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Due to their complex functions and dynamics, ports have a complex structure. Complex structures are investigated through simulation techniques instead of analytical methods. Simulation of port systems can be carried out for different goals such as port design, planning, capacity increase, and productivity. In this study, bottleneck points were investigated under overloading conditions. Based on the results generated through simulation experiments, it was determined that the most critical bottleneck points are created by loading/unloading vehicles. An investment strategy was applied to the model at this point for load balancing of the port. As a result, simulation was used to study improvements by adding resources within economic limitations.

Keywords: Port simulation, AweSim, output analysis, port investment

1. Introduction

Seaports that constitute the foundation of maritime lines have a complex structure. Complex systems have been investigated by simulation techniques instead of analytical methods. Simulation is a scientific methodology that is performed to understand the behavior of a real system without disrupting its environment. Simulation has been used in different systems such as urban, economic, production, transportation, and the maritime field [1]. In the maritime field, for example, simulation methods were constructed to analyze the impact of terminal layouts and to determine the optimum level of equipment investment [2].

Trabzon Port is a place where cargoes of all kinds enter and leave by means of transport vehicles such as ships and trucks. The port contains four docks with cargo-handling cranes (loading/unloading vehicles), open and covered stores, and cargoes. Major problems at the Trabzon Port include dealing with loading/unloading vehicles, scheduling ship loading and unloading operations, and storing cargoes in the yard and quay for passenger ships. Port managers wanted to know the most important problem and the amount of investment needed to eliminate this problem. To evaluate the future of the port and to ensure optimum investment strategies, simulation models have been used [2]. In this study, a simulation method was constructed to select investment strategies of a model in the maritime field. For this purpose, we present a port simulation model and analyze the investment needed for mechanical handling equipment. Statistical analysis was used for simulation results. This simulation model is designed for the Trabzon Port, which is situated at the Black Sea coast of Turkey. AweSim, the computer simulation language [3], was used as a primary modelling tool on the PC.

Simulation has been used for many applications in different systems. In the maritime field, simulation models have been used for port terminal operations in general. For example, Carpenter and Ward [4] developed a flexible model related to the overall operations of a marine terminal, Teo [5] proposed software that has a workstation-based animated simulator of a container port, Ramani [6] designed and developed an interactive computer simulation model to support the logistics planning of container operations, and Nevins et al. [7] developed a two-dimensional animation and a three-dimensional visualization capability for POTSIM. However, there are also studies concerning simulators [2, 8, 9] and genetic algorithms [10] for seaports. In Blümel et al. [11], terminal port simulations were classified by considering the research scope, the social factors, the purpose of the software designed, and the software and hardware used. The purpose of this study is to determine the optimum level of investment for loading/unloading vehicles.

2. Trabzon Port

Trabzon Port, which is the biggest seaport on the eastern Black Sea of Turkey, plays an important role in the transit transport between eastern European and Middle East countries. The port services the ships coming from various

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countries and can accommodate between ten and fifteen ships at any one time, depending on the ships' lengths.

As seen in Figure 1, the port consists of a main breakwater (pier), four main quays, open and closed stores, and loading/unloading vehicles (cranes, forklifts, etc.). The length of the quays is about 1500 meters. The total terminal area is about 30 hectares. Approximately 500,000 tons of cargo can be stored in the open and closed areas at the same time, and 3 million tons of cargo can be manipulated by loading/unloading vehicles in a year.

2.1 Port Operation

There is inland, air, and maritime transport in Trabzon, but there is no railroad transport; therefore, cargoes arriving at the port by ships are transported to other places by inland vehicles, and cargoes arriving at the port by inland vehicles are transported to other places by ships. The port operation can be better understood when it is divided generally into four main operations [1, 12]. The sequence of operations in the simulated port is given in Figure 2.

Ship operation usually begins with the ship's arrival to the port area. Depending on the state of congestion, the ship may or may not have to wait in the anchorage area. Usually, one or more tugboats are assigned to guide the ship to the berth. After berthing, the cargo is unloaded onto the quay, and a pilot tugboat is assigned to guide the ship as it leaves the port.

The cargo-handling operation begins with preparing the ship for unloading, and then cranes and gangs are assigned for unloading cargo. The cargo can then be directed to inland transport, or it is moved into the storage system.

The warehouse operation is concerned with the storage system. The unloaded cargoes are transferred to the warehouses by trucks, forklifts, railways, and so on. Then, equipment and gangs are assigned for unloading, and cargo is stowed in an open or closed place.

For inland transportation, cargo is loaded from the warehouse or directly from the ship after equipment and gangs have been assigned and is transported to final destinations. If the cargo is loaded onto the ship (exported cargo), it follows the reverse process.

3. The Port Simulation Model

Port systems are complex because of different ship arrivals, different dimensional ships, multiple quays and berths, different loading/unloading vehicles, and so on. Therefore, as an alternative, simulation is used for these systems.

Simulation has the ability to experiment with the real system without incurring any direct capital investment, allowing alternative strategies to be tested, future port development to be created, and the real time of the port operations to be compressed [13]. Also, simulation can be used as a decision support tool for port performance evaluation, port expansion (port investment), port improvement studies, and so forth [1]. Usually, however, it takes a long time to develop the basic simulation model. Moreover, there are difficulties in developing the process with simulation. For example, one of the general difficulties with a simulation targeted to a specific scenario is that it may not be easily adaptable to other scenarios.

3.1 Modelling Method

Simulation is recommended for analyzing port designs and port operations. There are many port simulation models in the literature such as PORTSIM [5, 7] and TRANSNODE [9]. However, some of the simulation models were written with general-purpose algorithmic languages (e.g., FORTRAN, C, PASCAL) and simulation languages (e.g., SIMAN, SLAM, GPSS). In this study, we used the AweSim simulation language for the Trabzon Port. AweSim includes Visual SLAM, a new modelling language based on familiar SLAM II constructs [3]. The port model is designed and programmed as an interactive system. Therefore, a user does not need to have any knowledge of the simulation. Our model provides estimates for bottleneck points for the port overloads and for various operating strategies.

3.2 Port Model Structure

The port model, which is an investment simulation model, can easily be adapted or extended with subprograms. For example, other port capacity expansions and their economic imports can be extended [e.g., 1, 12].

In general, simulation models integrate main actual operations of the port by simplifying complex activities, and these operations are defined according to port type. In this study, various objects were observed in the real port and called "model elements." As seen in Figure 3, model elements of the Trabzon Port can be separated into five groups:

1. Ships
2. Cargoes
3. Loading/unloading and transportation vehicles
4. Quays
5. Warehouses

General trade ships constitute the first and most important element of the model. These are multipurpose ships, container ships, Ro-Ro ships, coal ships, and so forth. The functions of ships in ports are defined as loading or unloading. Ships that arrive at the port are divided into three types according to the size of ship: type I, type II, and type III (see Input Data subsection). Ship type is an indicator of the size of the ship. There are also priority ships that transport urgent cargoes besides these. Ship types have an arrival probability and distributions of the interarrival time. Cargoes of various types are loaded onto ships from quays and then transferred to the warehouses or vice versa. In general, coal, containers, general cargo, cars, bulk dry cargo,

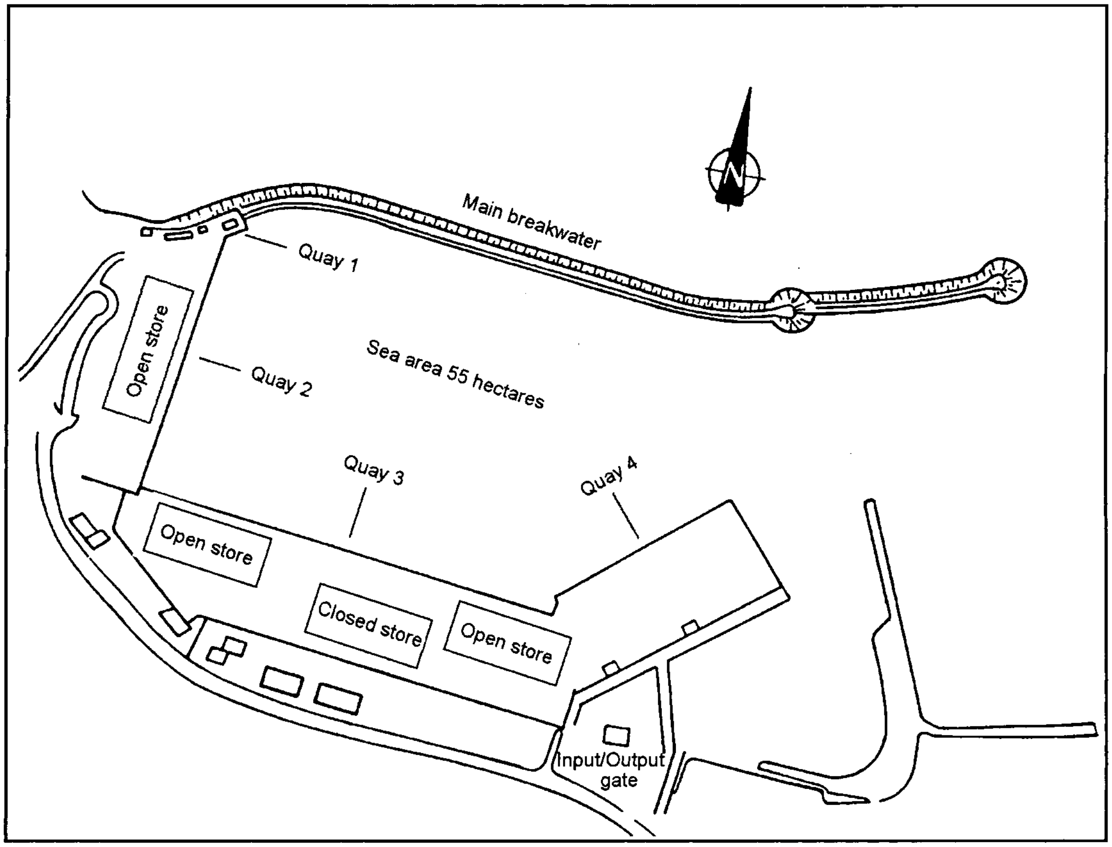

Figure 1. Trabzon port

and special cargo are handled in the port. There are also ship loading/unloading and transportation vehicles. Transportation vehicles consist of yard cranes, forklifts, trailers, and tractors in the port and are used to transport cargoes. Ship loading/unloading vehicles deal with quay cranes and are used to drive the quayside operation.

Loading/unloading operations include lifting the export/import cargoes. The export cargoes brought by the transportation vehicles from the warehouses are placed in the ships. The import cargoes taken from the ships are placed onto transportation vehicles for transportation to the warehouses. Ship loading/unloading and transportation vehicles are independent. Quays where cargoes are loaded and unloaded have berths and cranes. Sizes and depth of berths define the ship type. Warehouses are areas where different-type cargoes are stored. Depending on their type, cargoes are stored in open or closed warehouses.

4. Data Collection

The data related to the port operation, which include prepared forms and port documentation records, were investigated. These forms and records give details of ship and cargo movement information, such as ship arrival and departure dates, ship tonnages and lengths, cargo types, destinations, and so forth. Afterward, the port managers and experts on port operations were interviewed. Moreover, to produce statistics and check the detailed data, we made field observations. Information about quays, vehicle equipment, warehouses, and distances were obtained from the plans of the working area.

To determine the limitations of the model, we collected data about the model elements. For this purpose, we investigated port documentation records, interviewed port managers and experts on the port operations, and made field observations [14].

4.1 Input Data

After the data collection, the form of the input data was derived. The data were analyzed to find appropriate theoretical distributions, averages, and other input data. The input data consist of port characteristics, ship characteristics, and strategies. Port characteristics include the number of berths, number of loading/unloading vehicles, number of warehouses, ship arrival and service time distributions,

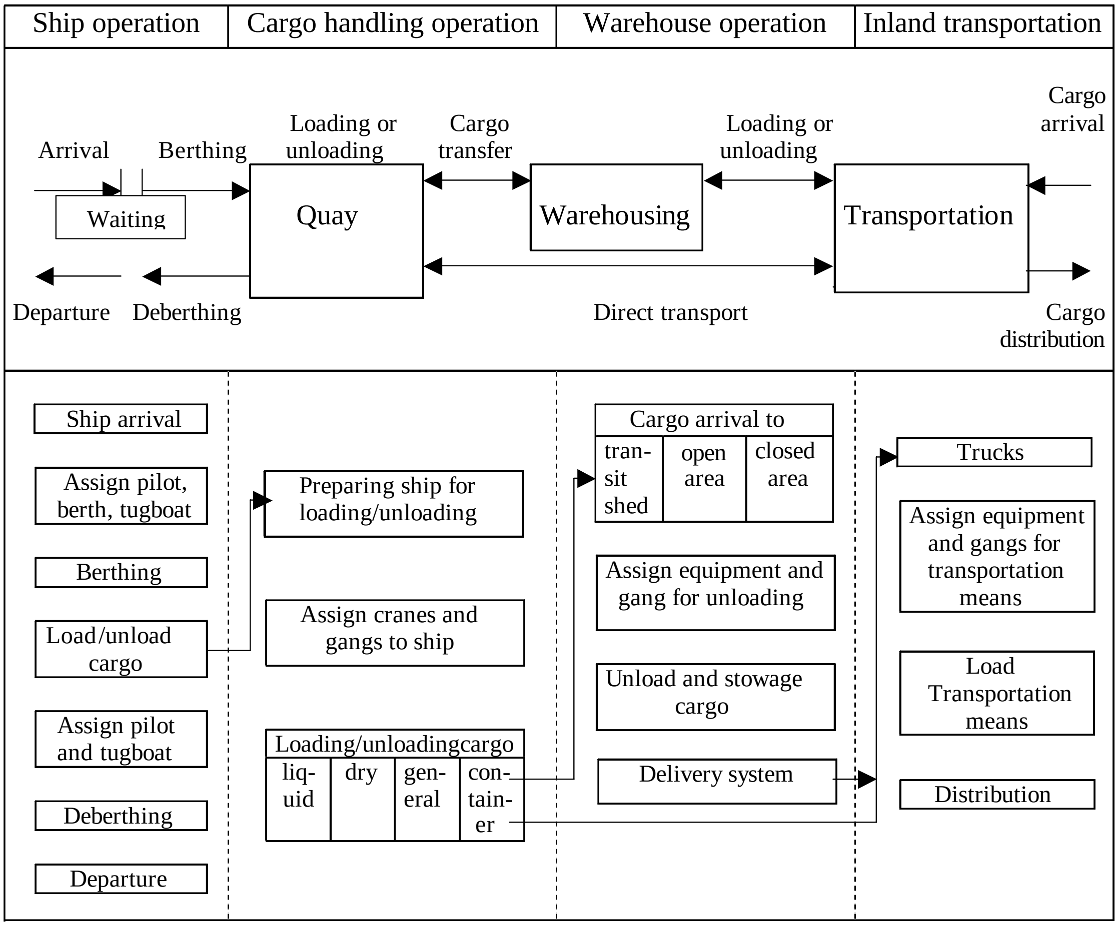

Figure 2. Port operation and sequence

and so forth. Ship characteristics include ship types and ship arrival probability distribution of the interval time between ships. Strategies include priority rules, full-capacity strategies, and investment strategies.

As seen in Table 1, ships were separated into three groups—G1, G2, and G3—according to the sizes of ships. Arrival probabilities and distributions of these ship types to the quays were calculated. Moreover, average loading/unloading times of loading/unloading vehicles for each ship type were determined from the data collected. Numbers of cranes, quays, berths, and warehouses are given in Table 1.

4.1.1 Ship Arrival and Service Time Distributions

According to the port documentation records, 297 ships arrived at the port in 1997. Ship interarrival times were classified, and it was seen from historical data that the average interarrival time was exponentially distributed for each type of ship. In the same way, service times of the loading/unloading vehicles for each type of ship were exponentially distributed and also tested statistically. This distribution type and the average interarrival times are given in Table 2.

After data collection, the validity of the data was checked against a set of real data and scenarios, and both sets of data behaved similarly. The other validities are mentioned in Section 5.3.

4.2 Strategies

Some strategies can be applied to conduct operations in a short time, such as loading/unloading, berthing, and warehousing. Organization strategies, which are the strategies of the simulation model, were defined as the following.

4.2.1 Priority Rules

First, assigned berths are allocated to the ships that transport urgent cargoes, such as live animals and fresh

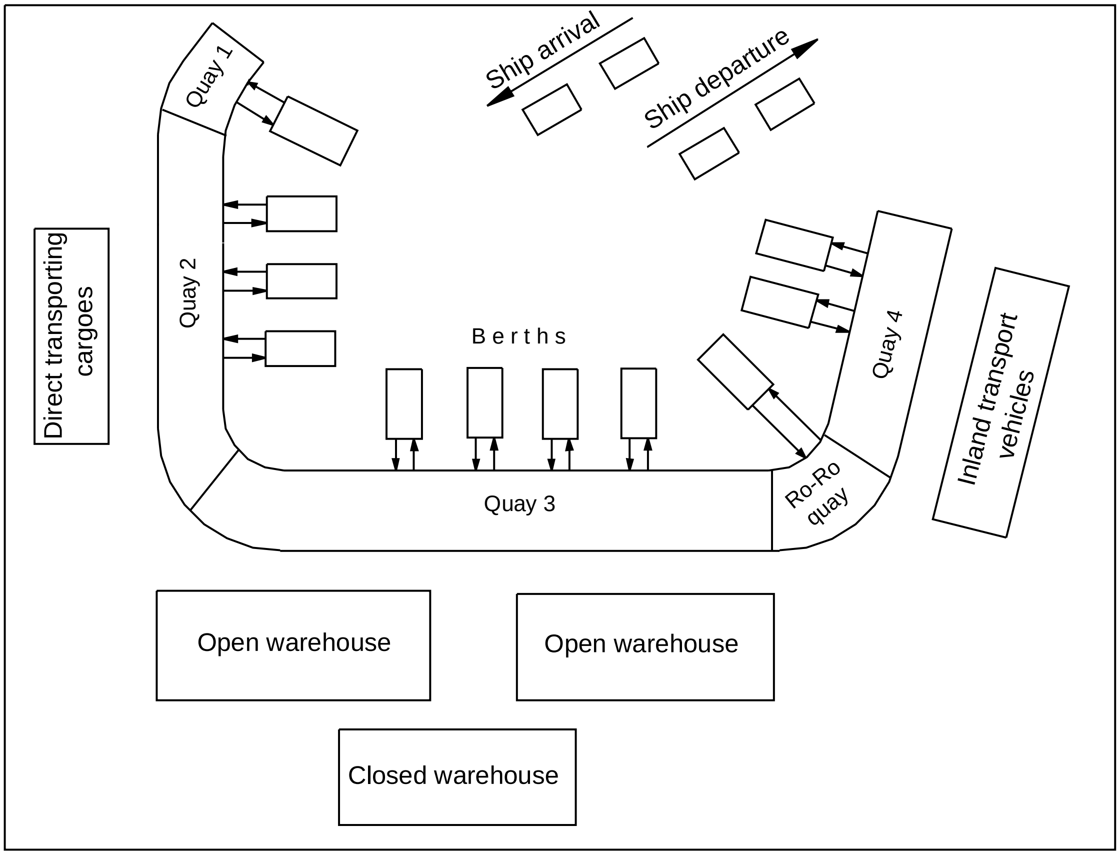

Figure 3. The port model

Table 1. Ship and port data

Ship Types	G1				G2				G3			
Ship characteristics (meters)	0-60				60-120				≥ 120			
Ship arrival probabilities (%)	37				57				6			
Service times (h)	66				98				88			
Number of loading/unloading vehicles	6 = 3 tons				4 = 10 tons 1 = 5 tons				1 = 25 tons			
Distributions to quays (%)	2	37	42	19	1	26	42	31	0	63	31	6
Quay number	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
Number of berths	1	3	4	2	1	3	4	2	1	3	4	2
Number of warehouses:	1 open, 2 closed											

vegetables. The following rules are applied to ships that do not transport urgent cargoes. The assigned berths were allocated to other ships in waiting lines according to four priority rules:

- FIFO: First in, first out
- LIFO: Last in, first out
- LSF: Low size first
- HSF: High size first

If there is no ship waiting for berthing in the port, the assigned berths are allocated to the ships arriving at the port according to the FIFO rule.

4.2.2 Full-Capacity Strategy

This strategy is invoked so the port can work at full capacity. The behavior of the port is investigated by sending ships according to the capacity of the port, and bottleneck points of the port are researched for investment. There-

Table 2. Model input data

Ship characteristics:
Distribution of the interarrival time: Exponential

Average interarrival time: 28 hours

Ship types: G1 = less than 60 meters
G2 = 60-120 meters
G3 = more than 120 meters

Ship arrival probabilities:
G1 = 37%
G2 = 57%
G3 = 6%

Distributions of ships to the quays:
G1: R1 = 2%, R2 = 37%, R3 = 42%, R4 = 19%
G2: R1 = 1%, R2 = 26%, R3 = 42%, R4 = 31%
G3: R1 = 0%, R2 = 63%, R3 = 31%, R4 = 6%

Tugboats: Number of tugboats = 4

Quay number: R1, R2, R3, R4
Number of berths: R1 = 1, R2 = 3, R3 = 4, R4 = 2

Loading/unloading vehicles:
Distribution of the service time: Exponential

Ship Type	Average Service Time	Quay Cranes		
		1	2	3
G1	66 hours	6	0	0
G2	98 hours	0	5	0
G3	88 hours	0	0	1

Strategies:
Priority rules: FIFO, LIFO, LSF, HSF
Full-capacity strategy
Investment strategy

Simulation time: 1 year (8760 hours)

Note. FIFO = first in, first out; LIFO = last in, first out; LSF = low size first; HSF = high size first.

fore, ship arrivals are increased until the capacity of the port becomes full.

4.2.3 Investment Strategy

When the port is overloaded, bottleneck points are investigated, and then port equipment (loading/unloading vehicles or quay cranes) is added at the most loaded bottleneck points. This strategy is used to investigate the effects of adding equipment to the port.

4.3 Assumptions and Limitations of the Model

Before a simulation is run, assumptions and limitations of the model have to be identified. Some of the assumptions and limitations considered in developing the port simulation model are as follows:

1. Daily operation is twenty-four hours, and the study period is one year.
2. The ship interarrival times can be expressed by means of a statistical distribution form.
3. The model starts with the system empty.
4. The port has sufficient gangs and warehouse capacity.
5. Storms do not influence ship maneuvers because the port is protected from storms.
6. The model does not include passenger ships.

4.4 Model Input Data

Model input data must be easy, simple, rapid, and understandable for the user. Data on the characteristics of the elements of the model mentioned above have been organized and are shown in Table 2. These are ship, quay, warehouse, and loading/unloading vehicle characteristics and strategies.

Ship types are defined by size as type I, type II, and type III or G1, G2, and G3. G1 is shorter than 60 meters, G2 is between 60 and 120 meters, and G3 is longer than 120 meters in length. The data mentioned earlier, such as the distributions of the interarrival time between ship arrivals, ship arrival probability, distributions of the service time, service times, number of tugboats and berths, are given in Table 2. It can be seen that varying numbers of quay cranes are assigned per ship based on the ship type.

5. Application of the Simulation Model

Data are inputted into the model, and simulation starts by generating the ship arrivals in the port using the distribution type. According to priority rules, ships are identified for accommodation in the assigned berths. If there is no ship in the waiting lines, the assigned berths are allocated to each arriving ship. In other cases, ships are put in their appropriate waiting lines. Loading/unloading and moving operations by means of port equipment start according to operation rules and procedures, as shown in Figure 4. Simulation stops at the end of the simulation time. Simulation output shows indicators such as ship turnaround time, ship waiting time, the number of ships waiting per ship type, and the quay utilization ratio.

5.1 Statistics of Simulation Outputs

Statistics of simulation outputs serve different purposes such as validation, performance estimates, and interaction between users. After these strategies are applied to compare the changes in the port performances, some indicators

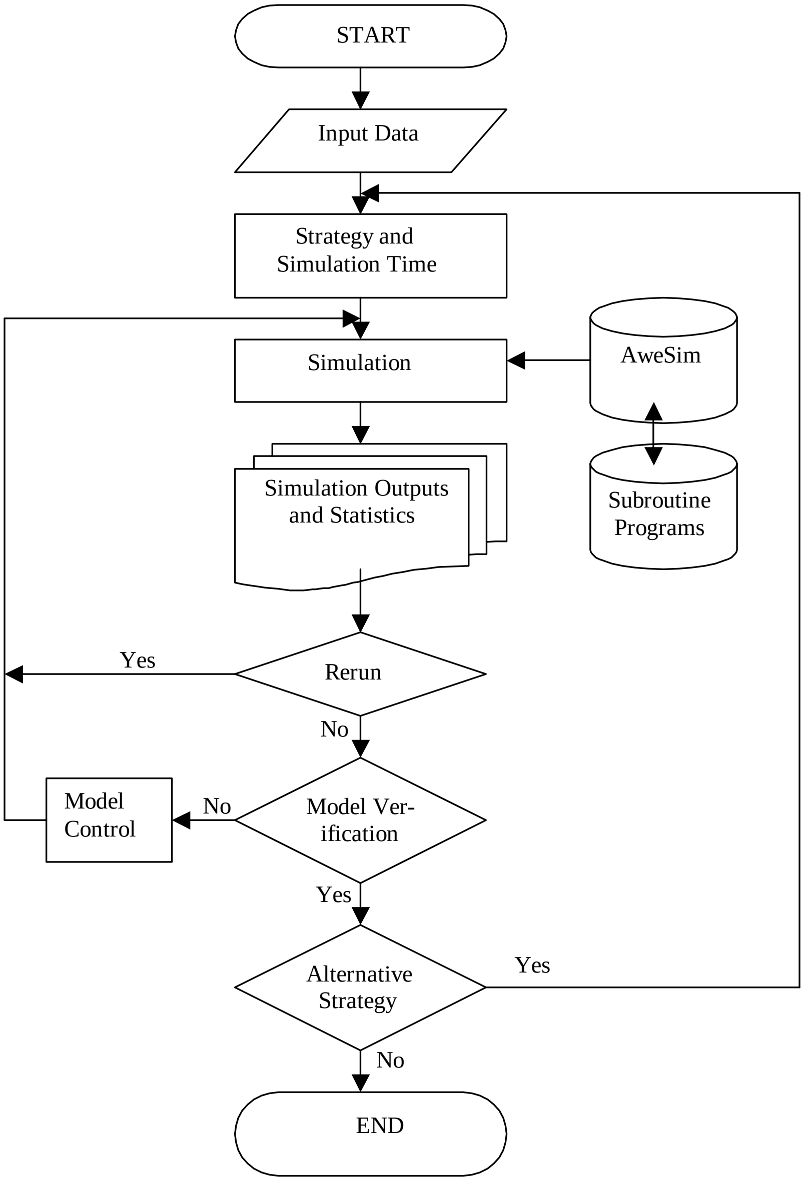

Figure 4. Operational sequence of simulation runs

are defined as the following. Our model generates the indicators at the end of the simulation.

- *Service time:* This is the amount of time required for the ship operations of loading and unloading.
- *Ship waiting times:* The total waiting time of a ship consists of the waiting time for a berth, the waiting time to start loading and unloading operations, and the waiting time at the berth after completing all operations [6].
- *Ship turnaround time:* Ship turnaround time is the total of ship waiting times and the working time for loading and unloading operations.
- *Quay utilization ratio:* The quay utilization ratio is called the berth occupancy. This indicator defines the level of demand for port services and is the percentage of the total time a quay is occupied by a ship for loading/unloading its cargoes [6]. It indicates either port congestion or inefficient utilization of the port equipment.

5.2 Execution Method

The purpose of this study was to make estimates of indicators mentioned above when the port works at full capacity. Therefore, the experiment for a strategy is given, and the model generates the outputs for each performance indicators.

The simulation execution method selected for the model is the replication method. This method makes more than one experiment. The basic analysis for simulation output data was made for the number of experiments, and the first step was to run a pilot study [15]. Twenty-five replications were used for a pilot run, but the number of replications was changed according to the port performance indicators (e.g., Figs. 5-6). In this regard, the number of replications was increased.

Figure 5 demonstrates the variations in the ship turnaround times according to the number of replications. The first twenty-five replications is the initial transient period. After this period, variations in the ship turnaround time become less, and these replications are recommended for performance indicators. Figure 6 shows the number of ship types berthed over the number of replications. It is seen that number of ships berthed was almost constant.

As a result, forty-five replications were made for a given strategy, with each representing the behavior of the port over one year. The averages and confidence intervals related to the performance indicators were completed (see Table 5, presented later).

5.3 Model Validation

The model should be validated before productive simulation runs are started. To do this, the input values for the model (e.g., ship arrivals, ship types, service times, etc.) generated through probability distributions were validated with real data [16]. In general, model validation is made by comparing the simulation model outputs with the historical data of the port. The following procedures were used for the model validation.

- The project team made field visits and interviewed experts to evaluate the simulation results. The real system's outputs were found compatible with the simulation outputs.
- According to the port managers, the biggest problem of the port is loading/unloading vehicles. Simulation outputs indicate that bottlenecks occur where the loading/unloading vehicles are positioned.
- The historical data of the port were compared with the simulated results (Table 3). The averages of performance measures were determined from forty-five replications, and simulation results appeared to be compatible with the real system for the measure of performance at the 0.05 significance level.

6. Experiments

The performance indicators were compared for each strategy using the same input data, and the bottleneck points were analyzed for investment. From this point of wiew, forty-five different runs were made for each strategy.

6.1 Existing State

The first forty-five runs relate to the existing state of the port operations. Here, the averages and confidence intervals of the performance indicators were given according to the FIFO rule (Table 5). The results of the existing state appeared to be compatible with the real system. For example, it was seen that quay utilization ratios were low. This matter was discussed with port managers, who stated that the real system had also worked at low capacity.

6.2 Results of Priority Rules

Priority rules (FIFO, LIFO, LSF, and HSF) were tested to compare the results of the model. To illustrate the changes among these priority rules, we tested the model according to the investment strategy, and the maximum queue in the quays was taken as the performance indicator. Table 4 shows the results of forty-five runs for each priority rule. As seen in Table 4, maximum queues in quays change little or not at all according to the priority rules. Preston and Kozan [17] also stressed that there was little difference in the average performance between the FIFO and LIFO. Therefore, other strategies were tested on an FIFO basis.

6.3 Results of the Full-Capacity Strategy

One of the most prevalent problems that confront decision makers are when, where, and how to adjust to increases in port demands [1]. The port was loaded at full capacity to see how it worked. To get the port working at full capacity, ship interarrival times were reduced by increasing ship arrivals. In this connection, the average interarrival times equaled 15 hours after 10 to 20 hours of full-capacity experiments. These times were reduced from 28 to 15 hours at the end of the iterative process, but other input data were kept the same. Under these conditions, forty-five runs were made, and the results are given in Table 5. Table 5 reflects changes in the averages and confidence intervals of the indicators according to the existing state. The highest increase was seen in the waiting lines, and in this regard, the average ship turnaround times also increased. This state shows that loading/unloading and transportation vehicles create the biggest bottlenecks in the port. First of all, the expansion or investment strategy should be applied at this point. Moreover, when the field visits were made, it was seen and discussed with experts that loading/unloading vehicles had bottleneck points and that there were no problems with the quays.

6.4 Results of the Investment Strategy

Since the investment strategy includes adding new port equipment when the port works at full capacity, it was proposed that new loading/unloading vehicles be added where the bottlenecks occur. It is important to decide how many vehicles can economically be added. Therefore, at the

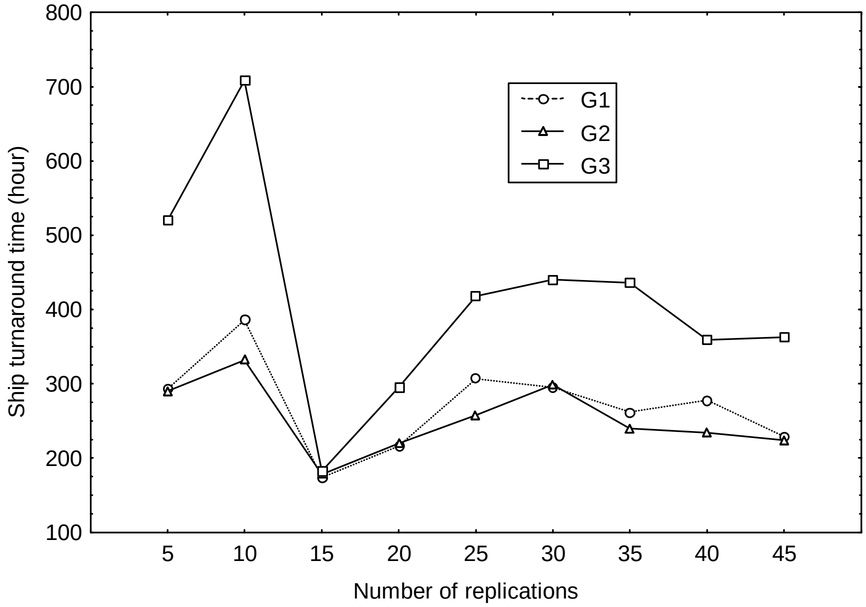

Figure 5. Turnaround times for ship types

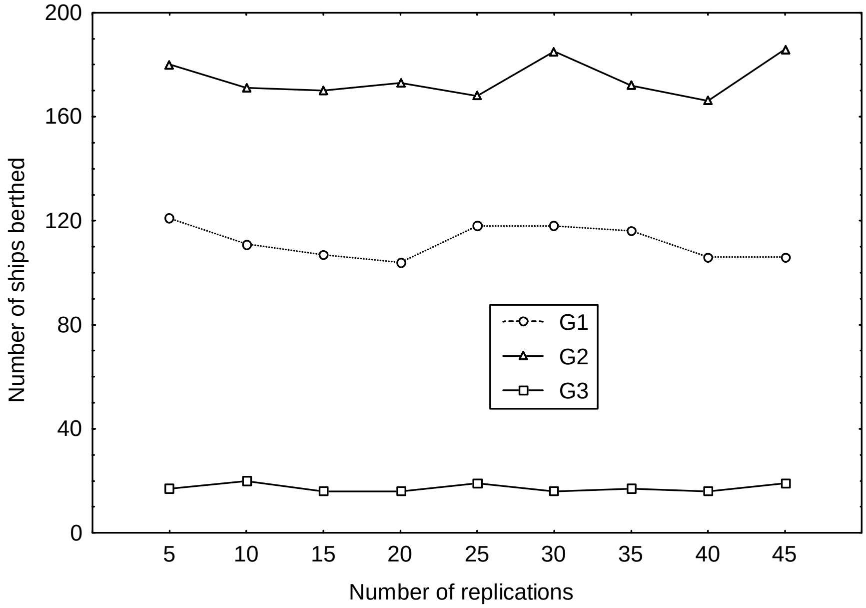

Figure 6. Number of ship types berthed

beginning, one vehicle for each ship type was suggested. According to Table 1, the number of berths for each ship type are 10 for G1 and G2 and 9 for G3, and the average service time of one loading/unloading vehicle is approximately 7 hours for G1 and 10 hours for G2 and G3 (average service time = service time/number of berths). Service times for each ship type were obtained: $66 - 7 = 59$ hours for G1, $98 - 10 = 88$ hours for G2, and $88 - 10 = 78$ hours for G3 (Table 5). As a result, service times were reduced. But the distribution of the average service times and other input data were not changed. G1, G2, and G3 had 59, 88, and 78 hours of service time instead of 66, 98, and

Table 3. Model validation results over one year

Performance Measure		Model		
The Number of Ships Berthed	System	Average	Confidence Intervals	Difference
G1	109	111.14	106.8 – 117.1	0.02
G2	169	174.42	169.6 – 179.2	0.03
G3	19	17.28	15.7 – 18.8	–0.09
Total	297	303.68	292.9 – 314.5	0.02

Table 4. Changes in maximum queue by priority rules

Priority Rules				
Quays	FIFO	LIFO	LSF	HSF
R1 [ship]	1.04	1.04	1.04	1.04
R2 [ship]	72.6	72.6	72.6	72.6
R3 [ship]	32.3	32.37	32.3	32.3
R4 [ship]	3.8	3.8	3.8	3.8

Note. FIFO = first in, first out; LIFO = last in, first out; LSF = low size first; HSF = high size first.

Table 5. Results of simulation experiments

Performance	Existing State^{a}		Full Capacity^{b}		Investment^{c}	
Indicators	Average	CI	Average	CI	Average	CI
Average turnaround time						
G1 (hour)	272.33	225.89-318.76	963.95	878.77-1049.12	765.35	688.1-842.5
G2 (hour)	304.86	160.90-448.81	777.55	713.75-0841.34	609.60	553.6-665.5
G3 (hour)	413.90	321.49-506.30	1389.82	1262.43-1517.20	1197.70	1069.6-1325.7
Average queue in quays						
R1 (ship)	0.024	0.00-0.0057	0.007	0.00-0.014	0.005	0.00-0.01
R2 (ship)	6.500	4.73-8.200	41.46	37.47-45.44	35.79	31.80-39.60
R3 (ship)	0.860	0.60-1.120	22.71	18.99-26.42	14.03	10.92-17.13
R4 (ship)	0.026	0.00-0.056	0.23	0.14-0.31	0.14	0.09-0.18
Average waiting						
R1 (hour)	3.89	0.54-8.32	6.74	0.20-13.27	5.37	0.09-10.60
R2 (hour)	534.67	401.28-668.05	1907.87	1756.13-2059.60	1644.20	1491.70-1796.60
R3 (hour)	56.29	40.68-71.89	805.77	684.45-927.08	500.00	396.00-603.00
R4 (hour)	1.69	1.10-2.27	13.87	9.79-17.94	8.68	6.40-10.80
Maximum queue in quays						
R1 (ship)	0.95	0.83-1.07	1.04	0.92-1.15	1.04	0.9-1.1
R2 (ship)	16.97	14.08-19.85	84.02	77.41-90.62	72.60	65.8-79.3
R3 (ship)	6.93	5.86-7.99	47.24	41.30-53.17	32.30	27.6-36.9
R4 (ship)	1.80	1.18-2.41	4.57	3.73-5.40	3.80	3.2-4.3
Quay utilization ratio						
R1 (%)	0.039	0.00-0.47	0.070	0.00-0.50	0.063	0.000-0.501
R2 (%)	0.893	0.45-1.33	0.990	0.55-1.42	0.987	0.548-1.425
R3 (%)	0.628	0.19-1.06	0.956	0.52-1.39	0.953	0.514-1.391
R4 (%)	0.267	0.00-0.70	0.498	0.06-0.94	0.447	0.008-0.885

CI = confidence interval. Ship types = G1, G2, and G3. Quays = R1, R2, R3,and R4.
a. Interarrival time: 28 hours. Service times: G1 = 66 hours, G2 = 98 hours, and G3 = 88 hours.
b. Interarrival time: 15 hours. Service times: G1 = 66 hours, G2 = 98 hours, and G3 = 88 hours.
c. Interarrival time: 15 hours. Service times: G1 = 59 hours, G2 = 88 hours, and G3 = 78 hours.

88 hours, respectively (Table 5). Under these conditions, forty-five runs were made again, and results are given in Table 5.

As seen in Table 5, after the investment strategy was used, the average turnaround time of each ship type decreased by about eight days (192 hours) for G1, seven days for G2, and eight days for G3 as compared to the results of the full-capacity strategy.

For R1 and R4 quays, the results were about the same as those before using the investment strategy because

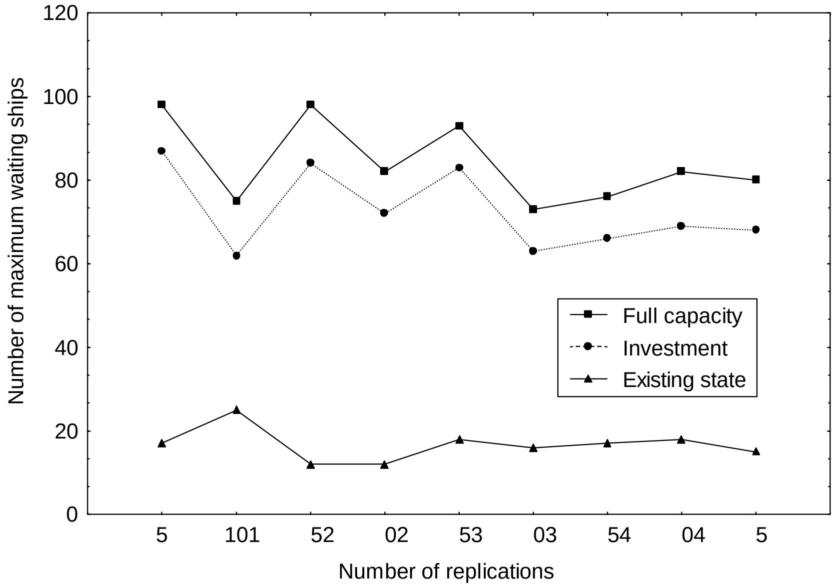

Figure 7. Simulation results for the number of waiting ships in the R2 quay after investment

distributions of ships to R1 and R4 quays were low (see Table 2). The average or maximum number of ships decreased by about 14% in the R2 quay. At the same time, the average and maximum number of waiting ships decreased about 32% and 38% in the R3 quay, respectively. The waiting time also decreased approximately at the same proportion (14% for R2 quay and 38% for R3 quay). The utilizations of the quays did not change much because the quays did not have bottlenecks. In addition to these statements, the results of the strategies are given in Figure 7. After implementing the investment strategy, the number of waiting ships decreased according to the full-capacity strategy. This can be directly seen in Figure 7.

7. Conclusions

A simulation model was constructed to analyze port operations and was run especially for investment planning. This paper discusses the simulation model results of Trabzon Port, which were performed within a research project. The project was focused on the investigation of bottleneck points and the addition of new port equipment at these points. Three vehicles for each ship type were added to the loading/unloading vehicles having the bottlenecks. As part of the investment planning strategy, only three vehicles could be added because of economic constraints in the model. The model was run under these conditions. Our model has demonstrated a reduction of almost eight days in ship turnaround time and a decrease in the number of ships and the time spent waiting in lines by applying the investment strategy. As a result, the port performance for a number of alternative strategies was evaluated, and it was seen how the system could behave. But the investment on a port does cause a cost increase. The port simulation model can be used as a decision support tool for analyzing and evaluating port performance by the port management.

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