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Simulation Modeling As a Tool of Decision Support During Reorganization of the Diagnostic Department of a Multidisciplinary Hospital

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ABSTRACT Steadily growing flow of patients and a constant increase in the requirements for the quality of medical care more and more often lead to the need to reorganize the work of various departments of medical hospitals. However, such actions are very costly and do not always give the desired result. One of the effective methods of preliminary planning, as well as predicting the results of proposed transformations, is the method of simulation modeling of medical and diagnostic processes based on a specially created model. In this article we describe the original data on the operation of the admission and diagnostics department (ADD) of N.V. Sklifosovsky Institute, which served as one of the grounds for its reorganization, as well as the creation of a simulation model of ADD, reconstructed on the principles of a patient-oriented approach. We considered all stages of the model construction in detail and thereby justified its structure and the qualitative and quantitative parameters which formed the basis therein. The temporal and numerical results of modeling the flow of patients through the ADD, as well as the flow of changes in the parameters of the model to the throughput of the ADD are presented. Thus, specific examples show how problem areas of the existing diagnostic and treatment process can be identified, and what options are available for its optimization and modernization. In addition, suggestions are made for further improvement of the created model and options for its use, for example, for the study of various contingencies and emergencies, mass revenues, etc.

Keywords: information technologies in medicine, simulation modeling, organization of medicine, multidisciplinary hospital, diagnostic department

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АРМ — автоматизированное рабочее место
ИМ — имитационная модель
КТ — компьютерная томография
ПДО — приемно-диагностическое отделение
УЗИ — ультразвуковое исследование
ЭКГ — электрокардиография

STATEMENT OF THE PROBLEM

Significant changes taking place in the social, economic and demographic structure of developed countries affect, among other things, the situation in the medical care of the population. The load on medical institutions and, first of all, on emergency and urgent care services is constantly growing; the amount of health encounter per year in some European countries exceeds 20% of the total population [1]. This leads to the fact that emergency medical care in hospitals is rapidly developing and acquiring increasing importance not only from a professional medical point of view, but also from the point of view of economic policy.

The same situation is observed in the Russian Federation, especially in megalopolises and large cities. According to statistics collected at the N.V. N.V. Sklifosovsky Research Institute for Emergency Medicine, the number of visits to the reception and diagnostic departments over the past 10 years has increased by more than 1.5 times (by 54%) - from 51 600 in 2009 (141 people per day) to 79 500 in 2018 (218 people per day), and the number of hospitalizations increased almost 2 times (by 96%) - from 22 600 to 46 300 [2].

Under the current conditions of modernization in order to increase the efficiency of domestic health care, the management of medical institutions has to make decisions on the reorganization of departments to maintain high quality and efficiency of work. To support decision-making on changes in the structure of the department and its resource equipment, simulation methods are successfully used. For example, similar methods were used to analyze the development of the inpatient department of the I.I. Dzhanelidze St. Petersburg Research Institute of Emergency Medicine [3]. In connection with the above, in 2016–2017 a simulation model of the existing at that time the central admission and diagnostic department (ADD) of the Institute in the AnyLogic tool environment, which schematic diagram is shown in Fig. 1.

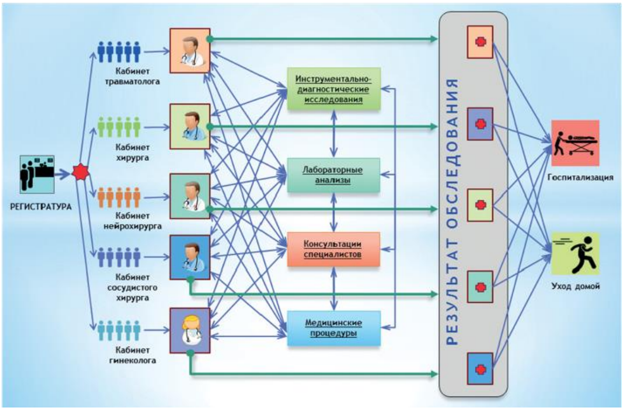

Fig. 1. The basic block diagram of the main patient flows distribution in the ADD of N.V. Sklifosovsky Research Institute in 2017 for building a simulation model

