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ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА
МОРСКОГО И РЕЧНОГО ФЛОТА ИМЕНИ АДМИРАЛА С. О. МАКАРОВА

ВОДНЫЕ ПУТИ СООБЩЕНИЯ И ГИДРОГРАФИЯ

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ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ ДЛЯ ОЦЕНКИ ВЛИЯНИЯ СУДОПОТОКА И ДНОУГЛУБИТЕЛЬНЫХ РАБОТ В ПОДХОДНОМ КАНАЛЕ МОРСКОГО ПОРТА

A SIMULATION TECHNIQUE FOR THE PORT TRAFFIC AND DREDGING IN ITS APPROACHING CHANNEL INTERFERENCE ASSESSMENT

Дано описание обобщенной концептуальной модели первого уровня, отражающей общий подход к решению задачи составления оптимального расписания дноуглубительных работ в подходном канале произвольного морского порта. Оптимизация расписания состоит в минимизации потерь как следствия появления взаимных помех между операциями по обработке судов в порту и работами по дноуглублению в его подходном канале. Цель модели — возможность получить объективную оценку взаимного влияния заданного трафика судов и дноуглубительных работ в подходном канале порта. Эта оценка, в свою очередь, позволяет предложить объективную методику оптимизации расписания дноуглубительных работ путем его координации с прибытием в порт судов, движущихся по расписанию или в случайном порядке.

The paper introduces a simplified (first level) model designated to demonstrate the general approach to the problem of the development of the schedule for dredging work to be conducted in the approaching channel to a port which would minimize the losses connected with its interference with the port traffic. The goal of the model development is to provide a way how mutual interdependency of the port traffic and dredging activity in a port approaching channel could be assessed. This assessment in its turn will enable to optimize the time schedule of dredging works by coordination them with a given schedule or random pattern of ship arrivals.

Ключевые слова: имитационное моделирование, развитие порта, оптимизация, дноуглубление.
Key words: simulation, port development, optimization, dredging.

Introduction

Seaports are the most critical infrastructural links in the operations of logistic chains [1], [2]. A port must maintain its operability all the time, since any small break would send a heavy shockwave along the whole delivery network connected to it. On the other hand, the port needs to develop constantly to comply with the shipowners' demands to introduce vessels of permanently growing size and handling them in the shortest time possible. This contradiction boosts the importance of the investment program as a part of port management, in order to enhance its availability and competitiveness. Simple and short-term modernization works might not affect the port operation significantly, while long-term activities dramatically reduce its efficiency, which necessitates a sophisticated planning.

Dredging is a rather frequent and important aspect of port development strategies. A thorough analysis of several factors is required to conduct beforehand, among them the vessel traffic, the proper type of equipment and the level of its efficiency. High costs of dredging pair with the costs of losses of port operators and shipowners incurred by vessels waiting in queues to pass the areas of development works. To optimize the efficiency of a dredging project it is necessary to assess the interference between the dredging activity schedule and traffic pattern in terms of the costs. This paper presents a simulation model which enables to estimate this impact of dredging activities on the vessel traffic in the port and thus provides a way to find a required balance.

Description of the model

Let us assume that there is an abstract entrance channel leading from the entrance buoy to the port. For the sake of simplicity in the description below we will deal only with the ships entering the port, since the introduction of the reversed ship flow introduces no difficulties in the model realization.

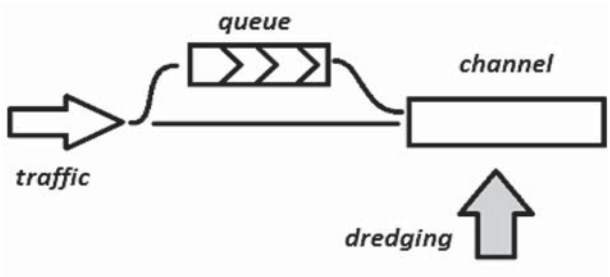

Fig. 1. Graphical model of the traffic and dredging interference

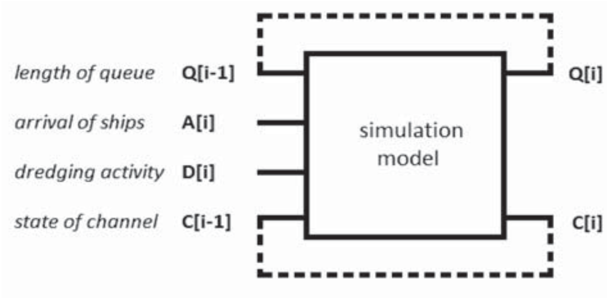

Fig. 2. Discrete time simulation model of the traffic and dredging interference

The channel in some periods of time might be blocked by the dredging works performing in it. In this case a ship arrived to port will join the queue in front of the entry point of the channel (anchorage) waiting for the break in dredging works. This is displayed by Fig. 1.

A simplified discrete time event simulation model for this case is shown by the Fig. 2.

The state of the model at any time interval (i) is defined by the number of ships arrived to the entrance buoy, number of ships waiting in the queue and these entered the approaching channel. In other words, the state of the model is determined by the state and events at the previous interval (i-1). These reason-sequence connections could be described by the following rules:

Entrance channel: if there is no dredging activity in the channel, the ship waiting in the queue or just arrived to the port could enter the channel. If there is the dredging activity, no ship can move.

Anchorage queue: if a ship entered the entrance channel, the queue length is diminished by 1, if it was not zero. If a new ship arrived to the port and did not pass straight to the channel, the queue length is increased by 1.

The logic of this mechanism is shown by Fig. 3.

The state of the model at every time quantum [i] is described by two variables: length of the queue Q[i] and the number of ships in the approaching channel C[i]. These state depend on the values of those variables at previous quantum [i], i.e. Q[i-1] and C[i-1]. In additions, the current state of the model is affected by external events of two categories: the ship arrival at this quantum A[i] and the dredging activity at this quantum D[i], blocking the approach channel for ships.

The pattern of ships arrival and the schedule of dredging activity form to reference flow of events, causing the state of the model to change by time. This changing of the state by time is the dynamic behavior of the system under study. An example of this behavior is given by Tab. 1.

Table 1

Discrete time simulation model for given arrival and dredging schedule

Time	(i-1)	(i)	1	2	3	4	5	6	7	8	9	10
Arrival to entrance buoy	1	0	1	0	0	1	1	0	0	1	0	1
Anchorage queue	1	2	1	1	1	1	2	2	1	0	1	1
Entrance channal	0	0	1	1	0	0	0	1	1	1	0	0
Dredging activity	1	0	0	1	1	1	0	0	0	1	1	1

