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Simulation for Service Quality and Berths Occupancy Assessment

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ABSTRACT: Current development of the maritime transportation system, namely fleet and ports specialization, growth of vessel sizes, rationalization of routs, trade regionalization etc., has made many traditional approaches and calculation techniques practiced for many long years in port design procedures to be inadequate and insufficient. A generally acknowledged tool for this task today is the simulation technique. In the same time, modern object oriented simulation approach provides usually only ad hoc solution for a project. It lacks the generality that was the main and natural feature of its traditional analytical predecessors. Very high time and labor consumption of simulation comes to a conflict with a very narrow scope of the resulting model's application domain. This paper describes a new approach used to create a simulation tool for the port designers and planners combining the universality and generality of the analytical (so called "static") methods with the efficiency and accuracy of the object-oriented simulation. The concept represented in the paper was implemented in the software product, which enabled to conduct experiments that proved the validity and adequacy of the model. The simulation tool was used in several sea port design project and now is a common instrument of several leading port design and consulting company in Russian Federation.

1 INTRODUCTION

In 1985 a fundamental study was published [1] which for long decades defined the views over the port development. One of the most prominent results of the study was the employment of the queuering theory. Under some restrictions (not important at that time) this tool enabled to achieve the results before considered impossible: the introduction of the berth utilization coefficient K_{occ} as a control parameter tied together infrastructural and commercial characteristics of the port. Really, port always used to be a collision point of ship owners and terminal operators interests: both would like to see their expensive assets earning money. The ship owner likes to see all the berths in the port idle and waiting for his ship to serve; the port operator dreams of all berths occupied, preferably with the queue of ships waiting for a first berth to free. The queuing theory offered a simple and understandable way to set a desired balance of port and ship losses.

2 SEA PORT AS A QUEUING SYSTEM

A port could be treated as a queuering system with ships as the jobs (vessels) arriving to the servers (berths) [4]. The mean arrival rate could be determined by the number of ships calling at the port within a year N or the mean interval between arrivals T_{int}:

$$\lambda = \frac{N}{365} = \frac{1}{T_{\text{int}}}$$

The ship berthing time in this case could be interpreted as an average serving time T_{serv}. The jobs served and leaving the system are described by the serving rate

$$\mu = \frac{1}{T_{serv}}.$$

The value $\alpha = \frac{\lambda}{\mu}$ is called the relative density of arrival. This value shows how many vessels would arrive during the berthing time of one vessels. The number of ships which should be served simultaneously defines the number of berths in the port. Insufficient number would cause the queues and losses for the ship owners, redundant number would lead to losses for the port owners due to poor utilization of expensive capital assets (berths). The queuering theory offers a way to find the balance of these losses thus finding the optimal value of n_{opt}. Specifically, the theory provides a formula for the average length of the queue m_s

$$m_s = \frac{\dfrac{\alpha^{n+1}}{n \cdot n!\left(1-\dfrac{\alpha}{n}\right)^2}}{\sum_{k=0}^{n}\dfrac{\alpha^k}{k!} + \dfrac{\alpha^{n+1}}{n!(n-\alpha)}}$$

This formula includes as variables the number of servers n and the relative density α . Since $K_{occ}=\alpha/n$, for practical purposes it is more illustrative to express m_s as a function of K_{occ}.

This dependence was presented in [1] as a table, without sufficient explanations and with references to rather rare literature sources. The missing link in reasoning put certain obstacles to development of advance perception and heuristic enhancement of the proposed approach. As an additional unpleasant consequence, the value K_{occ} started to be generally treated as a design parameter, while the nature of this value makes it just an intermediate one.

It is more logical to set a direct explicit relation of two main values critically important for ship owners and port operators – average waiting ratio and utilization of berths – as functions of the annual cargo turnover Q and number of berth n in the port.

The dependence of K_{occ} from Q at given berth number n in this case is trivial: $K_{occ}=(N*T_{serv})/(n*365)=(Q*T_{serv})/(n*365*V)$, where V is the ship capacity. In more complicated cases treated below, this dependence is not as simple. If we denote the berth productivity as $P=V/T_{serv}$, then to handle the annual cargo turnover Q we would need the time interval $T_{work}=Q/P$ would needed. Since the annual budget of time for n berths is $n*365$, eventually we have $K_{occ}=Q/(P*n*365)/$

Thus we can offer a new structure for the gueuering system model as given by Figure 1.