The experiments carried out to model the temporal parameters of the passage of the patient flow, described in the article [4], took into account the unevenness of the patient flow during the day. The obtained simulation results indicated that with a given number of admitted 200–210 people/day, the length of the queues and the time spent in the ADD sharply increase, which ultimately leads to the collapse of its functioning during peak loads. At the same time, no local changes in the existing structure (an increase in the number of doctors in the most demanded specialties or the most busy diagnostic services) did not allow obtaining fundamentally better results.

Using the linear extrapolation method, it was calculated that this level of intake during peak loads can be achieved in the near future. In this regard, it was suggested that it is necessary to restructure the admission department and organize its work on qualitatively different principles of service. The reform was based on a patient-oriented model designed to significantly improve the comfort of patients in the admission department and optimize its logistics. A schematic diagram of reconstructed and reorganized admission department is shown in Fig. 2.

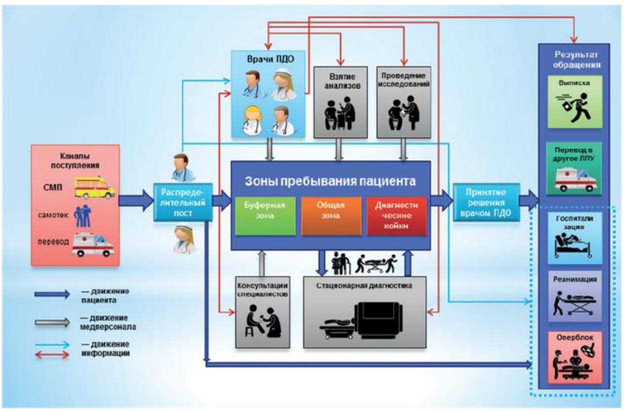

Fig. 2. The basic block diagram of the logistics of patients, medical staff and information flows in a patient-oriented ADD model

With such an organization of the ADD work, after the patient is admitted, registered and placed in a diagnostic bed, all further studies, consultations and procedures are carried out directly on the spot, and only stationary studies are carried out when the patient moves accompanied by medical staff. The patient-centered approach made it possible to shorten the time it takes for patients to pass through the admission department and to reduce the amount of time and resources.

In order to further optimize and increase the efficiency of the Institute's ADD activities in the described framework, we created an agent-based simulation model of reorganized central ADD, which took into account most of the processes that regularly occur in the admission department.

BASE POINTS AND METHODS OF STUDY

As in previous studies [4], when constructing the model, the standard library for modeling the processes of the AnyLogic PLE 8.0.4 software was used as one of the convenient and advanced simulation tools available for scientific and educational purposes.

The main starting points used in building the model were as follows:

- the flow of patients was considered as a Poisson flow [5];

- planned admissions and admissions of patients requiring emergency medical intervention and transported by the ambulance team directly to the emergency intensive care unit or operating unit were not simulated, since these admissions do not significantly load the work of the central ADD;

- seven main medical profiles of ADD were selected for simulation: surgical, traumatological, neurosurgical, angiosurgical, gynecological, neurological and therapeutic;

- simulation was performed for the most densely loaded day of the week - Monday, taking into account the daily irregularity of patient admission (Fig. 3).

