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EVALUATION OF SHIP TURNAROUND TIME IN PORT WITH APPROACH CHANNEL

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Abstract: The operation efficiency of a port with an approach channel to a great extent depends on decisions made by the port authority and harbor master over the channel scheduling. Currently there are no formal methods which allow to evaluate the influence of the channel schedule on the ship turnaround time, especially when the throughput capacity is restricted. The relevant system has a complex structure that rules out common mathematical methods. The paper studies some typical structures of these systems and offers an approach for developing adequate simulation models. These models enable the conduct of comparative studies of different variants of approach channel scheduling and serve as a toolkit to support the decision-making procedure for harbor master and port operators.

Keywords: seaport, approaching channel, queueing system, ships turnaround time, simulation modeling.

1. INTRODUCTION

One of the most important characteristics of seaport efficiency, which is of keen interest for the shipowners, is ship turnaround time in port [Alderton 2013; UNCTAD 2019]. This value defines how many ships should be used on a service string and what speed should be maintain along the voyage. As these characteristics directly influence the efficiency of shipowner activity, port operators cannot ignore it [United Nations 1985; Slack et al. 2018].

Ship turnaround time consists of cargo handling time and time for auxiliary operations like towing, mooring, removal of hatch covers etc. [Shahpanah 2014]. At the same time, for seaports located in river deltas and those with approach channels (e.g. Saint-Petersburg and Kaliningrad), ship turnaround time also includes time needed to transit the channel. This time depends on the technical characteristics of a channel (particularly, if one- or two-way traffic is allowed). In case of two-way traffic, the approach channel only limits ship speed within a certain distance, while one-way traffic increases the likelihood that ships will wait for permission to enter the approach channel occupied by other vessels. Moreover, special rules of ship movement that restrict cargo vessel traffic could be applied [General Rules... 2020]. For example, when a tanker or a passenger ship enters a channel, no other ships can move.

At the same time, terminal operators cannot control the approach channel schedule since it is a prerogative of the port authority and harbor master. As a consequence, the decisions made by the port authority concerning the channel scheduling define the efficiency of ship service at a port. However, there are no common tools to analyze different variants of channel scheduling. The paper is dedicated to the development of such an instrument. Given that ship arrival time, time needed to transit the approach channel, and time needed for cargo handling operations are stochastic values, and that the whole system of a port with an approach channel has a very complicated structure, it is impossible to apply common mathematical methods used in traditional port design and planning practice. The simulation modeling approach appears to be the only solution to the problem described above [Popov 2017; Kuznetsov, Kirichenko and Shcherbakova-Slyusarenko 2018; Kuznetsov, Kirichenko and Zaikin 2019].

2. SEAPORT AS A QUEUEING SYSTEM

In the simplest case a port or a terminal with a number of quays can be regarded as a queueing system where quays are servers and ships are jobs entering the system [Allen 2014]. A ship which has arrived to a port goes to any free quay. If all the quays are busy, the ship joins a queue located in or outside the port aquatory, waiting for a free quay (Fig. 1).

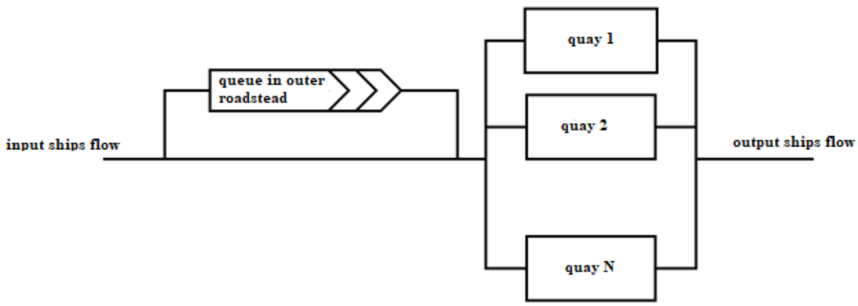

Fig. 1. A terminal as a queueing system

The quality of the service is usually estimated by the length of the queue L_q, and the efficiency of the system's operation is judged by the average time a job dwells in the system – in this case the ship turnaround time, and its relative wait time. Every server is characterized by the job handling time (which is the time of cargo handling operations T_{op} in this case). For this case this time is determined by the volume of cargo unloaded and loaded (V_{imp} and V_{exp}) and the quay productivity P_{berth}:

