are to place them side by side and one on top of the other if they need to be discharged in the same port. In vessel loading, as the containers with bigger tonnage need to be loaded first, lighter containers are stacked on top of the heavier ones. When planning import containers, yard reservation is done based on discharge amount without doing so much categorization. The reason is; not knowing the transport type and the information of the delivery during discharge of containers. However, by having this information, discharge distribution can be made accordingly. Common strategy for discharge containers is; stacking the same dated discharge containers in the same place. Due to not being able to estimate the delivery process of containers, yard and planning do not suit each other. Effectiveness of warehouse planning depends on a strategy which has a well determined stack configuration and a good estimation of distribution of containers' arrival. Due to the difficulty of defining these two factors, re-organizing continuously becomes inevitable. For this reason, most terminals use a stack strategy which is known as mixed stacking. According to this strategy, discharge plans are done based on a specified home port instead of vessel's arrival. Planning is done based on the information that is sent by agency before the vessel arrives. When the vessel arrives to the port, it is anchored to the appropriate yard on the wharf. By choosing the stack location, containers are stacked on top of each other based on their discharge port, type and weight information. Containers which belong to a vessel are distributed internally and stochastically without the need for warehouse reservation. As there is no reservation for stacking, a bigger yard in the warehouse can be used. At the same time, stacking and vessel loading criteria also match more; therefore, the frequency of re-handling is reduced.

In order to improve logistic processes, apart from container properties in stacking concepts, there are also additional parameters that need to be taken into account. During loading operations, stacking the containers in close yards reduces the transfer distance to a minimum level. Thus, operation can be completed with a high performance. Performance of stacking cranes (RTG) and transport equipment are lower than performance of quay cranes (SSG) in terms of their operation speed. For this reason, containers which belong to same vessel are distributed to couple of blocks in order to avoid potential bottlenecks and unnecessary waiting times in vehicles. As adding more work load to the equipment which have high usage frequency causes awaiting, work load of all stack equipment needs to be taken into account. It is possible to develop a solution that enables the most effective equipment usage by considering all these factors [2].

Export, import and empty containers are all landed to terminals in different ways. Import containers are firstly taken by quay crane to land or trolleys. Carriers take containers to a stacking yard which is not attached to quay. Soon after, container usually is taken to railway or motorway vehicles from stacking yard to deliver to the receiver. Stacking method is also affected by delivery mode of these containers. Once containers are discharged from quay cranes, they can be stored different yards depending on whether they will be shipped via motorway or railway transport. Export containers, on the other hand, are stored in a close area to loading wharf. They are taken to quay crane based on loading plan to ship. Empty containers follow the same process with export containers but stack processes are carried out in a different area [3].

## 2.2. Literature review

When the literature regarding container terminals is reviewed in detail, it can be categorized under three main topics which are simulation, mathematical modelling and heuristic algorithms. Some studies about this subject are mentioned below:

