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The study of the Dynamics of the Spread of Viral Infection in the Premises of the Critical Infrastructure Using a Hybrid Model on the Example of a Medical Organization

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***Abstract*— The article is devoted to studying the influence of the spread of viral infection in the buildings of critical infrastructure facilities based on a simulation model. It is proposed to build the simulation model as a hybrid, including an event component, a pedestrian model, and an agent component within the AnyLogic simulation environment. This approach allows us to evaluate the effectiveness of various organizational decisions in terms of reducing the spread of viral infection. As an example of the application of the technique, one of the types of medical organization with mass flows of agents is considered. As part of the simulation approach, the effect of the rates of admission of emergency infected patients has also been investigated.**

***Keywords*— hybrid model, Anylogic modeling environment, critical infrastructure**

I. INTRODUCTION

The problem of the spread of viral infection during the period of exacerbation in the corresponding seasons is a constantly recurring problem. Despite the success of health care and the measures taken, this problem cannot be completely eliminated. One of the main reasons is the persistence of a large number of contacts between an already infected individual and those who are still healthy. This is especially relevant in connection with the emergence of new, previously unknown viral infections. This strongly requires research on various aspects of prevention, infection spread, therapy and rehabilitation of the population. The most effective in modern conditions is the use of mathematical and simulation modeling.

It is known that the most visited organizations in the period of exacerbation are medical organizations, where infection often occurs. Note that from the point of view of infrastructure criticality, medical organizations can be classified as such objects, and their information systems as critical information infrastructures. In this regard, it is of particular interest to study the spread of infection in small buildings that are visited by a large number of people in a short time during the period of mass infection with viral infections. It is important that the research methods and results can be used to study other objects.

Is an organization that performs activities in the field of health or medical services, supports the development of medicine as a science, and is engaged in activities to maintain health and provide medical care to people through the study, diagnosis, treatment, and possible prevention of diseases and injuries.

Examples of medical organizations: hospitals, clinics, sanatoriums, medical institutes and universities, etc., as well as international medical organizations (International red cross and red Crescent movement, world health organization, etc.).

One of the types of medical organizations with mass attendance, namely, a polyclinic, will be considered as the ultimate case of mass contacts.

The polyclinic is carefully isolated from the hospital and is located in separate buildings or buildings adjacent to the hospital. The entrance for patients to the polyclinic is separated from the entrance to the hospital. In front of the entrance is equipped with a recreation area for visitors at the rate of 0.5 m2 per visit per shift. An area close to the street is reserved for the polyclinic. Access roads are located nearby.

II. SUGGESTED APPROACH

Let us determine in which cases simulation is used. A simulation model is built when experiments on the modeling object are difficult or impossible at all, or when it is impossible to reduce the dependencies in the modeling object to a mathematical model, etc.

Since the model of movement of the patient flow in the clinic can be implemented in different ways, for example, using different approaches to modeling, we should single out the target groups of specialists for whom it is being developed, because their requirements for the model may be inconsistent or opposite. At this stage of the study, we distinguish only 2 target groups of specialists:

1) Use the model to visualize the movements of the patient flows and their intersections with different layouts of rooms in the clinic, and to demonstrate the possible consequences of such intersections.

2) Use the model to obtain statistical data, for example, with the accepted discipline of patient care, about the average workload of the doctor, or examination rooms in the hospital.

For two groups, the ideal model will look different, but the Anylogic package for creating simulation models allows us to combine this into one model, in the first case we will create a "physical" model diagram based on the pedestrian library and modeling agent. In the second case, we will create the "logic" of the model and connect it to the physical circuit. We will add various graphs and histograms to the logic to display the information necessary for the second group.

III. The Basic Provisions of the Model

A. *Features of the research approach.*

Since the object of modeling is a complex system containing both a fixed structure and freely acting entities, to conduct simulation experiments, it is necessary to build a hybrid model that includes two methodologies - agent-based and event-based approaches to modeling. In addition, for the movement of agents it is required to specify a complex structured training ground, based on the structure of the building of the medical organization.

B. *Features of the set and layout of the premises.*

The layout of the premises of the building should provide short and direct routes for the movement of patients, the convenience of communication. It is advisable to separate the flows of patients entering and leaving the clinic.