$$T_{op} = \frac{V_{imp} + V_{exp}}{P_{berth}}$$

Relative wait time T_{wait} is the average time that a ship spends in the queue T_{que} divided by the mean time of cargo handling operations T_{op}:

$$T_{wait} = \frac{T_{que}}{T_{op}}$$

For example, if a ship spends 12 hours waiting for a free quay and cargo operations take 24 hours, the relative wait time is 0.5.

If some specific assumptions concerning the input flow are observed, the queueing theory provides some analytical formulae to calculate these characteristics. These assumptions become more and more unreal for modern ports, thus making the analytical approach not applicable. Consequently, simulation modeling is a common alternative to define system operation efficiency. An example of modeling results is represented in Figure 2.

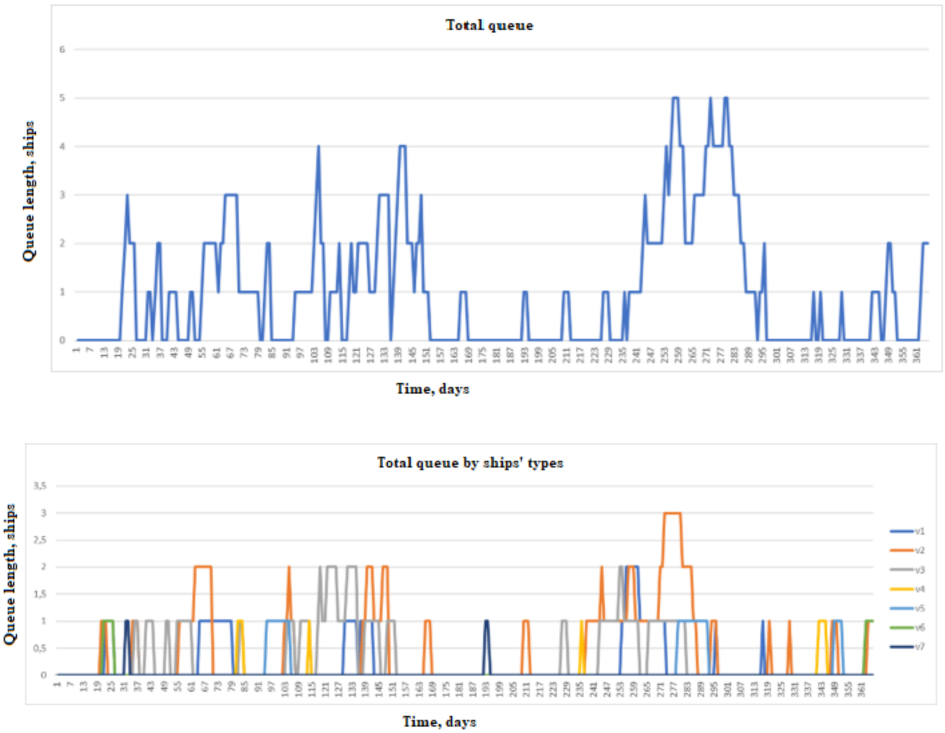

Fig. 2. An example of queueing system modeling results

Another specialized queueing system appears when the seaport's approach channel has a limited capacity, thus restricting the ship flow throughput, or has a specific time schedule for traffic. The ship flow on the entrance goes directly into the channel or directed to the queue located in an outer roadstead (Fig. 3).