ARENA software utilized within the scope of this study was initially used by Merkuryev et al. [4] for container terminal operations of Riga Port. Esmer and Tuna [5] investigated simulation as a decision support system in port operations and analyzed the importance of this subject in national and international literature. Huang et al. [6] classified vessels and wharfs based on actual data and compared the results of classified and unclassified scenarios by the help of simulation. Lee et al. [7] proposed a mixed integer programming model for quay crane scheduling problem. Sacone and Siri [8] studied on the operational planning of port container terminals with an integrated method of simulation and optimization. Hadjiconstantinou and Ma [9] used simulation in order to verify the results of the optimization model for container terminal operations, to test the effectiveness of the use of port carriers, and to analyze the resource requirements for future port expansion. Lee and Wang [10] proposed a mathematical programming model for the quay crane scheduling problem. They also developed a proximity algorithm to obtain solutions close to the optimum solution. Carteni and Luca [11] presented simulation models for planning a container terminal at tactical and strategic level. Kemme [12] evaluated the system by comparing the carrier crane system with the existing system through simulation. Chen et al. [13] have proposed a scheduling model that optimizes assignment of berths, equipment structure and conveyor routing at the container terminals. They used a two-step genetic algorithm in order to solve the model. Esmer et al. [14] proposed a simulation-based modeling approach for continuous berth allocation of İzmir Alsancak port. Lin and Ting [15] applied the simulated annealing algorithm to solve the dynamic port allocation problem for discrete and continuous events. Golias et al. [16] proposed a model for a port entry schedule to minimize the total service time given to vessels at the container terminals. XiaoLong et al. [17] used a particle swarm optimization algorithm for the berth layout model to minimize the total duration of staying at the port and the additional costs of the vessel at the wharf. Tao and Qiu [18] developed a method using an integrated evolutionary search function and simulation by studying on a vehicle shipment problem that regulates the loading and unloading tasks of the vehicles at the container terminals. He [19] studied to provide a compromise between energy and time saving on integrated berth and quay crane assignment problem. It is aimed to reduce energy consumption in port operations with the help of a mixed integer programming model. Pratap et al. [20] proposed a decision support system by using meta-heuristic models to minimize the waiting times of vessels and deviations between customer priorities. Budipriyanto et al. [21], handled berth allocation problem by using discrete event simulation. They presented two scenarios as non-collaborative and collaborative response in order to evaluate port performance under uncertainty. Stopka and Kampf [22] studied on determining the most appropriate location for storage and handling operations in a container port.

Today, intensive use of maritime transport arrangements in an efficient manner will reduce costs of port operations and, ultimately, the costs of shipping companies. Discharge yard planning based on arrival dates of vessels as in blocks is considered to be an appropriate approach for both optimal yard use and reducing handling operations. Simulation is effectively utilized in order to evaluate different scenarios for layout problems as shown in the study of Azimi and Soofi [23]. In this study, simulation has been utilized as a decision support system in order to determine suitable yard layout in a container port. By the way, it is aimed to decrease the operation time, to provide fair usage of the equipment, to reduce the idle waiting times and accordingly the energy and labor costs.

When the studies about yard layout at ports are examined in depth, we observe that a study which provides low labor and energy costs, fair usage of equipment and minimum discharging and waiting times together and achieves these objectives concurrently has not been realized. This is the original contribution of this paper.

# 3. Results

## 3.1. Simulation modelling for a container terminal

This study was carried out in a medium-sized port in the Marmara region in Turkey, which operates internationally. When the current situation is examined, the process starting with vessels' approaching to the port is completed with the containers being discharged from the vessel and placed in the importing yards and then being removed from the port with the appropriate way of transporting the containers. Currently there are 5 yards available for import, export and inspected containers. Since we examined discharging operations, this study is realized for effective assignment of import containers to mentioned yards. In this context, it is aimed to complete the discharge procedures of the vessels coming to the port as soon as possible, to minimize the waiting times of quay and yard cranes of the carrier vehicles and to ensure fair use of all equipment. Alternative scenarios developed for this aim were compared with each other with the help of performance indicator values which were obtained by using the Arena 14.0 simulation program. Thus, the most appropriate layout was decided. Figure 1 shows the yards that can be used for import containers.

