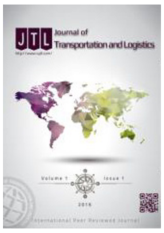

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JTL

Journal of Transportation and Logistics
7 (1) 2022

İSTANBUL UNIVERSITY PRESS

DOI: 10.26650/JTL.2022.1039692

RESEARCH ARTICLE

Examining the Efficiency of Automation in Container Terminals

Yaser Jobran[1], **Gökhan Kara**[2]

ABSTRACT

An increase in container traffic, larger tonnage of vessels, scarcity of port area, and shorter turnaround times have driven terminals to process more containers in less time and less space. Thereby, the increasing focus on costs, safety, and environmental control is forcing terminal operators to search for innovative solutions. Automated container terminals are the potential candidates to improve the performance of container terminals and represent a challenge to any subsequent future fluctuations in maritime transport.

In this study, we examine the improvement in the performance of container ports by adopting automation through simulation modeling. The effect of the automated guided vehicles and automatic stacking cranes-based automatic container terminal system (AGV-ACT/Automated Guided Vehicles - Automatic Container Terminal system) on container handling operations was evaluated. To create a complete port simulation model, the main objects of the container terminal such as tugboats, berths, quay cranes, stacking blocks, stacking cranes, horizontal transport vehicles, external trucks, and the layout of the terminal are simulated as a whole. Firstly, we created a model representing the existing port to evaluate the overall performance of the port and to validate the simulation model by comparing the actual data with those of the real system. Then, a simulation model for the proposed automatic system was created and evaluated. The simulation model was divided into four main logics: ships arrival and berth allocation, ship loading/unloading, external trucks arrival, and containers storage/retrieval logic.

The results of the two systems were compared based on the performance criteria such as ship turnaround time, external trucks turnaround time, and equipment utilization rate. Automation has reduced the turnaround time of the ships and provided a smooth movement for the equipment which showed a high utilization rate. The automated system decreased the ship turnaround time from 9.52 hours to 7.81 hours (18%). The reduction in the waiting times of the container transport vehicles for quay cranes reached 47% and 30% in berths 1 and 2, respectively. On the other hand, external trucks' turnaround time increased by 124% as only one ASC (Automatic Stacking Crane) is run in each block to perform both seaside and landside operations (seaside operations were prioritized). Automation has improved the overall performance of the terminal. Also, the layout of the automated handling system raised the storage capacity of the port. In the new proposed automated layout, the storage area capacity increased by 27.27%.

Keywords: Container Terminals, Simulation, Automation

Submitted: 21.12.2021 • **Revision Requested:** 22.01.2022 • **Last Revision Received:** 12.02.2022 • **Accepted:** 19.02.2022

[1] **Corresponding author:** Yaser Jobran (Dr.), Istanbul University- Cerrahpaşa, Department of Maritime Transportation Management, Istanbul, Turkiye.
E-mail: yasserjobran@ogr.iu.edu.tr ORCID: 0000-0002-6309-8258

[2] Gökhan Kara (Doç. Dr.), Istanbul University- Cerrahpaşa, Department of Maritime Transportation Management, Istanbul, Turkiye. E-mail: karagok@istanbul.edu.tr ORCID: 0000-0001-5796-8707

Citation: Jobran, Y., & Kara, G. (2022). Examining the efficiency of automation in container terminals. *Journal of Transportation and Logistics, 7*(1), 137-155. https://doi.org/10.26650/JTL.2022.1039692

1. Introduction

Shipping lines have begun operating larger, faster, and deeper vessels to handle the increasing freight volume and reduce their operating costs by capturing economies of scale. The port authorities are faced with enormous pressures to find and deploy effective solutions to process more containers in less time and less space at a lower cost. This is an expected result owing to new massive container ships, more container traffic, and shorter turnaround times, safety requirements, the need to reduce costs, ever stricter environmental regulations, as well as the scarcity of the land, the increase of labor cost, and lack of labor resources.

At the same time ports and terminals have evolved and from the 2010s have entered into a fifth stage of evolution characterized by their digital transformation and alignment with Industry 4.0 practices. Internet of Things and sensing solutions, cybersecurity, horizontal and vertical system integration, and simulation and modeling are the pillars of Industry 4.0. The Fourth Industrial Revolution (Industry 4.0) is the trend towards automation and data exchange in manufacturing technologies and processes.

Recently, there had been an emphasis in research on the optimization and control of systems. Besides, advances in information technology, telecommunications, data management, computation tools, and robotics have paved the way for automation as a new approach to a container handling system [1].

Terminals reached a higher level of automation in comparison with other types of freight terminals. This is attributed to the practical characteristics of container terminals, such as the standardization of the means of transport (containers), the standardization of how freight is handled, and the high level of interchanges taking place [2].

The first automation experience was in ECT Delta Terminal in 1993 (Rotterdam). The terminal used automated unmanned yard cranes (RMGs) for handling containers in the storage yard, and automated guided vehicles (AGVs) for horizontal quay-yard container movement. Later on, HHLA's CTA facility in Hamburg implemented the automation of container handling systems in 2002. Since that time, automation in container terminals has become the standard for designing and operating large terminals, providing a cost-efficient alternative for traditional operations [3-4].

The list of automated and semi-automated terminals has not stopped growing. Currently, almost 40 numbers of semi or fully ACT are working worldwide with an estimated $10 billion investment [5]. Thus, after decades of continuing development, automation has become an opportunity that most container terminal operators cannot overlook.

An automated container terminal is a terminal with the most advanced technologies in the world that realizes real-time control and dynamic scheduling of container handling, reduces the turnaround time of ships and trucks, reduces labor and maintenance costs, increases the efficiency of cargo handling, and supports energy conservation and environment protection.

One survey shows that almost 75% of container terminals consider automation risky in order to remain competitive in the next 3 to 5 years, while 65% see it as a key for a secure operational system [21]. Automation introduces an opportunity for terminal operators to create additional value in terms of greater safety and heightened environmental protection. Automation minimizes the potential for human error and improves safety. It also helps to avoid unexpected interruptions that impact productivity and profitability. Automated terminals enhance occupational safety by separating the manpower and the machines. All operations will be controlled from the control rooms, which in turn will increase productivity. However, the most crucial safety element in any automated terminal is maintaining strict separation between automated areas and those with people working in them. Access control, safety systems, and physical boundaries need to be taken into consideration when implementing automation to the system.

