THE INFLUENCE OF THE NON-STATIONARY STATE ON THE BULK-CARGO TERMINAL OPERATION

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KEY WORDS: barge, crane, bulk-cargo, queuing theory, unloading.

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INTRODUCTION

Terminal for unloading of the bulk cargo (figure 1.) exists as link in the whole chain of transportation, between the river and technological plant/storage. Function of the terminal could be defined as follows: River bulk-cargo terminal presents the organization of various activities, related to handling and governing of the material flows from the vessel to the transportation system of the technological plant/storage, which provide maximal servicing of the composition of barges with minimal costs.

The bulk materials, which are to be unloaded differ among themselves by: granulation and mass by volume unit. Materials are relatively dry so that do not compose compact mass and they can course freely, i.e. to occupy exact shape of the vessel where they are situated (cargo-space of barge). Very important characteristic of those materials is fact that the costs of the transportation present important part of their final value. [1]

It is possible to carry out unloading of the bulk materials by unloading bridges (cranes) with the grab (figure 2.) or by the gadget for continuous unloading.

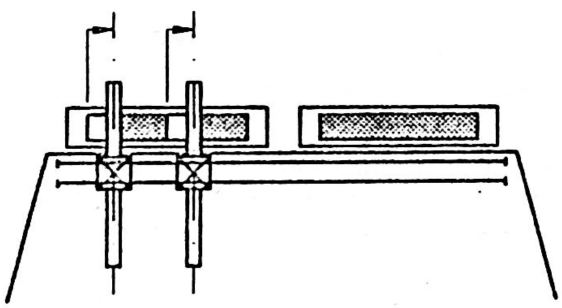

Figure 1.

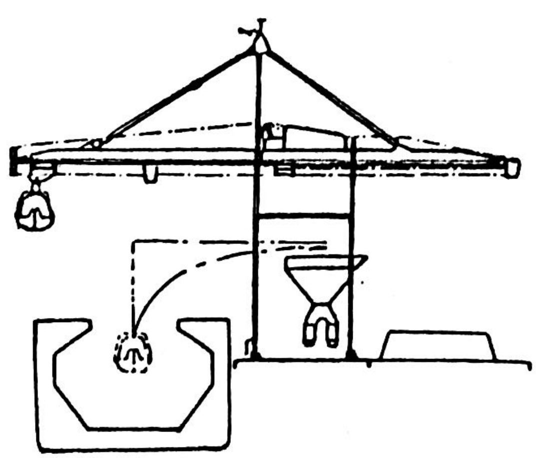

Figure 2.

MODELLING OF THE PROCESS UNLOADING

Modelling of the process of unloading, as a phase in project, has its function for dimensioning of bulk-cargo plant.

During the production of project simpler analytical models of queuing theory are more applicable then the complicated analytical models of queuing theory and simulation models, because by those simpler models it is easier to obtain rough parameters for dimensioning of bulk-cargo plant (there is no need for computer program).

Detailed calculations, with use of complicated analytical models of queuing theory and simulation models, with taking into consideration of non-stationary state (stohastics), as well as other complex activities related to the work of bulk-cargo plant, are applied during the making of major projects.

Work of bulk-cargo plant could be described by following models of queuing theory: [3], [4], [5]:

1. Model of multi channel system with limited waiting queue;
2. Model of multi channel system with limited waiting queue and complete reciprocal help between channels;
3. Model of multi channel with limited waiting queue and bulk arrival to the system.

Here and after will be shown the non-stationary model of multi channel system with limited waiting queue, bulk arrival of units to the system and cancellation of the whole group. The difference between this model and the model under the number 3 is that behind the non-stationary state, the model number 3, if T is not possible to accept the whole group, understands cancelation only for those unites that can not stand in waiting queue.