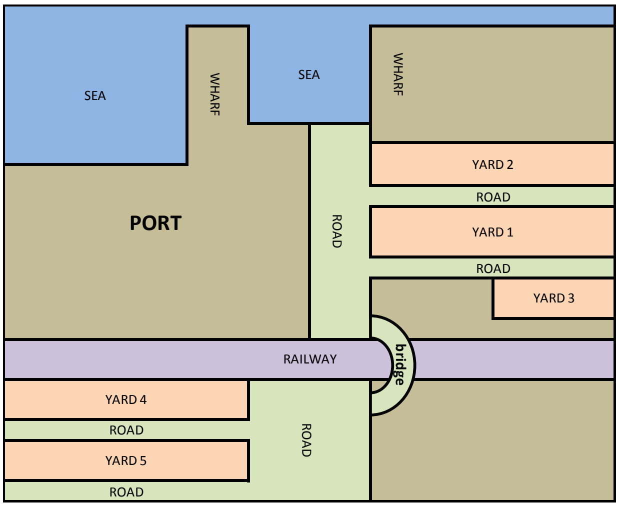


**Figure 1.** Layout for container port

Import containers discharged from vessels that are arriving to port can be stacked as in 4-5 layers in yards numbered 1-2-3-4 according to mixed discharge yard planning. Import containers that have been inspected at the port in average within 1-1.5 days, are stacked on the average of 2-3 layers in the yard number 5. For this reason, it is necessary that these two container types should not be stored in the same place, because the stacking of the inspected containers and the import containers, which are newly discharged, will increase the number of re-handing due to having them in the same place. In the literature survey, it was determined that in stacking 4 layers of above, the total number of re-handling in “the mixed discharge yard planning” is higher than “the discharge yard planning based on containers' arrival dates as in blocks”.

In this study, minimizing the total duration of discharge operation based on the yard planning in blocks for the services that belong to vessels, the removal of the bottlenecks and balancing the work load distributions of the equipment were determined as the performance indicators of the study. For this purpose, two different scenarios were developed as alternatives to the current situation. Outputs of these three cases were obtained by simulation were compared each other and the most suitable yard layout was determined.

In the current situation, the first sections of the yards numbered 4 and 5 have been allocated to import containers. What is important here is that the containers which were inspected and stacked in the yard 5 should not be stacked in the same block with the containers which is about to be discharged from the vessel. In Scenario 1; the first sections of yards 1 and 2 and the last sections of yards 3 and 4 are reserved for import containers. Scenario 2; the first section of the yard 1, whole of yard 2, the last section of yard 3 and the first section of yard 5 are reserved for import containers. Simulation studies assume that weather conditions are appropriate, there are no faults in the equipment, and the port is operating with the same performance on three shifts.

There are 8 vessel lines operating in this port. The two-month data related to number of total import containers belonging to each vessel line were collected for this container port. The statistical distributions of the obtained data were determined by using the Input Analyzer module of Arena program. The data obtained from this module were used as input in the simulation. The number of import containers arriving to the port with the vessels regarding these lines and their statistical distributions are shown in Table 1.

**Table 1.** Distribution information for discharging amount of each vessel

| Vessels | Discharging Amount | Distribution | Distribution Information |
|---|---|---|---|
| Vessel A | 174 - 297 | Uniform | UNIF(174, 297) |
| Vessel B | 11 - 54 | Beta | 10,5 + 44 * BETA(0.463, 0.341) |
| Vessel C | 27 - 164 | Exponential | 27 + EXPO(30.1) |
| Vessel D | 62 -309 | Beta | 62 + 247 * BETA(0.715, 0.803) |
| Vessel E | 82 - 238 | Normal | NORM(152, 46.7) |
| Vessel F | 7 -141 | Normal | NORM(48.8, 34.9) |
| Vessel G | 184-279 | Beta | 184 + 95 * BETA(0.565, 0.601) |
| Vessel H | 278 - 513 | Beta | 278 + 235 * BETA(2.13, 2.2) |

There are two types of equipment transporting containers (20' and 40') in the port as quay crane (SSG) and yard crane (RTG). The unit carrying times of the equipment operating in the discharging operation are shown in Table 2. Since the containers are generally discharged as double during the operation, it is assumed that SSGs discharge the 20' containers in this manner. There is no difference between the discharging times of the 20' and 40' containers. The stacking times of RTGs for 40' and a couple of 20' containers are presented separately in Table 2.

**Table 2.** The unit stacking times of equipment

| Equip. | Stacking time (sec) | Distribution | Distribution Information | Definition |
|---|---|---|---|---|
| SSG | 98.5-191 | Beta | 98.5 + 92 * BETA(0.717, 0.923) | 20' and 40' containers |
| RTG | 189-261 | Beta | 189 + 72 * BETA(0.522, 0.806) | 40' containers |
| RTG | 192-310 | Beta | 192 + 118 * BETA(0.363, 0.313) | A couple of 20' containers |

The results obtained from simulation model are presented as follows.