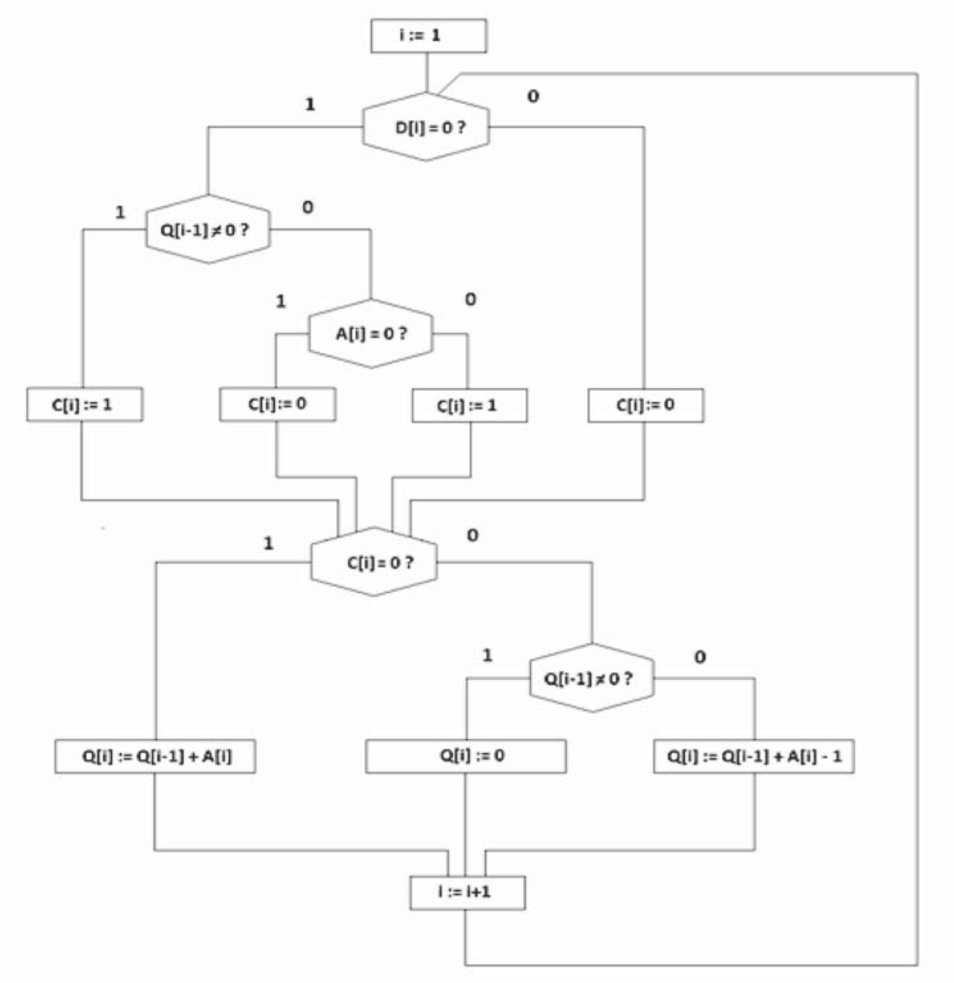

Fig. 3. Simplified inner algorithm of the model

As this figure shows, the interference of traffic and dredging leads to appearance of the queue. The length of this queue as the function of time is given by Fig. 4.

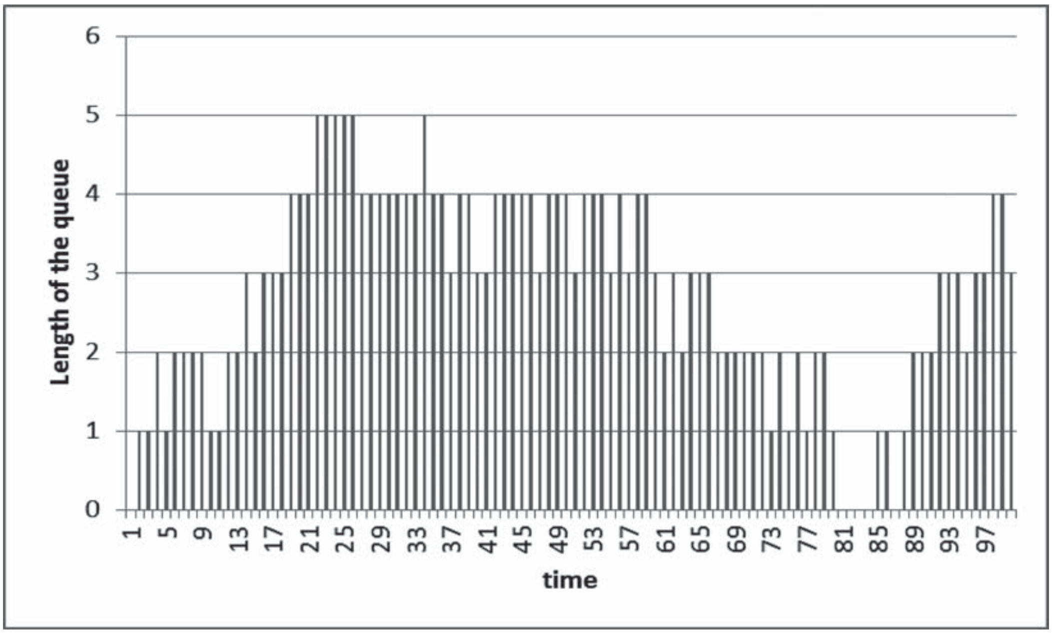

Fig. 4. Length of the queue caused by the interference

The waiting time in the queue is connected with direct financial losses for the ship owner and indirect losses for port operator. In order to make a judgment about these losses, it is necessary to estimate the cost of dredging activity under different scenarios.

Cost of dredging works

Let us assume that we know the unit (say, hourly) constant cost of dredging (working or not), the unit variable costs (when working), the cost of moving the dredging caravan to and from the site of activity. Let us assume that these costs are as given by Tab. 2.

Table 2

Costs example

Specification	Value	Unit
unit constant cost	10	[money/hour]
unit variable cost	10	[money/hour]
unit cost of moving	500	[money/move]

For the sake of simplicity here let us assume that we plan a dredging activity module of the schedule as given by Tab. 3.

Table 3

An example of dredging schedule module

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	1	1	1	0	0	0	1	1	1	0	0	0	1	1	1	0	0	0	1	1	1	0	0

The module presented by this figure consists of 10 hours, 5 of which are working and another 5 are idle. This particular schedule required 4 moves of the dredging caravan to the site of activity and 4 moves back. The cost calculation for this module in some arbitrary monetary units is given by Tab. 4.

