Introduction

Warehouse and transshipment infrastructure of seaports that does not meet the demand to process rising cargoes flows generates congestions at the hinterland. From the other hand, inefficient access from/to seaports can lead to transport congestions. V. Roso\textsuperscript{1} stresses that progress only in the maritime part of the transport chain and in seaport terminals, without improvements in seaport inland access is not sufficient for the entire transportation chain to function.

The main gateway of Russia (St. Petersburg seaport) locates at the North-West marine basin. Currently the total throughput of the seaport is around 50 Mt (million tons) with a 20 Mt of container cargoes. Seaport is considered will be able to maintain leading positions in future. However, there are impediments that restrict its further development. Among ecological impacts the geographical location of the seaport within the urban infrastructure has negative effect. For the latter reason, seaport cannot be extensively built at the site.

Almost all coast lands of the seaport are occupied. Moreover, the capacity of the maritime part of the seaport exceeds the capacity of inland access to the port by 20-30%.

According to the Strategy of seaport infrastructure development by 2030, the demand for transshipment of container cargoes at the North-West marine basin can reach 97.9 Mt in case of moderately-optimistic scenario (fig. 1). That

\textsuperscript{1} V. Roso: \textit{The dry port concept}: Thesis for the degree of doctor of philosophy. Chalmers University of Technology, Göteborg, Sweden 2009, p. 80.
is why it is planned to increase capacity of the terminals operating at the seaport: The First Container terminal by 4 Mt up to the year 2012, Petrolesport by 23.5 Mt (2013), and Forth Stevedoring Company by 10.5 Mt (2012).

Note: Figures are multiplied by thousand.

Fig. 1. Forecast of container cargos throughput in Russian marine basins

Source: Strategy of seaport infrastructure development by 2030.

The necessity to simultaneously develop transport system of the hinterland and seaport infrastructure construction is mentioned in the Strategy. Despite this fact the opponents of the Strategy, argue that construction of one road (West speed diameter) to the seaport is insufficient. By their estimation the bottleneck of the road (toll bridge) causes difficulties even now. And in future when thousands of lorries appear on the road it will be paralyzed. Thus, the problem of managing transport flows is becoming acute.

Transport flows managing

Currently there are a number of variants for solving transport congestions (technical tools, information technologies, mathematics methods, and simulation models for managing). The methods allow to find dependencies and analyze the processes in organizational and technical environment, for example, in transport system. The management of transport flows is an area where to make an experiment is hardly possible. In this situation the simulation modeling is be-

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Simulation of transport flows and their analysis

coming the sole instrument for empirical evidence and measured decisions\(^3\). The advantage of simulation in comparison with analytic solutions in transport flows management is numerous experiments with a system in finding a better solution.

At this article the problem of congestions on the road from/to seaports analyzed from the aspect of imperfection of queuing systems (toll bridge). Queuing system is a complex of channels, stations, tools (operators, sale counters, telecommunication lines and so on) that processes an entities coming to the system at random or determined moments\(^4\). The queuing system is set up if the following propositions are in place:

- Distribution function that characterize the inter-arrival time of entities to the system.
- The system comprise from queue block to store entities, and service block to process entities.
- The service time follows one of the distribution laws.
- The rules that control the amount of entities within a system.
- The queuing discipline that defines the order in which entities are serviced.

Simulation of queuing system was performed in AnyLogic program that was invented by Russian company XJ Technologies. The program has been occupied by more than 15,000 users in 60 countries\(^5\). The name for the program was given due to unique technic that enable to use system dynamic, discrete event and agent modeling simultaneously. In this paper a discrete event modeling is applied. This method is broadly used for simulating processes as a sequence of events upon the entities. Entities could be people, documents, lorries and the like. It is a method for modeling queuing system practically of any complexity. This type of modeling is related to the medium level of abstraction when the physical dimensions of objects, their speed, and distances are not important. But the time for processing entities, the delivery period from one point to another is considered. Depending on the type of the model AnyLogic allows to put a call to a probability distribution functions. For instance, into the Delay time parameter of a Delay or Service object. Each entity passing the object will get a new sample of the distribution.

On the ground of queuing theory in the circumstance of irregular traffic the questions of optimal amount of technical equipment were researched by Bezel


\(^4\) Y. Karpov: *Simulation of the systems. Introduction to AnyLogic* 5. 400 p., 2006.

\(^5\) Website of simulation software and services. XJ Technologies. Available at: [www.xjtek.ru/anylogic/](http://www.xjtek.ru/anylogic/)
B.S., Degtyarev G.N., Matunin I.E., Padnya V.A., Smehov A.A., Klyushin Y.F., Pavlov I.I., Yolkin A.V. The goal of queuing theory is to produce recommendations for efficient modeling of queuing systems, their rational work, and regulating of entities flows. The tasks related to this theory are to find relations between the work of the queuing system and its technology, character of the entities flow, the capacity and the queuing discipline. The analysis of the system allows to determine the performance measures like the average number of entities in the queue, or the system; the average time spent in the queue, or the system, the probability the queue is full, or empty. Random generator of entities leads to uneven loading of the system. At the entrance can be accumulated the queue of entities waiting the service (overloading of the system) or the amount of entities can be less than spare channels (underutilization of the system). The effectiveness of the system is estimated by the quantity of entities that are processed.

