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ON TRANSPORTATION SYSTEM WITH DETERMINISTIC SERVICE TIME

ABSTRACT

Most of transportation systems behave as M/M/1 queuing type which is widely explored throughout scientific literature. On the other hand, there are a few real life examples of transportation systems with deterministic service time. In this paper we explore one of such systems and propose solution finding for tactical port operational problem by queuing model and heuristic method. A heuristic approach is developed as an alternative to mathematical model solution finding. Between these two methods, good solutions of known quality are provided quickly. Through simple example of bulk loading terminal, defined as M/D/1 system, comparison of the heuristic solutions to the mathematical model indicates that the corresponding results match closely. On the basis of the experiment, we assume that the same heuristic with a slight modification would give acceptable solution for a real life M/D/S problem where search for feasible solution by mathematical model is a tough and unacceptable task in practical use.

KEY WORDS

queuing system M/D/1, marine transport, deterministic service time, tactical operation planning

1. INTRODUCTION

Many organizations ship their products or materials to their customers, or to their own distribution centers or manufacturing facilities, on a recurrent basis. Often the shipments are not initiated by orders from the receiving locations, but rather the shipper must schedule the shipments to assure that the receiving locations do not run out of stock. This is the case for materials that are shipped in large volumes such as bulk materials. Coal, iron ore and similar bulk materials in their distribution chain from shipper to receiver most often transit bulk sea ports. The materials are carried by bulk carriers, ships built specifically to carry such type of cargoes. In size, they vary from handy size (abt. 24,000 DWT) to large Cape size bulk carriers of more than 270,000 DWT. In such a delivery environment decisions are made concerning the routing and schedule of the delivery ships, when to call on each port (delivery location) and how much to deliver. Since the consumption of the products at the delivery locations may be stochastic, the actual delivery quantity varies through the time and poses a problem in planning port operations and investments. This type of problem is known as the mass queuing problem. The objective of the queuing theory is to find such a capacity of service place which will ensure both, optimal operation of service place and giving optimal service to the customer. Large volume product storage facilities are substantial capital investments that are not made easily. Therefore, port storage facilities usually operate with limited storage capacity at their origins. This limited storage capacity necessitates planning of cargo reception to prevent storage overflow at the port. Such overflow will result in reduction or even stoppage of cargo discharge from the ships. In case of recurrences of the situation, eventually the cargo shippers may decide to use in the future alternative port to ship their cargo to. As a result, the former port may lose customers that can lead to reduction of cargo turnover and underemployment of the facility.

During the last decade, a significant amount of attention was directed towards queuing system problems in the field of informatics, electronics and various production plant operations (see recent papers by Morimoto and Yoshida [20], Baita et all [2], Blanc [5], Boyer et all [7] and Bard et all [4]). However, the queuing theory has rarely been used in modeling sea port systems (see recent papers by Asperen et all [1] and Cullinane et all [11]). For some recent work on variants of queuing theory application on transportation and product stocking problems, see Brandao and Mercer [8], Ronen [24], Salhi and Nagy [25] and Sariklis and Powell [27]. Larger scale (as far as the volume of shipments is concerned) queuing system problems exist in marine transportation, but these problems are of a somewhat different character. In contrast to the vast body of literature dedicated to queuing system problems, relatively little attention has been directed to the port as a queuing system, Cullinane [12]. Strategic decisions determine the required storage capacities and facility inventory (e. g. ship discharging cranes, storage cranes and conveyors) at the port. The tactical decisions comprise cargo quantity contracting, cargo timing, facility work scheduling, maintenance and repair work scheduling, etc.

This work addresses a tactical port operation problem considering sea port as a queuing system, with berths as service places and ships as customers or arrival entities. Objective of the paper is to determine bulk sea port operation indices based on cargo turnover, while accounting for the port facility limitations. The major contribution of this work is in the development of a heuristic approach as an alternative to mathematical model solution finding. The next section provides a description of the problem. It is followed by the mathematical model and heuristic method used to solve it, and results for bulk loading port as an example. Finally, practical extensions are outlined.

