

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 modelling of multi-channel queuing systems with waiting (with unlimited and limited queue). The research is based on the use as an analytical platform of the simulation environment AnyLogic, which allows 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 modelling queuing systems with expectation from different subject areas. The basis of the methodology used for modelling 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 analysing 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 modelling and performance analysis of many complex systems, such as computer networks, telecommunication systems, call centres, flexible manufacturing systems and service systems. Recently, the queueing theory including queueing systems and networks arouses mathematicians, engineers and economics interests. A queueing system consists of inputs, queue and servers as service centres. 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 queueing systems are described by distribution of inter-arrival times, distribution of service times, the number of servers, the service discipline and the maximum capacity etc. [7-10]. Besides, queueing theory and systems can be used to optimization manufactory, conveyer systems or terminals [11,12]. The monograph [1] gives a detailed review of 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 queueing systems, we clearly need to understand that factors inside queueing system can be dependent. And for analysis such kind systems it need to use different combined methods [9].

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

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

For developing queueing models can used the following programs: AnyLogic, Arena, Bizagi Modeler, Business Studio, Enterprise Dynamics, ExtendSim, Flexsim, GPSS W, Plant Simulation, Proccess Simulator, Rand Model Designer, Simio Simul8. The main idea all of the systems is 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 demonstrate warehouse modeling. The demonstrated model can give information for analysis multiparametric complex system based on methods introduced in papers [14-25].

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 from the point of view of 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 $S_0, S_1, S_2, \dots, S_k, \dots$ the convenience of the state of the system are numbered according to the number of applications located in the QS.

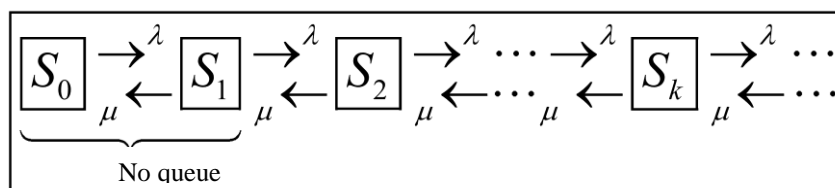


Figure 1. State graph for single-channel QS with unlimited queue.

The system can be in one of the following states: S_0 - the channel is free; S_1 - the channel is busy (it serves the application), no queue; S_2 - the channel is busy, one application is in the queue; ... S_k - the channel is busy, the $(k - 1)$ applications are in the queue; ...

For all arrows the stream of applications with intensity λ moves the system from left to right, and d from right to left is the flow of service with intensity μ .

Let's consider an n - channel (multi-channel) system with an unbounded queue. The flow of applications entering the QS has an intensity λ . The flow of services has μ intensity. Figure 2 shows the state graph of the system

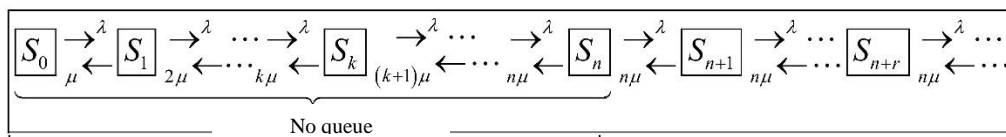


Figure 2. A graph of states for a multichannel QS with an unlimited queue.

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

We can say that with $\frac{\rho}{n} \geq 1$ the queue will grow to infinity, otherwise the following formulas will work:

1. The probability that the system is in a state S_0 :

$$p_0 = \left(\sum_{i=0}^n \frac{\rho^i}{i!} + \frac{\rho^{n+1}}{n!(n-\rho)} \right)^{-1};$$