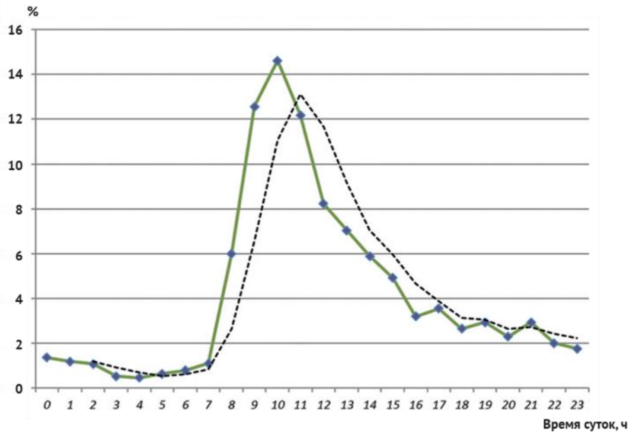

Fig. 3. The intensity of patient admission during the day with approximation

One of the useful properties of the Anylogic tool environment is the ability to work with room layouts, where processes take place based on real plans of buildings included in the program in one of the generally accepted graphic formats (jpeg, png, gif, bmp, etc.). Fig. 4 shows an animation diagram of a simulation model built on the basis of the architectural plan of the 1st floor of building 21B of the N.V. Sklifosovsky Institute, where the central reception department is located. On the diagram, the areas of beds for temporary stay of patients, areas of the location of diagnostic services and the location of automated workstations (AWS) of personnel are highlighted in color.

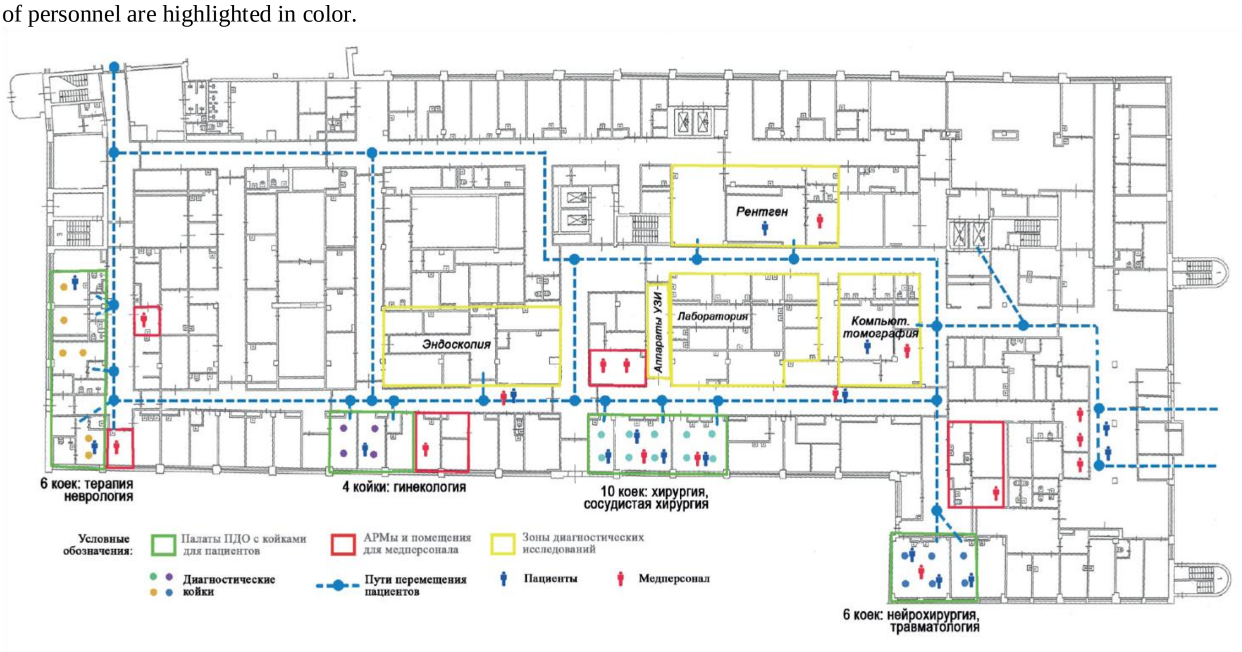

Fig. 4. The animation scheme of the simulation model of the central ADD of N.V. Sklifosovsky Research Institute for Emergency Medicine

When constructing the model, the following main types of instrumental studies carried out in the PDO were taken into account: X-ray examination, ultrasound examination (ultrasound), electrocardiography (ECG), endoscopy, computed tomography (CT). The average number of these types of research carried out per day, presented in Table. 1 was obtained as the average of ten standard Mondays.