Generally, automatic equipment can perform the work cycle without human intervention. Practically, automated container terminals can be fully or semi-automated. In the fully automated terminals, automation of the horizontal transport equipment in the yard and yard cranes has been automated. The ECT Delta Terminal has adopted automated stacking cranes (ASC) for storage operation and automated guided vehicles (AGV) for transferring containers between quay cranes and yard cranes. In semi-automated container terminals, just yard cranes are automated while manual vehicles are still used for horizontal transport operation.

Many research papers were published to compare automated container terminals and conventional terminals for different sizes and capacities in terms of cost and productivity. Kim et al. [6] introduced different new conceptual automated containers handling systems. The study shows that automation can increase the productivity of the entire container handling system. However, they stated that the cost of construction is very high, and in some situations, the throughput rate of the system can be adversely affected due to lower flexibility during operations. Rademaker [7] investigated the feasibility of terminal automation for container terminals with a handling capacity of up to 500,000 TEU (mid-sized terminals) by analyzing the costs and benefits of the automated terminal. Based on the discounted cash flow calculations, he illustrated that, though the rate of return for the automated terminal concept is 5% higher than that of a conventional terminal concept, it is not sufficient for the project to be feasible. He stated that the main reason for the negative result of the financial feasibility study lies in the high initial capital outlay that is required, and the results of the calculation can be positively influenced by spreading the financial investment required over an extended period while increasing the terminal throughput and controlling the handling charge per TEU. Saanen [3] presented a comparison employing simulation and cost modeling between the operational productivity of an AGV-RMG and an ALV-RMG (Automated Lifting Vehicle-Rail Mounted Gantry) terminal. Besides, he compared the two automated concepts with a manually operated shuttle carrier (a one over one straddle carrier, in essence). He mentioned that even though the project risk may be higher, the overall cost of the automated alternative is significantly lower than the manual alternative and with a difference in cost per move of approximately 3 Euro. The additional investment will pay back after 100,000 QC moves. Therefore, automation pays off and is the right concept for the future. Liu et al. [8] designed and evaluated 4 different ACT concepts. A simulation model was developed and used to evaluate the performance of each terminal system for the same operational scenario. A cost model was used to evaluate the cost associated with each terminal concept. The results indicate that automation could improve the performance of conventional terminals substantially and at a much lower cost. Among the four concepts considered, the one based on automated guided vehicles was found to be the most effective in terms of performance and cost. A manual low-volume container terminal equipped with straddle carriers was compared with an automated container handling system (ASC and AGV) by Ballis et al. [9]. For both systems the layout was designed, a reasonable level of service was adopted, and the required amount of equipment was determined using computer simulation. The results showed that the total cost per container and the layout requirements do not differ extremely though differences exist in the investment capital and the personnel required.

The previous studies were conducted specifically to compare manual or conventional container terminals with automatic container terminals. Many studies have been conducted to enhance the throughput or efficiency of automated container terminals (Yanga et. al, 2018; Luo Yanga et. al., 2016; Luo and Wu, 2015; Lau and Zhao, 2008; Duinkerken et. al., 2008; Vis and Harika, 2004; Grunow et. al., 2004).

Besides a large number of scientific research relevant to automated container terminals, many studies have been implemented by various port authorities and terminal operators looking to intensify and enhance their existing container handling operations. TraPac terminal in Los Angeles decided to convert operations on the terminal from manual to a highly automated system. Automation has helped the TraPac terminal stay competitive in an increasingly challenging business environment and stand against the rapidly rising labor and regulatory compliance [10]. Likewise, DP world Brisbane Terminal, with an investment budget of about 250 million dollars, has been converted from reach stackers to automatic stacking cranes in an integrated solution with manned shuttle carriers. The overall annual capacity has risen from around 500,000 TEU to 900,000 TEU, which added to the DP World Brisbane Terminal a significant future development capability [11].

Automation has its benefits on productivity, but at the same time, it has a considerable capital investment cost that would not be recovered unless there is a specified throughput that keeps the utilization of the automated equipment at a high level and reduces the payback period. Therefore, the decision for automation is highly dependent on the characteristics of the terminal, such as availability of land, land price or lease, the calling pattern, local labor costs, the demands from the shipping lines, and the evaluation of alternative handling systems.

The main contribution of this study is to show how strategic decisions regarding the future development of a container terminal can be supported by a simulation study. One of the most important advantages of this study is that it simulates the terminal as a whole, taking in consideration by details all operations and resources in the terminal.

This paper is organized as follows. In section 2, The steps that were followed to conduct this study are provided. In section 3, a detailed description of the simulation model that used in this study is introduced. Numerical experiments and the computational results are presented, analyzed, and discussed in section 4. Finally, conclusions are given in section 6.

2. Methodology

- A literature review of automated container terminals and simulation methods used to improve port performance was conducted.
- A simulation model has been created that reflects the existing terminal layout and related container handling operations.
- The simulation model has been modified to suit the proposed automated system (AGV-ACT).
- Each simulation model was run based on the same operational scenario, i.e., containers' volumes, draft, and the length of berths.
- Performance criteria including ship turnaround time, truck turnaround time, and the equipment utilization rate were used to evaluate and compare the systems.
- Finally, the simulation results were presented and discussed.

3. Port Simulation Model

Simulation is a recommended tool for analyzing complex systems such as ports. The following main steps for building a simulation model can be recognized [12]:

1. Problem analysis and information collection: At first, the problem itself should be analyzed. The modeler collects information that represents the problem properly. This activity includes identifying input parameters, performance parameters of interest, relationships among parameters and variables, rules governing the operation of system components.
2. Data collection: It is necessary to estimate the model input parameters. Modelers are able to make assumptions about distributions of random variables in the model. In case of missing data, it is possible to assign parameter ranges and simulate the model according to those ranges. Also, we need data collection to validate the model. That is, the output statistics of the model are compared with their counterparts in the real system.
3. Building the model: Once we have thoroughly studied the problem and collected the required data, we can create a model and implement it as a computer program. The computer language used may be a general (e.g., C++, Visual Basic, FORTRAN) or special-purpose language simulation (e.g., Arena, Promodel, GPSS).