2. PROBLEM FORMULATION

Bulk materials are shipped in large volumes between sea ports by bulk carriers. Bulk port facilities often consist of loading and unloading terminals. The difference in cargo operation on those two terminals has impact on the shore cargo handling equipment and stipulate selection of appropriate theoretical method for terminal operation modeling. Since the interoperability between those two terminals is usually low due to different cargo equipment installation, the approach used here separates the solution of the problem into two parts. In this paper we shall focus on the bulk cargo loading terminal, while modeling of unloading terminal will be the subject of our further research.

The problem is to determine the optimal facility capacity for the existing and future projected cargo turnover. The facility capacity implies: number and length of berths, draught limitation on berths, type and capacity of shore cargo handling equipment, capacity of storage and capacity of cargo conveyors. Furthermore, hinterland connection will have influence on port capacity. Course of cargo operation activities of the bulk facility that depend on issues such as number of ships and their time of arrival, cargo quantities arrived, cargo dispatch by rail is subject to random changes, therefore, the queuing theory is selected for modeling the terminal operation. To explore loading terminal as a mass servicing system, we shall take the following assumptions:

- arrival time of ships can not be predicted with certainty,
- terminal is an open system since the ship entries are not part of it,
- terminal has one or more specialized berths for which ship queuing lines are eventually formed at anchorage,
- unlimited number of ships waiting on service,
- ships are patient clients, they do not abandon queue,
- arrival rate is Poisson distributed which is determined with statistical c^2 test,
- servicing time, that is, time that ship spends at the terminal for loading has deterministic distribution because loading is continuous without breaks,
- mutual assistance between loading and unloading terminals does not exist,
- FIFO service rule is applied, without priority.

Through statistical data analysis on the number of ship arrivals per day and month of the chosen terminal, it can be established that no significant dependence exists in the sequence of daily arrivals of bulk ships, i. e. that arrivals are statistically random. It follows that the number of ship arrivals can be taken as random variable and, in addition, the empirical distribution of this variable approximated with the appropriate theoretical distribution. In such cases, queuing theory can be applied for computing indices of any traffic system, such as bulk cargo terminal operations. Due to aforementioned, for the purpose of determination of production indices we shall set the $M/D/1$ queuing model. Through the analysis of present state of the terminal, the question that emerges is whether it is justifiable to invest in modernization and reconstruction of the terminal in order to produce better business effects or it would be more appropriate to build a strategy for optimization of usage of existing resources.

Ship arrivals as defined through stationary Poisson course have properties [19, p. 495] such as: time independence property (in arbitrary short time probability to arrive more than one ship is very small), "no memory" property (arrivals of ships are independent) and stationary property (intensity of a ship course is time-independent since it is constant value dependent only on length of the observed period).

Basic parameters for the $M/D/1$ queuing model for bulk loading terminal are λ and μ. Parameter λ may represent the average number of bulk ships or quantity of bulk cargoes at the terminal during an observed time unit (e. g. during a year, month or day). In this paper, arrival entities (arrival rate λ) are bulk ships arrived into loading terminal on yearly basis. The average number of bulk ships (or the average quantity of bulk cargo) that can be serviced in a time unit at certain berth is service rate μ. The ratio between arrival rate and service rate of cargo quantity is traffic rate or utilization factor, i. e. traffic intensity of the berth ρ ($\rho=\lambda/\mu$).

3. MATHEMATICAL MODEL

Queuing models M/G and M/D are explored in scientific papers to some extent [13], [20], and [23]. For the $M/G/1$ queue, Gong and Hu [16] recovered the formulas for the moments of the system time and delay, including the Pollaczek-Khinchin mean-value formula. Boyer et all [7] analyzed the $M/G/1$ processor sharing queue with heavy tailed services and with impatient customers. It is assumed that impatience depends on the value of the service required. Fendick and Whitt [14] used measurements and approximations to describe the traffic system and predict the average workload and behavior in a single-server queue.

