Simulation and optimization of the cargo terminal in the AnyLogic environment

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Abstract. The paper considers the formal theoretical bases of the analytical, simulation and optimization simulating of multi-channel queuing systems with waiting (with the unlimited and limited queue). The research is based on the use as an analytical platform of the simulation environment AnyLogic, which allows us to carry out simulation and optimization experiments, as well as perform parametric analysis of solutions and studies on sensitivity. Practical approbation of models is based on solving and researching a wide range of tasks on simulating queuing systems with an expectation from different subject areas. The basis of the methodology used for modeling and optimization is the provision of using as an optimization criterion (objective function) the total reduced costs in both service channels and queue losses. The research is aimed at reviewing and analyzing queuing systems with various event flows in the AnyLogic simulation environment.

1. Introduction
Queueing theory is used for complex systems analyzing [1-6]. It constitutes a powerful tool in modeling and performance analysis of many complex systems, such as computer networks, telecommunication systems, call centers, flexible manufacturing systems, and service systems. Recently, the queuing theory including queuing systems and networks arouses mathematicians, engineers and economics interests. A queueing system consists of inputs, queue, and servers as service centers. Generally, it consists of one or more servers for serving customers arriving in some manner and having some service requirements. The customers (the flow of entities) represent users, jobs, transactions or programs. They arrive at the service facility for service, waiting for service if there is a waiting room, and leave the system after being served. Sometimes customers are lost. The queuing systems are described by the distribution of inter-arrival times, distribution of service times, the number of servers, the service discipline, and the maximum capacity, etc. [7-10]. Besides, queuing theory and systems can be used to optimization manufactory, conveyer systems or terminals [11,12]. The monograph [1] gives a detailed review of simulation modeling (SM) systems as of late 1995; more than 20 years after its publication have passed and a great deal of new advanced structural and simulation modeling systems (SSMS) have appeared. The article [2] provides more than 10 promising SSMS with their application ratio [13]. Also, then we are talking about queuing systems, we need to
understand that factors inside the queueing system can be dependent. And for analysis such kind systems it needs to use different combined methods [9].

The main aim is to present a review of the most popular queueing systems. And introduce how to increase the quality of analyzing queueing systems using modern products [13]. In this paper, the use of queueing theory is presented in the context of a variety of real systems.

The paper is organized as follows. Section 2 briefly describes the queueing theory with a limited and unlimited queue. Section 3 describes the practical realization of the cargo terminal queueing system. It demonstrated a combination dynamic model with an imitational model. It helps include dependencies between internal features (factors) [11,12,14,15].

For developing queueing models can use the following programs: AnyLogic, Arena, Bizagi Modeler, Business Studio, Enterprise Dynamics, ExtendSim, Flexsim, GPSS W, Plant Simulation, Process Simulator, Rand Model Designer, Simio Simul8. The main idea of all of the systems is the opportunity of creating structural models. The comparison of SSMS was introduced in [13]. In this paper, AnyLogic was used for creating queueing systems. This paper demonstrates warehouse modeling. The demonstrated model can give information for analysis multiparametric complex system based on methods introduced in papers [14-26].

2. The Brief description of queueing systems

The queueing system (QS) can be represented in the form of two main subsystems: (i) - source of applications (SoA) for maintenance (requirements, tracks, information and material flows, etc.); (ii) - system of servicing (SoS) - execution of applications (technical facilities, points service, terminals, computing power, etc.).

However, the optimization of individual subsystems can have mutual contradictions. So the minimum expenses for applications are provided with large reserves capacity of service systems when the delays of applications in the queue and on service are minimized. But the creation of reserves of technical capacity means and systems of service is associated with high costs for their creation and maintenance. Minimization of costs for service systems occurs in the event of their most complete use, i.e. lack of free reserves, and this leads to an increase in time finding applications in the queue.

Therefore, global optimization is required for the whole (system-forming) QS. Therefore, in the interaction of the service system and the applications it serves, there should be a rational ratio of the intensity of the receipt of applications with the number of technical facilities and their throughput. It is expedient to determine the optimum value of these parameters by the criterion of the minimum of the aggregate reduced costs.