Table 4

Cost calculation for the example of dredging schedule module

Specification	Amount	Cost
Number of hours	10	100
Number of working hours	5	50
Number of moves	8	4000
Dredging work utilization and cost	0,5	4150

If we know the total amount of working hours required to perform the dredging task, it is possible to calculate the amount of modules needed and, eventually, the cost of the total dredging mission. For the given example these calculations are displayed by Tab. 5.

Table 5

Cost calculation of dredging

TOTAL COST OF MODULE		4150
REQUIRED AMOUNT OF WORKING HOURS	1000	
NUMBER OF MODULES NEEDED	200	
COST OF DREDGING WORKS		830000

It is clear that the calculated cost depends on the amount of working hours in this 10-hour module and number of the caravan moves. This dependency is illustrated by Tab. 6 and Fig. 5.

Table 6

Cost of dredging as function of working hours and moves

Cost of dredging		Number of caravan moves				
		1	2	3	4	5
Working hour in 10-hour module	1	1110000				
	2	560000	1060000			
	3	376666	710000	1043333		
	4	285000	535000	785000	1035000	
	5	230000	430000	630000	830000	1030000
	6	193333	360000	526666	693333	
	7	167143	310000	452857		
	8	147500	272500			
	9	132222				
	10	120000				

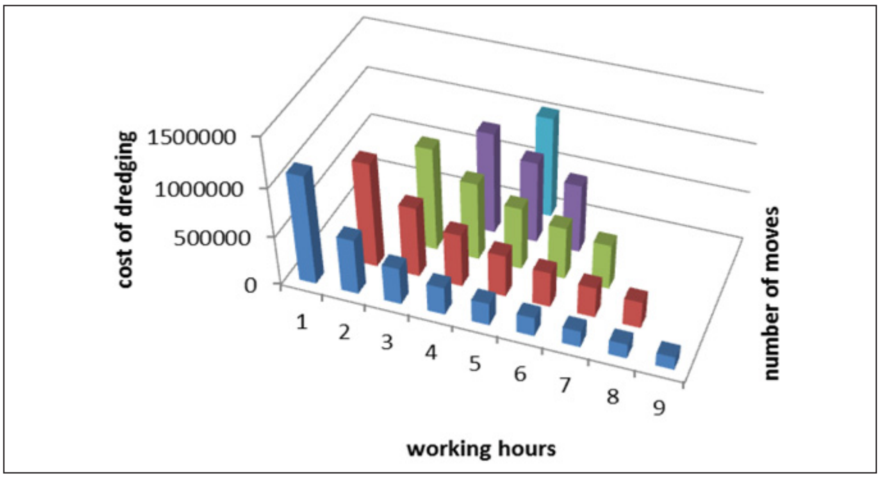

Fig. 5. Graph of the cost of dredging as function of working hours an moves

Different utilization of module time resource and different organization of continue work periods would leave to different costs of dredging.

In the same time, experiments with the model will enable to assess total time ships spend in the queue (Fig. 6).

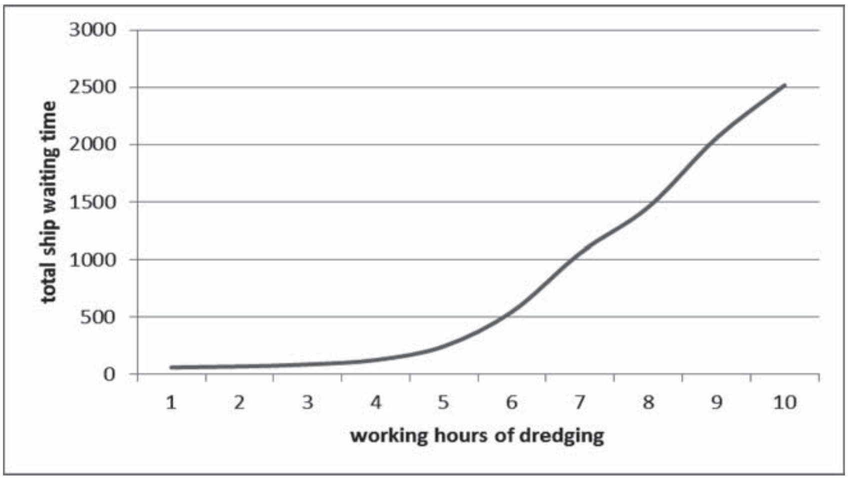

Fig. 6. Total time ships spend in the queue

If the cost of a ship hour is known, it makes possible to calculate the ship losses. The multiple and detailed study of different scenarios will enable to compare the costs with the losses caused by the ship waiting time.

Planning of the experiments with the model

Principally, there is a wide specter of possible variants with different combinations of traffic patterns and dredging scheduling.

On one side of this specter there is a solution when all the traffic is hold until the dredging works are over. In this case the cost of the dredging works is minimal, but the traffic losses are maximal.

On the other side of this specter there is a solution when the dredging activity is performed so that it does not affect the port traffic, i.e. the dredging is performed only in the time intervals between the ship arrivals long enough to do it. In this case the traffic is not affected by the dredging, but the dredging works will take a longer time and cost more.

Between these two extreme variants there is an optimal solution - optimal in the sense of selected economic criteria and under existing technological restrictions.

Dredging priority

This variant does not require any specific simulation, since the scenario simply implies that all the ships are not permitted to enter the port, they will have to wait in the outer anchorage or not call at the port at all. Still, the simulation in this case could give an informative picture about the losses caused by this situation. An example of simulation of this scenario is given by Fig. 7.

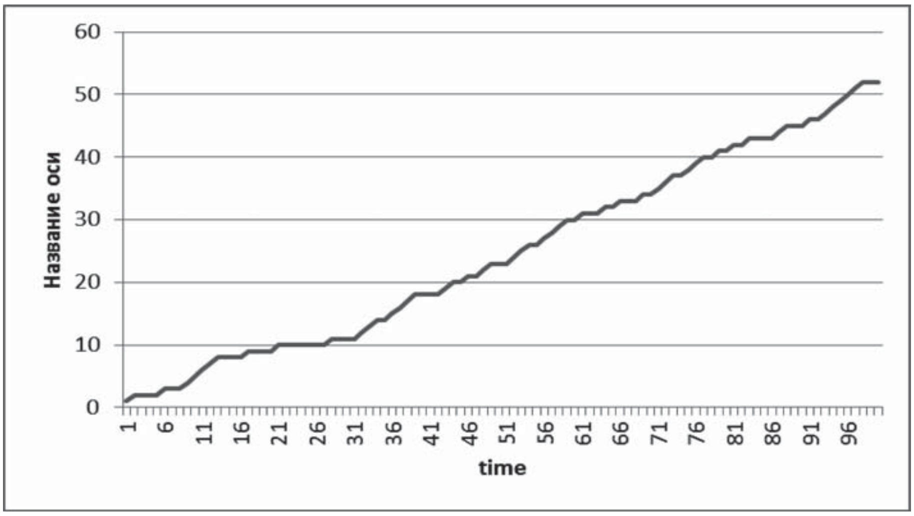

Fig. 7. Growth of the queue length in case of traffic ban

The area under the curve on this figure gives the total amount of hours ships (bound to call at the port by the schedule) spent in the queue. In this example it is 2468 hours.

The cost of dredging in this case is easy to calculate multiplying the unit hour cost (constant plus variable) by total amount of hours needed to perform dredging and adding two move costs of the dredging caravan (21000 of arbitrary monetary units only), thus also needing no simulation.

Traffic priority

The dredging in this case would be performed only when there long enough time period free of passing ships. In case of the scheduled traffic pattern this variant also does not require any simulation, since the schedule gives the possibility to calculate the total time available for dredging and number of moves for the caravan during the module of schedule. In its turn, this enables to calculate the required amount of these modules and calculate the total cost of the dredging works as was explained above.

If the arrival pattern is random (stochastic), then the simulation experiments are needed to determine the actual number of intervals and their length available to perform the dredging works, as Fig. 8 shows.

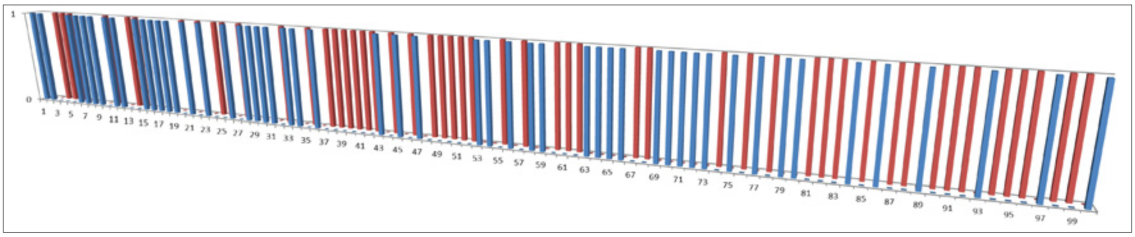

Fig. 8. Intervals allowing dredging defined by simulation of ship arrivals

In this example dredging is permitted for 50 hours out of 100 and requires 52 moves of the caravans. The calculation of the total dredging work's cost in the similar way as described above would give the results presented by Tab. 7.

Table 7

Calculation of the dredging costs with the traffic priority

Specification	**Value**	**Unit**
Unit constant cost	10	[money/hour]
Unit variable cost	10	[money/hour]
unit cost of moving	500	[money/move]
Specification	**Amount**	**Cost**
Number of hours	100	1000
Number of working hours	50	500
Number of moves	52	26000
Dredging work utilization	0,5	27500
TOTAL COST OF MODULE		27500
REQUIRED AMOUNT OF WORKING HOURS	1000	
NUMBER OF MODULES NEEDED	20	
COST OF DREDGING WORKS		550000

As this figure shows, the total cost is 550000 arbitrary monetary units, thus being 25 times higher than one in the case of dredging priority.

The practically significant experiments should involve a longer schedule modules and more realistic data on duration and unit costs of dredging works. A sample of simulation with a 24-hour schedule module for one week period is presented on Fig. 16.

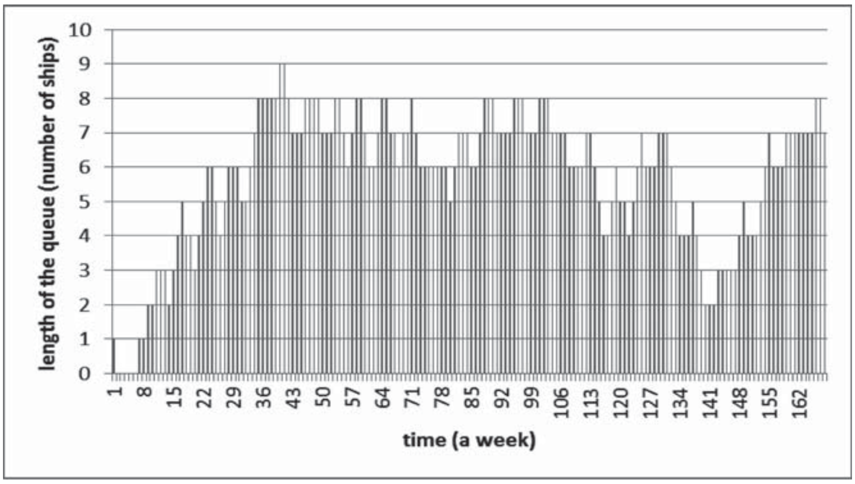

Fig. 9. Weekly queue dynamics caused by a given 24-hours schedule of dredging

Ship arrival pattern

Many studies were taken to find a best way to describe the ship arrival patterns for different cargos and different port statuses [3] – [5].This paper does not concern this very specific and complicated topic. For the sake of universality it is assumed that the ship arrival intervals would be governed by Erlang distributions of any given order. The higher is the order of Erlang distribution, the lower is the dispersion of the random values around the mean value. The Erlang distribution of the first order is totally random and coincide with one of Poisson. The distributions of higher orders come closer and closer to regular intervals.

Thus, the Erlang distributions are the most common ones for description of any ship traffic patterns at early stages of the study [6] – [10]. With more knowledge about the traffic some other probability lows could be introduced as well as specific determined schedules of the ships arrivals.

The examples of these distributions with different orders and the same mean values are given by Fig. 10.

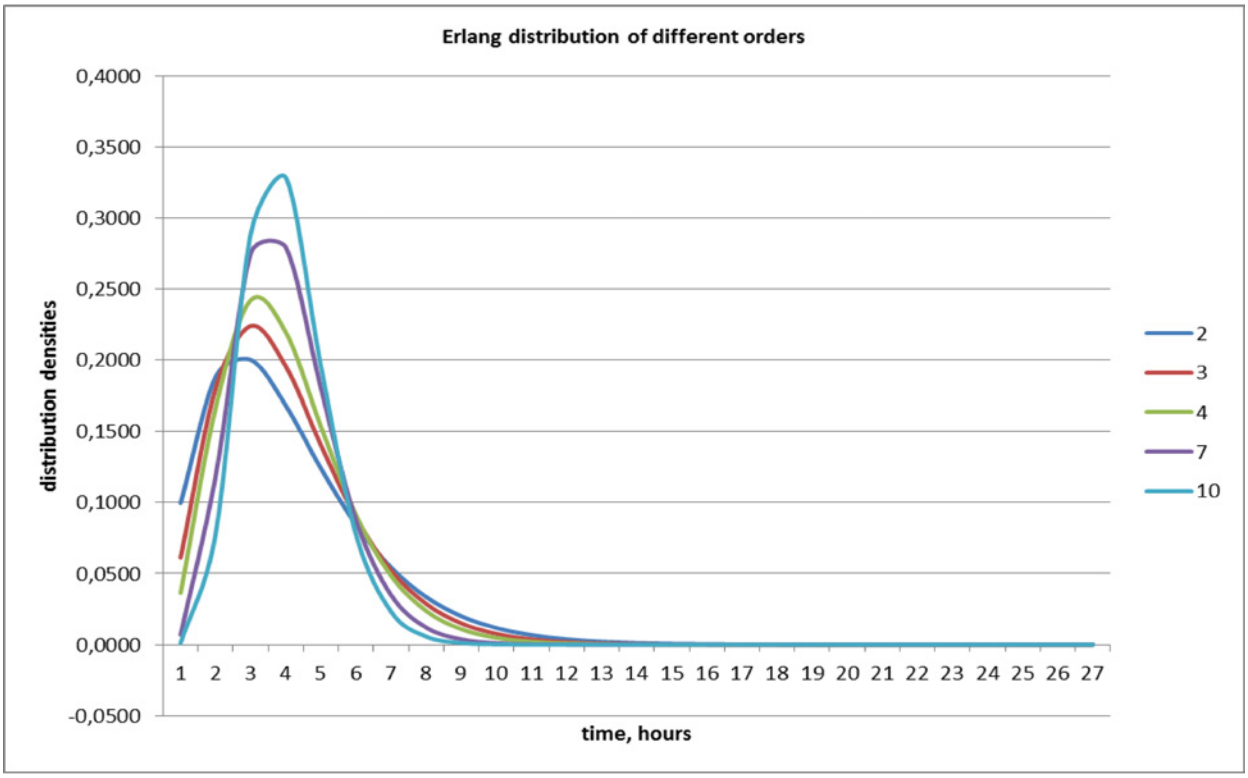

Fig. 10. Erlang distribution probability densities of different order

Fig. 11 shows the examples of ship arrivals generated for Erlang 2 distribution (random, above) and Erlang 20 one (more regular, below).

Fig. 11. Ship arrival intervals generated by Erlang 2 and Erlang 20 distributions

A single experiment with a selected Erlang distribution for different dredging time utilization levels enables to assess the ship time wasted in the queue (Fig. 12).

In the same time, for every level of dredging time utilization it is possible to calculate the cost of dredging as described above (an example is given by Fig. 13).

If the ship hour cost can be estimated, Fig. 12–13 provide the classical optimization task for selecting the best scenario of dredging activity, illustrated by Fig. 14.

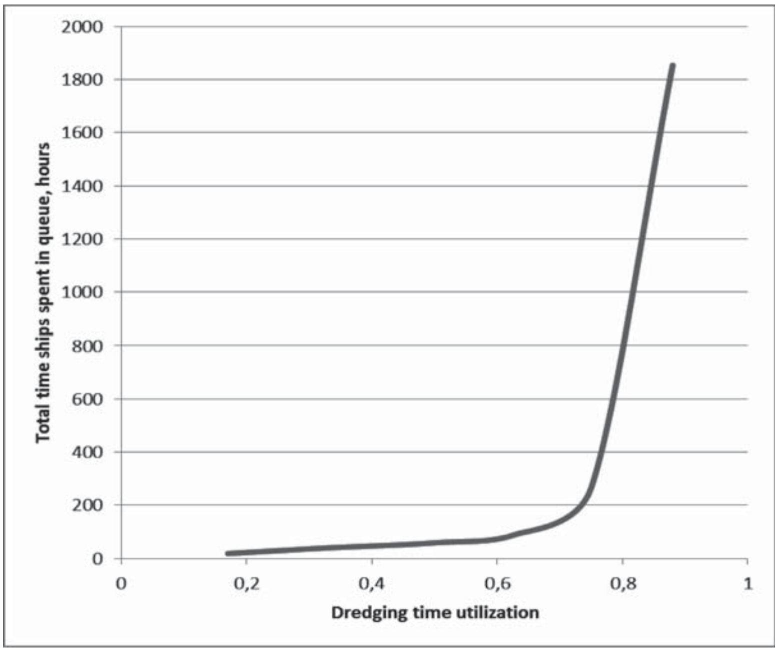

Fig. 12. Ship time lost in the queue

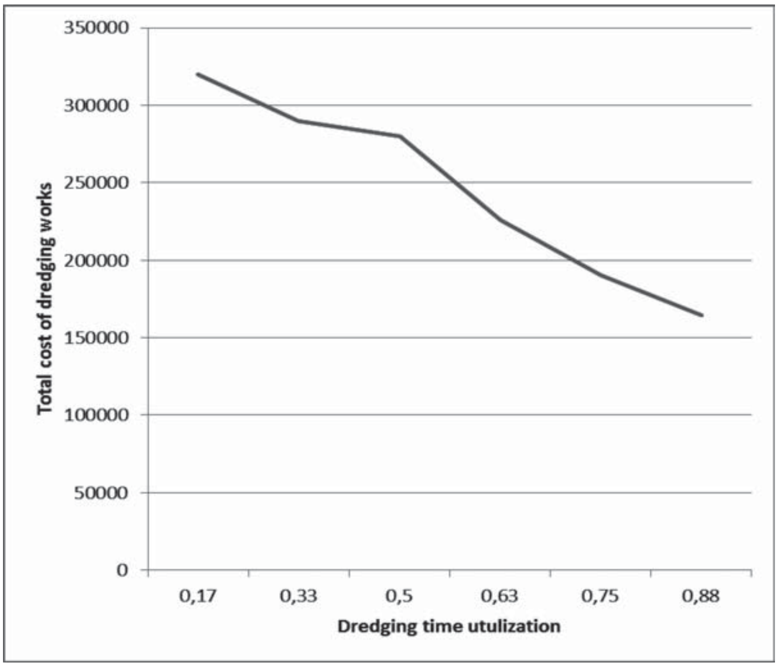

Fig. 13. The total cost of dredging for different time utilization

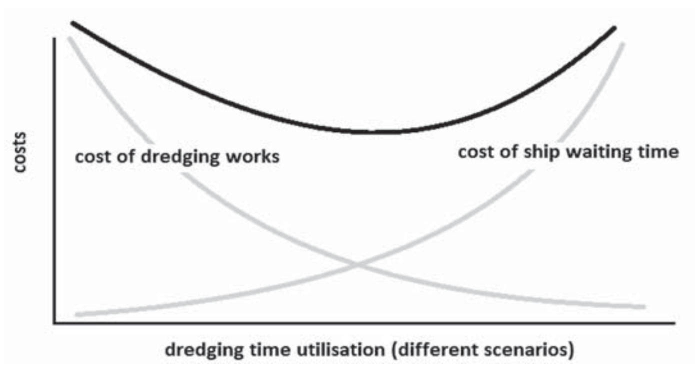

Fig. 14.The idea of optimization task

Conclusions

A simulation model is introduced to describe the way how the assessment of mutual interdependency of the sea traffic and dredging activity in a port approaching channel could be made.

This model enables to assess the ship losses caused by the time spent in the queue while the dredging works are performed.

A way to calculate the total dredging works' cost in different scenarios of their scheduling is presented.

It is shown how simulation performed for different scenarios could help to optimize the time schedule of dredging works by coordination them with a given schedule or random pattern of ship arrivals.

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ОБЕСПЕЧЕНИЕ БЕЗОПАСНОГО СУДОХОДСТВА НА ВНУТРЕННИХ ВОДНЫХ ПУТЯХ С ИСПОЛЬЗОВАНИЕМ НАВИГАЦИОННОЙ АППАРАТУРЫ ПОТРЕБИТЕЛЯ

PROTECTION OF SAFETY NAVIGATION ON THE INLAND WATERWAYS WITH USING NAVIGATION CONSUMER EQUIPMENT

В настоящей статье представлено решение комплексного подхода использования путевых точек в навигационной аппаратуре потребителей (Д) ГНСС ГЛОНАСС/GPS для обеспечения безопасного перехода судна по внутренним водным путям. Рассмотрены последние изменения в Кодексе внутреннего водного транспорта, касающиеся «порядка планирования рейса судна и обеспечения безопасности его плавания», которые дела-