Due to Poisson distributed arrival rate, deterministic distribution of service time, one berth as service place and unlimited number of entities in queue, we shall set up loading terminal as $M/D/1/\infty$ model which represents a special case of $M/G/1$ model. The $M/G/1$ model has Poisson arrivals and general independent service times, with the mean (average) value E[t] and the variance Var[t], $t \geq 0$. The shortfall of this model is limitation regarding obtaining some results. It is impossible to compute the probabilities p_n (probability that n entities are in system), therefore, only the basic parameters will be determined – the number of entities in queue L_Q, the number of entities in system L, the waiting time in queue W_Q, and the waiting time in system W.

Let λ be the expected number of ship arrivals in Poisson distribution, and service time distribution with E[t] and Var[t], where t is nonnegative random variable, $t \geq 0$, then the model $M/G/1$ has the following formulae [3, pp. 428]:

– the expected number of entities in system, known as Pollaczek-Khintchine (P-K) formula:

$$L = \lambda E[t] + \frac{\lambda^2 (E^2[t] + Var[t])}{2(1-\lambda E[t])}, \quad \text{where } E[t] < 1, t \geq 0 \tag{1}$$

and by insertion the service rate μ=1/E[t] the formula is:

$$L = \frac{\lambda}{\mu} + \frac{\left(\frac{\lambda}{\mu}\right)^2 + \lambda^2 Var[t]}{2\left(1-\frac{\lambda}{\mu}\right)} \tag{2}$$

– the expected number of entities in queue:

$$L_Q = L - \lambda E[t] = L - \frac{\lambda}{\mu} \tag{3}$$

– the expected waiting time in system:

$$W = \frac{L}{\lambda} \quad \text{or} \quad W = W_Q + \frac{1}{\mu} \tag{4}$$

– the expected waiting time in queue:

$$W_Q = \frac{L_Q}{\lambda} \tag{5}$$

With the assumption of constant service time the model transforms into the $M/D/1$ model. According to the mentioned assumption Var[t] = 0. In that case, a Pollaczek-Khintchine formula is simplified [3, pp. 430] and becomes:

$$L = \rho + \frac{\rho^2}{2(1-\rho)} \tag{6}$$

where $\rho=\lambda/\mu$, and μ is constant rate of service.

For a bulk terminal with more than one berth, represented as $M/D/S$ system with service places $S>1$, methods are too complex for a simple formula. Using generating functions Crommelin [10] derived a general expression for the waiting time distribution of the $M/D/S$ queue for all $S \in \mathbb{N}$, which for $S=1$ corresponds to Erlang's result. If P_n denotes the stationary probability of the system containing no more than n customers, Crommelin's result reads:

$$P\{W \leq x\} = \sum_{n=0}^{S-1} P_n \sum_{k=0}^{m} \frac{\{-\lambda(x-mD)\}^{(k+1)S-1-n}}{\{(k+1)S-1-n\}!} e^{-\lambda(x-mD)}, \quad mD \leq x < (m+1)D \tag{7}$$

where:

W – waiting time

D – constant time

x – time unit

n – number of customers

Prabhu [22] proved that for $S \geq 1$ Erlang's integral equation yields a solution of type (7), where P_n is replaced by some alternatively defined constant α_n. However, it is unresolved how to interpret α_n as the cumulative state probability. Apart from this, Crommelin's result is not really practical for numerical purposes, due to alternating terms which are in general much larger than their sum. As a way to get around the problem of round off errors, a recursion scheme based on Crommelin's argument is described in Tijms [29]. However, for increasing S and ρ this recursion scheme will ultimately be hampered by round off errors, in which case an asymptotic expansion is recommended.