2.1. Queueing system with an unlimited queue

Figure 1 shows the state graph for a single-channel system, where for $S_0$, $S_1$, $S_2$,...,$S_k$,... the convenience of the state of the system are numbered according to the number of applications located in the QS.

![State graph for single-channel QS with unlimited queue.](image)

The system can be used in one of the following states: $S_0$ state shows that the channel is free; $S_1$ state shows that the channel is busy (it serves the application), no queue; $S_2$ state shows that the channel is busy, one application is in the queue; $S_k$ state shows that the channel is busy, the ($k-1$) applications are in the queue. For all arrows the stream of applications with intensity $\lambda$ moves the system from left to right, and $d$ from right to left is the flow of service with intensity $\mu$.

Let’s consider an $n$ channel (multi-channel) system with an unbounded queue. The flow of applications entering the QS has an intensity $\lambda$. The flow of services has $\mu$ intensity. Figure 2 shows the state graph of the system.
Figure 2. A graph of states for a multichannel QS with an unlimited queue.

The system can be used in one of the following states: $S_0$ state shows us there are no applications in the QS (all channels are free); $S_1$ state shows that one channel is busy, the rest are free; $S_2$ shows that two channels are occupied, the others are free; $S_k$ corresponds that $k$ channels are busy, the rest are free; $S_n$ shows that all channels are occupied (no queue); $S_{n+1}$ state shows that all of $n$ channels are occupied, one application is queued; $S_{n+r}$ state shows all of $n$ channels are occupied, $r$ of applications is in the queue.

We can say that with $\frac{p}{n} \geq 1$ the queue will grow to infinity, otherwise the following formulas will work [26,27].

3. Practical realization

The terminal plans to receive a new cargo flow with intensity $G$ (ton/day). It is assumed that one access will be used. That is, in this case, the problem of modeling a single-channel queueing system with an unlimited queue is being investigated [2]. If this is not enough, it will be necessary to use several entrances to the terminal. It is necessary to determine the optimal terminal capacity $CT$ (ton/day) by the criterion of the minimum aggregate (for vessels and terminal) of the given (per ton of turnover) costs.

The employment of the terminal is determined by its load factor $\rho$, then the terminal costs can be found as follows:

$$ f_T = kpZ^p_T(CT) + (1 - kp)Z^\text{wait}_T(CT), $$

where $k$ is the technological coefficient of the terminal; $Z^p_T$, $Z^\text{wait}_T$ are costs for the terminal during operation and idle time per day, respectively; $CT$ is the terminal capacity.

Transportation costs can be found as follows:

$$ f_s = \lambda(t_{\text{goods}} + t_{\text{wait}} + t_T)Z_s = \lambda(t_{\text{goods}} + t_{\text{wait}} + k_T t_{\text{goods}})Z_s, $$

where $t_{\text{goods}}$, $t_{\text{wait}}$, $t_T$ are the duration of cargo operations, their expectations and technical operations respectively; $Z_s$ is the cost of transport per day; $k_T$ is the technological coefficient.

Then the optimization problem will be formulated as follows:

$$ f = \frac{(1 + \gamma(\rho) + k_T)Z_s + kZ^p_T(CT) + (1/\rho - k)Z^\text{wait}_T(CT)}{CT} \rightarrow \min; \rho \cdot CT = G $$

Increasing the capacity of the terminal will lead to an increase in expenses on the terminal and, accordingly, a decrease in the transport component of expenses.

This task was solved in AnyLogic using dynamic programming with following start parameters: $\lambda = 1$, $CT=5500$, $G = 4500$, $k_T = 0.12$, $k = 0.87$, $\rho = 0.82$ In accordance with the initial data presented in the figure, the cumulative reported costs are 1.723 (conventional units/ton).

Having carried out the optimization experiment, we obtain a solution following $\rho = 0.398$ the minimum value of the objective function is $f^* = 0.672$ (conventional units/ton). The results were created after solving the optimization task, introduced in Table 1.

| Name         | CT   | $p_0$ | $L_q$ | $L_s$ | $f_s$ | $f_t$ | $f$   |
|--------------|------|-------|-------|-------|-------|-------|-------|
| Inputs       | 4520 | 0.12  | 4.1   | 3.2   | 6500  | 1410  | 1.4   |
| Optimization | 9500 | 0.62  | 0.34  | 0.79  | 2510  | 4050  | 0.698 |

The results of the working terminal introduced in Figure 3. We have made a research with the models created in AnyLogic [12].
Figure 3. A visual model of terminal in AnyLogic.

In Figure 4 was created a statistical model of the terminal in AnyLogic. And Figure 5 shows a logic model of the terminal in AnyLogic.

![Figure 4. Statistical model of terminal in AnyLogic.](image)

4. Practical realization

The AnyLogic program also allows optimizing models. This paper discusses the optimization of the main parameters: the number of automated trucks, the number of places for unloading/loading, the number of arriving machines per hour for unloading/loading. To optimize the parameter “the number of automated carts”, 1 discrete and 4 fixed parameters are set, represented in Table 2.

| Parameter                        | Type   | Value |
|----------------------------------|--------|-------|
| The number of places for unloading | fixed  | 5     | 4.1  |
| Number of places for loading     | fixed  | 3     |
| Number of cars per hour per load | fixed  | 10    |
| The number of machines per hour for unloading | fixed  | 7     |
| Number of automated carts        | discrete| 1     | 30   | 1    |
Figure 5. A logic model of terminal in AnyLogic.

The best value of automated trolleys will be 28. To optimize the parameter “the number of places for unloading/loading”, 2 discrete and 3 fixed parameters are set, which are shown in Table 3.

As a result of optimization, the best value of the parameters for unloading will be 4, for loading - 1.

To optimize the parameter “the number of arriving machines per hour for loading/unloading”, 2 discrete and 3 fixed parameters are set, represented in Table 4.

### Table 3. Parameters for "number of machines per loading / loading".

| Parameter                                | Type   | Min | Max | Step |
|------------------------------------------|--------|-----|-----|------|
| The number of places for unloading       | discrete | 1   | 5   | 1    |
| Number of places for loading             | discrete | 1   | 5   | 1    |
| Number of cars per hour per load         | fixed  | 10  |     |      |
| The number of machines per hour for unloading | fixed  | 7   |     |      |
| Number of automated carts                | fixed  | 15  |     |      |

### Table 4. Parameters for "number of machines per loading / loading".

| Parameter                                | Type   | Min | Max | Step |
|------------------------------------------|--------|-----|-----|------|
| The number of places for unloading       | fixed  | 3   |     |      |
| Number of places for loading             | fixed  | 2   |     |      |
| Number of cars per hour per load         | fixed  | 7   | 15  | 1    |
| The number of machines per hour for unloading | discrete | 7   | 15  | 1    |
| Number of automated carts                | fixed  | 15  |     |      |

The best value of the parameters for unloading is 4, for loading is 1.
5. Conclusions
The presented work combines a set of minimally necessary (and sufficient) theoretical material and practical approbations for the study of multi-channel queuing systems with the expectation of the AnyLogic simulation package in the environment. Practical implementation covers a wide range of examples, demonstrating the development of optimization projects in the modeling environment and the relevant assessments of the functioning of the QS, as well as their optimization parameters. The carried out research is brought to practical implementations in the form of a set of formal knowledge and their applications in various subject and problem areas.

Practical approbation of models is based on solving and researching a wide range of tasks on modeling queuing systems with the expectation from different subject areas. The basis of the methodology used for modeling and optimization is the provision of using as an optimization criterion (objective function) the total reduced costs in both service channels and queue losses. The research is aimed at reviewing and analyzing queuing systems with various event flows in the AnyLogic simulation environment. Also, modeling tools can be used to create adaptive samples for learning neural networks. Also, an urgent task is the combination of modeling tools and artificial intelligence methods. Besides, the directions of modeling complex systems presented in the works [27-34] are considered as promising. And in the following research works, we will try to combine artificial intelligence methods and simulation of discreet systems for preparing the best parameters for the simulation model.

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