DESIGN OF A BULK-CARGO TERMINAL SYSTEM USING NON-STATIONARY QUEUING MODELS WITH BULK ARRIVALS

Djordje Zrnić, Uglješa Bugarić**

Original science work
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INTRODUCTION

Terminal for unloading of the bulk cargo (fig. 1) exists as a link in the whole chain of transportation, between the river and the storage or some technological plant. Function of the terminal could be defined as: terminal for bulk cargo presents the organization of various activities, connected with operating and leading material ~~course~~ FLOW from the vessel to the given system (user), which provide maximum of service of composition of barges with minimum of expenses. [1]

The bulk materials, which are to be unloaded, are different by the granulation and by the density. The materials are

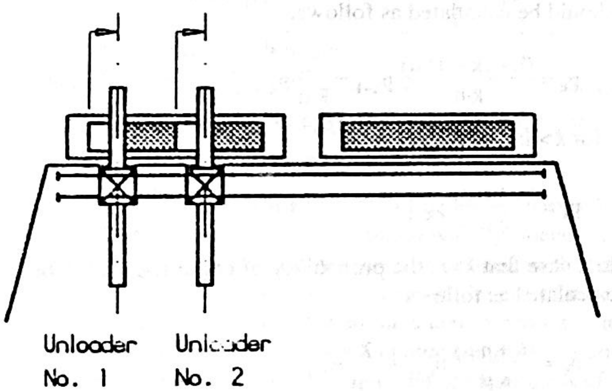

Fig. 1

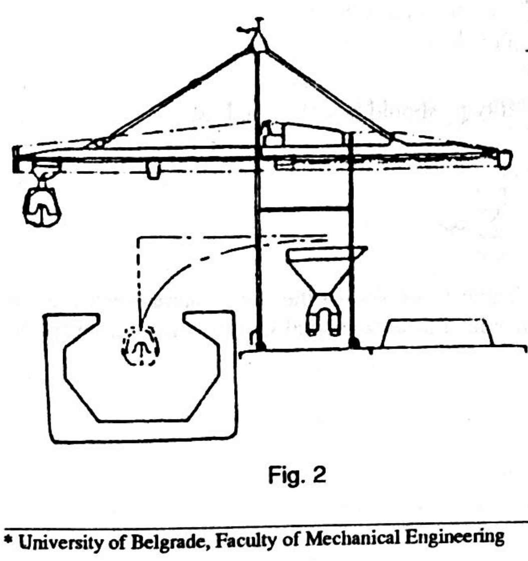

Fig. 2

relatively dry, so that they can not make compact mass and that they can run, i.e. to take a shape of the vessel in which they are settled (loading space of the barge). The very important characteristic of those materials is the fact that the expenses of the transportation and manipulation present immense part of their final value. [1]

Unloading of the bulk materials ~~has to~~ could be done by unloading bridges (cranes) with the bucket (fig. 2) of by the for continuous unloading.

THE BASIC NOTIONS OF THE QUEUING [4],[7]

- UNIT THAT NEEDS SERVICING - barge.

- UNIT FLOW - all barges that come to the port (system).

- λ - intensity of arrivals of the composition of barges , i.e. reciprocal value of average time between the arrival of two neighboring units.

- WAITING QUEUE - queue made by barges which can not be immediately accepted to the unloading, such barges are placed in an anchorage ground.

- SERVICING CHANNELS - means for unloading, unloading bridges (cranes) with grab.

- SERVICING TIME - time needed by a crane to unload one barge. The barges arriving to the system are not the same by capacity, and also they are not transporting the same materials. For all those reasons, it is taken that the time of unloading of barge has exponential distribution with the following function and density of distribution:

$$F(t) = 1 - e^{-\mu t} \quad ; \quad f(t) = \mu \cdot e^{-\mu t} \;, t \geq 0$$

where parameter μ presents intensity of barge unloading and is equivalent to the reciprocal value of the average time of the barge unloading, i.e. mathematical expectance of the time of barge unloading.

- SERVICING SYSTEM - Border of the system is anchorage ground from one side, and the operative coast (unloading place) from the other side.

MODEL WITH THE BULK ARRIVAL OF BARGES TO THE SYSTEM AND LIMITED WAITING QUEUE [4], [7]

If the group of the coming barges find all the cranes to be free, servicing is accepted as follows: if $r>n$, n - of barges is to be serviced immediately, while r-n of barges is placed

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at the waiting queue, but if $r<n$ all barges are accepted to be serviced. If a group of coming barges find in system k $(k<n)$ of barges, then for a case $r>(n-k)$, $(n-k)$ of barges will be immediately accepted for servicing, and $r-(n-k)$ of barges will be placed in a waiting queue, while in a case $r<(n-k)$ all barges would be accepted for servicing. When there is k $(k>n$ and $k<(n+m))$ of barges in system, coming group of barges, in case that $(k+r)<(n+m)$, will be accepted in system and will be placed in a waiting queue. In a case that $(k+r)>(m+m)$, $(n+m)-k$ of barges will be accepted in system (they will be placed in waiting queue), while the others be canceled.