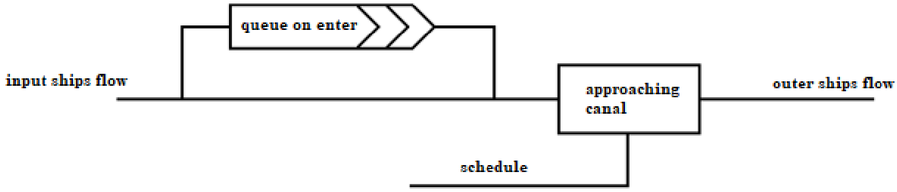

Fig. 3. Seaport approach channel as queueing system

Consequently, the ship flow at the exit of the channel could show a specific behavior: for example, a uniform stochastic flow would form "packs", matching the intervals of movement permission. In other case, the "packs" observed in the input flow would be spread due to restricted intensity of ship movement through the channel. The output flow can more or less differ from that of the imput at the entrance of the channel. An example of queue dynamics in the inner and outer roadstead when a channel works 50:50 of daytime to let ships in and out is represented by Figures 4–5.

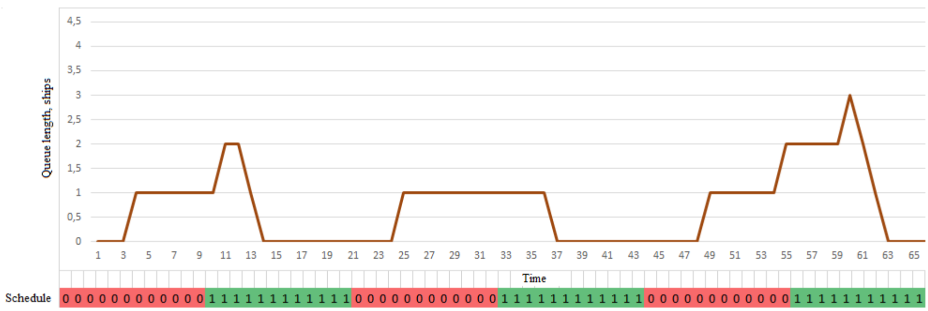

Fig. 4. Ship queue formation at the entrance to a channel

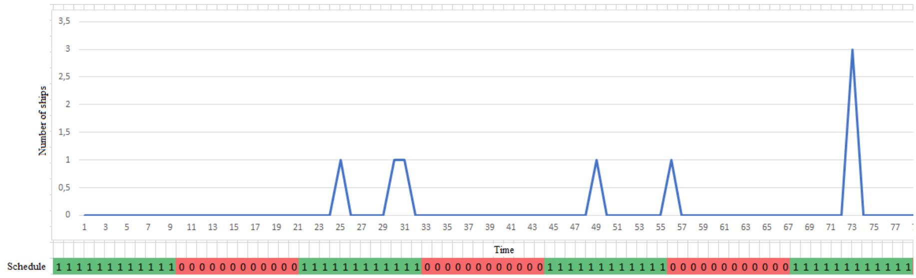

Fig. 5. Ship queue formation at the exit from a port

The schedule in this case can be represented as matrix, where the red area means that the traffic through a channel is prohibited while the green shows that it is permitted (Fig. 6).

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

Fig. 6. Schedule of approach channel

3. THE MODEL OF A SEAPORT WITH AN APPROACH CHANNEL

Now let's address a situation when a random ship flow comes to an approach channel that leads to a port where the ships are to be served at the quays. Accordingly, there are two systems tied together by one ship flow, which makes them interact. In this case, a ship can be put into a queue (i) in cases when the approach channel is occupied, (ii) when there is no free space in an inner roadstead or (iii) all the quays are busy. A ship can leave the queue and enter the channel only if two statements are true: (i) there is a space in inner roadstead and (ii) movement through the channel is allowed (Fig. 7).

This kind of interdependency in the queueing theory is called "an ensemble of interacting systems", since the elements of both systems influence each other's activity. A more complex system appears when ships serviced in a quay leave the port through the exit channel which also has its own throughput capacity and schedule (Fig. 8).