### 3.1.1. Results of current situation

As a result of the current situation, the total discharging time was determined as 33.68 hours. The average waiting time of the carriers under the RTG was 1 min, the maximum waiting time was 2 min. In the current situation, a total of 8 RTGs are used, 2 of which are each RTG. The average waiting time is 4 min and the maximum waiting time is 7 min for carriers under SSG. The average operation completion times of arriving vessels are shown in Table 3 and the usage rates of RTG and SSG equipment for current situation are given in Figure 2 and Figure 3 respectively.

**Table 3.** Operation completion time of vessels for current situation

| Vessels | Average Discharging Time (hour) |
|---|---|
| Vessel A | 5.85 |
| Vessel B | 3.49 |
| Vessel C | 3.31 |
| Vessel D | 2.19 |
| Vessel E | 4.74 |
| Vessel F | 3.35 |
| Vessel G | 4.85 |
| Vessel H | 5.9 |

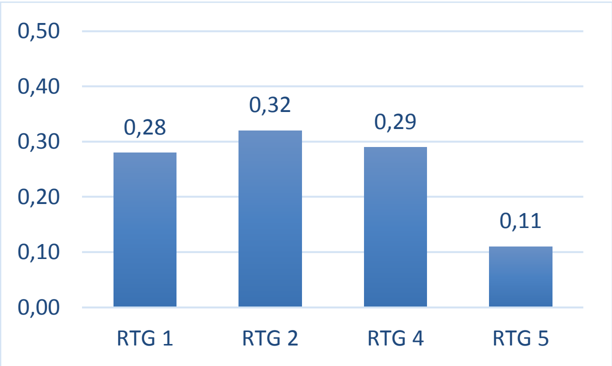


**Figure 2.** Usage rates of RTGs for current situation

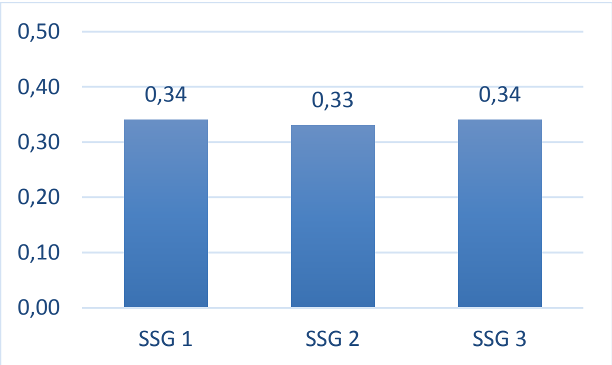


**Figure 3.** Usage rates of SSGs for current situation

For the validation of the simulation model, the average discharging times belonging to real life were compared with the average discharging times related to current situation, and the obtained results are shown in Table 4. It is seen that the error margin is less than %2.

**Table 4.** Comparison of average discharging times regarding real life operation and simulated current situation

| Vessels | Real life | Simulated current situation |
|---|---|---|
| Vessel A | 6.28 | 5.85 |
| Vessel B | 3.10 | 3.49 |
| Vessel C | 3.54 | 3.31 |
| Vessel D | 2.41 | 2.19 |
| Vessel E | 4.65 | 4.74 |
| Vessel F | 4.20 | 3.35 |
| Vessel G | 4.65 | 4.85 |
| Vessel H | 5.50 | 5.9 |
| Total | 34.33 | 33.68 |

In this simulation, each scenario was replicated ten times. In addition, t-test was applied to average times in Table 4 and it is determined that, there was no statistical difference between discharging times of real life and simulated current situation with significance level of 5 percent. As a result of validation, it is seen that our simulation model is credible.

### 3.1.2. Results of scenario 1

As a result of Scenario 1, the total discharging time was determined as 24.76 hours. The average waiting time of the carriers under RTG is 1 min and the maximum waiting time is 7 min. The average and maximum waiting time of carriers under SSG are 4 min and 7 min, respectively. The average operation completion times of arriving vessels are given in Table 5 and the usage rates of RTG and SSG equipment for scenario 1 are given in Figure 4 and Figure 5 respectively.