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MODEL WITH BULK ARRIVAL OF BARGES TO THE SYSTEM, LIMITED WAITING QUEUE AND CANCELLATION OF WHOLE GROUP [4], [5]

If the composition of barges which comes find all cranes free, it is accepted to the system in a way that as much barge from the composition as there are free cranes is accepted immediately (each barge is unloaded by one crane), and all other barges form composition should stand in a waiting queue. When a certain number is occupied, from the composition of coming barges will be accepted as much as barges free cranes, while the other barges from the composition will stand in the queue. In case that all cranes are occupied, and the number of free places in queue is bigger or equivalent to the number of barges in the composition, the whole composition of barges that is coming will be accept into system and will stand in a queue. For a case when all the cranes are occupied and when the number of free places is less then the number of barges in the coming composition, the whole composition of barges should be canceled.

For easier perceiving of work of the model, equations that describe the change of state probabilities for given model will be set for a real bulk-cargo plant with two cranes, thirty two places in a queue and six barges composition (c=2; m=32; r=6). [2]

State of system should be determined by the number of barges in the system. Figure of system state has following shape (figure 3.):

In the stationary state of work in the system (λ=const., μ=const., $t \to \infty$) system of differential equations should pass to the system of algebra equations:

$$0 = -\lambda \cdot p_0 + \mu \cdot p_a;$$

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

....

$$0 = -(\lambda + 2 \cdot \mu) \cdot p_i + 2 \cdot \mu \cdot p_{i+1}; \quad \text{for } i=2,3,4,5.$$

.... (2)

$$0 = -(\lambda + 2 \cdot \mu) \cdot p_i + 2 \cdot \mu \cdot p_{i+1} + \lambda \cdot p_{i-6}; \quad \text{for } i=6,\dots,28.$$

....

$$0 = -2 \cdot \mu \cdot p_i + 2 \cdot \mu \cdot p_{i+1} + \lambda \cdot p_{i-6}; \quad \text{for } i=9,\dots,33.$$

....

$$0 = -2 \cdot \mu \cdot p_{34} + \lambda \cdot p_{28};$$

By solving the system of differential equations change of probabilities of state during certain time period should be obtained, while by solving the system of algebra equations should be obtained the probabilities of system state in stationary state of work. After of work long enough, system from the non-stationary state passes to the stationary state. Change of probabilities of state, obtained by solving the system of differential equations (1) in a period of time, is getting closer asymptotically to the probabilities which could be obtain by solving the system of algebra equations (2).

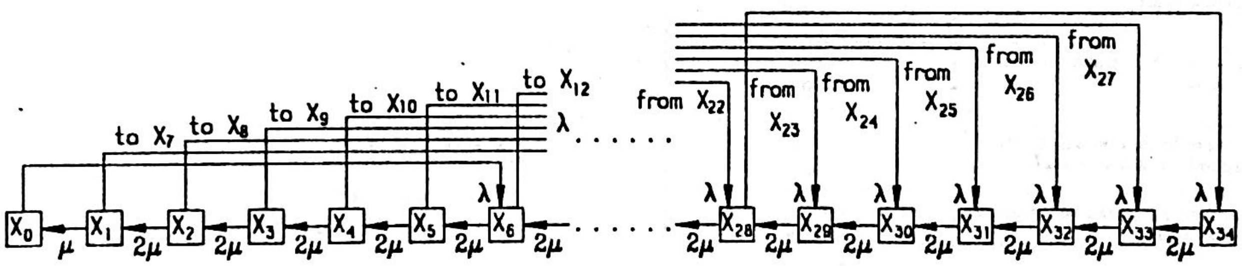


Figure 3.