Table 1
The average daily volume of basic instrumental studies conducted in the ADD

Study	Average number of studies	Number of doctors	Number of devices
Endoscopy	3	1	1
X-ray	70	2	1
Ultrasound scan	40	2	2
ECG	23	1	1
CT	22	1	1

The values of the time parameters used in the research were initially taken from the standards of the Ministry of Health of the Russian Federation [6–8], but then, due to their obvious overestimation, they were adjusted taking into account the actual time indicators and expert assessments of specialists. Generalized estimates of the accepted time ranges, which lay at the base of the model, are presented in Table 2.

Table 2
The execution time of the main types of instrumental research

Type of study	Minimum, average and maximum time put in the system (min)	Based on orders (min)
X-ray	3, 15, 17	10, 12, 35
ECG	3, 5, 10	13, 15, 24
Ultrasound scan	10, 15, 20	20, 30, 60
Endoscopy	10, 15, 30	55, 76, 100
CT	15, 20, 40	30, 40, 60

The laboratory tests performed in the ADD were not simulated, since this type of research is carried out in parallel with others, and they do not affect the total time spent in the ADD.

In the constructed model, patients are considered as agents passing through the entire scheme of treatment and diagnostic services from the moment they are introduced into the model until they leave. The rest of the subjects and objects of modeling are department resources that are involved in servicing agents. The main path of agents consists of the following stages - arriving at the registry, registering at the counter, assigning a diagnostic bed, initial examination by a doctor of the appropriate profile, passing instrumental examinations, repeated examination by a doctor, going to the hospital for hospitalization or leaving the ADD. Fig. 5 shows the block diagram of the simulation model (SM) of the central admission department we created.

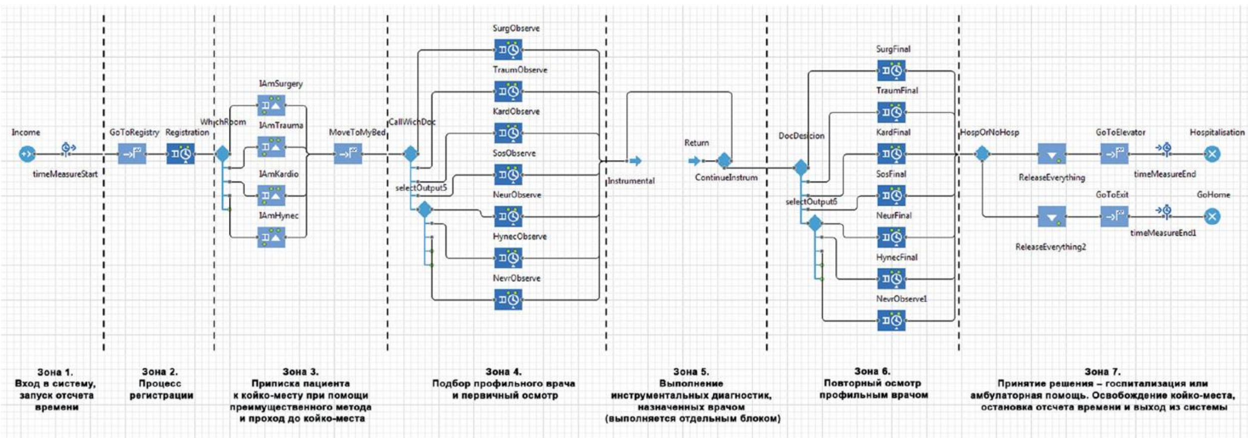

Fig. 5. A simulation model of the central ADD of N.V. Sklifosovsky Research Institute for Emergency Medicine. Flowchart of the diagnostic and treatment process for agents — ADD patients

The entrance to the system (Zone 1) is carried out by the Income block of the Source type, which performs two functions - it regulates the flow of incoming patients according to the arrival intensity schedule (see Fig. 3), and also determines the specialist's field for the patient, based on the distribution of patients by specialty per day (Fig. 6). Immediately after the agent appears in the model, its individual countdown of the time it passes through all blocks of the system is started.