**Table 5.** Operation completion time of vessels for scenario 1

| Vessels | Average Discharging Time (hour) |
|---|---|
| Vessel A | 2.74 |
| Vessel B | 3.54 |
| Vessel C | 2.15 |
| Vessel D | 1.95 |
| Vessel E | 2.95 |
| Vessel F | 2.92 |
| Vessel G | 2.92 |
| Vessel H | 5.59 |

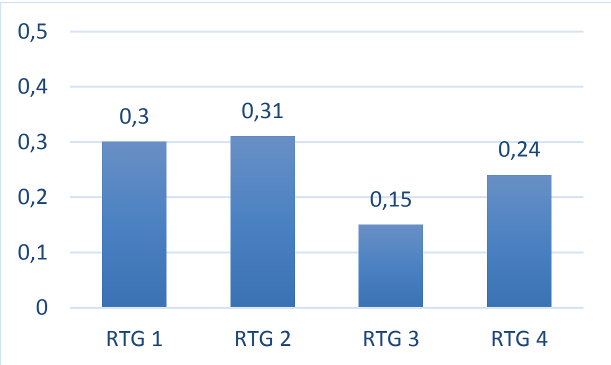


**Figure 4.** Usage rates of RTGs for scenario 1

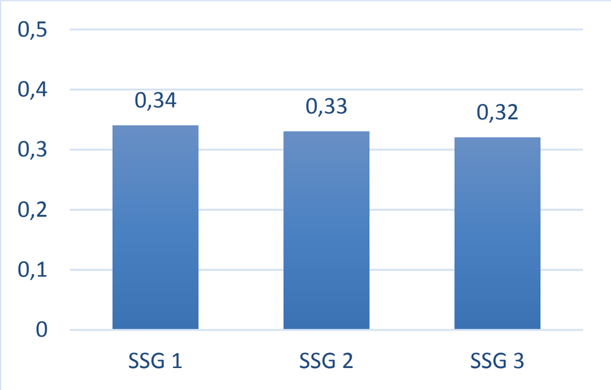


**Figure 5.** Usage rates of SSGs for scenario 1

In Scenario 1, there are 2 for RTG 1-2 and 4 each, 1 from RTG 3 and a total of 7 RTG was used. Therefore, the usage rate of each RTG is around 0.15.

### 3.1.3. Results of scenario 2

As a result of Scenario 2, the total discharging time was determined as 23.02 hours. The average waiting time of the carriers under RTG is 1 min and the maximum waiting time is 3 min. Average and maximum waiting time of carriers under SSG are 5 min and 8 min, respectively. The average operation completion times of arriving vessels are given in Table 6, and the usage rates of RTG and SSG equipment for scenario 2 are given in Figure 6 and Figure 7 respectively.

**Table 6.** Operation completion time of vessels for scenario 2

| Vessels | Average Discharging Time (hour) |
|---|---|
| Vessel A | 2.79 |
| Vessel B | 2.25 |
| Vessel C | 2.21 |
| Vessel D | 2.18 |
| Vessel E | 2.87 |
| Vessel F | 2.77 |
| Vessel G | 2.66 |
| Vessel H | 5.29 |

In Scenario 2, a total of 7 RTGs were used: 2 from RTG 1, 3 from RTG 2, 1 from RTG 3 and RTG 4. Therefore, RTG 1-2 and 3 usage rates are around 0.15. In this scenario, the yard at the end of the inspection yard is used as the stacking yard, so the RTG 4 stacks in a very small yard. Therefore, the usage rate is low. Table 7 provides a comparison of the current situation and scenario results.

When Table 7 is examined, scenario 2 shows a 31.65% improvement in the total operation time of the current situation. In Scenario 2, when the minimum RTG usage rate is determined, the usage rate of RTG 4 is ignored because this RTG stacks on a small area. It is seen that scenario 2 provides the most appropriate layout when the objectives such as the improvement of operation time and fair usage of the equipment are taken into account.