On the basis of above figure of system state we obtain system of defferential equations of probabilities of system state:

$$p_0'(t) = -\lambda(t) \cdot p_0(t) + \mu(t) \cdot p_1(t);$$

$$p_1'(t) = -[\lambda(t) + \mu(t)] \cdot p_1(t) + 2 \cdot \mu(t) \cdot p_2(t);$$

....

$$p_i'(t) = -[\lambda(t) + 2 \cdot \mu(t)] \cdot p_i(t) + 2 \cdot \mu(t) \cdot p_{i+1}(t); \quad \text{for } i=2,3,4,5.$$

.... (2)

$$p_i'(t) = -[\lambda(t) + 2 \cdot \mu(t)] \cdot p_i(t) + 2 \cdot \mu(t) + \lambda \cdot p_{i-6}(t); \text{ for } i=6,\dots,28.$$

....

$$p_i'(t) = -2 \cdot \mu(t) \cdot p_i(t) + 2 \cdot \mu(t) \cdot p_{i+1}(t) + \lambda \cdot p_{i-6}(t); \text{for } i=9,\dots,33.$$

....

$$p_{34}' = -2 \cdot \mu(t) \cdot p_{34}(t) + \lambda \cdot p_{28}(t);$$

The exact criteria for determination of moment of passing of system from non-stationary state does not exist. It is possible only to approximate the time interval during which the system passes from non-stationary state. The approximate moment of time from which we can take that the system is in stationary state, exact enough for engineering calculations, could be determined on the basis of difference in probabilities of states in stationary and non-stationary work orders. The moment when that difference is less then some given value we can take as a moment of entering of system to the stationary state.

The criteria applied in this work (3) is based on the realtive error of the difference between probabilities. The moment when the absolute values of the relative error of difference of all probabilities are less then 5% is the moment of entering of system to the stationary state.

$$\delta_i = \frac{|p_i(t) - p_i|}{p_i} \cdot 100 \leq 5\%; \text{ for } \forall i \in (0, 1, \dots, 34) \qquad (3)$$

where

$p_i(t)$ - change of *i* probability in time period, obtained by solving the system (1);

p_i - probability of stationary state of system, obtained by solving the system (2).

The approximate moment of reaching the stationary state of system depends on limits of applied criteria. As the limits are narrower (for example 1%, 0.5%, ...) the period of reaching stationary state is longer.

In table 1. are shown the main characteristics of system with bulk arrival of units, limited waiting queue which includes cancellation of whole composition.

Table 1.

The system characteristics:	Bulk arrival of the units to the system
Probability of servicing $[P_{ops}]$	$\sum_{k=0}^{c+m-r} p_k$
Average number of occupied cranes (channels) $[c_z]$	$\sum_{k=0}^{c} k \cdot p_k + n \cdot \sum_{k=c+1}^{c+m} p_k$
Probability that all the cranes are occupied $[P_{pzk}]$	$\sum_{k=0}^{m} p_{c+k}$
Probability of existing of the queue $[P_{pr}]$	$\sum_{k=1}^{m} p_{c+k}$
Average number of barges in queue $[N_w]$	$\sum_{k=1}^{m} k \cdot p_{c+k}$
Average time which barge spends in a queue $[t_w]$	$\frac{N_w}{\lambda}$
Average number of barges in system $[N_s]$	$\sum_{k=1}^{c+m} k \cdot p_k$
Average time which barge spends in a system $[t_{ws}]$	$\frac{N_s}{\lambda}$

RESULTS OF ANALYSIS OF UNLOADING PROCESS

Analysed process of unloading which is performed by two cranes and with 32 places in a queue, for different intensity of crane loads (ρ_c). On the basis of [2] and [6], average time needed that crane unloads the barge amounts to t_{un} =4.6 h, and according to [2], the interval of the arrival of barge composition amounts to t_s=2.2525 days or 64.04 h. The analysis was performed for the stationary state of system, and for the time period needed that system passes to the stationary state (non-stationary state).

Figure 4. represents, depending on load of crane, the time period after which system enters the stationary state.

The results of analysis presents several statistics parameters as: probability of servicing, average number of occupied cranes, probability of occupation of both cranes, probability of queue existence, average number of barges in a queue, average time of a barge in a queue, average number of barges in a system and average time of barges in the system.