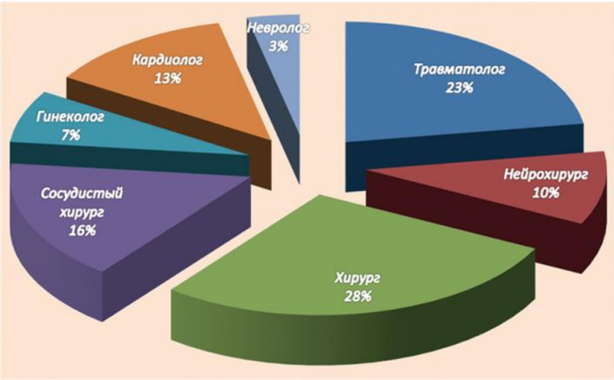

Fig. 6. Distribution of incoming patients by medical specialties per day

Registration of incoming patients (Zone 2) is carried out at the reception desk by four employees within 2–5 minutes. This function is implemented in the model by a block of type Service. Further (Zone 3) by the WhichRoom of the SelectOutput type the patient is directed to one of four profile zones: IAmSurgery / IAmTrauma / IAmKardio / IAmHynec units of the Seize type simulate preferential rules for assigning a bed to the patient for each zone. All places are divided into four zones, depending on the specialty. If there are free places, the patient occupies a bed in the zone of his specialty, but if there are not enough places, he can take a bed in the nearest free zone. This does not apply to gynecology, as gynecological patients always occupy an empty bed of their specialty, while other specialties are not allowed there. If there are no beds, patients are placed in the corridor, and then occupy the first free bed.

The initial examination by a specialized physician (Zone 4) is modeled by [X] Observe blocks of the Service type - a currently free physician comes to the patient and assigns a list of examinations that must be performed. The time of the initial examination was determined based on expert judgment.

Then the patient undergoes all instrumental examinations assigned to him (Zone 5). Each study type is tied to a corresponding Instrumental block of the Enter type. Since the order of examinations is arbitrary, the Instrumental block of the Exit type directs the patient to the Enter block, which is currently the least loaded. To minimize delays in examinations, a priority algorithm can be used: the program takes the examinations that the patient needs, measures the length of queues to each of the specialists, calculates the average lost time, which is the sum of the time spent in the queue and the time of the exam itself, and as a result forms the queue in an optimal and even redistributes the load on resources. After passing one of the studies, it is deleted from the list. The ContinueInstrum block of type SelectOutput checks to see if there are still pending studies. If yes, then the patient goes to the Instrumental block again, if not, it follows on.

Re-inspection (Zone 6) is similar to the initial inspection, but takes less time. After that, with an a priori given probability, defined as the percentage of hospitalizations at the Institute during the study period (see data [2]), the patient is accompanied to hospitalization or to the hospital (Zone 7). Time countdown stops and the agent is removed from the system in a Sink type Hospitalization or GoHome block.

RESULTS AND DISCUSSION

Several series of simulation experiments were carried out at various values of the model parameters. The main parameters should include:

- time spent on examinations of specialists;
- time spent on diagnostic tests;
- the number of diagnostic beds;
- the number of ADD doctors for each specialty;
- the number of units of instrumental diagnostics.

Since the program allows changing the parameters of the system during simulation, it is possible to analyze how the model behaves in different situations: with a uniform distribution of the flow of patients, with “mass admissions” of one specialty, with different combinations of specialties, etc. In addition, by changing the parameters of the model itself (the number of beds, medical personnel, diagnostic devices, etc.), one can consider the corresponding changes in the throughput of the admission department and identify factors that are important for its optimal operation.

1. Examination by specialists

The time spent on the initial and repeated examination was taken from the totality of expert assessments of specialists from each of the seven specialties involved in the ADD.

2. Research time

Initially, the model was planned to use the time recommended by the Ministry of Health of the Russian Federation for instrumental diagnostic studies. However, the behavior of the model was not consistent with the real data - the waiting time and the length of the queues turned out to be much longer than the actual ones. Therefore, a variant of expert estimates of the time spent on research was suggested. These indicators were taken as the basis for constructing SM.

3. Number of diagnostic beds and specialists

The total number of diagnostic beds, as well as the staffing of specialists on duty in the admission department, cannot be changed at the moment, and therefore in SM was a fixed value.

4. Number of instrumental diagnostic devices

In our case, the system showed difficulty in working with a large flow of trauma or surgical patients. As seen from Fig. 7A, the main difficulties arise from the queue for X-ray examinations with one operating device. The specified study time - from 10 to 35 minutes - creates queues of up to 5 people with a large number of patients. This is associated with the fact that the X-ray room in the admission department serves about 40% of all patients and about 70–75% of traumatological and surgical patients (which, in turn, are leading). Fig. 7B shows that the addition of a second X-ray device significantly affects the situation - the queues for an X-ray examination are reduced to 2 people.

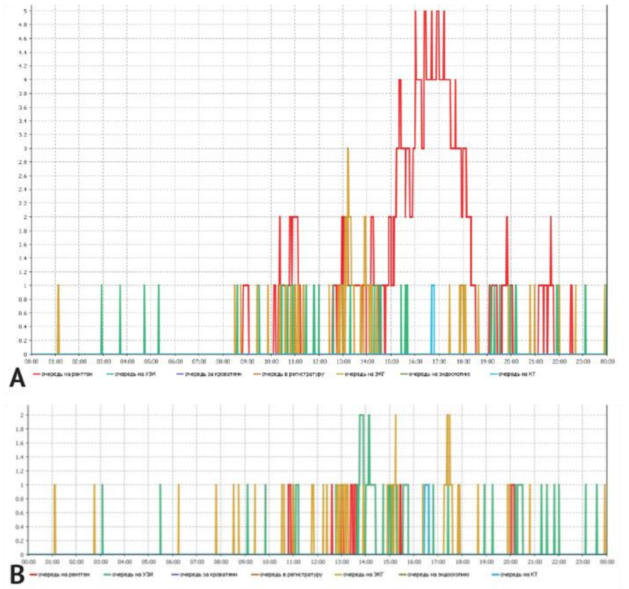

Fig. 7. The length of the queues in the ADD depending on the time of the day. A — one x-ray device; B — two x-ray devices

According to the Table 3, the use of a second X-ray device reduces the average time spent in the ADD of hospitalized patients by 10 minutes, non-hospitalized patients by 4 minutes. In this case, the maximum time is reduced by 40% / 50%, respectively.

CONCLUSION

The performed studies show the broad possibilities of simulation and indicate the advisability of using this approach as a decision support tool in the tasks of organizing medical and diagnostic services for hospital patients.

The simulation model of the central reception and diagnostic department developed by us adequately reflects the current organizational scheme of medical care for patients in the admission and diagnostic department of the Institute. The presented model can be further developed. For example, introduction of parameters for the participation of junior medical personnel, who accompanies patients from the diagnostic bed to the department or to the instrumental examination room, can help identify the importance of this factor for the operation of the admission and diagnostic department. In addition, further improvement of the organization of patient path will take into account service priorities depending on the severity of the condition.

We should note the promising possibilities of using simulation modeling in the construction and conduct of simulation experiments for the study of various emergencies, mass admissions in different specialties, etc., which is of particular importance due to the complexity of assessing such situations by analytical methods. Thus, for emergency hospitals, with a tendency to increase the flow of incoming patients and a high significance of the time factor, such use of tools for predicting and supporting decision-making to optimize treatment and diagnostic services both within the framework of daily routine activities and in the context of many complex emergency situations is especially relevant.

Analyzing the results of the conducted simulation experiments and the obtained statistical data, the following conclusions can be drawn:

1. The results of the experiments indicate an improvement in the functioning of the reception and diagnostic department according to the new scheme, which in turn confirms the positive result of the reorganization carried out.

2. The constructed simulation model allows you to identify rough spots in the organization of medical services and propose options for their elimination.

3. Changing the initial parameters of the model with the same flow of patients and studying the corresponding responses of the system, one can find the most optimal variant of the operation of the admission and diagnostic department.

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