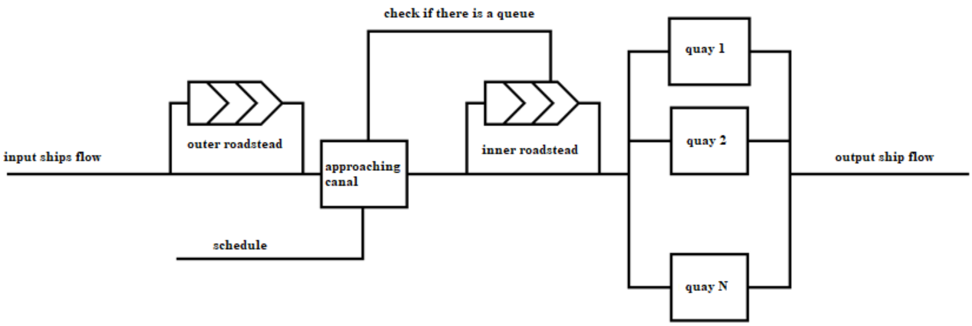

Fig. 7. Interaction of approach channel and port quays

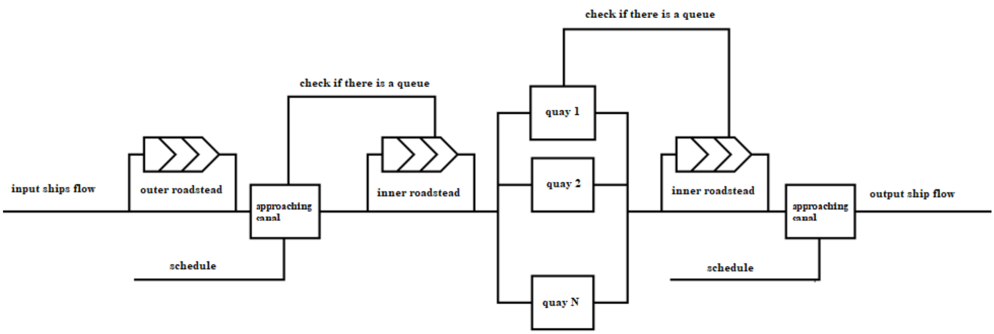

Fig. 8. Interaction of two channels and one port

In this case, lack of free space in the inner roadstead, where ships are waiting for the permission to leave the port through the channel, could limit the possibility to release a serviced ship from a quay. In its turn, the situation when all the quays are occupied leads to the lack of space in the inner roadstead. Consequently, ships cannot transit the channel and stay in the outer roadstead waiting for quay relief. As a result, this can make entering the channel impossible and produce overcrowding in the outer roadstead.

An ensemble of interacting systems, has few feedbacks. The system becomes even more complex when one roadstead is shared by the ships that enter a port and the ones that leave after being serviced. Moreover, there can occur the situation when they also share the approach channel to enter and to leave the port. This channel operates under its own schedule formed according to the current queues in the inner and outer roadstead (Fig. 9).

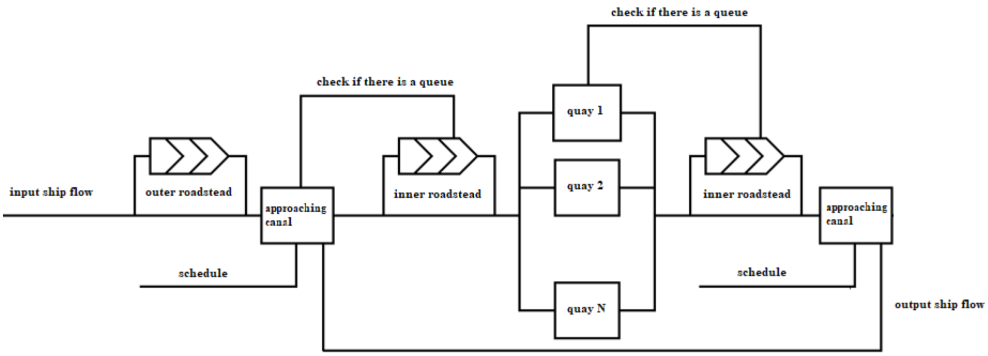

Fig. 9. Interaction of a terminal with only one channel

Due to the limited aquatory there can also occur the situation when a port has no inner roadstead at all, as Figure 10 shows.