At the figures 5-12 change of statistics parameters for different intensities of crane loads are shown.

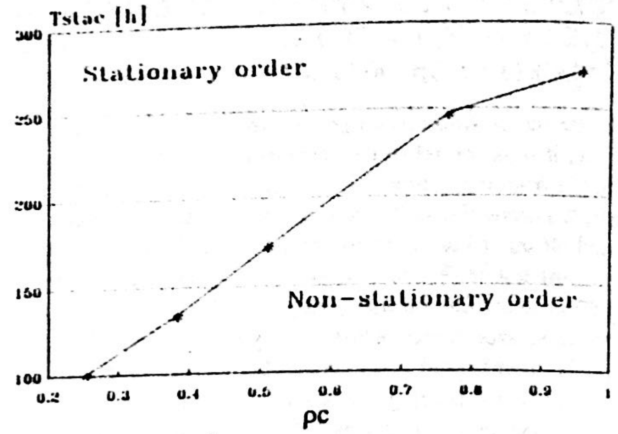
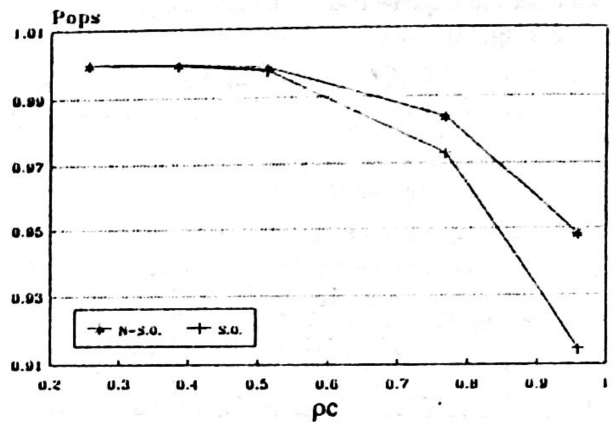


Figure 4.



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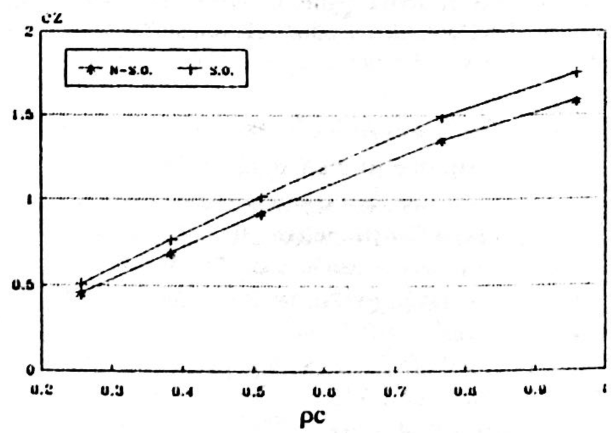

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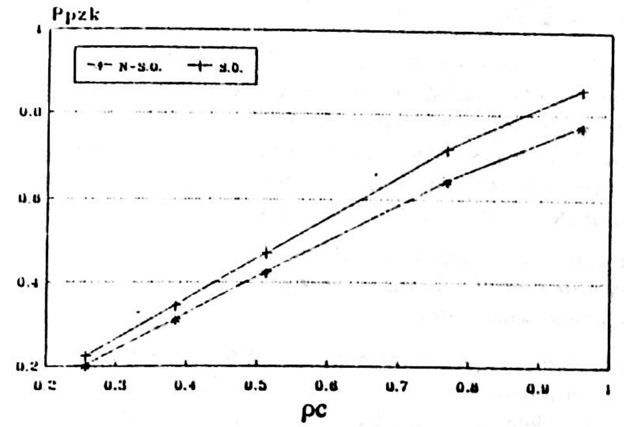

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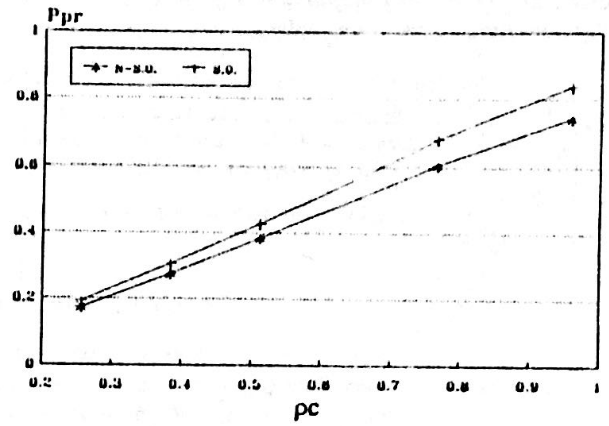

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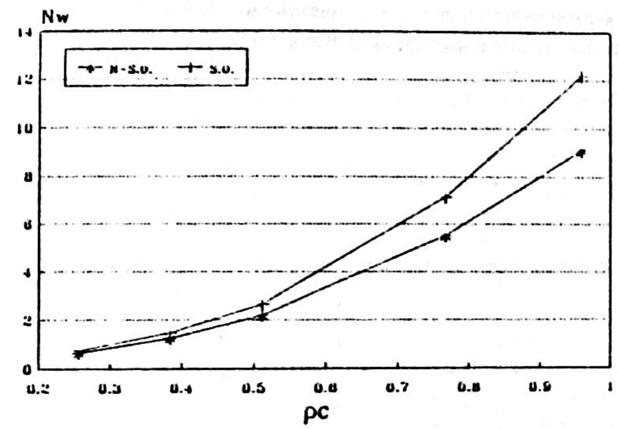

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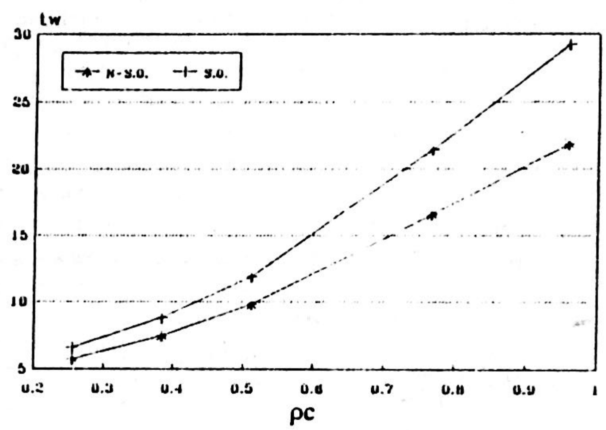

Figure 10.

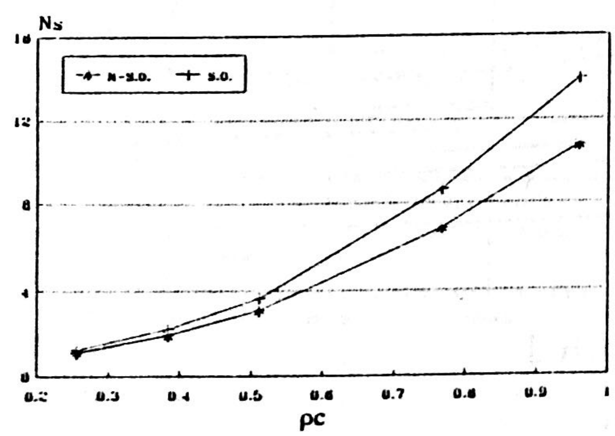

Figure 11.

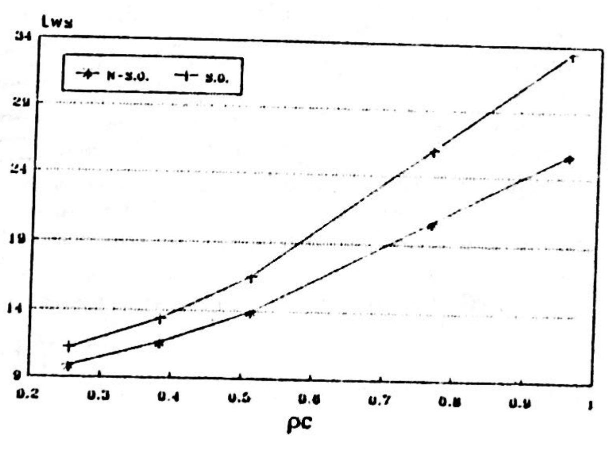

Figure 12.

Figure 13. presents the change of cancellation probability (cancellation is related to the whole barge composition) depending on number of places in a queue (anchorage of different dimensions were studied).

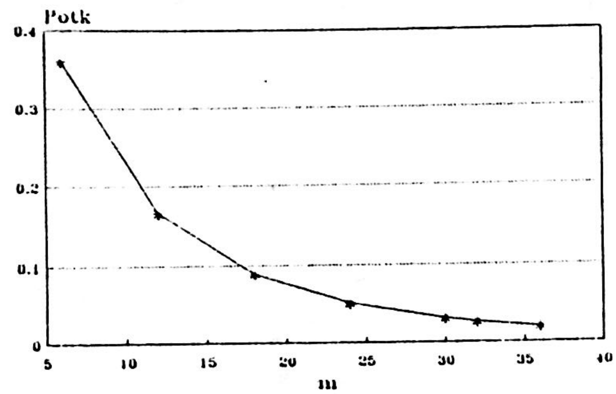

Figure 13.

Figure 14. presents change of couple of first probabilities of system state in a period of time, from beginning up to the moment in which the stationary state of the system is obtained.

CONCLUSION

Non-stationary state of system could shown up because of deviation of arrival of composition of barges from planned one (for example, when it comes to the emptiness of system), unpredictable damages, cancellation of cranes (when system starts working from beginning) in cases when the parameters of work of the system are being changed.

Procedure of determination of boundaries of non-stationary state used in this work is not given before, according to authors knowledge.

Results of analysis show necessity of taking into consideration non-stationary state of system while the bulk-cargo plant has been projected, because time needed for a system to reach the stationary state could not be neglected. The attention should be specially paid to the non-stationary state of work of the system if the system is working highly loaded, because in that case the non-stationary state lasts more than 10 days (figure 4.). That means that in the best solution (when there is no interrupts in work of the system, or changes of parameters of the system) first 10 composi-