In this study, Arena simulation software was used to create a simulation model of the port. Two different models were carried out to analyze port operations and evaluate the enhancement in port performance by the application of automation to the container handling operations. The first model has represented the existing layout and a manual operation system. It was used to evaluate the current performance of the port and check model validity. In the second model, the proposed automated system (AGV-ACT) was deployed. An automated system (AGV-ACT) is based on an automatic stacking crane for yard operations and an automated guided vehicle for the horizontal transport operations of containers. The second simulation model was used to analyze and examine the efficiency of automation in the container terminals and see how the port's overall performance can be developed by replacing a manual handling system with an automated one.

3.1 Problem analysis

The examined container terminal is one of Turkey's largest and most modern ports, with qualified human resources, renewed equipment groups, and automatic system investments that support high business volume. The container terminal can handle container ships up to 22 rows and 400 meters in length. The annual handling capacity is 2,100,000 TEU. Figure 1 shows the general layout of the port.

The port has a total of 6 berths with a total length of 2,180 meters. The features of the berths are summarized in table 1. Berths 1 and 2 are each equipped with 4 and 3 quay cranes, respectively, while six mobile harbor cranes serve berths 4 and 5. Berth 6 is used for small container ships and general cargo ships. The storage area consists of 22 storage blocks, each of which is equipped with one RTG. There are 28 RTGs in the port, 22 RTGs are in use, and 6 RTGs are used as a backup. The containers' horizontal transport operation inside the terminal is carried out with 59 manual terminal tractors. All the handling equipment of the port is shown in table 2. The annual number of ships calling at the port and the port's annual handling capacity are shown in Figures 2 and 3, respectively. The port operates 24 hours a day, with three 8-hour shifts each day.

Figure 1. Port layout

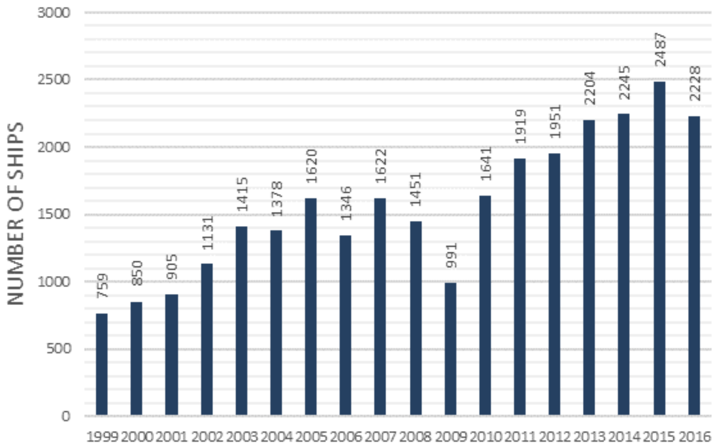


Figure 2. The annual number of ships calling at the port

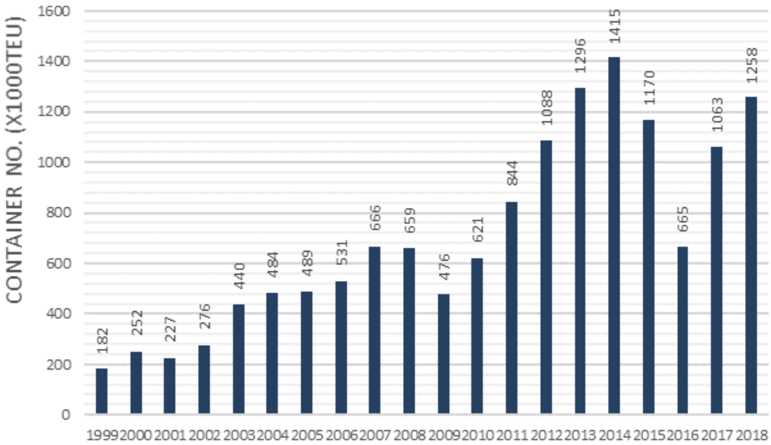


Figure 3. Annual throughput of the port

Table 1. Berths' dimension and classification

Berth No	Length	Width	Draft	Service Type
1	500 m	40 m	16.5 m	Container
2	420 m	35 m	16.5 m	Container
3	370 m	35 m	14.0 m	Container
4	370 m	35 m	15.0 m	Container/G. Cargo
5	370 m	35 m	12.0 m	Container /G. Cargo
6	150 m	40 m	9.0 m	General Cargo

3.2 Performance measures of interest

Performance measures that directly affect the average cost per container (ACC) handled at the terminal were used to evaluate the new proposed system and to compare it with the existing one. The performance measures used in simulation model evaluation are shown in table 3.

3.3 Input Data

The data used in the simulation model were obtained from the daily documentary records of the current terminal as much as possible, and all missing data were assumed based on previous studies similar to our case. The principal distributions and parameters used in the simulation model are summarized in table 4.

Table 2. Handling equipment of the port

Equipment	Number	Length	Capacity
SSG Crane	4	22 Row Outreach	55 ton
	3	20 Row Outreach	55 ton
	2	24 Row Outreach	65 ton
Mobile Harbour Crane	1	12 Row Outreach	104 ton
	2	18 Row Outreach	104 ton
	2	17 Row Outreach	104 ton
	1	18 Row Outreach	104 ton
Reach Stackers	14	5+1 High	45 ton
Empty Stacker	2	5+1 High	8 ton
	3	5+1 High	9 ton
	2	5+1 High	7 ton
Terminal Tractor	59	-	65 ton
RTG	4	7+1 wide, 5+1 high	45 ton
	24	7+1 wide, 6+1 high	40 ton

Table 3. Performance measures used in the simulation model.