State of system is defined with the number of barges in system. Graph of the condition of system looks as follows (fig. 3):

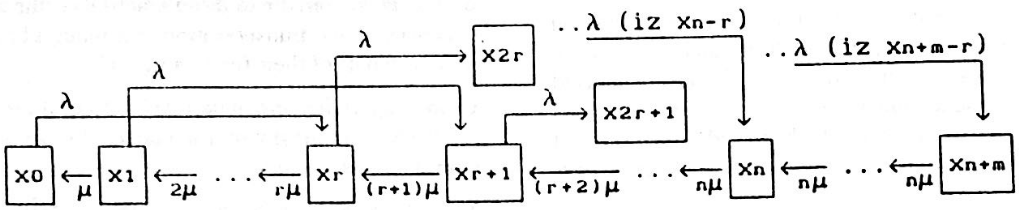

Fig. 3

On the basis of the graph of the condition of system, we obtain the following or differential equations of system condition probability:

$$\dot{p}_o = -\lambda(t)\cdot p_o(t) + \mu(t)\cdot p_1(t)\,;$$

$$\dot{p}_1(t) = -(\lambda(t) + \mu(t))\cdot p_1(t) + 2\cdot\mu(t)\cdot p_2(t)\,;$$

$$\cdots\cdots$$

$$\dot{p}_r(t) = -(\lambda(t) + r\cdot\mu(t))\cdot p_r(t) + (r+1)\,\mu(t)\cdot p_{r+1}(t) + $$
$$+ \lambda(t)\cdot p_o(t)\,;$$

$$\dot{p}_{r+1}(t) = -(\lambda(t) + (r+1)\cdot\mu(t))\cdot p_{r+1}(t) + (r+2)\cdot\mu(t)\cdot$$
$$\cdot\, p_{r+2}(t) + \lambda(t)\cdot p_1(t)\,;$$

$$\cdots\cdots \qquad (1)$$

$$\dot{p}_n(t) = -(\lambda(t) + n\cdot\mu(t))\cdot p_n(t) + n\cdot\mu(t)\cdot p_{n+1}(t) +$$
$$+ \lambda(t)\cdot p_{n-r}(t)\,; \quad (\text{for } n>r)$$

$$\cdots\cdots$$

$$\dot{p}_{n+m}(t) = -n\cdot\mu(t)\cdot p_{n+m} + \lambda(t)\cdot(p_{n+m-1}(t) + \ldots$$
$$+ p_{n+m-r+1}(t))\,;$$

In stationary work order of the system (λ = cons., μ = cons., $t \to \infty$) the system of differential equation becomes the system of algebra equations:

$$0 = -\lambda\cdot p_o + \mu\cdot p_1\,;$$

$$0 = -(\lambda+\mu)\cdot p_1 + 2\cdot\mu\cdot p_2\,;$$

$$\cdots\cdots$$

$$0 = -(\lambda + r\cdot\mu)\cdot p_r + (r+1)\cdot\mu\cdot p_{r+1} + \lambda\cdot p_o\,;$$

$$0 = -[\lambda + (r+1)\cdot\mu]\cdot p_{r+1} + (r+2)\cdot\mu\cdot p_{r+2} + \lambda\cdot p_1\,;$$

$$\cdots\cdots \qquad (2)$$

$$0 = -(\lambda + n\cdot\mu)\cdot p_n + n\cdot\mu\cdot p_{n+1} + \lambda\cdot p_{n-r}\,; \quad (\text{for } n>r)$$

$$\cdots\cdots$$

$$0 = -n\cdot\mu\cdot p_{n+m} + \lambda\cdot(p_{n+m-1} + \ldots + p_{n+m-r+1})\,;$$

By solving the system of equations, probabilities of condition is obtained:

- for $k<n$:

$$p_k = \frac{(\lambda + (k-1)\cdot\mu)}{k\cdot\mu}\cdot p_{k-1} \qquad (3)$$

In a case that $k<n$ and $k>r$, the probability of condition should be calculated as follows:

$$p_k = \frac{(\lambda + (k-1)\cdot\mu)}{k\cdot\mu}\cdot p_{k-1} - \frac{\lambda}{k\cdot\mu}\cdot p_{k-r-1} \qquad (4)$$

