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A SIMULATION METHOD IN MODELING EXPLOITATION FACTORS OF SEAPORT QUEUING SYSTEMS

While a considerable amount of research effort has been devoted to modeling seaport systems, models capable of producing results that match the data are proving elusive. In this paper, we have contributed to the literature which models port systems as the queuing processes and builds a general equilibrium model which is suitable for both the analyzing of a number of potential determinants of the systems behaviour, and the carrying out of a numerical analysis of the port system operation indices. Furthermore, we seek to establish the potential role played by various elements that impact the operational behaviour of the system. The proposed model is tested with real data of the Bakar bulk cargo terminal. Using several years data set, we have synthesized variances in terminals' operation indices. Following the assumption that the discharging terminal for bulk cargo presents the queuing system type M/M/1, while the loading terminal shows the behaviour of the queuing system type M/D/1, the goal is to create the simulation model that will result in the functional explanation of the behaviour indices and assist in the decision making procedure to improve the effectiveness of the seaport system.

Key words*: simulation method, modeling service systems, discharging and loading terminals for bulk cargo.*

1. INTRODUCTION

Processes in bulk cargo ports that are characterized with unpredictability and changeability are called stochastic because the parameters that determine these processes are the stochastic ones.

For the scientific research of the processes that take place in the port, the queuing theory can be used. Interdependence between entity arriving at the Bakar bulk cargo terminal, waiting for service, and their leaving the system, is determined by mathematical models of the queuing theory. Assumption has been made that the discharging terminal for bulk cargo behaves as the queuing system type M/M/1, while the loading terminal shows the behaviour of the queuing system type M/D/1.

Since the real situation can be very complex, it is not always possible to apply the analytical methods. The queuing process can be relatively simply simulated by using simulation models. The model will be tested with real data of the Bakar bulk cargo terminal.

Before illustrating and applying the simulation method, it is necessary to give some basic features of the port system.

2. BULK CARGO TERMINAL IN BAKAR

When analyzing a port as a queuing system the following assumptions are made [9, p. 493]:

- It is not possible to anticipate the exact time of arrival of ships at the terminal, as it depends on the ship's route and speed, weather conditions, organization of maritime transportation processes and other reasons.
- It is not also possible to predict accurately the service time of a ship, i.e. the duration of the transshipment, as it depends on the type of cargo, the quantity of the cargo loaded on board a ship, capacity and technology of transshipment facilities, weather conditions, organization of port transshipment processes etc.

As a result of these factors, the irregular berth employment appears. If the number of ships arriving is greater than the berth capacity, i.e. the number of ships who can be serviced in a unit of time, then the ships queue or, conversely, if there are few ships, they do not queue, however, the berth (or facility) is unemployed.

A change in number of berths has an impact on certain terminal indices - through the increase in the number of berths, in the number of ships in the queue and at the terminal, as well as in the waiting time and length of the ship's stay at the terminal.

From the queuing theory viewpoint, a bulk cargo terminal has the following characteristics [16, p. 54, 55]:

- the terminal is an open system as ships are not an integral part of the system,

- the Bakar bulk cargo terminal has two specialized quays (a loading and discharging one) as servicing places for which on sea or eventually at anchorage ship queuing lines are formed,
- an unlimited number of ships waiting for service,
- the ships are patient clients, they do not abandon the queue,
- the number of the ship's arrivals as well as the duration of the service i.e. length of the ship's stay at berth for discharging is allocated according to certain theoretical distributions (most often based on Poisson's and Erlang's distribution order *k*, where *k* is a natural number). The service time of a ship, together with the time spent in queuing, represents the ship's stay at the terminal and is one of the most significant indices of bulk cargo port operations,
- the servicing time, that is the time a ship spends at the quay for loading purposes, has a determined distribution because the time of loading is constant, since loading is assumed to be without breaks and bottlenecks,
- a mutual help between the loading and discharging terminals does not exist,
- as regards the queuing discipline, a bulk cargo terminal is a system where servicing is most often carried out according to the FIFO rule (first come-first served), without any priority.