In the clinic, the following departments are distinguished:

1) Laboratory diagnostic;

2) Physiotherapy department;

3) The main premises of the clinic;

4) Ancillary facilities.

C. *Event Model Building*

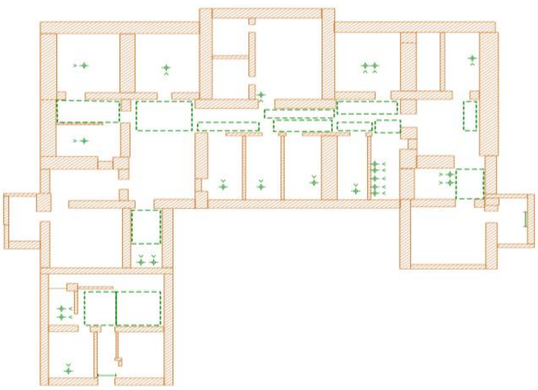

Fig. 1. A medical organization plan with added components of the agent model restrictions

To illustrate the method, let's take an existing building plan of a medical organization on the basis of which we will formulate its simulation model. For the simulation model, a simplified plan of the building of a medical organization is used with the addition of the necessary components of restrictions, shown in figure 1.

To simulate the work of a medical organization, we will create a flow diagram of the service process, for this we use the following elements of the Anylogic pedestrian library [1-3]: PedSource, PedService, PedSelectOutput, SelectedOutput, PedGoTo, PedSink, Hold.

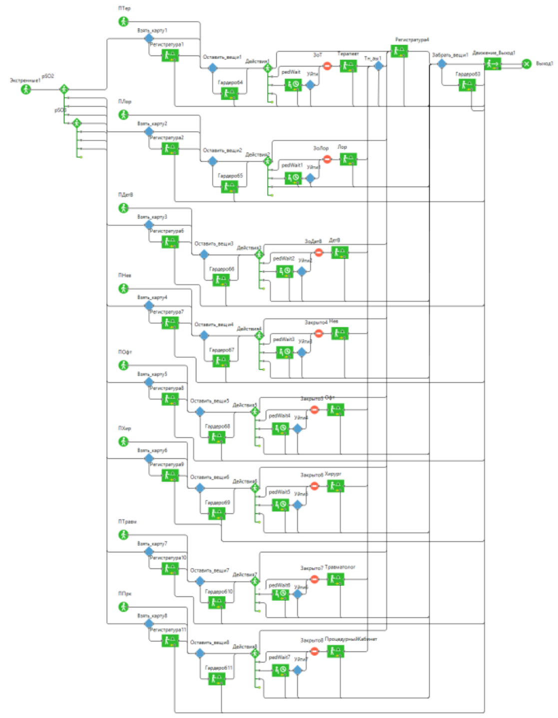

Fig. 2. Healthcare Organization Service Discipline

The doctor's service plan is constructed by repeating the number of employees of the medical organization, taking into account that when visiting some doctors, additional examinations are not required, a complete flow chart of the functioning of the medical organization is shown in Figure 2. The parameters of the PedSourse, PedService elements regarding the distribution of appearance and service intensity are taken as. As a distribution of time intervals for the arrival of elective patients, a uniform one is adopted. The distribution of time intervals for the arrival of emergency patients is exponential with the parameter $\lambda = 6$. The distribution of service time at the doctor is normal with parameters N(20;5).

D. *Creating a Patient Agent for a Model of a Medical Organization*

Since agents are described by sets of possible states, let's add Patient to the agent model, Statechart elements used in AnyLogic to describe agent states, create three Statechart elements since Patients on the model can be of three types: healthy, sick, sick come again. Next, we define the beginning of the state diagram and transitions between states. Transitions between states will occur according to the following rules [10; 14-15]:

1) Agents fall into a state of "healthy" in all cases, except for those that have fallen into a state of "sick who has come again";

2) It is possible to get into the state of "ill come again" with a probability determined by the formula (3.1).

3) We set the transition from the state of "healthy" to the state of "ill", when the condition is triggered: the parameter health <= 0;

$$P_{I.R.V} = \frac{\sum Patient.Infected}{\sum Patient} * \%R.V, \qquad (1)$$

where $P_{(I.R.V)}$ is the probability of a repeat visit by an infected person, $\sum Patient.Infected$ is the sum of the "patient" agents in the infected state, $\sum Patient$ is the sum of all the "patient" agents of the model, %R.V is the percentage of repeated visits on the model.

The state diagram after adding the elements is shown in Figure 3. Add the actions that the agent performs inside the states:

1) For the "healthy" state, this will be the wait for the Infected message, and if it is received, the Health parameter will be reduced by 1 unit;

2) For the conditions: "sick came again", "sick". Sending "Infected" messages to all healthy patients around.

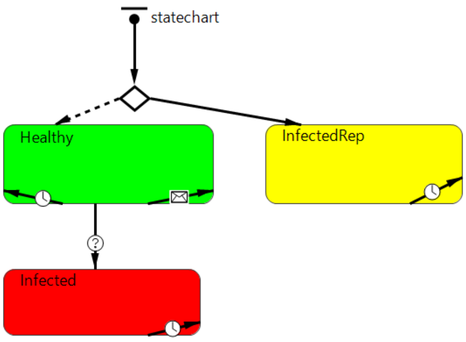

Fig. 3. Statechart agent chart "Patient".

In the "Infected" and "InfectedRep" states, the patient will search for a healthy patient in the Infection Radius from himself at any given time (so as not to send useless Infected messages to already infected patients). If a healthy patient is found and the probability of infection has worked, he will be sent an Infected message.

The model allows you to display the simulation results not only with graphs, but also with a density map, this map through colors shows how many patients were in the zone at one time. Colors are distributed from blue to red, the rules for the distribution of colors can be found in table 1.

TABLE I. COLORING RULES FOR THE DENSITY MAP

Value	Color
X< 1	«red»
1>= X <2	«green»
2>= X <3	«orange»
3>= X	«blue»

The zone is painted in the corresponding color within a certain radius from the agent "patient". Examples of such density maps are shown in Figures 4 and 5.

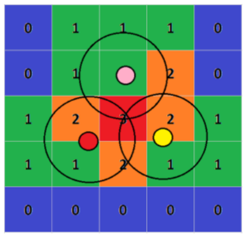

Fig. 4. Example density map for three agents.

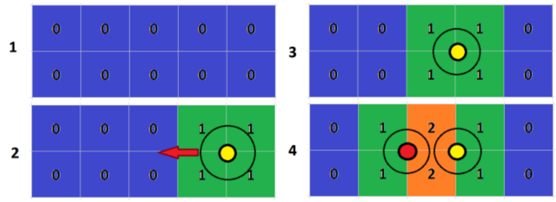

Fig. 5. example of a density map for two agents in dynamics.

As a result, in addition to the modeling process, a map of the patient movement densities by medical organization will be displayed on the model map [11-12].

IV. STUDY THE EFFECT OF EMERGENCY PATIENTS ON THE DYNAMICS OF PATIENT FLOW

For this experiment, we will use the previously constructed plan of a medical organization, as well as the classic version of modeling a medical organization as QS [19] and try to evaluate how strongly "emergency patients" affect the dynamics of patient flows with the following intensities: 2 emergency patients per hour, 20 emergency patients per hour, 50 emergency patients per hour.

Figures 6,7,8 show density maps for three modeling options when using the compact structural type of a medical organization.

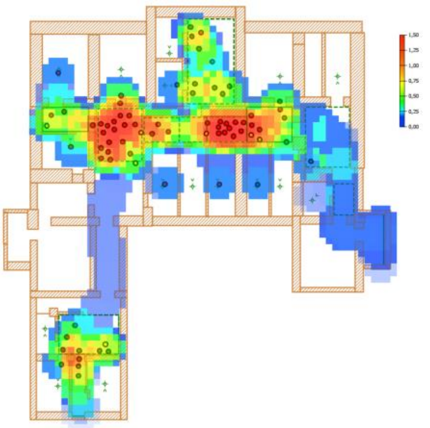

Fig. 6. Example of a density map for 2 emergency patients per hour.