- for $k>n$:

$$p_k = \frac{(\lambda + n\cdot\mu)}{n\cdot\mu}\cdot p_{k-1} \qquad (5)$$

In a case that $k>r$, the probability of condition should be calculated as follows:

$$p_k = \frac{(\lambda + n\cdot\mu)}{n\cdot\mu}\cdot p_{k-1} - \frac{\lambda}{n\cdot\mu}\cdot p_{k-r-1} \qquad (6)$$

From the condition:

$$\sum_{k=0}^{n+m} p_k = 1 \qquad (7)$$

probability p_o should be calculated as:

$$p_o = \frac{1}{\sum\limits_{k=0}^{n+m} p_k} \qquad (8)$$

In the Table 1. are shown the basic characteristics of the system with the bulk arrival of units and the restricted queue.

Table 1.

The system characteristics:	Bulk arrival of the units to the system
Probability of servicing [Pops] OF THE BARGE	$\sum_{k=0}^{n+m-r} p_k$
Average number of occupied cranes (channel) [nz]	$\sum_{k=0}^{n} k\cdot p_k + n\cdot\sum_{k=n+1}^{n+m} p_k$
Probability of busyness of the crane (channel) [Pzk]	$1-p_0$
Probability that all the cranes are occupied [Ppzk]	$\sum_{k=0}^{m} p_{n+k}$
Probability of existing of the queue [Ppr]	$\sum_{k=1}^{m} p_{n+k}$
Average time of the complete busyness of the cranes [tpz]	$\frac{1}{n\cdot\mu}$
Average time of the complete busyness of the cranes [tnpz]	$\frac{1}{n\cdot\mu}\cdot\frac{1-p_{pzk}}{p_{pzk}}$
Average number of barges in queue [kr]	$\sum_{i=1}^{m} i\cdot p_{n+1}$
Average time which barge spends in a queue [tr]	$\frac{\bar{kr}}{\lambda}$
Average number of barges in system [k]	$\sum_{k=1}^{n+m} k\cdot p_k$
Average time which barge spends in system [t]	$\frac{\bar{k}}{\lambda}$

DEFFINING OF AVERAGE TIME OF BARGE UNLOADING

Time of barge unloading directly influences the time which barge would spend in system and in waiting queue. Time needed for barge unloading should be defined on the basis of: type of unloading material, average length of the unloading cycle, quantity of material taken by grab, size and capacity of barge, size of loading space, number of compartments on barge, demanded grade of cleanliness of loading space, number of unloading bridges (cranes) which unload the barge etc. [1]

In the table 2. enclose please find changes of the important parameters depending on the type of unloading material.

Table 2.

material	density [t/m³]	volume of bucket [m³]	dim. of bucket jaw [m]	coeff. of the bucket loading	capacity of crane [t]
iron ore	2.7	3.2	3.5x1.75	0.7	12.5
iron ore	2.45	3.2	3.5x1.75	0.75	12.5
iron ore	2.2	3.2	3.5x1.75	0.8	12.5
limeston	1.3	5	4.25x2	0.8	12.5
eanthracite	0.8	5	4.25x2	0.85	12.5

The characteristics of barge (loading space is without compartments):

- capacity: Q = 1700 t,
- dimensions: LxBxH = 77x11x2.83 m,
- dimensions of the loading space: 67x8.54x2.97 m.

Having taken into consideration all above mentioned parameters and on the basis of [2] and [5], average time needed that one unloading crane unloads the barge amounts to:

$$\bar{t}_{un} = 4.6 \text{ h}$$

Time needed for the unloading barge could be approximately defined by the expression: [1]

$$t = \frac{Qa}{Ka\cdot c} + \frac{Qb}{Kb\cdot c} = \frac{1415}{0.812510} + \frac{285}{0.3\cdot 510} = 5.28 \text{ h}$$

Because of more precise way of defining the time of unloading (speed of the trolley moving, speed of lifting the cargo, length of duration of unloading cycle should be taken into consideration), accepted average time needed for unloading or barge is: t_{un} = 4.6 h, which means that the capacity of unloading of barge with one crane amounts to:

$$\mu = \frac{1}{\bar{t}_{un}} = 0.217 \ {}^{1}/_{h}$$

DEFINING OF THE AVERAGE TIME BETWEEN THE ARRIVAL OF THE COMPOSITION OF BARGE

Bulk material which should be unloaded, is transported with the help of composition of barge. It is possible to have 2, 4 or 6 barges in the composition, which depends od the type and capacity of barge, as on the size of the navigation road.

On the basis of collected statistic materials in connection with transportation of the materials by the river for a given production plant (the composition of 6 barges was accepted [3], [5]), work condition of unloading plant (time conditions table 3.), organizational and conditions, it is possible to define the average time between the arrival of composition of barge.

Table 3.

obstacle	duration period (day/year)
ice	38
fog	6
wind	3
total	47

From the table 3. navigation period per year should be obtained:

$$tn = 365 - 47 = 318 \text{ days}$$

On the basis of the project of the first stage of construction of the unloading plant [5], the material quantity which should be delivered per year amounts to;

$$Qd = 1440000 \text{ t/year}$$

Average material quantity which is delivered into the harbour daily is:

$$Qm = \frac{Qd}{tn} = \frac{1440000}{318} = 4528.3 \ {}^{t}/_{day}$$

As the material has been delivered with composition of 6 barges, one composition delivers:

$$Qs = 6xQ = 6x1700 = 10200 \text{ t of material}$$

Finally, the interval of the arrival of barge composition amounts to:

$$\bar{t}s = \frac{Qs}{Qm} = \frac{10200}{4528.3} = 2.2525 \text{ days or } 54.06 \text{ h}$$

THE ANALYSIS OF THE UNLOADING PROCESS

The analysis of the unloading process was performed under assumption that the unloading should be done with the help of 2 cranes and with 32 places in the waiting queue, for the different intensity of the arrival of the barge composition. This high number of places in a waiting queue is a conseqence of a fact that no cancellation should be allowed in the system. The assumption that the system is empty at the beginning was accepted.

Histogram on the figure 4 shows the chaning of the intensity of the barge composition arrival (per months) in a year period (empirical data).

The analysis consists of defining, time changing and system condition probability for a period of one year, as well as for a period of one month.

Model shows that the present non-stationary conditions are consequence of:

1. Change of intensity of composition arrival, studied in a long time period (one year for example), and

2. At the beginning of the exploitation (when servicing system is empty), up to the moment of achieving stationary condition, and at the moment of beginning of the arrival rate change up to the moment of achieving the stationary condition for a given intensity of flow.

Results of modeling show that, when constructing a general model which should present work of the system in a long time period (one year, for example), the influence of the non-stationary condition is not very relevant for the results of experiment, so that is possible to apply the queuing theory models for a stationary work order.

By the detailed modeling of system using the analytical model, when is needed to study the behavior in particular time periods when the non-stationary order is present (beginning of the work, change of arrival rate), queuing theory models for a non-stationary order are in use.

The analysis of the unloading process showed that in a particular case stationary state is achieved after 50-70 hours of continuous work of the system (at the beginning or while changing arrival rate).