The course of the ship arrivals is stationary Poisson course with the following properties [9, p. 495]:

- time independence, in the arbitrary short time the probability of the arrival of more than one ship is very small, i.e. ships enter a port separately,
- "no memory" property, the ships'arrivals are independent,
- stationarity, intensity of a ship course is time independent since it is a constant value depending only on the length of the observed period.

The basic parameters of a bulk cargo terminal are the ship's arrival rate λ and the rate of service μ.

For a bulk cargo terminal queuing system, the parameter λ represents the average number of bulk carriers or the quantity of bulk cargoes that arrived at a port within an observed time interval (e.g.within a year, month or day).

It the period of time that elapses between the two consecutive ship's arrivals, an arithmetical mean, which represents the average interval between two consecutive ship's arrivals ($\bar{t}_{arr}$), can be computed. This interval is, in fact, the reciprocal value of the ship's arrival rate:

$$\bar{t}_{arr} = 1/\lambda \text{ or } \lambda = 1/\bar{t}_{arr}.,$$

The service rate can be explained analogously. It represents the average number of bulk cargo ships or the quantity of bulk cargoes that can be serviced in a time interval at particular berths.

If the number of ships that can be serviced within an observed time interval is unknown and the duration of the service per ship is only known, then the arithmetical mean pattern represents the average service duration per ship ($\bar{t}_{serv}$) and the time is the reciprocal value of the service rate:

$$\bar{t}_{serv} = 1/\mu, \text{ or } \mu = 1/\bar{t}_{serv}$$

The parameter μ represents the accommodation capacity of a berth and the multiplicand $S \cdot \mu$, where S is the symbol for the number of berths, represents the accommodation capacity of a terminal.

The arrival and service rate quotient represents the berth employment rate or the traffic rate ρ:

$$\rho = \lambda / \mu$$

In practice, the parametre values λ and μ are determined on the basis of the empirical data or assessment depending on the goal and subject of research.

The bulk cargo terminal in Bakar contains the discharging and loading bulk terminals.

These terminals are assigned to handle various types of bulk cargoes, iron ore, coal, bauxite, phosphate. However, in the last few years, coal represents the majority of cargo being handled in that port. The terminals have a maximum degree of utilization for cargoes with bigger specific gravity, for example iron ore. The limiting possibility for expanding the port capacities, so far as forwarding is concerned, rest on the number of stationed wagons per day. The amount of cargo transported by wagons equals to 7,000 - 8,000 tons a day, and the maximum capacity of the wagon distribution center is 14,000 tons. The facility capacities are presented in table 1.

It should be noted in table no. 1 that the crane no. 1 was dismantled in 2004 and the crane no. 3 was installed in 2002. However, this new crane has not yet been used for discharging purposes, except for the test period, and therefore will not be considered in calculations throughout this paper.

Since the transshipment process consists of several technological operations (cargo weighing, transport of cargo with a conveyor from the storage to the ship, loading on board a ship), the theoretical maximum capacity of the loading terminal includes the maximum capacity of every single equipment that takes part in the transshipment (cranes, conveyors, distribution station, weighbridge, storage, wagons). The theoretical maximum capacity implies the maximum capacity of the equipment with the minimum capacity in the transshipment chain.

Table 1. Facility capacities of the bulk cargo terminal in Bakar

Quay Podbok				
length: 394 m	maximum depth: 18.5 m		ship: max 160 000 DWT	
Storage				
	length x width (m)	capacity in tons		Equipment
		iron ore	coal	
Podbok	330 x 27	300,000	100,000	discharging equipment with conveyor
Dobra	340 x 19	80,000	25,000	conveyor
Plato	160 x 36	80,000	26,000	unequipped

Cranes			
	capacity in t/h	Year of manufacture	quantity
discharging equipment no.1	800	1967	1
discharging equipment no.2	1,600	1978	1
discharging equipment no.3	3,000	2002	1
loading equipment	600	2002	1
storage conveyor	500	1967	1
Conveyors			
capacity for iron ore	1,600 t/h		
capacity for coal	1,300 t/h		

Capacities in tons according to the type of cargo		
	Ore	Coal
single storage capacity in tons	400,000	150,000
tech. Capacity ship-storage for crane 45+16 t/shift	8,167	3,268
tech. Capacity ship-storage for crane 45 t/shift	-	2,400
tech. Capacity storage-wagon for storage gantry crane in t/shift	2,500	-
theoretical max. capacity in tons	4,960,000	3,000,000
real capacity in tons	3,500,000	2,000,000
Technological-market capacity in tons – discharging term.	2,000,000	
Technological-market capacity in tons – loading terminal	1,100,000	

Source: Port of Rijeka [11]

The terminal capacity is the maximum terminal capacity reduced for the cargo that has not been transshipped during breaks which include breaks caused by mechanical failures of the equipment, caused by maintenance and cleaning of the facility, working breaks and time spent on the ship's mooring and unmooring procedure.