In the article the task is to model queuing system (tall bridge). The time of lorries arrival is described by different distribution laws. Lorries leave the seaport and directed to the entrance of West speed diameter (tall bridge). The distance between seaport and entrance to the road is 21 km. Speed of the lorry is 50 km per hour. The delay time for processing entity (lorry) is always distributed triangularly. The triangular distribution is often used for service times, travel times, or, in general, for the duration of operations in conditions of limited sample data. From observations is known that it takes a minimum of 2 minutes, most likely 3 minutes, and a maximum 4 minutes to process a lorry. The delay time associated with this operation in AnyLogic is modeled by function triangular (min, mode, max) with these parameters: triangular (2, 3, 4). The time of running model equals 1 month.

The Discrete Event model was compiled from the objects of Enterprise Library of AnyLogic program (fig. 2). The queuing model was built from five objects Source-Queue 1-Conveyer-Queue-Delay-Sink:

Source generates entities that are distributed in accordance with probability function.

Delay has triangularly distributed delay time.

Queue and Queue1 is used as storage of entities because objects of Conveyer and Source do not able to store entities.

Conveyer is used to transfer entities along the way with installed distance and speed of the lorry.

Sink deletes entities from the system.
Six experiments will be performed with a model. In each of them the flow of lorries (or probability distribution function) will be changed. The analysis of model is focused on estimation of the average time of lorry in the system and average number of served lorries.

In the first experiment the entities (lorries) are generated in accordance with Poisson distribution (or Poisson law of small numbers). It is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event. Thus, lorries leave the seaport at fixed intervals. The intensity is one lorry per ten minutes. Randomness is set in the object of Source in the Interarrival time box: 0.1/minute(). The results of running the model over model time of 1 month shows that maximum length of the queue at the toll bridge is 6 lorries. The mean time of lorry in the system reached 30.67 minutes. Total amount of served lorries equals 154.
The second experiment characterized by the flow of lorries that is described by Exponential function. The function indicates the time between events at a Poisson process, i.e. when events occur independently at a constant average rate. Exponential distribution is used as inter-arrival time of customers, parts, calls, orders or lorries like in this model process. Lorries leave a seaport at a certain global average rate. One lorry moves out the seaport on average every ten minutes. Source object of the Enterprise library calls to probability distribution function: exponential (0.1)* minute ()

After running the model the results were generated. The efficiency of the model is 166 lorries that were served over the model time of 1 month. The longest queue of lorries is 3, with an average time of entity in the system of 30.5 min.

In the third experiment the distribution function was changed to uniform distribution function. It is widely used in practice to generate a flow of entities that are evenly spread over a rectangular area. It is applied when known the minimum and the maximum values but there is a zero knowledge about how the values are distributed in between, i.e. you do not know if there are any values more frequent than others and assume a constant likelihood of a value being in any place between min and max. The Source object calls for uniform distribution law by AnyLogic function: uniform(10,12)* minute(). It means, that the maximum interval is 12 minutes and minimum of 10 minutes. The performing of this model allows to find stochastic measurements: the number of lorries that was processed in the system (128), with the mean time of 29.21 min. The queue was empty.

The fourth experiment was conducted with a lorries flow followed by triangular distribution function that was described previously in simulating the time of servicing the entity. Here, the Source object will generate entities by AnyLogic function: triangular(10,12,15)* minute() where 10 is minimum value, 15 maximum value and12 is most likely. The amount of lorries that passed through the system of 114, and mean time spent in the system of 29. 26 minutes. The queue in the system was not identified.

The experiment number 5 was with lorries flow that was distributed by normal law. Normal distribution function gives a good description of the data that tend to cluster around the mean. For example, the height of an adult male person, the observation error in an experiment, etc. By calling AnyLogic function normal(1,5)*minute(), lorries will leave the seaport over the time periods distributed in diapason 5–1 and 5+1 i.e. with period from 4 to 6 minutes. Thus, the expected value is 5 minutes, dispersion is 1 minute. The output of the model is as follows: total amount of lorries 283 with a queue length of 1 lorry, and mean time of 29.52 minutes.
In the sixth experiment, the input data was based on discrete uniform distribution of lorries’ flow. This distribution is used to model a finite number of outcomes that are equally probable, or when you have no knowledge about which outcomes are more likely to occur. Example, a person chooses a friend to communicate an idea. In this case minimum and maximum values are included in the set of possible results. So a call of uniform_discr(7,10) may return 7,8,9, or 10 minutes. After the simulation, were detected an average time of lorry in the system (29.3 minutes), and the total amount of lorries that were processed (168).

Conclusion

At present time the problem of traffic congestions is snowballing, especially for the marine cities. In Russia the most difficult situation on the roads is in Moscow and soon to be expected in St. Petersburg that is a main gateway from the sea. According to Strategy of seaport infrastructure development the throughput of the seaport will be dramatically increased. However, it is considered that the transport network at the hinterland will be developed not in coherence with enlargement of seaport infrastructure. The bottleneck of the road called West speed diameter could be the toll bridge.

In the article the queuing system (toll bridge) was performed in AnyLogic program. The analysis of the system, that was compiled from objects of Enterprise Library, allowed to determine the performance measures like the average number of entities (lorries) in the system; the average time spent in the system, the probability the queue is full, or empty. The experiments with a system have differed from each other by the flow of lorries that were generated in accordance with the six probability functions. The analysis of the system allows to find a better way for servicing lorries, and respectively increase the amount of lorries that can be processed in the system. On the ground of provided input data, the biggest number of lorries and minimum queue were fixed in the experiment when lorries flow followed by normal probability distribution function.

References

6. Website of simulation software and services. XJ Technologies. Available at: www.xjtek.ru/anylogic/