2. The probability that the application will be in the queue:

$$P_q = \frac{\rho^{n+1}}{n!(n-\rho)} p_0;$$

3. Average number of requests in the queue (queue length):

$$L_q = \frac{\rho^{n+1} p_0}{n \cdot n! \left(1 - \frac{\rho}{n}\right)^2};$$

4. Average number of applications in the system:

$$L_s = L_q + \rho;$$

5. The average time for the application to stay in the queue:

$$T_q = \frac{L_q}{\lambda}$$

6. Average time of application stay in the system:

$$T_s = \frac{L_s}{\lambda};$$

7. The ratio of waiting time in the queue to the service time:

$$\gamma = \frac{L_q}{L_s - L_q};$$

8. Relative throughput. Probability that an application will be served:

$$Q = 1;$$

9. Absolute system capacity. the average number of applications serviced per unit time:

$$A = \lambda Q = \lambda;$$

10. Average number of channels occupied:

$$\bar{k} = \frac{\lambda}{\mu} = \rho.$$

2.2. Queueing system with an limited queue

If there is a limit on the queue (its length can not exceed the number m), then if the application arrives at the point in time when all channels are busy. It leaves the queue. Figure 3 shows a graph of the states of a single-channel QS with a limited queue. Each arrow has corresponding intensity of event streams. And on the right-to-left arrows the system translates the service flow whose intensity is μ multiplied by the number of occupied channels.

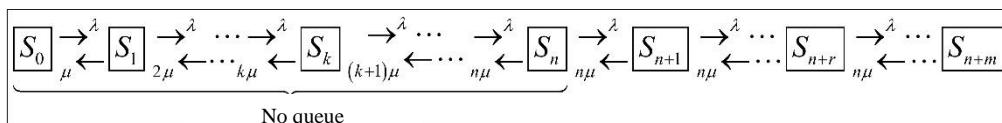


Figure 3. A graph of states with a limited queue length.

Here are the formulas for a queuing system with a limited queue length:

1. The probability that the system is in a state:

$$p_0 = \left(\sum_{i=0}^n \frac{\rho^i}{i!} + \frac{\rho^{n+1} \left(1 - \left(\frac{\rho}{n} \right)^m \right)}{n \cdot n! \left(1 - \frac{\rho}{n} \right)} \right)^{-1};$$

2. Average number of requests in the queue:

$$L_q = \frac{\rho^{n+1} p_0 \left(1 - \left(m + 1 - m \frac{\rho}{n} \right) \left(\frac{\rho}{n} \right)^m \right)}{n \cdot n! \left(1 - \frac{\rho}{n} \right)^2};$$

3. Average number of occupied channels:

$$\bar{k} = \rho \left(1 - \frac{\rho^{n+m}}{n^m \cdot n!} p_0 \right);$$

4. Average number of applications in the system:

$$L_s = L_q + \bar{k};$$

5. Relative throughput:

$$Q = 1 - \frac{\rho^{n+m}}{n^m n!} p_0;$$

6. Absolute system capacity:

$$A = \lambda Q.$$

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 queuing 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.

Obviously, the employment of the terminal is determined by its load factor ρ , then the terminal costs can be found as follows:

$$f_T = k\rho Z_T^p(CT) + (1 - k\rho)Z_T^{wait}(CT),$$

where k is the technological coefficient of the terminal; Z_T^p, Z_T^{wait} 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:

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

where t_{goods}, t_{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:

$$f = \frac{(1 + \gamma(\rho) + k_T)Z_s + kZ_T^p(CT) + (1/\rho - k)Z_T^{wait}(CT)}{CT} \rightarrow \min: \rho \cdot CT = G$$

Obviously, increasing the capacity of the terminal will lead to increase of expenses on the terminal and, accordingly, decrease of 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 in accordance with $\rho = 0.398$ the minimum value of the objective function is $f^* = 0.672$ (conventional units/ton). After solving optimization task was created results, introduced in the Table 1.

Table 1. The characteristics of the current and optimal solutions.

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 working terminal introduced in Figure 4. We have made research with the models created in Anylogic [12].

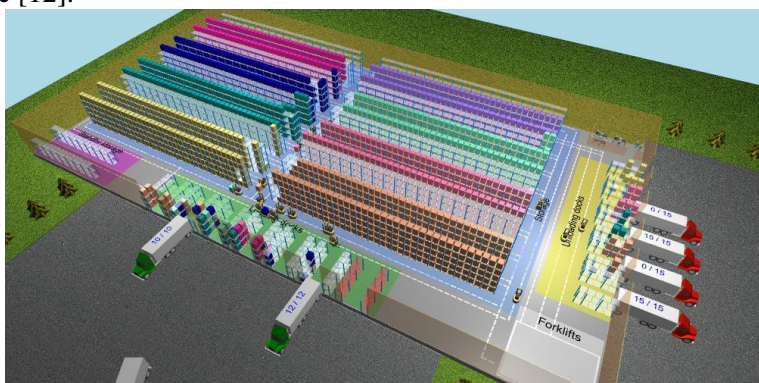


Figure 4. A visual model of terminal in Anylogic.

In Figure 5 was created a statistics model of terminal in Anylogic. And Figure 6 shows a logic model of terminal in Anylogic.

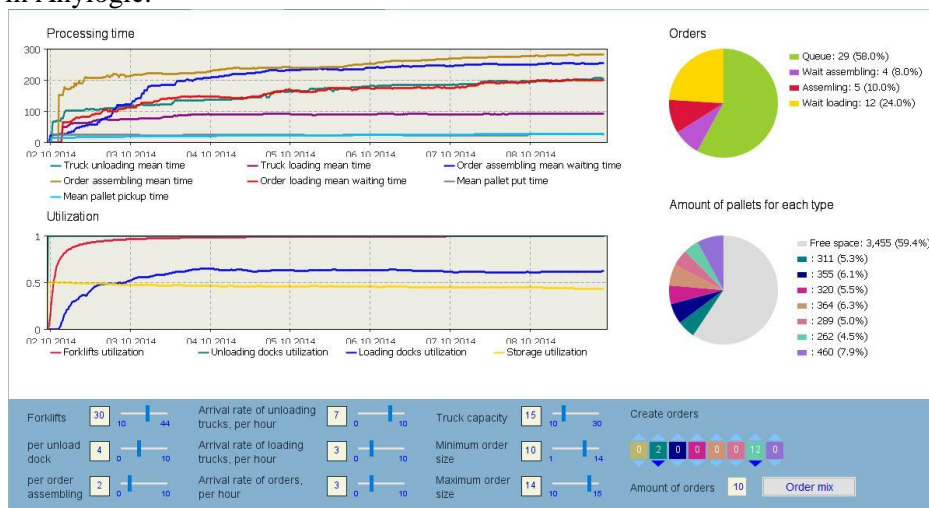


Figure 5. Statistics model of terminal in Anylogic.

4. 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 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 expectation from different subject areas. The basis of the methodology used for

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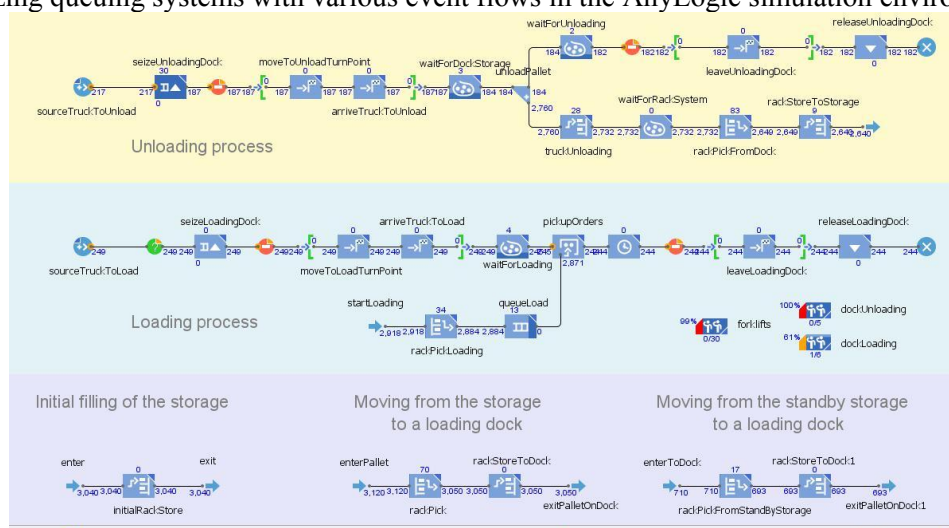


Figure 6. A logic model of terminal in Anylogic.

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