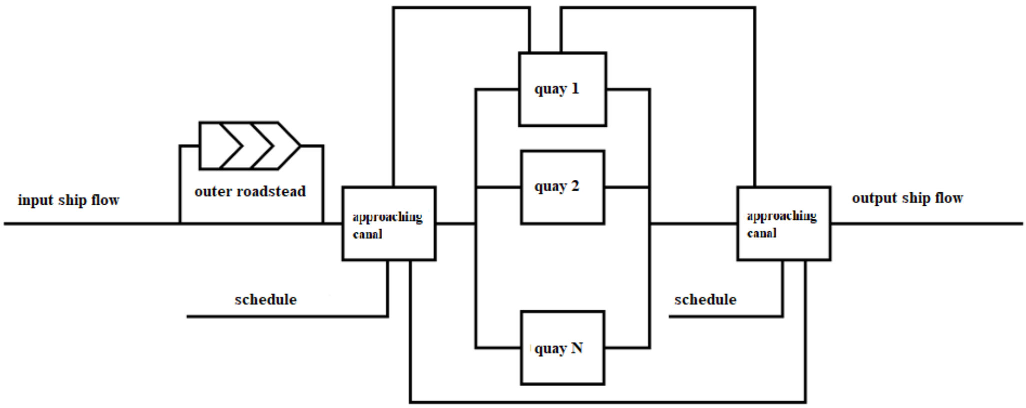

Fig. 10. Interaction of a channel with port without inner roadstead

As a result, the input ships' flow which is modulated by the channel schedule would restrict the possibility of the served ships to leave the port. As was indicated earlier, that would render it impossible for new ships to enter the port because there are no free quays for the ships to be served. Despite the fact that the structure of feedback is simpler than the one represented by Figure 4, the lack of inner roadsteads acting as buffers for the ships that have entered could influence the characteristics of input flow service in more severe fashion.

4. RESULTS

The schemas represented by Figures 4–10 describe the main principles that formed the approach to develop a class of channel simulation models. The objective of constructing the models was to analyze the efficiency of the described port operation systems featuring an approach channel. The developed models could be parameterized in accordance with any specific seaport-channel structure represented by Figures 4–10. This could be done by changing particular elements of the system.

The model principally consists of several different queueing systems which are connected by certain rules that describe their positions in the system structure. The input data for the simulation model are stochastic ship flow, the number and productivity of port quays and the schedule of approach channel operations which are entered as a daily enter-exit schedule matrix: its elements take the value of 0 if there is no possibility to enter or exit a port through a channel and the value of 1 in the other case.

The results examples of simulation modeling are the graphics of ship waittime at the entrance to and at the exit from the channel (Fig. 11–12).

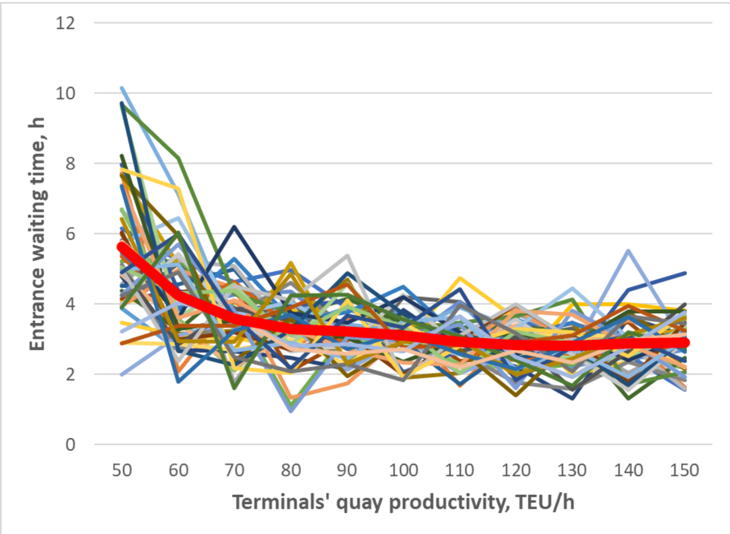

Fig. 11. Wait time at the entrance to a channel as function of the quay productivity