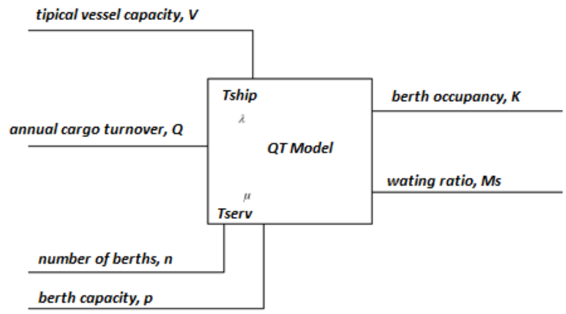

Figure 1.New structure of the gueuering model

3 THE RESTRICTIONS OF THE QUEUERING MODELS

Today, with much wider vessel size range, complicated rationalization of routes and new port infrastructure design, nearly all main assumptions of the ship arrival discipline needed to imply the queuering system model are not observed. The arrival flow is never stationary due to commercial circumstances, with some ships arrive randomly and some obey different schedules. Moreover, the most important is totally different interpretation needed for the berths as servers.

Historically, a berth as construction entity was equal to administrative (management) unit. Since the ship's sizes were close to the berth length, this fact did not cause any inconveniences. The constant growth of the ship and berth sizes caused problems in interpretation of berth occupancy, since in some cases several ships could be served at one berth and in other cases one ship could occupy more than one berth.

The definition of K_{occ} in this case could be corrected as $K_{occ} =(\Sigma\, l^{ship}_i \cdot t^{ship}_i) / L \cdot T_б$, but anyway it would ruin the basic assumption enabling to use the queuering theory.

4 THE DESCRIPTION OF GENERAL MODEL

Let us assume that we would like to estimate the maximal cargo turnover Q during an interval T realized with the ships with different capacity, whose inputs in Q are defined by the probability distribution $P(V)$. An example of this distribution is given by Figure 2.

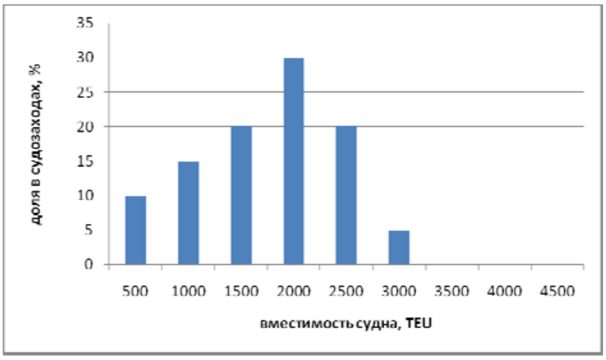

Figure 2. Histogram of ship capacity distribution

This distribution gives probabilities p_i of appearance among all N ships arriving within a given interval T the ships with capacity v_i, i.e.

$$\sum_{i=1}^{I} p_i = 1 \quad ; \quad \sum_{i=1}^{I} n_i v_i = Q \quad ; \quad n_i = N p_i$$

Thus we have

$$N \sum_{i=1}^{I} n_i p_i = Q \quad ; \quad N = \frac{Q}{\sum_{i=1}^{I} n_i p_i}$$

This enables us to calculate the average number of calls of the ships of dfferent capacity:

$$n_i = \frac{Q\, p_i}{\sum_{i=1}^{I} n_i p_i}$$

For every ship type we can estimate the average arrival interval $\tau_i = T/n_i$. Naturally, the stochastic values of every ship type arrival interval fluctuates around this mean values. If we know the lows of these fluctuations, possibly different for every type, we could generate a partial arrival flows for every ship type (Figure 3).

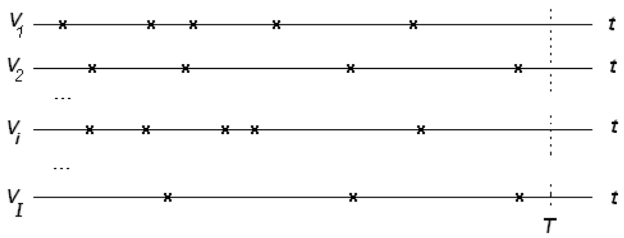

Figure 3. Partial arrival flows of different ship types

Let us further assume that we have several different berths, B_k, $k=1,\ldots,K$, whose characteristics (permitted ship length and draft, cargo handling equipment, commercial terms of the contracts with shipping lines etc.) permit to accomodate not all ships at every berth, while different productivity establish different turnaround time at different berths. In a general case the equipment could build a common pool to be distributed by some specific lows among singl berths in the group. The restrictions to use the berths could also have commercial nature.