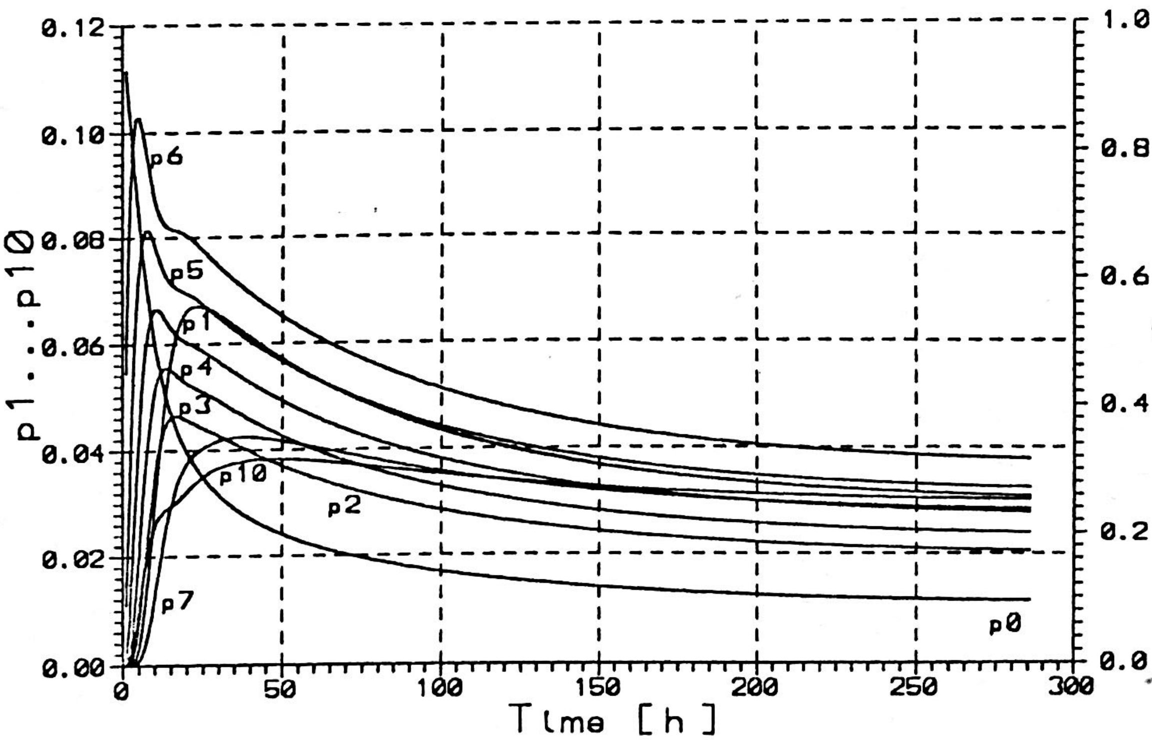

Figure 14.

tions approximately, should be unloaded in non-stationary state of work.

As one of factor which can soften non-stationarity of the process of unloading is the size of anchorage (number of places in queue). In case of increasing intensity of arrival of composition, anchorage accepts arrived barges, for the case that in the following time period, when intensity decreases, the system can work for a certain period of time without interruption. As it is not possible to make a anchorage with unlimited number of places, it is needed to decide about size of anchorage on the basis of economical analysis and calculation of system (figure 13.).

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List of used signs:

c - number of cranes (channels),
c_z - average number of occupied cranes (channels),
m - number of places in waiting queue,
N_s - average number of barges in system,
N_w - average number of barges in queue,
p_i - probability *i* in stationary state of system,
$p_i(t)$ - change of *i* probability in time period,
P_{ops} - probability of servicing,
P_{otk} - cancellation probability,
P_{pr} - probability of existing of the queue,
P_{pzk} - probability that all the cranes are occupied,
r - number of barges in composition,
t_s[h] - intarval of the arrival of barge composition,
T_{stac}[h] - time period after which system enters the stationary state,
t_{un}[h] - average time needed that crane unloads the barge,
t_w[h] - average time which barge spends in a queue,
t_{ws}[h] - average time which barge spends in a system,
δ_i - relative error of difference of probabilities $p_i(t)$ and p_i,
λ[1/h] - intensity of the arrival of barge composition,
μ[1/h] - capacity of unloading of barge with one crane.

UTICAJ NESTACIONARNOG REŽIMA NA RAD TERMINALA ZA ISTOVAR RASUTIH TERETA

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U radu je analiziran proces istovara rasutih tereta modelom teorije redova čekanja sa grupnim dolaskom jedinica u sistem (sastava barži), ograničenim redom čekanja i otkazom (otkaz se odnosi na celokupan sastav barži). Analiziran je period rada sistema do postizanja stacionarnog režima (nestacionarni režim) kao i stacionarni režim rada sistema. Dat je kriterijum nestacionarnosti.

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In this paper was discussed a process of unloading of bulk cargo by queuing theory with bulk arrival of units to the system (composition of barge), limited waiting queue and cancellation (cancellation is related to the whole composition of barge). The period of work of the system until stationary state is reached (non-stationary work order), and stationary order of work of the system were analysed as well. Non-stationary state criterion is given.

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