Performance measures	Definition
Annual throughput	It is the total number of imports, export, and transshipment containers handled by the quay cranes per year.
Ship's turnaround time	The time that is taken between the arrival of a vessel and its departure.
Truck's turnaround time	The average time the truck takes to enter, serve, and exit the door (processing time at the door is not included).
Equipment utilization rate	The equipment idle time.

Table 4. Input data used in the simulation model

Input data	Value	Unit
Number of working days	365	day
Number of working shifts	3	-
ships time between Arrival	4	hour
Containers Dwell time (Import-Export)	15/7	day
Transshipment Rate	70	%
TEU factor	50	%
Berth length	2,180	m
Number of berths	6	No.
Terminal area	402,115	m^2
Number of field slots	8,994	No.
Terminal capacity	2,100,000	TEU
Number of storage blocks	22	No
Stacking height of the containers	6 + 1	TEU
External trucks Time between arrival (Loaded-Empty)	EXPO (2)	min.
Number of tugboats	5	No.
Equipment travel distances *	-	m.
Equipment travel time **	-	min
Travel speed of equipment (RTG - TT)	130 – 660	m/min.
Cycle time of quay cranes (STS)	144	second
Cycle time of mobile harbor cranes (MHC)	240	second
Cycle times of yard cranes (RTG)	UNIF (2.5,3.5)	min.
Tugboat speed	420	m/min.
Time to tie and unfasten tugboat	10	min.
Number of port gates	3	No.
Service time at gates	TRAN (2,3,5)	min.
Number of gate lane	2	No.

* Equipment travel distances are simulated according to the actual plan of the port.
** Equipment travel times are automatically calculated by the program based on actual travel distance and equipment speed.

It was assumed that the ships arrive at the port at a fixed rate (ship every 4 hours). Later, the number of containers to be loaded and unloaded on each ship was determined. We divided the ships into three types (small, medium, and large), Features of the ships are shown in table 5.

Table 5. Ship's data used in the simulation model.

Ship Type	G1	G2	G3
Ship capacity (TEU)	8,000	4,000	1,500
Ship arrival probabilities (%)	40	40	20
Number of unloaded containers (TEU)	600	400	200
Number of loaded containers (TEU)	100	80	50

3.4 Assumptions and limitations of the model

The model should simulate the actual operating system and processes as much as possible. However, assumptions were made to avoid a high level of detailing that is not important for this study to primarily focus on aspects related to the assumed performance measures. The main assumptions of the simulation model are:

- Although yard cranes differ slightly in their technical specifications, it was assumed that all cranes are of the same type.
- It was assumed that the working conditions of the terminal are not affected by weather conditions and do not differ between working shifts.
- Cranes always work well and are assumed to be able to service vessels 24/7 at all times.
- Failure of equipment was not included.
- There are no restrictions on ship draft and water depth.
- Only one ship can dock per berth at the same time.
- The horizontal movement of the quay cranes is neglected and the cranes do not exceed (or overtake) each other.
- The productivity of cranes was taken as constant.
- It was assumed that all containers are TEU containers.
- There are no direct transactions between external trucks and quay cranes. In other words, all containers are stored in the storage blocks before being loaded on the ship or leaving the port by trucks.
- The storage blocks themselves are not simulated. Therefore, reordering (Marshaling) or re-mixing was not taken into account.
- Reefer containers were ignored.
- CFS operations were not included
- Ro / Ro and general cargo ships were not taken into account.

3.5 Building the Model

To create a complete port simulation model, the main objects of the container terminal, such as tugboats, berths, quay cranes, storage blocks, yard cranes, horizontal transport vehicles, external trucks, and the layout of the terminal were simulated as a whole. The simulation model was divided into four main logics: ship arrivals and berth allocation logic, ship loading/unloading logic, external trucks arrival logic, and containers storage/retrieval logic (Storage yard logic).

3.5.1 Ship arrivals and berth allocation logic

When a ship comes to the port, it tries to seize one of the available berths. If one berth is free, it was assumed that the ship is towed to the port with a single tugboat. There are five tugboats in total in the port. It was assumed that the anchorage area is 12,600 meters away from the tugboats station.

Considering the standard tugboat speed of 14 knots (420 meters/minute), the journey between the anchorage area and the berth takes about 30 minutes. According to the information obtained from actual operations, it was considered that linking up ropes with the vessel needs 10 minutes to be done. If there is no berth available, the ship waits in the anchorage area, and it is assigned to the end of a queue according to the FIFO (first-come, first-out) rule. The logic of ship arrivals and berth allocation created in the Arena simulation program is shown in Figure 4.