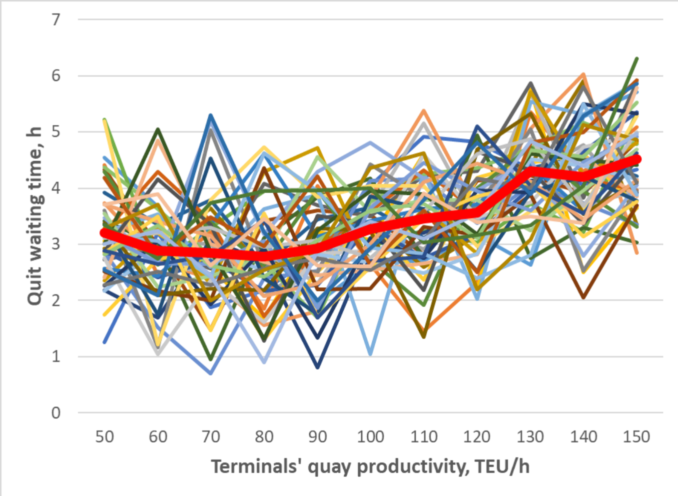

Fig. 12. Wait time on the exit from a channel as function of the quay productivity

The simulation was made for the situation represented in Figure 10. Every line of the graphics represents the result of an experiment, while each point of the line is average waittime of all ships in an experiment with a certain quay productivity. The red line shows the average time based on the data from all the experiments. The figures represent the mode of experiments when the annual cargoflow is a constant, but terminal quay productivity is a variant parameter.

In order to evaluate the influence of a channel schedule on ship turnaround time, two graphics should be compared: the one representing ship turnaround time without considering the channel and the one that shows total time of service in a port (Fig. 13).

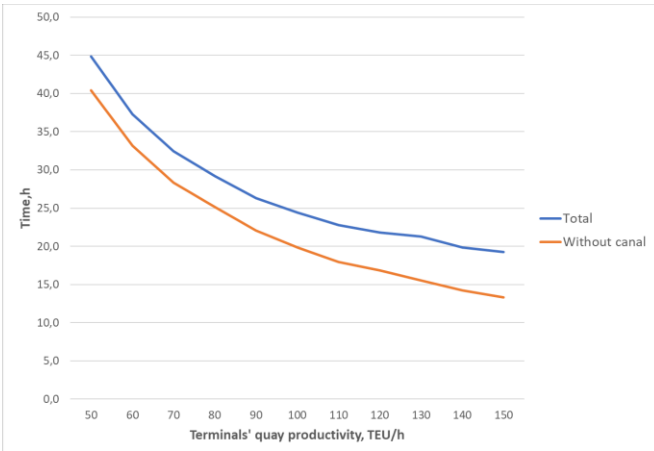

Fig. 13. Ship turnaround time for ports with and without a channel

In order to understand which channel schedule is more adequate for a certain port it is necessary to compare the result of simulation modeling with different channel timetables (Fig. 14).