Franx [15] presents an alternative probabilistic approach, leading to a simple formula for the waiting time distribution, which is numerically stable for all $\rho<1$. Formula (8 or 9) is derived without the use of generating functions or Laplace transforms. The derived expression (8) satisfies Erlang's integral equation. Defining the cumulative probability Q_m the formula is:

$$(\forall k \in \mathbb{N})(\forall u \in (0, D])\ P\{W \le kD - u\} = \\ = e^{-\lambda u} \sum_{j=0}^{kS-1} Q_{kS-j-1} \frac{(\lambda u)^j}{j!} \quad (8)$$

Substitution of $x = kD - u$ gives us the waiting time distribution:

$$P\{W \le x\} = e^{-\lambda(kD-x)} \sum_{j=0}^{kS-1} Q_{kS-j-1} \frac{\lambda^j (kD-x)^j}{j!},$$

$$\text{for } (k-1)D \le x < kD \quad (9)$$

where:

$$Q_m = \sum_0^m q_i$$

$q_i = \lim_{t\to\infty} P\{L_q(t) = i\}$ – stationary probability of finding a queue of length i

As this expression contains only a finite number of positive terms, it does not present any numerical complications, regardless of the traffic intensity ρ. However, for real life application, the use of expression may prove to be rather awkward due to determination of Q_m. While obtaining optimal solutions is desirable, deriving high-quality solutions quickly is essential for any practical application. For this purpose we suggest a heuristic approach (see next section) as an alternative to finding the optimal solution.

4. PROBLEM SOLUTION AND RESULTS ANALYSIS

Data that were selected from a port operation refer to bulk loading terminal of the Port of Rijeka used to assemble a problem of terminal operation. The loading terminal is capable to handle various types of bulk cargoes, iron ore, coal, bauxite, phosphate. Loading terminal has maximum degree of utilization for cargoes with bigger specific gravity, for example iron ore. The quantity of cargo handled in a port does not depend only on cargo loading equipment, transport and storage capacities, but also on external factors, such as cargo quantity that arrives at the terminal and cargo quantity that departs from the terminal. The later depends on railway and railway hub throughput, inland storages congestion, cargo demand by receiver/industry, breaks caused by weather or strikes, etc. Quantity of cargo transported by wagons amounts to 7,000 - 8,000 tons/day, and the maximum capacity of the wagon distribution center is 14,000 tons/day. Market capacity of the terminal (1,500,000 tons/year) includes these factors, and is calculated taking into account the terminal capacity and several-years record of cargo throughput.

Technological process on the terminal consists of the following procedures: cargo loading from storage on conveyor belts with storage gantry cranes, cargo transport from storage to port's loading equipment by conveyors, and ship loading. The assumption made here is that loading is continuous without any breaks and bottlenecks resulting in constant loading time, meaning, duration of ship service (time that ship spends at the loading terminal) has deterministic distribution. From statistical data of the Port of Rijeka follows that the loading terminal's arrival rate of cargo (coal) is 1,234,127 tons for year 2006. Besides, size of ships arriving at the terminal is in range of 8,500 - 11,900 dwt. For the sake of vessel description simplicity, we shall consider a representative ship of 10,000 dwt. Service time for such a ship equals to 2.5 days on the observed loading terminal, which means that 146 ships can be serviced per year (2006 and 2008). For the year 2008 expected coal turnover is 1,350,000 tons.

As stated in the mathematical model, the loading terminal is a queuing system with one service place and unlimited number of entities in queue, where service time is deterministically distributed with notation $M/D/1/\infty$. According to the appropriate queuing theory formulae for this type of queuing problem (see part 3) the terminal operation indices are computed and listed in Table 1.

Results of calculations shown above, for 2002 and 2005, were made on the basis of old facility equipment installed on the key and open storage (ship loading equipment, storage gantry crane and storage conveyers), whilst calculations for 2006 have taken into account new equipment installed in 2001 that become fully operational by the end of 2005. Therefore, service rate for 2002 and 2005 amounts to 126 ships/year, whereas service rate for 2006 and forecasted 2008 is 146 ships/year. Increase of cargo turnover from 2002 to 2005 has almost tripled and forced the port management to finalize installation of the new loading equipment superseding the old one. The decision has proved to be right since cargo turnover in 2006 has further increased for 34% compared to the previous year. It is evident that the utilization factor of the loading terminal for the year 2002 is very low. In contrast, utilization factors in years 2005 and 2006 are much higher amounting to 72.2% and 84.2%, respectively. Expected ship waiting time is decreasing with increase of cargo turnover and for 2008 ship waiting time is 2.1 hr. Following assumption that service time on the terminal is deterministic, reducing of ship waiting time can be done with appropriate ship scheduling decisions. Results give satisfactory operation indices of the observed terminal since ship waiting time is relatively low and the terminal traffic rate is considerably high.

In order to prove that the model used here is suitable for addressing a tactical port operation problem, we further examine behavior of the terminal applying the brute force simulation method and comparing the results with those computed above. We designed here

Table 1 - Computed loading terminal operation indices

Indices	Unit	2002	2005	2006	2008
		323,402 t/year	918,518 t/year	1,234,127 t/year	1,350,000 t/year
λ	ship/year	32.000	91.000	123.000	135.000
μ	ship/year	126.000	126.000	146.000	146.000
ρ	-	0.254	0.722	0.842	0.925
E[t]	year	0.008	0.008	0.007	0.007
Var[t]	year	0.000	0.000	0.000	0.000
L_Q	ship	0.024	0.072	0.056	0.032
L	ship	0.278	0.795	0.898	0.957
L_{serv}	ship	0.254	0.722	0.842	0.925
W_Q	hour	6.586	6.974	3.982	2.090
W	hour	76.110	76.498	63.982	62.090
W_{serv}	hour	69.524	69.524	60.000	60.000

a heuristic for observed loading terminal that tries to emulate the logic of a human planner. It tries to create a feasible solution while minimizing computation steps. Real operational processes of ship arrivals and service procedure are simulated in a given time period. The occupancy of service place and ship waiting time are recorded. A more detailed outline of the heuristic is available below.

Outline of the heuristic algorithm:

1. Start and load data
2. Arrange data within system processes
3. Determine the time unit of simulation and the simulation period
4. Initialization: i as integer
5. While $i \leq$ simulation period Do
   - 5.1. Generate a random number for variable x (time between consecutive arrivals) on the basis of cumulative probabilities
   - 5.2. Take deterministic service time, variable y
   - 5.3. Determine the starting and finishing hour of service
     - 5.3.1. If the terminal has been idle at the time of a new ship's arrival then register the terminal waiting period
     - 5.3.2. If the terminal has been occupied then register the ship's waiting period
   - 5.4. $i = i + 1$
6. End While

It was hoped that the heuristic will provide a good initial solution that will be used as a bound for mathematical model. The numerical experiments show that the heuristic gets a good solution similar to mathematical model within several minutes. The results are provided in Table 3. On the basis of the experiment, we assume that the same heuristic with a slight modification would give acceptable solution for an M/D/S problem.

Empirical data of the arrival time distribution between two ships are presented in Table 2. Service time for 10,000 dwt ship is deterministic and amounts 2.5 days. These data now make possible the simulation of loading terminal operation.

Table 2 - Time distribution between two ships' arrivals

Time between two arrivals (day)	x	Probability $p(x)$	Cumulative probability $P(X \leq x)$
0 – 2	1	0.25	0.25
2 – 4	3	0.56	0.81
4 – 6	5	0.12	0.93
6 – 8	7	0.05	0.98
8 – 10	9	0.02	1.00

From the data in Table 2 the average time between two ships' arrivals is obtained:

$$\bar{x} = \sum x \cdot p(x) = 3.06 \text{ days/ship}$$

$$y = 2.5 \text{ days/ship}$$

Traffic rate ρ equals to 0.817 and the average number of ships at the terminal (in queue and being serviced) with the assumption of Poisson arrivals and deterministic distribution of service time L is 0.878 ships. According to the indices the loading terminal is also quite busy considering input capacities. The simulation was made on the basis of 365 days i. e. one calendar year, in this case the year 2006 (see Table 3).

The last row of Table 3 contains results that are used for analysis of the loading terminal simulation model. Sum of variable x values amounts to 366 days.

Table 3 - Simulation of bulk cargo loading terminal (years 2006/2008)

ARRIVALS			SERVICE			WAITING	
No.	Var. x (day)	Ship arrival date & hr	Var. y (day)	Starting day	Finishing day	Terminal (day)	Ship (day)
1	3	03.01. 00	2.5	03.01. 00	06.01. 12	3	-
2	7	10.01. 00	2.5	10.01. 00	13.01. 12	4.5	-
3	3	13.01. 00	2.5	13.01. 00	16.01. 12	0.5	-
4	3	16.01. 00	2.5	16.01. 00	19.01. 12	0.5	-
5	5	21.01. 00	2.5	21.01. 00	24.01. 12	2.5	-
6	3	24.01. 00	2.5	24.01. 00	27.01. 12	0.5	-
7	3	27.01. 00	2.5	27.01. 00	30.01. 12	0.5	-
8	3	30.01. 00	2.5	30.01. 00	02.03. 12	0.5	-
9	1	31.01. 00	2.5	02.02. 12	04.02. 00	-	1.5
10	3	03.02. 00	2.5	04.02. 00	07.02. 12	-	1
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114	1	15.12. 00	2.5	17.12. 12	19.12. 00	-	1.5
115	3	18.12. 00	2.5	19.12. 00	22.12. 12	-	1
116	1	19.12. 00	2.5	22.12. 12	24.12. 00	-	2.5
117	3	23.12. 00	2.5	24.12. 00	27.12. 12	-	2
118	3	26.12. 00	2.5	27.12. 12	29.12. 00	-	1.5
119	3	28.12. 00	2.5	29.12. 00	01.01. 12	-	1
SUM	366		297.5			68.5	25
Simulation estimate for year 2008							
SUM	364		335			29	14.5

Table 4 - Results of ten experiments of bulk cargo loading terminal simulation (year 2006)

No.	Var. x (day)	Var. y (day)	Terminal wait.(day)	Ship wait.(day)	No. of observation	$\bar{x}'$	y'
1.	366	297.5	68.5	25.0	119	3.08	2.5
2.	364	295.0	69.0	26.0	118	3.08	2.5
3.	362	292.5	69.5	22.5	117	3.09	2.5
4.	365	300.0	65.0	24.0	120	3.07	2.5
5.	363	305.0	58.0	22.0	122	2.98	2.5
6.	362	295.0	67.0	21.5	118	3.07	2.5
7.	364	297.5	66.5	23.0	119	3.06	2.5
8.	366	302.5	63.5	24.0	121	3.02	2.5
9.	360	290.0	70.0	27.0	116	3.10	2.5
10.	365	295.0	70.0	24.5	118	3.09	2.5

Considering that the number of simulated steps is 119 the average value of variable x equals to $\bar{x}' = 3.08$ days. 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 do not depart from the starting ones. The reason for this is relatively long simulation period of one year. In order to confirm the result outcome, nine more experiments were done and the results of experiments are given in Table 4.

The average value of variable x for ten experiments amounts to $\bar{x}' = 3.064$ days and the service time is deterministic amounting to $y' = 2.5$ days. Next, standard deviation amounts $\sigma = 0.037$ and coefficient of variation is $V = 1.208$ %. Results of the variation coefficient point again to extremely low dispersion of single values from averages. Total waiting time of loading terminal is in average 66.7 days, which in total simulation period (365 days) results in proportion of 0.18. This means that the terminal was unoccupied 18 % of the time in year 2006, waiting on ships to come and 82 % of the time was occupied. Ships coming to load cargo were averagely waiting 23.95 days on free berth which is considerably low (6.6 % days of the year).

Comparison of the heuristic solutions to the mathematical model indicates that the corresponding results match closely. Ship waiting time computed by the mathematical model equals to 20 days while heuristic approach gives average value of 24 days, making the error acceptable considering observed period of one year. As far as traffic rate is concerned, both methods give the same results. Therefore, the solution obtained by heuristic method proved the validity of the method in real world problem applications where mathematical approach is hard to apply. That is the case with $M/D/S$ problems, with S identical servers, serving each customer on a first come first serve basis during a constant time D.

5. CONCLUSION

Many vertically integrated organizations ship bulk and semi-bulk products and materials among their facilities by ships, i. e. mineral companies ship dry bulk minerals, such as coal, iron ore, bauxite, and phosphate, to distribution centers and to commercial customers. This paper focuses on application of queuing theory on bulk sea port, and addresses the question of port facility capacity on the basis of yearly bulk cargo turnover, considering optimal engagement of the facility and reducing service time to the ship.

A common port queuing problem is presented and solved using a heuristic and a mathematical model $M/D/1$. A heuristic approach is developed as an alternative to mathematical model solution finding. Between these two methods good solutions of known quality are provided quickly. Instead of looking for feasible solutions using rules of thumb, tactical operation planning of bulk loading terminal with one service place can be performed with the explicit objective of queuing model.

Results obtained point to satisfactory operation indices of the observed terminal since ship waiting time is relatively low whilst terminal traffic rate is considerably high. In the case of cargo turnover increase that is expected in the near future eventually a new service place (berth) will be needed to expand the terminal capacity. Such a facility would become an $M/D/S$ system, thus the model presented here may then be extended to reflect additional practical considerations.

The solution obtained by heuristic method proved validity of the method application on simple example. Therefore, we expect relevance of the method in real world problem applications where mathematical approach is hard to apply. That is the case with $M/D/S$ problems, with S identical servers, serving each customer on a first come first serve basis during a constant time D. On the basis of the experiment, we assume that the same heuristic with a slight modification would give acceptable solution for an $M/D/S$ problem. Development of heuristic for the $M/D/S$ problem will be the objective of our further research. While obtaining optimal solutions is desirable, deriving high-quality solutions quickly is essential for any practical application.

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SAŽETAK

PROMETNI SUSTAV S DETERMINISTIČKIM VREMENOM USLUŽIVANJA

Većina prometnih sustava predstavlja red čekanja tipa M/M/1, istraživanje kojih je znatno zastupljeno u znanstvenoj literaturi. Međutim, postoji malo primjera prometnih sustava s determinističkim vremenom usluživanja. U ovom radu istražuje se takav jedan sustav i predlaže rješenje za problem donošenja taktičkih odluka uporabom modela reda čekanja i heurističke metode. Heuristička metoda razvijena je kao alternativa rješenju matematičkim modelom. Uporaba navedenih metoda rezultira brzim iznalaženjem zadovoljavajućeg rješenja. Usporedba rješenja dobivenih heurističkom metodom i matematičkim modelom na jednostavnom primjeru ukrcajnog terminala za rasute terete, definiranog kao M/D/1 sustav, ukazuje na podudarnost odgovarajućih rezultata. Na temelju provedenog eksperimenta pretpostavlja se da bi ista heuristička metoda s neznatnim prilagodbama dala zadovoljavajuće rješenje za realni M/D/S problem za kojeg je dobivanje rješenja s matematičkim modelom teško i neprihvatljivo za praktičnu uporabu.

KLJUČNE RIJEČI

red čekanja tipa M/D/1, pomorski prijevoz, determinističko vrijeme usluživanja, taktičko planiranje

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