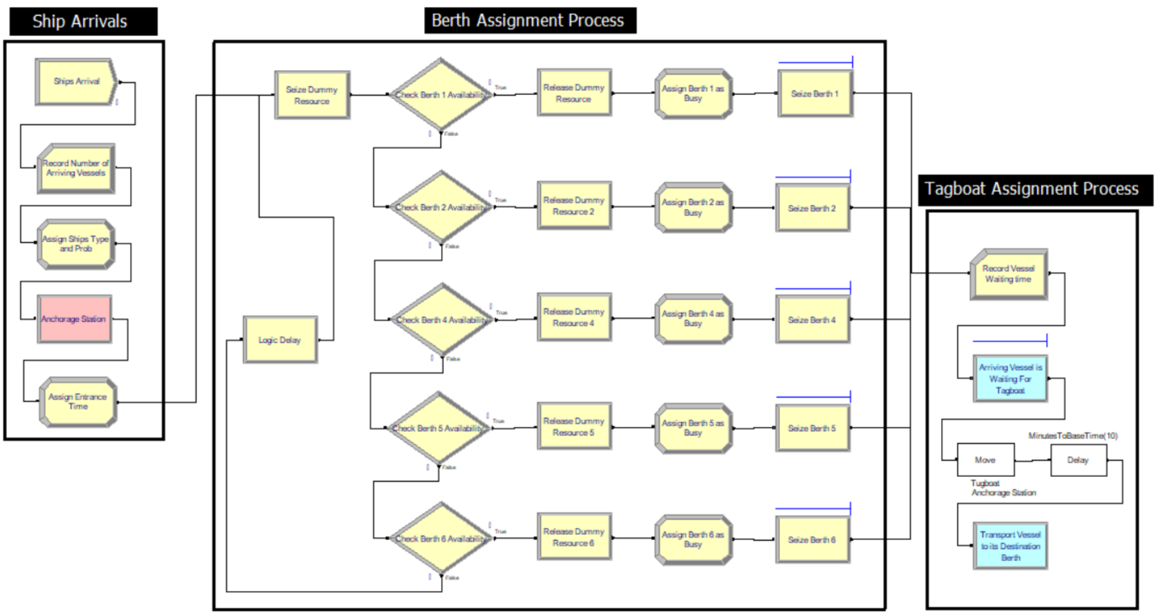


Figure 4. Ship arrivals and berth allocation logic

3.5.2 Ship loading and unloading logic

After the ship mooring process is done, the tugboat is released and the unloading operation begins. Meanwhile, 20 minutes was taken into consideration for the release of tugboat ropes and the ship mooring process. As with real terminals, quay crane operations are pre-ordered according to the ship's stacking plan. Therefore, in the simulation model, each quay crane carries out the assigned loading and unloading operations, following the predefined work sequence. In addition, a single cycle operation is used during ship handling. This means that the loading process starts after the unloading process is finished. In this study, cycle times of quay cranes measured in actual operation in the port were used. While the average cycle time of ship-to-shore quay cranes was 144 seconds, the average cycle time of mobile harbor cranes was 240 seconds. A transport vehicle is required to carry out each loading or unloading process. Containers are transported between the berths and the storage area by manned terminal tractor in the existing manual system and by automated guided vehicle in the proposed automated system. Each container transport vehicle is only allowed to transport one container at a time. The number of the manned terminal tractor was 59. However, the number of AGVs has been calculated by optimization studies (OptQuest for Arena). Optimization studies have shown that the number of AGVs required depends largely on the performance of ASCs. The number of AGVs was specified as 80 vehicles.

During the ship unloading process, the quay cranes are occupied by the containers and await the arrival of the required transport vehicle. When the container transport vehicle arrives, the transfer process is carried out and the quay crane is released. In this way, the transfer of containers between quay cranes and container transport vehicles is modeled realistically. Travel times between locations in the terminal is simulated, taking into account realistic values of the speed of travel, and real geometric distances. Considering the values specified in the technical specifications and obtained from real operations, the speed of terminal tractors was defined as 660 meters/minute, while the speed of the automated guided vehicle was 420 meters/minute. The Nearest Vehicle (NV) rule was used to assign transport vehicles to the transportation process. According to the Nearest

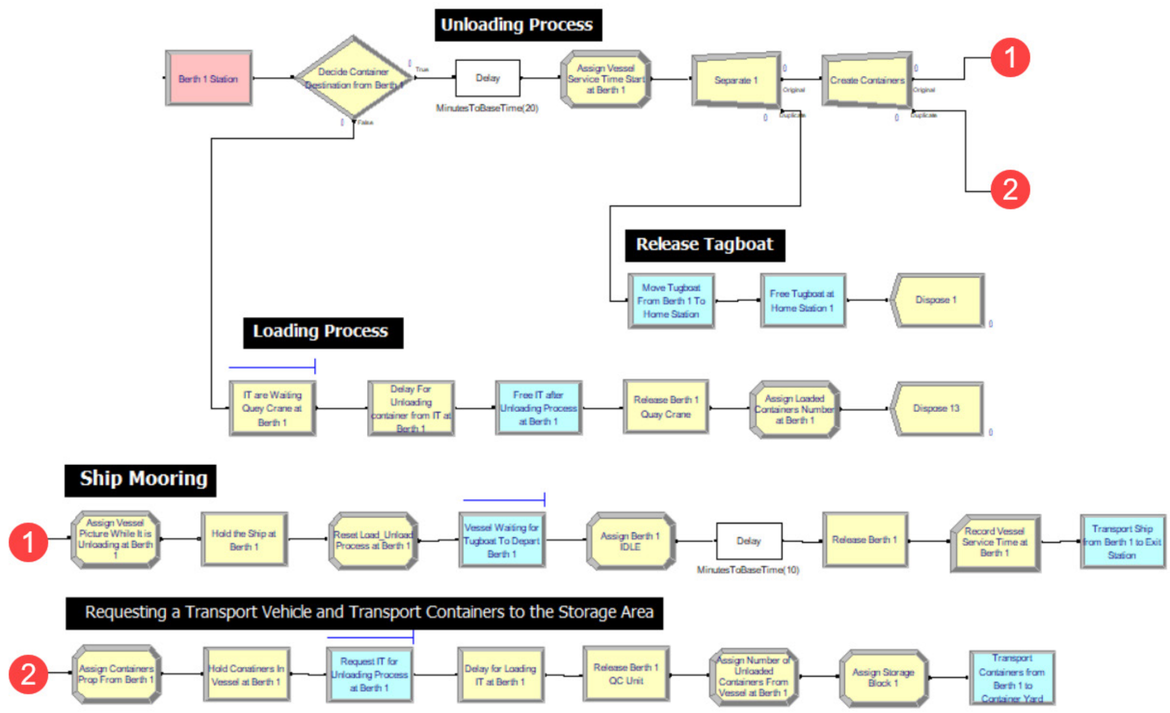


Figure 5. Ship loading/unloading and container horizontal transport logic

Vehicle rule, the free transport vehicle located closest to the relevant berth or yard crane is assigned to the process of transport. After the transport vehicle is loaded by the quay crane, they were directed to the nearest storage block with a minimum workload. After the specified number of import or transshipment containers are unloaded, the loading of the export containers begins.

The horizontal transport vehicles coming from the storage area are handled by the quay cranes, and the export containers are loaded directly to the ship. Figure 5 shows ship loading/unloading and container transport models created in the Arena simulation program. The ship is held at the berth during the loading and unloading process. After all the planned containers are handled, the ship leaves the berth with the help of one tugboat. All statistics regarding the arrival, departure, the time spent in the port, and the waiting time of the ships were collected during the simulation model creation.

3.5.3 External trucks arrival logic

In the simulation model, the external trucks coming to the port was divided into two groups; 1) Trucks delivering export containers, 2) Empty trucks coming to take import containers. The time between arrivals of trucks was simulated as an Exponential Distribution (EXPO (2) minutes). It was assumed that trucks arriving and leaving the port gates are stopped for 2 to 5 minutes for documentation and inspection checks. This has been simulated as a Triangular Distribution (TRIA (2,3,5) minutes). Through this logic, external trucks were directed to their destination to pick up or deliver the containers. Considering the distances between the port gate and the storage area and the speed of the external trucks in the port, it is supposed that 5 to 15 minutes are required for each truck to reach the storage area or container location. The triangular distribution is used to simulate this (TRIA (5,10,15)). External trucks' arrival logic is shown in figure 6.

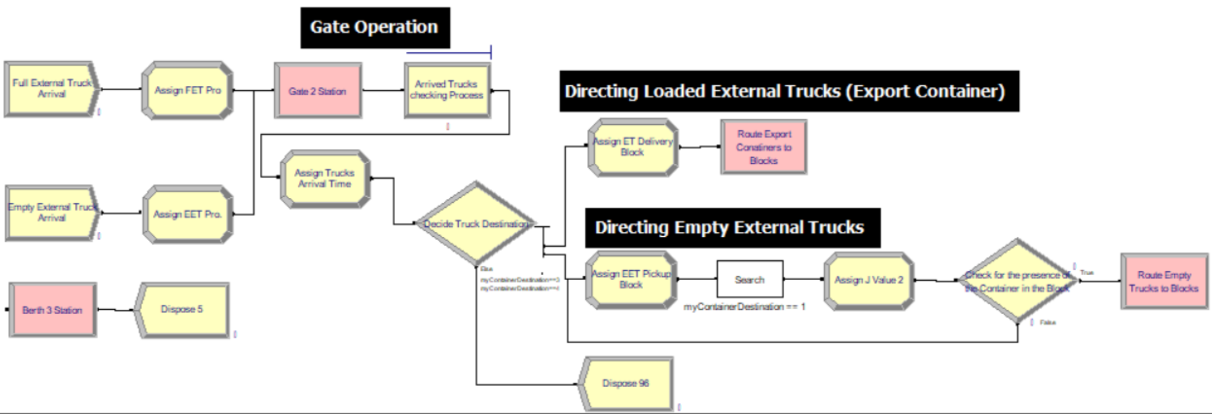


Figure 6. External truck arrivals and directing logic

3.5.4 Container storage/retrieval logic

In the first simulation model, the storage yard was simulated exactly like the real system. The storage area consists of 22 storage blocks, an empty container yard, CFS (Container Freight Station), and paths that are used by horizontal container transport vehicles and external trucks. Each storage block was assigned with one RTG crane. According to the standard specifications of RTG cranes, gantry speed was specified as equal to (130 m/min) and one move cycle time was specified as 2.5 to 3.5 minutes. RTG portal movements are performed automatically by the Arena program taking into account the specified speed and the length of the storage block. The transfer of cranes between different storage blocks was not allowed.

In the second concept, the layout of the manual port had been changed to be fully compatible with the new automated system. A total of 14 blocks now forms the storage yard, each one was assigned with one ASC. ASC width is assumed to be 7 TEU and row length as 47 TEU. The cycle time of the automatic stacking cranes was defined as equal to 60 seconds and their speed equal to 240 m/min. All paths between blocks were removed, loading and unloading of AGVs and external trucks are done in buffers at the end of automatic stacking cranes. We assumed that there are four transfer points at the end of each ASC. In the two systems, the maximum stacking height is equal to six containers. Figure 7 shows the container storage/retrieval logic of simulation models.

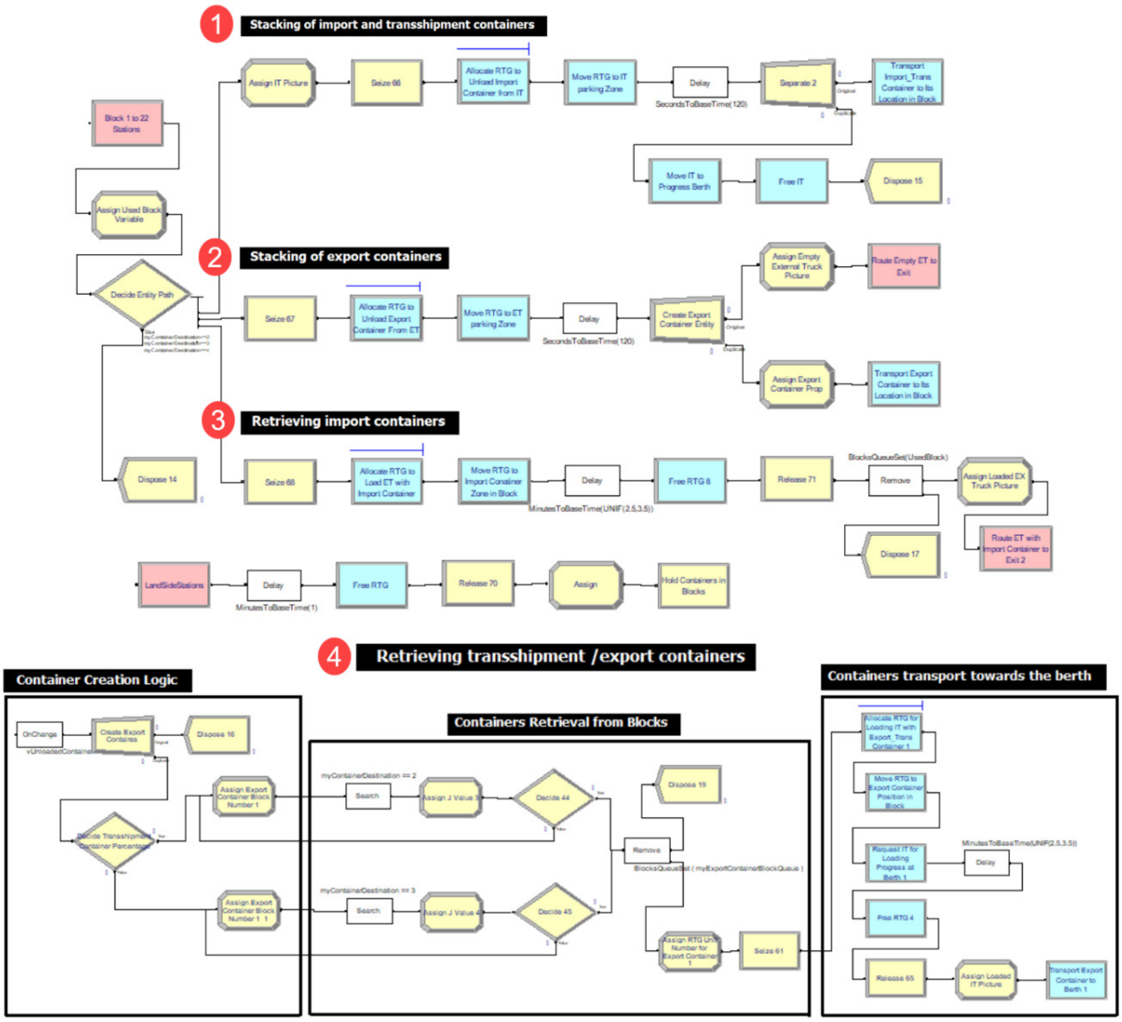


Figure 7. Storage yard logic

Four different operations are carried out in the storage yard;

1. Handling and stacking of import and transshipment containers from the seaside,
2. Handling and stacking of export containers that come with external trucks,
3. Retrieving import containers from blocks and loading the empty external trucks,
4. Retrieving transshipment/export containers from blocks and loading containers transport vehicles.

We defined the priority among these operations as follows. First, the priority was given to the seaside unloading process, then to the seaside loading process, after that to the unloading external trucks process, and finally to the loading external trucks process. The inspected port was simulated as a steady-state simulation, as it operates 24/7 and never stops or restarts. In addition, the simulation model was run for one year.

3.5.5 Model Validation

Animation has been recognized as an effective way to logically validate the simulation model. We used the special drawing features in the Arena simulation program to create a 2D animation model of the port.

This 2D model is directly connected to the logic models that represent the port operations showed above. In this way, the entire life cycle of an entity was followed and a comparison was made with the real system. Figure 8 shows the 2D animation models created with the Arena program.

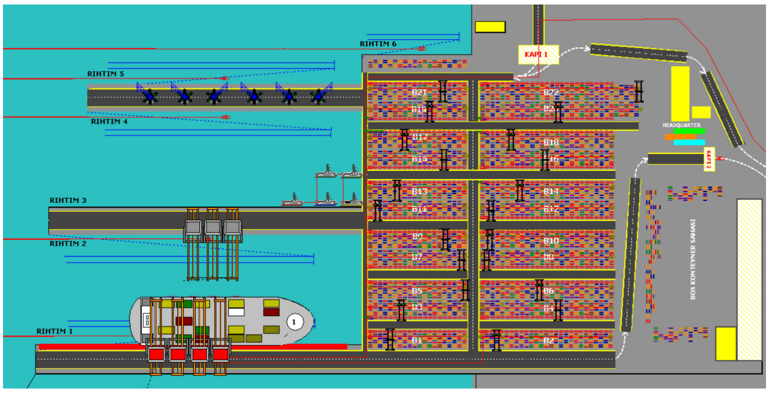
4. Results

In the first experiment, the simulation model of the existing manual system was used to analyze the existing layout, evaluate the performance of the current manual system, and examine the model validity. The simulation results are summarized below.

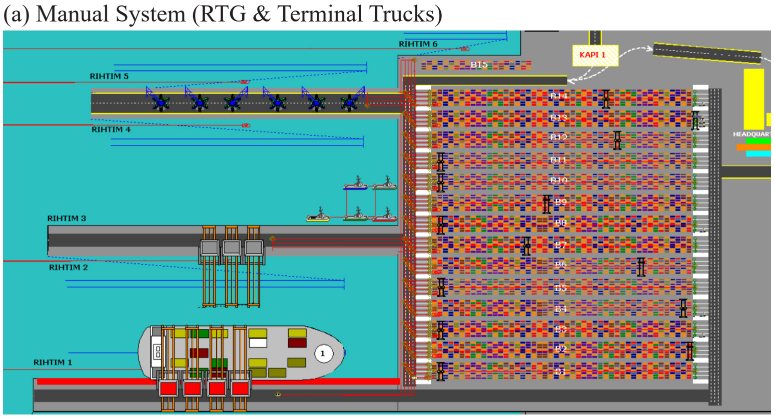
Table 6. Results of the existing manual system simulation model.

Performance measures	Value	Unit
Annual Throughput	1,171,131	TEU
The average number of ships handled annually	2,199	.No
(Average vessel turnaround time (service time	9.52	hour
The average number of external trucks handled annually	315,849	.No
(External trucks average turnaround time (does not include time at gates	0.46	hour
Berth 1 occupation rate	82	%
Berth 2 occupation rate	75	%
Utilization of QCs at Berth 1	60	%
Utilization of QCs at Berth 2	59	%
Utilization of terminal tractors	46	%
Utilization of RTG cranes	50	%
(QCs Average timing wait for empty terminal tractors (berth 1/berth 2	0.00/0.00	min
(Loaded terminal tractors average waiting time for QC (berth 1/berth 2	11.40/15.60	min
RTGs average waiting time for empty terminal tractors	1.80	min
.Loaded terminal tractors average waiting time for RTG Cranes	3.60	min
.Loaded external trucks' average waiting time for RTG Cranes	4.20	min
.Empty external trucks average waiting time for RTG Cranes	4.80	min

From the simulation results, we can notice that the annual throughput of the port is (1,171,131 TEU) and the number of ships handled per year is (2,199 No.). These results are very close to the actual numbers given in the presented data of recent years (Figure 2 and 3). Therefore, the validity of the model is considered to be sufficient in the development strategies and evaluate the new proposed automated system. Other performance measures such as equipment utilization rate and berth occupation rate are also shown in table 6.



(a) Manual System (RTG & Terminal Trucks)



(b) Automated System (ASC & AGV)

Figure 8. Animated 2D port layouts

From the simulation results, it can be understood that terminal tractors and RTGs operate at approximately half of their capacity; utilization rates are 46% and 50% respectively. This is because the working cycles of terminal tractors and RTGs are closely linked. In other words, RTGs and terminal tractors have to wait for each other to complete their work cycle. Considering the efficiency of the quay cranes, it is seen that they operate at almost 60% of their total capacity. This situation is due to the idle time of the berths (the occupation rates of berths 1 and 2 are 82% and 75 %, respectively).

During the simulation study carried on an existing manual system, we realized that any increase in container volumes will cause a bottleneck in the system. An optimization study was carried out on the system to specify the reason behind that bottleneck. It was recognized that the reason for the bottleneck in the system was the insufficiency of horizontal container transport vehicles. While the QCs unload the container from the ship, they will wait for the arrival of the container transport vehicles. The simulated model will stop at one point when all horizontal transport vehicles are busy with containers and the QCs are busy waiting for the arrival of these vehicles. However, it should be emphasized that the storage system can become a bottleneck at a certain point where the horizontal transport system will be sufficient. In this case, an optimization study should be carried out to achieve maximum integration between the two systems.

In the second simulation model, the automated container handling system (AGV-ACT) was simulated and evaluated taking into account the characteristics of the specified system and using other data considered in the manual system (Table 4). In Table 7, the results of the AGV-ACT simulation model are summarized.

Since the initial conditions of the simulation models are kept the same in the two models, the annual capacity of the port differs very slightly. However, the ship turnaround time remains the most important performance factor for measuring the improvement in port due to the implementation of the automated system.

Table 7. Results of the automated AGV-ACT system simulation model.

Performance criterion	Value	Unit
Annual Throughput	1,192,080	TEU
The average number of ships handled annually	2,208	No.
Average vessel turnaround time (service time)	7.81	hour
The average number of external trucks handled annually	314,496	No.
External trucks average turnaround time (does not include time at gates)	1.03	hour
Berth 1 occupation rate	81	%
Berth 2 occupation rate	78	%
Utilization of QCs at Berth 1	68	%
Utilization of QCs at Berth 2	69	%
Utilization of AGVs	41	%
Utilization of ASC cranes	72	%
QCs Average waiting time for empty AGVs (berth 1/berth 2)	0.00/0.00	min
Loaded AGV average waiting time for QC (berth 1/berth 2)	6.00/10.80	min
ASCs average waiting time for empty AGVs	0.00	min
Loaded AGV average waiting time for ASC Cranes.	6.60	min
Loaded external trucks average waiting time for ASC Cranes.	26.40	min
Empty external trucks average waiting time for ASC Cranes.	46.80	min

The results of the simulation model of the automated system show that ship turnaround time decreased from 9.52 hours to 7.81 hours (18%). The reduction in waiting times of container transport vehicles for quay cranes reached 47% and 30% in berths 1 and 2, respectively. This can help the port handle more ships in the same time window and make the port more attractive to customers. It is important to mention that external trucks turnaround time increased by 124%. This is because priority was given to seaside operations and only one ASC is assigned to each block to handle both seaside and landside operations (This conclusion is based on the optimization study conducted on the same model which will be covered in other articles).

Considering the high utilization rate of ASC cranes (72%), it is important to notice that ASC will create a bottleneck in the future. The simulation study indicates that the number of used ASCs and their specifications are critical to the performance of the port. Any bottleneck caused by ASC can be overcome by applying 2 ASC cranes per block (beyond the scope of this study). Looking at the other simulation results, the productivity of the berth and the utilization rate of quay cranes have also increased. The increase in the efficiency of quay cranes can also be noticed. The efficiency of the QCs at berths 1 and 2 increased by 13.33% and 16.95%, respectively. As a result, the automated handling system can improve the overall performance of the port.

From another point of view, in the new proposed automated layout the storage area capacity can reach 27,636 TEU. The existing manual layout has a storage capacity of 21,714 TEU, according to that a 27.27% increment in storage capacity can be seen in the new design. This increment is due to the elimination of paths between storage blocks and the optimal use of the yard area obtained from deploying automation in the port. This will increase the annual throughput per acre of the port, and this can be a very important advantage in the ports located in metropolitan areas.

5. Conclusions

When choosing a container port handling system, the decision must be made in favor of manual or automated equipment. Although automatic handling equipment requires high investment costs, it also lowers labor and equipment maintenance costs. In this study, the effect of the automated terminal system (AGV-ACT) on container handling operations was analyzed and the possibility of automated system implementation in container ports was examined.

It is essential to have in place an approach that ensures the quality of proposed solutions and minimizes the risk of investment. Therefore, testing the final decision through modeling and simulation of the operations becomes vital to the success of any development project. In this context, operators increasingly view simulation technology as an important tool for studying the available alternatives and making the right decision. In this study, we presented an integrated port simulation model that can be used in making any decision related to improving port performance.

This study showed that automation could enhance the overall performance of the port by decreasing the ship's turnaround time by 18% and reducing waiting times of container transport vehicles for quay cranes. Also, the layout of the automated handling system raised the storage capacity of the port by almost 27.27%. All these improvements in port performance will positively reflect on its competition power in the market and make the port more attractive to customers.

Peer Review: Externally peer-reviewed.
Author Contributions: Conception/Design of Study- Y.J.; Data Acquisition- Y.J., G.K.; Data Analysis/Interpretation- Y.J.; Drafting Manuscript- Y.J.; Critical Revision of Manuscript- Y.J.; Final Approval and Accountability- G.K., Y.J.
Conflict of Interest: Authors declared no conflict of interest.
Financial Disclosure: Authors declared no financial support.

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