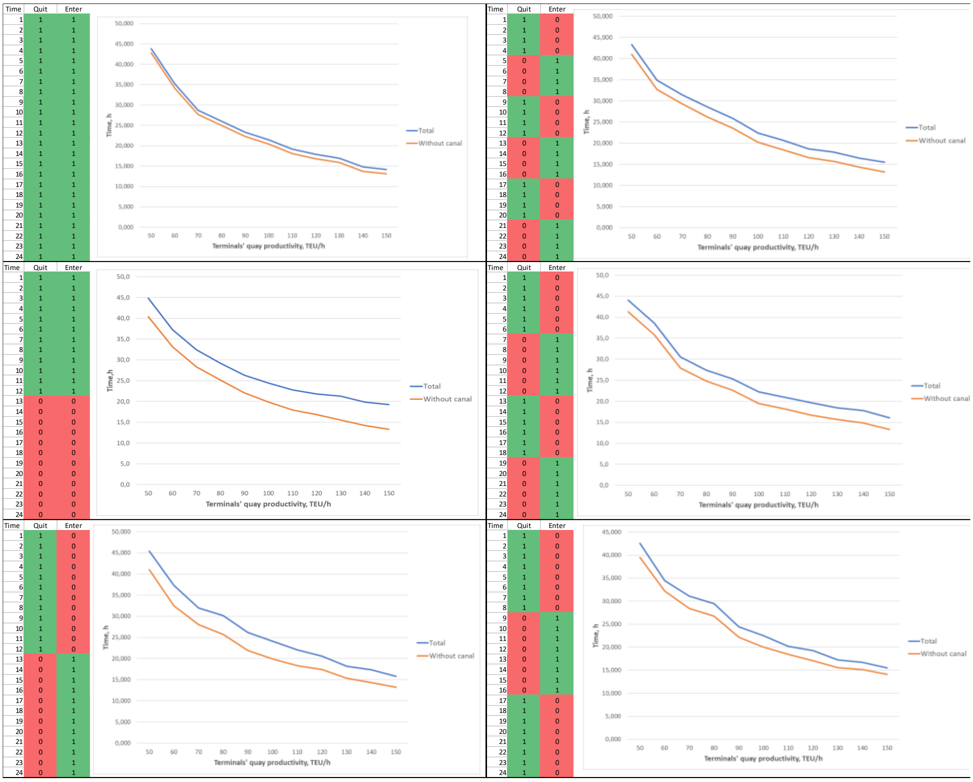

Fig. 14. Analysis of different channel timetables

The described models could be used not just to analyze the actual channel schedules but also to help a decision maker in his operational planning of channel operations. To do this the port authority has to obtain information about approaching ships, the ships being currently served in the port and the probability distribution of cargo handling time for different ships and cargos. In this case, a harbor master could forecast the time of ships' arriving and the time of their readiness to leave port and use that data to coordinate daily plans for ship entrances and exits.

5. CONCLUSIONS

1. The timetable of seaport approach channel which allows ships to enter and leave a port can dramatically influence ship turnaround time.
2. The operational features of approaching channels require ever-increasing complexity of the structure of relevant transport systems.
3. The approach offered in this paper enables production of a class of models which form a toolkit for the port and ship operators.
4. The adequacy of the models was proved by the serial experiments with the data collected from real port operation practice.

REFERENCES

Alderton, P., Saieva, G., 2013, *Port Management and Operations*, Taylor & Francis.

Allen, A.O., 2014, *Probability, Statistics, and Queueing Theory*, Academic Press.

Kuznetsov, A.L., Kirichenko, A.V., Shcherbakova-Slyusarenko, V.N., 2018, *Simulation in the Tasks of Sea Port Operational Analyses*, Vestnik Gosudarstvennogo Universiteta Morskogo i Rechnogo Flota imeni Admirala S.O. Makarova, Saint Petersburg, pp. 259–274.

Kuznetsov, A.L., Kirichenko, A.V., Zaikin, D.A., 2019, *Simulation of the Sea Cargo Front Operation*, Vestnik Gosudarstvennogo Universiteta Morskogo i Rechnogo Flota imeni Admirala S.O. Makarova, Saint Petersburg, pp. 33–42.

Popov, G.B., *Modelling of Marine Terminal Gate on the Side of Road Transport*, 2017, Vestnik Gosudarstvennogo Universiteta Morskogo i Rechnogo Flota imeni Admirala S.O. Makarova, Saint Petersburg, pp. 296–305.

Shahpanah, A., Hashemi, A., Nouredin, G., Zahraee, M., Helmi, S.A., 2014, *Reduction of Ship Waiting Time at Port Container Terminal Through Enhancement of the Tug/Pilot Machine Operation*, Jurnal Teknologi, 68.3.

Slack, B., Comtois, C., Wiegmans, B., Witte, P., 2018, *Ships Time in Port*, International Journal of Shipping and Transport Logistics, 10.1, pp. 45–62.

United Nations, 1985, *Port Development: A Handbook for Planners in Developing Countries*.

Internet sources

General Rules of Navigation and Mooring of Vessels in and on Approaches to Sea Ports of Russian Federation, 2020, https://www.pasp.ru/d/26909/d/general_rules.pdf.

UNCTAD, 2019, *Review of Maritime Transport* , United Nations publication. Sales No: E.19. II. D.20, New York and Geneva, https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf.