Discrete event simulation modelling of patient service management with Arena

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Abstract. This paper describes the simulation modeling methodology aimed to aid in solving the practical problems of the research and analysing the complex systems. The paper gives the review of a simulation platform sand example of simulation model development with Arena 15.0 (Rockwell Automation). The provided example of the simulation model for the patient service management helps to evaluate the workload of the clinic doctors, determine the number of the general practitioners, surgeons, traumatologists and other specialized doctors required for the patient service and develop recommendations to ensure timely delivery of medical care and improve the efficiency of the clinic operation.

1. Introduction

A discrete event simulation methodology appeared in the 60s of the twentieth century owing to the research of C. Shannon, a well-known American scientist. Since then, a great number of computer hardware tools have been developed: powerful processors whose data-processing capacity allows solving the most complex scientific problems; graphical user interface facilities (GUI), WIMP, DWIM. A fundamentally new methodology, named agent-based modeling, was developed in the 1990s. This methodology allows describing the rules and logic of the complicated system using the algorithms of the independent agents’ behaviour. New software tools for creating the simulation models also appeared. The most popular platforms for simulation modeling are AnyLogic, Arena, Simio, NetLogo, Repast, FlexSim, etc. Let us take a brief look at the peculiarities of the leading simulation software: AnyLogic, Arena, and Simio.

AnyLogic, developed by the AnyLogic Russian Company, has been the leading simulation software since 2017. This JAVA based simulation tool supports three leading methodologies of simulation modeling: discrete-event, dynamic, and agent-based modeling. The Java compiler, integrated in the AnyLogic environment, provides powerful capabilities for modeling, and also allows creating Java applets that can be launched from any browser. Using these applets, the AnyLogic models can be easily placed on websites. In addition to Java applets, AnyLogic Professional supports creation of Java applications which allow a user to run the model without AnyLogic installation.

Arena is a discrete event simulation and automation software developed by Systems Modeling in 1993, and then acquired by Rockwell Automation. For 30 years, Arena has been the world's leading discrete event simulation software. The program popularity can be explained by the rich functional, object-oriented interface, and facility to adapt to different application domains. When building a model, a sequence of blocks is created first, using the pre-defined library of objects (this
sequence presents a logic of system behaviour), then numerical characteristics are set for each block and probable patterns are described, thus allowing the generation of random events and numbers. After that, the animation is set up for entities, resources, conveyers, and environment elements. Once the model is debugged, the simulation experiment of any duration is carried out. The report created as a result of this experiment, contains all numerical parameters of the model with the elements of statistical analysis. For example, the system calculates minimum, maximum and average value for each parameter, builds charts, and diagrams. It is worth mentioning that the Arena environment provides new features, such as development of models without programming and facility to use the 3D objects library.

Simio is the youngest of the leading systems for simulation modeling. It was developed in 2007 by the Simio LLC. The founder of the company is Dennis Pegden who led the creation of SLAM and SIMAN modeling languages and also participated in creation of Arena, therefore many principles of model building in Arena and Simio are similar. Simulation modeling with Simi can be used to analyse the system behaviour over time and without programming. The program provides tools for designing, analysing and predicting the behaviour of complex systems. The Simio models are based on the intelligent objects that are available in the built-in libraries or taken from other prepared models. Simio provides built-in tools for 3D animation, enabling a user to choose a 2D or 3D model. The environment supports discrete as well as continuous objects. An important benefit of this system is the facility to analyse and estimate the risks when taking important management decisions for the business.

The latest trends in the simulation modeling development are visualization of the models using the 3D graphical environment; creation of 3D objects libraries; models integration with GIS-services; carrying out the simulation experiments with the use of cloud services and browsers. It should be mentioned that, despite of the rapid development of information technologies and creation of modern simulation modeling platforms and languages, the simulation IT-projects share in industry, economy and education is relatively low in comparison to others. On the one hand, it is related to the fact that the owners of the large enterprises and companies are not well informed of the simulation projects facilities and profits. On the other hand, there are no federal standards for the industrial enterprises, that is, the simulation experiments are not mandatory. The objective of this study is to introduce the young IT-specialists to functions and usage of simulation modeling for solving a wide range of tasks, such as analysis and design of complex system, business process studies, economic risk estimation, and forecasting the objects development dynamic.

2. Materials and methods
This study employs the following research methods: structure-functional analysis, mathematical modeling and simulation modeling, analysis of logic and characteristics of the complex economic systems, observation, computer-based experiment, elements of statistic analysis of numeric results obtained in the course of the simulation experiment.

Problem definition. The patients visiting a clinic have the problems of n types. The probability of arrival of patients with the problem of each type is known: $p_1, p_2, ..., p_d$. The time periods ($T_2$) between two patients are distributed exponentially. Each patient requires a certain medical treatment ($a_1, a_2, \ldots, a_k$) with the $p_{a1}, p_{a2}, \ldots, p_{ak}$ probability respectively. First, the patients come to the reception desk where the receptionists identify the patient problem, search for a medical treatment card, fill out the required documents, print an appointment slip and send the patient to a certain doctor. The clinic resources are the $d_1, d_2, d_3 \ldots$ doctors who service the patients of each type. There are 8 general practitioners(GP) in the clinic who service the patients of the first type. If general practitioners ($d_1$) are occupied, the patients of the first type will wait till they are free. If the specialized doctors ($d_2, d_3, d_4$) are occupied, the patients of these types will wait till they are free. If a specialist falls sick, the patients will get a refusal. The time required to service a patient of $n$ type is defined in Table 1. The patient service requests are received and distributed among the specialists by the receptionists ($s (3)$).
Source data. The incoming flow of patients is exponentially-distributed in time and has irregular intensity. The two thirds of patients visit the clinic before noon, at that, one third of them come during the first working hour. The time of a single request processing is subject to a normal law ($T_p \sim \text{norm}(3,1)$). The average number of patients for a single day is 450.

Table 1. The probabilities of the patients' arrival, service time and number of the clinic specialists

| Probability of arrival of patient of a certain type | $T_{11}$ | $T_{12}$ | $T_{13}$ | $p_{11}$ | $p_{12}$ | $p_{13}$ |
|-----------------------------------------------------|----------|----------|----------|----------|----------|----------|
| $p_1$                                                | 0.45     | 0.25     | 0.2      | 0.1      | 3        | 9        |
| $p_2$                                                |          |          |          |          | 9        | 15       |
| $p_3$                                                |          |          |          |          | 15       | 0.25     |
| $p_4$                                                |          |          |          |          | 0.25     | 0.45     |
| Number of doctors of each type                        | $T_{31}$ | $T_{32}$ | $T_{33}$ | $p_{31}$ | $p_{32}$ | $p_{33}$ |
| $d_1$                                                | 7        | 15       | 23       | 0.35     | 0.4      | 0.25     |
| $d_2$                                                |          |          |          |          |          |          |
| $d_3$                                                |          |          |          |          |          |          |
| $d_4$                                                | 11       | 18       | 25       | 0.7      | 0.15     | 0.15     |

The objective of this study is to improve the efficiency of patient service management in the clinic.

The aims of this study are to develop a simulation model of patient service management in the clinic; analyse the reasons of refusals to service the patients of each type and probability of refusals in every group; determine dependency between the working hours of doctors and probabilities of refusals; make a conclusion about the workload in each group of specialists and determine the measures required to improve the patient satisfaction.

Formalized description of model. The clinic is a multiphase, multi-channel queuing system of the open type (with refusals).

Figure 1. Clinic as a queuing system.

Based on the clinic structure, a model must consist of the following blocks: source of transactors; patient service processes; transactor terminator.

The main resources of the clinic: receptionists, general practitioners, and specialized doctors.

Transactors are the patients visiting the clinic.

The patients have the following attributes: type of the service request; type of the medical care; time required to service a patient. The time periods between the requests arrival are distributed exponentially. The type of the patient service request is identified by numbers 1, 2, 3, 4 (as n=4). The type of the medical care is identified by numbers 1…3 accordingly. The following source data are used: $p_1$… $p_4$ - probabilities of the service requests of 1…4 types accordingly; $p_{11}$… $p_{43}$ - probabilities of the service requests of 1…4 types with 1…3 types of medical care accordingly.

The following results obtained in the course of the simulation experiment show the following:

- number of the incoming patients of all types and the total number of patients
- total number of the serviced patients and number of the serviced patients of each type
cost relationship between the employment rate and clinic down time
occupancy rate for each type of the resources.

The discrete event simulation model of patient service management was created using the Arena simulation environment (version 15.0) developed by the Rockwell Automation company. This simulation modeling software provides all functions required to fulfill the task: user-friendly interface for the model development, animation facilities, and tools to generate the detailed statistical reports. Figure 2 shows the logic of the model created with Arena.

Figure 2. The simulation model of patient service management.

In order to obtain the reliable results, about 1000 simulation experiments were carried out. The clinic is an important social object dealing with the medical care delivery and responsible for preserving and improving the people’s health, therefore the first criterion of this study is the service refusals (fig. 3).

Figure 3. The probability of service refusals

Figure 4 shows the probability of service refusals in every group of patients. The maximum number of refusals has Doctor 2 (see Figure 4: Patient 2 - 42%). This refers to a large flow of patients who require to visit this specialist. Despite the high degree employment (100%), Doctor 2 is not able to see all patients during the working hours. So it is required to change the doctor working schedule or hire an additional specialist. Doctor 1 (see Figure 4: Patient 1 - 29%) also has a large number of service refusals, almost one third of patients get a refusal on the day of their first visit.
3. Study results and their discussion

The simulation model allows tracing the dynamics of the clinic patients flow. The results of the experiment show that the percent of service refusals is 34%, and the percent of serviced patients is 66%. These parameters describe the normal operation of the clinic. During the peak seasons, such as a Flu pandemic, the number of patients increases by several times and the number of service refusals grows accordingly. Using the network services for the patient appointments significantly decreases the problem of timely delivery of medical care, but does not solve it. A great number of patients, especially older patients, prefer face-to-face visit rather than appointment via Internet. The patient service management is not satisfactory, it is necessary to reduce the number of service refusals. The patients must be provided with the required medical care on the day of their first visit or at least during the next workweek. The number of patients visited the clinic during a month (20 working days) is shown in Figure 6, where Entity Patient is the total number of patients visited the clinic, Patient 1 - patients requiring to see a general practitioner (45%); Patient 2 - the surgeon patients (25%); Patient 3 and Patient 4 – the patients of other specialized doctors (20% and 10% accordingly).
Let us analyse the time required to provide medical services to a patient: total time in the system (Total time), time in the waiting area (Waiting time) and time spent with a doctor (VA time) – see Table 2. The average time spent in a queue ranges from 82.7% to 90%, whereas the time spent visiting a doctor ranges from 7.3% to 10% accordingly.

Table 2. Time spent in the clinic for all types of patients

| Patient type | Average | Maximum | Average | Maximum | Average | Maximum |
|--------------|---------|---------|---------|---------|---------|---------|
| Patient 1    | 72.5    | 212     | 59.9    | 195     | 12.6    | 23.6    |
| Patient 2    | 39.1    | 174     | 34.4    | 161     | 4.7     | 21      |
| Patient 3    | 31.1    | 179     | 27.9    | 76.3    | 6.2     | 18.4    |
| Patient 4    | 37.7    | 116     | 32.1    | 99      | 5.5     | 23.75   |

Figure 7 shows the employment rate of general practitioners, specialized doctors and receptionists. The coefficient of the general practitioners employment is very high, especially for the doctors working during the first working hours; it can be 1 or 100%. For the doctors working during the second part of the day, the coefficient is about 0.82-0.99. The relatively low coefficient of the specialized doctors’ employment (Doctor 3 - 0.83 and Doctor 4 – 0.41) can be explained by the irregular and low-level flow of patients of this type. If 8 general practitioners work regularly, the system production depends on the intensity of the incoming flow of patients and availability of doctors in the clinic.
4. Conclusion
The results obtained show that the average number of patients visiting the clinic is 450 per day. The coefficient of the receptionists’ employment is high during the first part of the day (1), whereas during the second part of the day this coefficient decreases to 0.77 due to the irregular arrival of patients. The simulation model helps to determine the optimal number of the general practitioners, surgeons, traumatologists, and specialized doctors. Having described the work schedule of the doctors, probabilities of arrival of the certain patients, time required to deliver essential medical care, it is possible to forecast the clinic work load both in a usual mode and in the event of epidemic and also provide recommendations on how to improve the patient flow management.

The main recommendation is to monitor the patients’ service quality on a day-to-day basis: number of patients visited the clinic, amount of refusals, length of queues, and patients’ satisfaction by medical care quality. If 20-40% of general practitioners are absent (on leave or fallen ill), other doctors see their patients, therefore it is required to increase their working time. If the majority of the doctors are on vacation, the problem can be solved by inviting specialists from other clinics. Following these recommendations will improve the delivery of health services, decrease the waiting time by 63% and significantly decrease the number of refusals. Moreover these measures will increase the quality of medical care and help to solve the problems that healthcare organizations face.

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