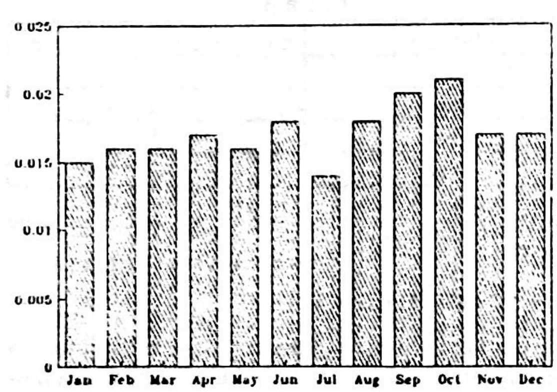

Fig. 4

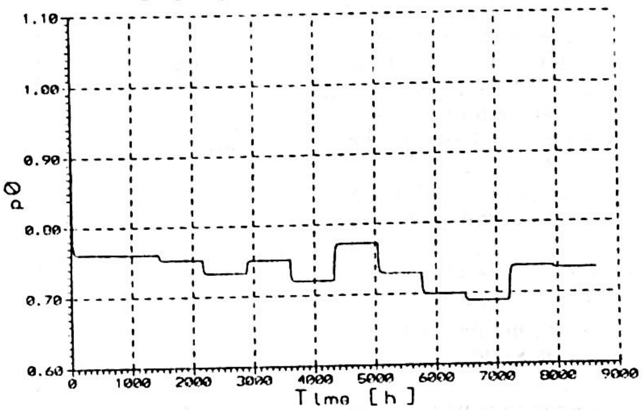

Fig. 5

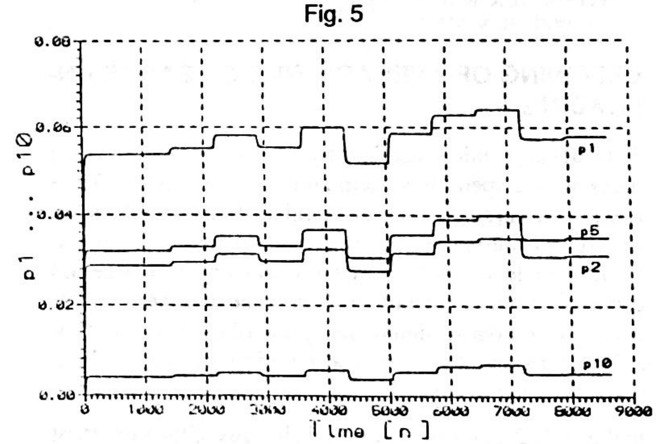

Fig. 6

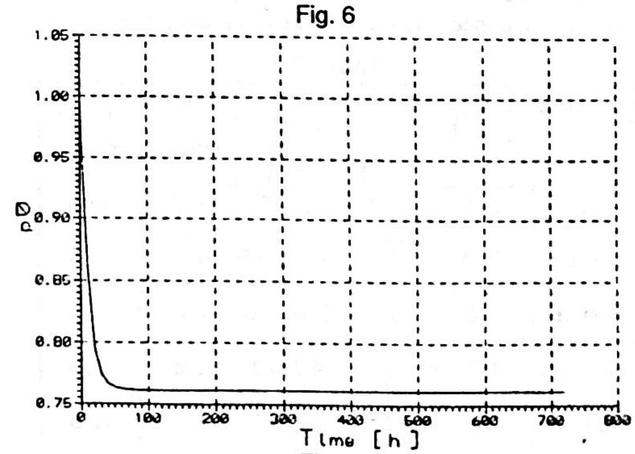

Fig. 7

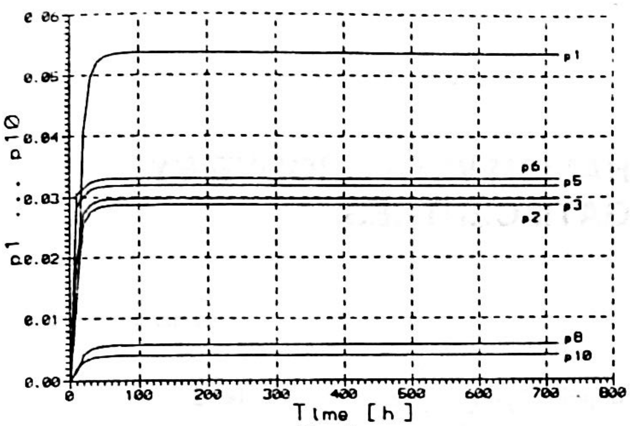

Fig. 8

Diagrams on figures 5 and 6 shows the changing of the probability of conditions in a year period, while diagrams on figures 7 and 8 shows the changing of the probability of conditions in a month period.

CONCLUSION

The general design of the unloading system of the bulk cargo asks for analysis of the work of the system in a longer period of time, so that on the basis of the obtained results, for the behavior of unloading system, global conclusions could be reached and laws could be settled. This part of the analysis of the unloading system should be obtained by the queuing theory models for a stationary work-order. [6]

For the detailed design of the unloading system, first it is needed to do the analysis of the subsystems (knot points) as an unloading bridge for example [2]. With those obtained results it is needed to go further, into detailed models (analytical or simulation) and to do the analysis in shorter time periods or with time changing parameters, so that the non-stationary work order of the unloading system should be emphasized.

The work of the real system is influenced by many obstacles which bring to the deviation from the scheduled arrivals of compositions (weather conditions, preparation of the composition in the harbour of origin - loading, etc, organization of traffic, information system, keeping up at the borders, possible damages, etc), so that it is needed to study all the elements which influence the work of the unloading system.

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DESIGN OF A BULK-CARGO TERMINAL SYSTEM USING NON-STATIONARY QUEUING MODELS WITH BULK ARRIVALS

Dj. Zrnić, U. Bugarić

In this work was analysed the process of unloading of the bulk cargo by the model of queuing theory with the bulk arrival of the units to the system (composition of barges). The non-stationary work order of the system with time changing intensity of the arrivals of the composition of barges was analysed as well.

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PROJEKTOVANJE TERMINALA ZA PRETOVAR RASUTIH TERETA KORIŠĆENJEM NESTACIONARNOG MODELA TEORIJE REDOVA ČEKANJA SA GRUPNIM DOLASKOM JEDINICA U SISTEM

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U radu je analiziran proces pretovara rasutih tereta modelom teorije redova čekanja sa grupnim dolaskom jedinica u sistem (sastava barži). Analiziran je nestacionarni režim rada sistema sa vremenski promenljivim intenzitetom nailaska sastava barži.

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