Let us introduce a matrix $[t_{ik}]_{I\times K}$, whose element t_{ik} shows, at what time a ship of capacity v_i is handled at the bert B_k. If t_{ik}=0, the ship cannot be accommodated at this particular berth (see Figure 4).

$$\begin{vmatrix} t_{11} & t_{12} & \ldots & t_{1K} \\ t_{21} & t_{22} & \ldots & t_{2K} \\ & \ldots & & \\ t_{i1} & t_{i2} & \ldots & t_{iK} \\ & \ldots & & \\ t_{I1} & t_{I2} & \ldots & t_{IK} \end{vmatrix}$$

Figure 4.Matrix of serving time at different berths

The general structure of the model dealing with the above mentioned assumptions is illustrated by Figure 5.

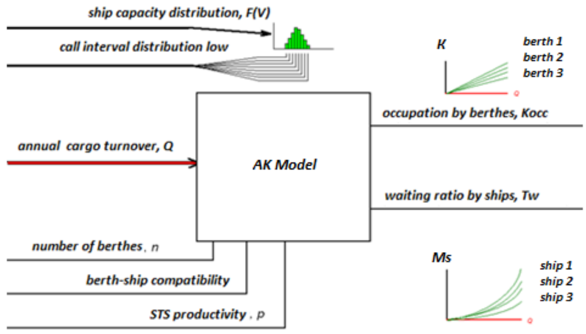

Figure 5. The structure of the proposed model

The proposed model enables us to undertake the study of two main parameters – occupation of different berths and waiting ratio for different ship types – as function of cargo turnover Q. In order to do so we will run the model (with a set of fixed external parameters) increasing the main variable (cargo turnover) from zero to any given value (or a value showing unlimited waiting ratio growth at least for one berth, giving the maximal terminal throughput, or its capacity).

5 IMPLEMENTATION OF THE MODEL

The described model is realized on a very sophisticated and licensed object-oriented platform. For many applications, for example for technological design of ports and terminals, when the number of berths and number of STS is under optimization, there would be enough to use a simplified versions, since the use of the advanced software would be connected with the barrier of learning. For this purposes a dedicated MS EXCEL version of the model was developed, where the well-known spreadsheets are used as a common or easily studying interface. The sophisticated software "engine" is hidden "under the hood" of this product, making the latter looks very simple and innocent.

The data are keyed in the screen forms shown on figures 6-8.

Description	Unit	Denomination	Value	
Total Quay Length	*[m]*	*L*	***3 500***	
Turnover by simulation interval	*[teu/interval]*	*Q*	***10 000***	
STS producivity	*[move/hour]*	P_0	***25***	
TEU factor	*[teu/box]*	K_{teu}	***1,00***	
Ship capacity utilization		K_{shp}	***1,00***	
Mooring gap		K_{un}	***0,10***	
Productivity decrease by the No of STS		K_{lin}	***1,00***	
Simulation interval	*[hour]*	*T*	***8 760***	
Annual cargo turnover	*[teu/year]*	*Qyear*	***10 000***	
RTG producivity (Sea->CY)	*[move/hour]*	*P1*	***8***	
RTG producivity (CY->Land)	*[move/hour]*	*P2*	***8***	
RTG producivity (Land->CY)	*[move/hour]*	*P3*	***8***	
RTG producivity (CY->Sea)	*[move/hour]*	*P4*	***8***	
Cargo turnover simulation range	**Begining**	**End**	**Step**	**No of steps**
Annual cargo turnover	***1 600 000***	***2 800 000***	***100 000***	***12***

Figure 6. General data on the project

Ship types			***v1***	***v2***	***v3***	***v4***	***v5***	***v6***	***v7***	***v8***	***v9***	***v10***
Capacity	*[teu]*	v_i	**1000**	**882**	**1890**	**2178**	**2430**	**2836**	**2926**	**1828**	**9000**	**10000**
Import party	*[teu]*	Im v_i	**1000**	**441**	**945**	**1089**	**1215**	**1418**	**1463**	**1645,2**	**8100**	**9000**
Export party	*[teu]*	Ex v_i	**0**	**441**	**945**	**1089**	**1215**	**1418**	**1463**	**1645,2**	**8100**	**9000**
Share of cargo turnover		α_i	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Number of calls		N_i	***10***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
STS required		n_i	4	2	2	2	4	4	5	5	6	6
LOA	*[m]*	l_i	180	180	180	180	300	350	400	400	400	400
Auxilliary operation time	*[hour]*	τ_i	0	4	4	4	2	2	3	3	3	3
Cargo operation time	*[hour]*	t_i	10,0	17,6	37,8	43,6	24,3	28,4	23,4	26,3	108,0	120,0
unloading	*[hour]*	Im t_i	10	8,82	18,9	21,78	12,15	14,18	11,704	13,1616	54	60
loading	*[hour]*	Ex t_i	0	8,82	18,9	21,78	12,15	14,18	11,704	13,1616	54	60
Total handling time	*[hour]*	T_i	10,0	21,6	41,8	47,6	26,3	30,4	26,4	29,3	111,0	123,0
Call interval distribution	*code*		равномерно	эрланг	эрланг	эрланг	эрланг	эрланг	эрланг	эрланг	эрланг	эрланг
Parameter 1			2	2	2	2	2	2	2	2	2	2
Parameter 2												

Figure 7. Ships description

Ships	***v1***	***v2***	***v3***	***v4***	***v5***	***v6***	***v7***	***v8***	***v9***	***v10***	Berth length	No of STS
STS alocated	***4***	***2***	***2***	***2***	***4***	***4***	***5***	***5***	***6***	***6***		
BERTHS											*[m]*	*[unit]*
B1	**1**	**1**	**1**	**1**	**1**	**1**	**1**				**200**	**2**
B2	**1**	**1**	**1**	**1**	**1**	**1**	**1**				**200**	**2**
B3	**1**	**1**	**1**	**1**	**1**	**1**	**1**				**200**	**3**
B4	**1**	**1**	**1**	**1**	**1**	**1**	**1**				**380**	**3**
B5											**380**	**4**
B6											**380**	**4**
B7											**440**	**5**
B8											**440**	**5**
B9											**440**	**6**
B10											**440**	**6**

Figure 8. Berths description and ship/berth compatibility

Figures 9-10 display the screenshots of the model's serial run over some interval where the cargo turnover reaches maximally accepted values for a given ship capacity distribution and specified berth's characteristics.

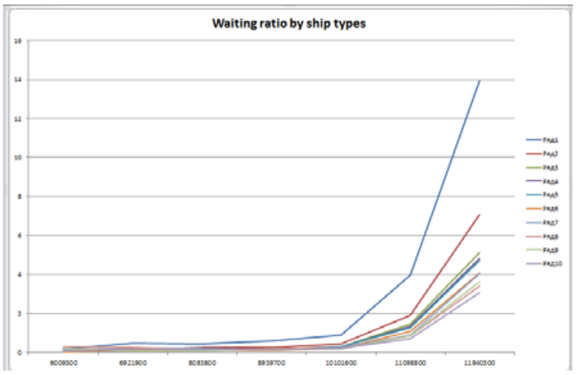

Figure 9. Waiting ratio growth with cargo turnover

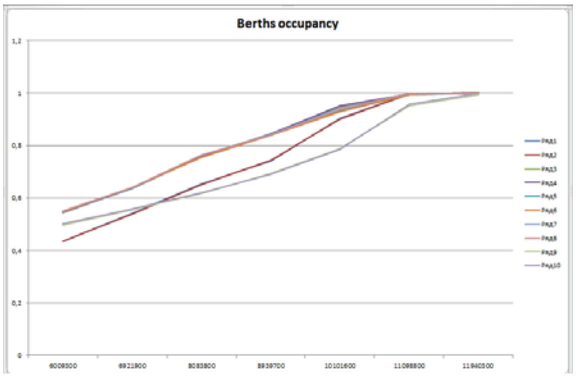

Figure 10. Bert utilization growth with cargo turnover

6 CONCLUSIONS

1. The approach is described which could be treated as a logical extension of the queuering theory for modern berths and cargo handling equipment in port design procedures.
2. The adequacy of the approach is proven by the comparison with the queuering theory results when applicable.
3. The approach is implemented both in a highly specific product (built in the full-scale simulation model used for the task of global resource optimization software under development) and a stand-alone version using MS EXCEL as a friendly interface.
4. The MS EXCEL version proved to be useful and efficient at the stage of port and terminal design for the optimization of berth number and STS fleet justification.
5. The product could be recommended for any persons engaged in the optimization of the number of berths, berth productivity, number of cranes on the berths, the influence on the port capacity of the different ship calls distribution.
6. Especially usefully this instrument could be when design and planning of port operations for non-interchangeable berths.
7. Any interested specialists could apply for an advanced simulation tools with much wide scope and enhanced research features.

LITERATURE

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