Finally, the quantity of the cargo transshipped in a port does not depend only on the equipment, transport and storage capacities, but also on some external factors. These are:

- the transport of cargo in and out of port depending on the railway flow rate, flow rate of the railway hub and inland storages,
- the cargo demand,
- breaks caused by weather conditions or strikes.

The technological-market capacity of the terminal includes the above factors, and is calculated by taking into account the terminal capacity and the several-year cargo flow record.

3. SIMULATION OF THE BULK CARGO TERMINAL IN BAKAR

We propose that the discharging bulk cargo terminal behaviour is observed as the queueing system type M/M/1 and the loading bulk cargo terminal behaviour as the queueing system type M/D/1. The processes in the port will be examined through the simulation method. The results of the simulation model can serve as indicators of the system behaviour.

In modeling the processes the following is essential:

- to dispose of the data on the system processes that are mainly collected by statistical recording, and then followed by a statistical analysis,
- to form a simulation model, in the process of which it is important to determine the time unit of simulation, the simulation period, and the simulation mode. It is possible, in each time interval, to simulate the number of the ship's arrivals or (as is in this case) to simulate the time between particular arrivals. The model can be descriptively presented in the following steps:
  - generate the random number for variable x, that is the time between two breaks, using the recorded distribution,
  - generate the random number for the variable y, that is the service time,
  - determine the starting and finishing hour of service, in which the process terminal occupancy has to be addressed; if the terminal has been idle at the time of a new ship's arrival, then register the terminal waiting period, and, on the contrary, register the ship's waiting period,

- repeat the simulation from the first step to the end of the time determined as a simulation period,
- make an analysis and get a conclusion.

3.1. Simulation of bulk cargo discharging terminal

Empirical data of arrival time distribution between two ships are presented in table 2, and data of ship's service time are shown in table 3. On the basis of these data the simulation of terminal operation can be done. The prior step is to determine the intervals of random numbers on the basis of cumulative probabilities.

Table 2. Time distribution between two ships' arrivals

Time between two arrivals (day) x		Probability p(x)	Cumulative probability
0 – 3	1.5	0.09	0.09
3 – 6	4.5	0.29	0.38
6 – 9	7.5	0.33	0.71
9 – 12	10.5	0.19	0.90
12 – 15	13.5	0.08	0.98
15 – 18	16.5	0.02	1.00

Table 3. Probability distribution of service times

Service time (day)	Probability	Cumulative probability
3	0.06	0.06
4	0.21	0.27
5	0.26	0.53
6	0.33	0.86
7	0.14	1.00

On the basis of data presented in previous tables, average arrival time and average service time have been calculated:

$$\bar{x} = \sum x \cdot p(x) = 7.32 \text{ days/ship}$$

$$\bar{y} = \sum y \cdot p(y) = 5.28 \text{ days/ship}$$

Next, the system parameters and the occupancy rate of service place (traffic rate) are to be calculated, and thereupon simulate terminal operation during the simulation period.

Discharging bulk cargo terminal operation indices are:

- arrival rate of ships

$$\lambda = \frac{1}{\bar{x}} = 0.1366 \text{ ship/day} = 4.1 \text{ ships/month,}$$

- service rate

$$\mu = \frac{1}{\bar{y}} = 0.1894 \text{ ship/day} = 5.7 \text{ ships/month,}$$

- traffic rate

$$\rho = \frac{\lambda}{\mu} = 0.7212,$$

- the average number of ships at the terminal (in queue and being serviced) with the assumption of Poisson arrivals and distribution

$$L = \frac{\rho}{1-\rho} = 2.587 \text{ ships.}$$

According to the indices the discharging terminal is exploited in great percentage considering input capacities. The simulation has been made on the basis of 365 days that is one calendar year, in this case year 2005. The results are presented in table 4.

Table 4. Simulation of bulk cargo discharging terminal (year 2005)

No.	ARRIVALS		SERVICE			WAITING	
	Var. *x* (day)	Ship arrival (date and hour)	Var. *y* (day)	Starting date and hour	Finishing date and hour	Terminal (day)	Ship (day)
1	7.5	08.01.12	3	08.01.12	11.01.12	7.5	-
2	10.5	19.01.00	6	19.01.00	25.01.00	7.5	-
3	7.5	26.01.12	4	26.01.12	30.01.12	1.5	-
4	7.5	03.02.00	5	03.02.00	08.02.00	3.5	-
5	10.5	13.02.12	6	13.02.12	19.02.12	5.5	-
6	1.5	15.02.00	3	19.02.12	22.02.12	-	4.5
7	4.5	19.02.12	6	22.02.12	28.02.12	-	3
8	13.5	05.03.00	4	05.03.00	09.03.00	4.5	-
9	1.5	06.03.12	6	09.03.00	15.03.00	-	2.5
10	4.5	11.03.00	6	15.03.00	21.03.00	-	4
11	7.5	18.03.12	5	21.03.00	26.03.00	-	2.5
12	7.5	26.03.00	5	26.03.00	31.03.00	-	-
13	7.5	02.04.12	4	02.04.12	06.04.12	2.5	-
14	10.5	13.04.00	6	13.04.00	19.04.00	6.5	-
15	4.5	17.04.12	6	19.04.00	25.04.00	-	1.5
16	7.5	25.04.00	5	25.04.00	30.04.00	-	-
17	10.5	05.05.12	4	05.05.12	09.05.12	5.5	-
18	10.5	16.05.00	6	16.05.00	22.05.00	6.5	-
19	7.5	23.05.12	4	23.05.12	27.05.12	1.5	-
20	7.5	31.05.00	6	31.05.00	06.06.00	3.5	-
21	7.5	07.06.12	7	07.06.12	14.06.12	1.5	-
22	10.5	18.06.00	7	18.06.00	25.06.00	3.5	-
23	4.5	22.06.12	6	25.06.00	01.07.00	-	2.5
24	1.5	24.06.00	4	01.07.00	05.07.00	-	7
25	1.5	25.06.12	6	05.07.00	11.07.00	-	9.5
26	7.5	03.07.00	5	11.07.00	16.07.00	-	8
27	10.5	13.07.12	3	16.07.00	19.07.00	-	2.5
28	4.5	18.07.00	3	19.07.00	22.07.00	-	1
29	10.5	28.07.12	5	28.07.00	02.08.12	6.5	-
30	13.5	11.08.00	6	11.08.00	17.08.00	8.5	-
31	10.5	21.08.12	6	21.08.12	27.08.12	4.5	-
32	10.5	01.09.00	5	01.09.00	06.09.00	4.5	-
33	4.5	05.09.12	6	06.09.00	12.09.00	-	0.5
34	7.5	13.09.00	6	13.09.00	19.09.00	1	-
35	4.5	17.09.12	6	19.09.00	25.09.00	-	1.5
36	7.5	25.09.00	5	25.09.00	30.09.00	-	-
37	7.5	02.10.12	5	02.10.12	07.10.12	2.5	-
38	10.5	13.10.00	6	13.10.00	19.10.00	5.5	-
39	4.5	17.10.12	5	19.10.00	24.10.00	-	1.5
40	7.5	25.10.00	5	25.10.00	30.10.00	1	-
41	7.5	01.11.12	5	01.11.12	06.11.12	2.5	-
42	7.5	09.11.00	5	09.11.00	14.11.00	2.5	-
43	10.5	19.11.12	3	19.11.12	22.11.12	5.5	-
44	4.5	24.11.00	7	24.11.00	01.12.00	1.5	-
45	10.5	04.12.12	4	04.12.12	08.12.12	3.5	-
46	1.5	06.12.00	3	08.12.12	11.12.12	-	2.5
47	7.5	13.12.12	6	13.12.12	19.12.12	2	-
48	7.5	21.12.00	5	21.12.00	26.12.00	1.5	-
49	4.5	25.12.12	5	26.12.00	31.12.00	-	0.5
SUM	358.5		250			114	55
Comparison for yr. 2002	364		119			249	-

3.2. Simulation analysis of discharging bulk cargo terminal

The last two rows of table 4 contain results that are used for analysis of the discharging terminal simulation model.

Sum of variable x values amounts to 358.5 days. Hawing in mind that the number of simulated steps is 49 then the average value of variable *x* is

$$\overline{x'} = 7.316 \text{ days},$$

and the average service time

$$\overline{y'} = 5.102 \text{ days}.$$

These are results of the first experiment. Similarly, another nine experiments were done and the results of experiments are given in the following table (table 5).

Table 5. Results of ten experiments of bulk cargo discharging terminal simulation (year 2005)

No.	Var. x (day)	Var. y (day)	Terminal waiting (day)	Ship waiting (day)	No. of observation	$\overline{x'}$	$\overline{y'}$
1.	358.5	250	114	55	49	7.32	5.10
2.	362	253	108	53.5	50	7.24	5.06
3.	357.5	249	108	51.5	49	7.30	5.08
4.	360.5	252	108.5	52	49	7.36	5.14
5.	358	248	110	54	48	7.46	5.17
6.	360	254	106	57	50	7.20	5.08
7.	361.5	252	109.5	52.5	51	7.09	4.94
8.	359.5	250	108	55	49	7.34	5.10
9.	362	254	106	53	48	7.54	5.29
10.	364	253	111	61	50	7.28	5.06

Compared with the averages calculated on the basis of empiric data obtained by statistical recording, it can be σconcluded that the averages obtained by simulation don't depart from the starting ones. The reason for this is most probably relatively long simulation period of one year.

The average value of variable x for ten experiments amounts to $\overline{x'}$= days, and the average service time to $\overline{y'}$ = 5.102 days. Next, standard deviation and variance of the results of these ten experiment for variable x are $\sigma = 0.127$, V = 1.737 %, and for variable y standard deviation $\sigma = 0.089$, and variance V = 1.755 %. Results of variance points to extremely low dispersion of single values from averages of variable x and variable y.

Total waiting time of terminal in 2005 in average amounts to 108.9 days, which in total simulation period (365 days) results in proportion of 0.30. This means that the terminal was 30 % of time unoccupied during 2005, waiting on ship to arrive. Ships were waiting in total 54.45 days on free berth. Comparing these values, it is obvious that "booking" of ships were not done in the sense of optimal capacity employment of the terminal. However, considering results for year 2002 (251.5 days waiting time of terminal) noticeable is a huge leap in terminal's productivity.

3.3. Simulation of bulk cargo loading terminal

Empirical data of arrival time distribution between two ships are presented in table 6. Service time of ship is deterministic and amounts 3 days for ship of 10,000 deadweight. These data make possible the simulation of loading terminal operating.

Table 6. Time distribution between two ships' arrivals

Time between two arrivals (day) x		Probability p(x)	Cumulative probability
0 – 2	1	0.22	0.22
2 – 4	3	0.49	0.71
4 – 6	5	0.13	0.84
6 – 8	7	0.09	0.93
8 – 10	9	0.07	1.00

From the data in table 6, the average time between two ships' arrivals is obtained:

$$\bar{x} = \sum x \cdot p(x) = 3.6 \text{ days/ship}$$
y= days /ship

Next, the calculation of the system parameters and traffic rate will be done, followed by simulation of the terminal operation during the simulation period.

Loading bulk cargo terminal operation indices are:

- arrival rate of ships

$$\lambda = \frac{1}{\bar{x}} = 0.278 \text{ ship/day} = 8.333 \text{ ships/month},$$

- service rate

$$\mu = \frac{1}{\bar{y}} = 0.333 \text{ ship/day} = 9.999 \text{ ships/month},$$

- traffic rate

$$\rho = \frac{\lambda}{\mu} = 0.835,$$

- the average number of ships at the terminal (in queue and being serviced) with the assumption of Poisson arrivals and deterministic distribution

$$L = \rho + \frac{\rho^2}{2(1-\rho)} = 2.948 \text{ ships}.$$

According to the indices the loading terminal is also quite busy considering input capacities. The simulation has been made on the basis of 365 days that is one calendar year, in this case year 2005. The results are presented in table 7.

Table 7. Simulation of bulk cargo loading terminal (year 2005)

No.	ARRIVALS		SERVICE			WAITING	
	Var. x (day)	ship arrival day	Var. x (day)	Starting day	Finishing day	Terminal (day)	Ship (day)
1	3	04.01.	3	04.01.	07.01.	-	2
2	1	05.01.	3	07.01.	10.01.	-	4
3	1	06.01.	3	10.01.	13.01.	-	4
4	3	09.01.	3	13.01.	16.01.	-	4
5	3	12.01.	3	16.01.	19.01.	-	4
6	3	15.01.	3	19.01.	22.01.	-	4
7	3	18.01.	3	22.01.	25.01.	-	2
8	5	23.01.	3	25.01.	28.01.	2	-
9	7	30.01.	3	30.01.	02.02.	-	-

10	3	02.02.	3	02.02.	05.02.	4	-
11	7	09.02.	3	09.02.	12.02.	-	-
12	3	12.02.	3	12.02.	15.02.	-	-
13	3	15.02.	3	15.02.	18.02.	-	-
14	3	18.02.	3	18.02.	21.02.	-	-
15	3	21.02.	3	21.02.	24.02.	-	-
16	3	24.02.	3	24.02.	27.02.	-	2
17	1	25.02.	3	27.02.	02.03.	-	2
18	3	28.02.	3	02.03.	05.03.	-	4
19	1	01.03.	3	05.03.	08.03.	-	4
20	3	04.03.	3	08.03.	11.03.	-	4
21	3	07.03.	3	11.03.	14.03.	-	4
22	3	10.03.	3	14.03.	17.03.	-	4
23	3	13.03.	3	17.03.	20.03.	-	6
24	1	14.03.	3	20.03.	23.03.	-	6
25	3	17.03.	3	23.03.	26.03.	-	6
26	3	20.03.	3	26.03.	29.03.	-	2
27	7	27.03.	3	29.03.	01.04.	-	2
28	3	30.03.	3	01.04.	04.04.	-	2
29	3	02.04.	3	04.04.	07.04.	-	2
30	3	05.04.	3	07.04.	10.04.	-	4
31	1	06.04.	3	10.04.	13.04.	-	4
32	3	09.04.	3	13.04.	16.04.	-	4
33	3	12.04.	3	16.04.	19.04.	-	6
34	1	13.04.	3	19.04.	22.04.	-	4
35	5	18.04.	3	22.04.	25.04.	-	4
36	3	21.04.	3	25.04.	28.04.	-	4
37	3	24.04.	3	28.04.	01.05.	-	4
38	3	27.04.	3	01.05.	04.05.	-	6
39	1	28.04.	3	04.05.	07.05.	-	2
40	7	05.05.	3	07.05.	10.05.	2	-
41	7	12.05.	3	12.05.	15.05.	-	-
42	3	15.05.	3	15.05.	18.05.	-	-
43	3	18.05.	3	18.05.	21.05.	-	-
44	3	21.05.	3	21.05.	24.05.	-	2
45	1	22.05.	3	24.05.	27.05.	2	-

46	7	29.05.	3	29.05.	01.06.	4	-
47	7	05.06.	3	05.06.	08.06.	-	2
48	1	06.06.	3	08.06.	11.06.	-	2
49	3	09.06.	3	11.06.	14.06.	2	-
50	7	16.06.	3	16.06.	19.06.	-	-
51	3	19.06.	3	19.06.	22.06.	4	-
52	7	26.06.	3	26.06.	29.06.	4	-
53	7	03.07.	3	03.07.	06.07.	-	2
54	1	04.07.	3	06.07.	09.07.	-	-
55	9	13.07.	3	13.07.	16.07.	4	-
56	5	18.07.	3	18.07.	21.07.	2	-
57	3	21.07.	3	21.07.	24.07.	-	2
58	1	22.07.	3	24.07.	27.07.	4	-
59	9	31.07.	3	31.07.	03.08.	-	-
60	3	03.08.	3	03.08.	06.08.	-	2
61	1	04.08.	3	06.08.	09.08.	2	-
62	7	11.08.	3	11.08.	14.08.	-	-
63	3	14.08.	3	14.08.	17.08.	-	2
64	1	15.08.	3	17.08.	20.08.	4	-
65	9	24.08.	3	24.08.	27.08.	2	-
66	5	29.08.	3	29.08.	01.09.	2	-
67	5	03.09.	3	03.09.	06.09.	-	-
68	3	06.09.	3	06.09.	09.09.	-	-
69	3	09.09.	3	09.09.	12.09.	-	-
70	3	12.09.	3	12.09.	15.09.	6	-
71	9	21.09.	3	21.09.	24.09.	2	-
72	5	26.09.	3	26.09.	29.09.	-	2
73	1	27.09.	3	29.09.	02.10.	-	4
74	1	28.09.	3	02.10.	05.10.	-	4
75	3	01.10.	3	05.10.	08.10.	-	4
76	3	04.10.	3	08.10.	11.10.	-	4
77	3	07.10.	3	11.10.	14.10.	-	2
78	5	12.10.	3	14.10.	17.10.	-	4
79	1	13.10.	3	17.10.	20.10.	-	6
80	1	14.10.	3	20.10.	23.10.	-	6
81	3	17.10.	3	23.10.	26.10.	-	8

82	1	18.10.	3	26.10.	29.10.	-	8
83	3	21.10.	3	29.10.	01.11.	-	6
84	5	26.10.	3	01.11.	04.11.	-	6
85	3	29.10.	3	04.11.	07.11.	-	6
86	3	01.11.	3	07.11.	10.11.	-	8
87	1	02.11.	3	10.11.	13.11.	-	8
88	3	05.11.	3	13.11.	16.11.	-	2
89	9	14.11.	3	16.11.	19.11.	4	-
90	9	23.11.	3	23.11.	26.11.	-	-
91	3	26.11.	3	26.11.	29.11.	2	-
92	5	01.12.	3	01.12.	04.12.	-	-
93	3	04.12.	3	04.12.	07.12.	-	-
94	3	07.12.	3	07.12.	10.12.	-	-
95	3	10.12.	3	10.12.	13.12.	-	-
96	3	13.12.	3	13.12.	16.12.	4	-
97	7	20.12.	3	20.12.	23.12.	-	-
98	3	23.12.	3	23.12.	26.12.	-	-
99	3	26.12.	3	26.12.	29.12.	-	-
100	3	29.12.	3	29.12.	01.01.	-	-
SUM1	362		300			62	216
Comparison for yr 2002	360		114			249	

3.4. Analysis of loading terminal simulation

The last two rows of table 7 contain results that are used for analysis of the loading terminal simulation model.

Sum of the variable x values amounts to 362 days. Considering that the number of simulated steps is 100 then the average value of variable x equals to

$$\overline{x'} = 3.62 \text{ days, days,}$$

and service time is taken as deterministic and amounts to

$$y' = \text{days.}$$

Here again, another nine experiments were done and the results of experiments are given in the following table (table 8).

Table 8. Results of ten experiments of bulk cargo loading terminal simulation (year 2005)

No.	Var. x (day)	Var. y (day)	Terminal waiting (day)	Ship waiting (day)	No. of observati on	$\overline{x'}$	$\overline{y'}$
1.	362	300	62	216	100	3.62	3
2.	364	303	61	200	101	3.60	3
3.	360	297	63	203	99	3.64	3
4.	361	294	67	209	98	3.68	3
5.	362	300	62	210	100	3.62	3
6.	360	297	63	216	99	3.64	3
7.	361	294	67	218	98	3.68	3
8.	365	306	59	214	102	3.58	3
9.	360	303	57	217	101	3.56	3
10.	363	303	60	213	101	3.59	3

Compared with the averages calculated on the basis of empirical data obtained by statistical recording, it can be concluded that the averages obtained by simulation don't depart from the starting ones. The reason for this is most probably relatively long simulation period of one year.

The average value of variable x for ten experiments amounts to days, and the service time is deterministic amounting to = 3 days. Next, standard deviation and variance of the results of these ten experiment for variable *x* are $\sigma = 0.040$, V = 1.105 %. Results of variance points again to extremely low dispersion of single values from averages.

Total waiting time of loading terminal is in average 62.1 days, which in total simulation period (365 days) results in proportion of 0.17. This means that the terminal was unoccupied 17 % of time in year 2005, waiting on ship to come, and 83 % of time was occupied. Ships coming on bulk cargo load were averagely waiting 211.6 days on free berth, which is considerably high (58 % days of the year). Comparing these values, it shows again that "booking" of ships were not done in the sense of optimal capacity employment of the terminal. However, considering results for year 2002 noticeable is a huge leap in terminal's productivity.

4. CONCLUSION

In the paper, for research of operation processes and behavior indices that take place in port the queuing theory is used. Interdependence between entity arrivals at bulk cargo port Bakar, waiting on service and their leaving the system is determined by mathematical models of the queuing theory. Processes in bulk cargo ports that are characterized with unpredictability and changeability are determined with stochastic parameters. Since the real situation can be very complex, it is not always possible to apply the analytical methods.

Assuming that discharging terminal for bulk cargo behaves as the queuing system type M/M/1, while loading terminal shows behavior of queuing system type M/D/1, we built a general equilibrium model which proved to be suitable both for analyzing a number of potential determinants of the systems' behavior, and also for carrying out a numerical analysis of the port system operation indices.

Using data sets for years 2005 and 2002 (not shown in this paper for the sake of space conservation) we constructed a simulation model resulting in functional explanation of behavior indices and decision making procedure to improve effectiveness of the sea port system

Bulk cargo port Bakar has two specialized terminals for transshipment of bulk cargoes - loading and discharging terminals. The loading terminal is defined as the queuing system M/D/1, which means that ships' arrivals are Poisson distributed, service time is constant and the terminal has one quay, representing service place. Appropriate parameters as well as indices are calculated.

The exploitability of both terminals in 2005 has drastically changed in contrast to year 2002, and has amounted to 83 % for loading terminal and 79 % for discharging terminal. Still there is a space for improvements and better utilization of existing resources. This is especially true taking into account capacities of loading terminal facility.

Taking into account capacity of crane no. 3, it is clear that discharging terminal is over capacitated and in the near future there is no need to invest in capacity enhancement and facility expansion. In due course a strategy should be developed to draw new cargoes in order to keep busy the existing facility.

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Sažetak

METODA SIMULACIJE U MODELIRANJU EKSPLOATACIJSKIH FAKTORA LUČKIH SUSTAVA MASOVNOG OPSLUŽIVANJA

Premda je mnogo truda uloženo u istraživanja posvećena modeliranju lučkih sustava, modeli koji će dati rezultate u suglasju s opažajnim podacima nisu dosada u potpunosti zadovoljavali. Ovaj rad daje prilog istraživanju modeliranja lučkih sustava po principu sustava masovnog opsluživanja, te postavlja opći model koji je primjenjiv za analizu potencijalnih čimbenika koji imaju utjecaj na ponašanje sustava i za provođenje numeričke analize operacijskih pokazatelja lučkoga sustava. Nadalje, istraživanje je usmjereno u smjeru određivanja uloge različitih čimbenika koji utječu na operacijsko ponašanje sustava. Postavljeni model testiran je sa stvarnim podacima luke za rasute terete Bakar. Koristeći višegodišnje podatke, sintetizirane su varijacije u pokazateljima lučkoga poslovanja. Polazeći od pretpostavke da se iskrcajni terminal ponaša prema pravilima sustava masovnog opsluživanja M/M/1, dok se ukrcajni terminal ponaša u skladu s pravilima sustava M/D/1, cilj je učiniti model simulacije koji će rezultirati u funkcionalnom objašnjenju pokazatelja ponašanja i pomoći u postupku donošenja odluka u cilju unapređenja efikasnosti poslovanja lučkoga sustava.

***Ključne riječi**: metoda simulacije, modeliranje sustava masovnog opsluživanja, terminal za ukrcaj i terminal za iskrcaj rasutih tereta*

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