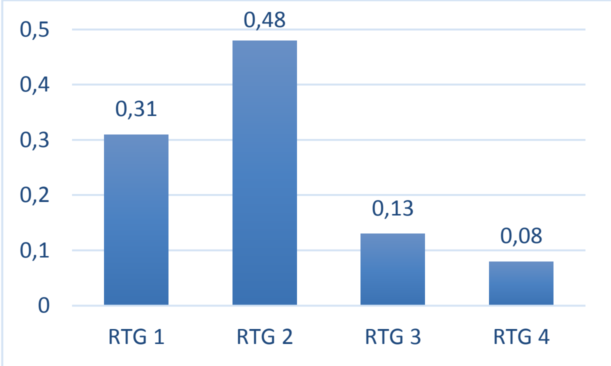


**Figure 6.** Usage rates of RTGs for scenario 2

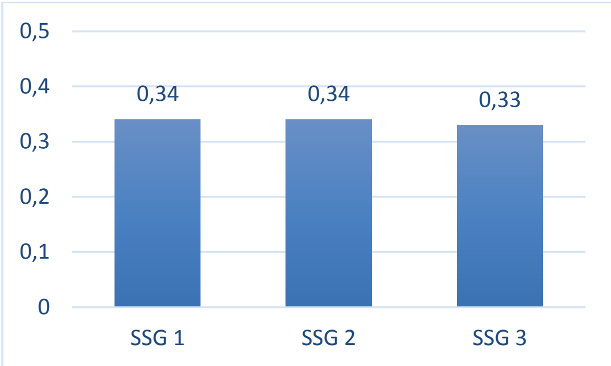


**Figure 7.** Usage rates of SSGs for scenario 2

**Table 7.** Comparison of current situation, scenario 1 and scenario 2

| | Current Situation | Scenario 1 | Scenario 2 |
|---|---|---|---|
| Total discharging time (hour) | 33.68 | 24.76 | 23.02 |
| Usage rate of RTG (min/max) | 0.11/0.16 | 0.12/0.16 | 0.13/0.16 |
| Usage rate of SSG (min/max) | 0.33/0.34 | 0.32/0.34 | 0.33/0.34 |

## 4. Discussion and Conclusion

Ports are an important part of the international supply chain. The role of container ports, where vessels are unloaded and loaded, is a major factor in the international maritime transport. For this reason, the most efficient way of carrying out intra-port activities is important for increasing customer service level. This study was conducted to determine the effective yard layout at a container port. It is aimed to minimize the discharging time of vessels that are arriving to port, reduce waiting times of carriers, use equipment fairly and decrease their energy and labor costs as a natural result.

The current situation and the two designed scenarios are simulated according to the collected data and the obtained results are summarized as in Table 7. When the duration needed to complete the discharge operation is examined, it is determined that the discharge duration in scenario 2 is shorter than the current situation and the duration of the other scenario. Also, if scenario 2 is implemented, 31.65% of the total discharge operation duration will be improved compared to the current situation. On the other hand, the decline in the discharging time also means a decrease in energy and labor costs. When the hourly fuel expenditure of the equipment is calculated, it is found that the selection of scenario 2 results in a fuel cost of 9,600 TRY less than the current fuel cost.

There is no big difference in the results of these three scenarios to examine the bottlenecks that can arise in the yards. It is stated by the port management that the waiting time under the RTG is about 1 min. Distribution of discharged containers equally to RTGs is also one of the important issues. For this purpose, it is aimed to have the equipment usage rates close to each other. In current situation and designed scenarios, RTGs (1 and 2) operating in these yards are slightly higher, due to the fact that discharging of main vessels are planned closer to the port and to RTG 1 and 2 yards which have higher capacities.

In Scenario 2, container inspection is carried out on a part of the yard number 4, so import containers can only be stacked on the other part of the yard. Because this yard has a lower storage capacity, the usage rate of RTG 4, which runs on yard, is also lower. Decreasing the number of RTGs used in the proposed scenario contributes to the reducing of labor, equipment and energy costs. When all the results are evaluated collectively, it is seen that scenario 2 is the best alternative to achieve the purpose of this study. As a future research suggestion, optimum yard layout can be obtained by mathematical modelling for this container port.

## Acknowledgment

This study was supported by Kocaeli University Scientific Research Projects Unit (Project number: 2017/017). The authors thank to Kocaeli University Scientific Research Projects Unit.

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