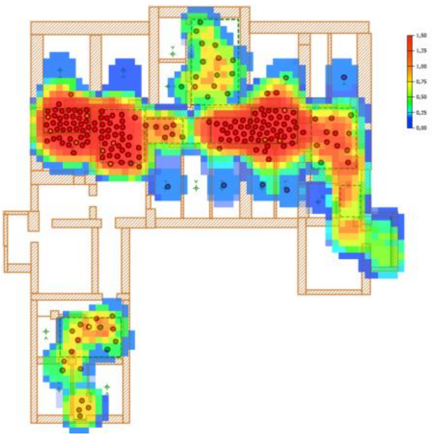

Fig. 7. Example of a density map for 20 emergency patients per hour.

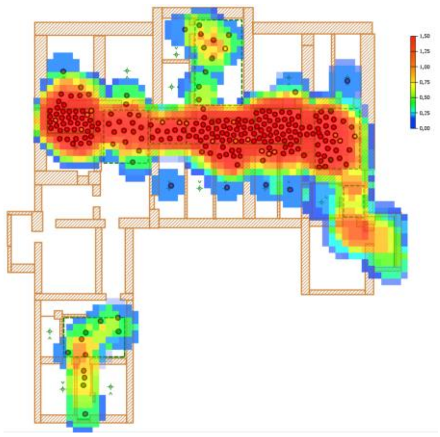

Fig. 8. Example of a density map for 50 emergency patients per hour.

Figures 9-12 show a graph of the dependencies of indicators on simulation time.

Obviously, such parameters as the size of the queue in the system, the time in the system nonlinearly increased with the increase in the number of emergency patients, which in turn provoked an increase in the number of patients in the building at the same time and increased the spread of infection among the model agents.

Fig. 9. « Time spent in the system »

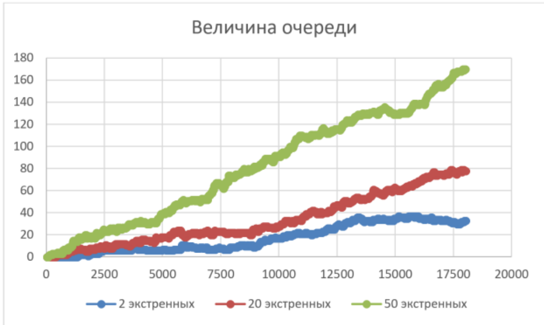

Fig. 10. « Queue Size »

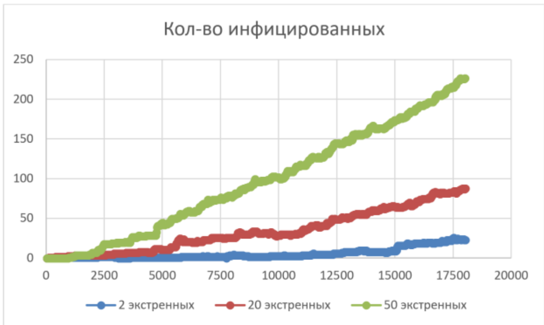

Fig. 11. « Number of infected »

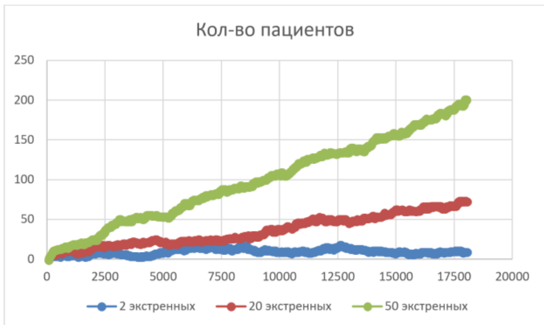

Fig. 12. « Patient count »

V. STUDY THE EFFECT OF DECISIONS ON CHANGES IN DISCIPLINE AND PLACEMENT OF SERVICE LOCATIONS ON THE DYNAMICS OF PATIENT FLOWS

Consider the impact on the outcome of decisions to change the placement of jobs and the structure of flows.

A visual representation of the test site with the results of the operation of the model with an unoptimized patient flow is shown in Figure 13. As can be seen from the graphs in the case of an unoptimized patient flow, the number of patients in the system increases and reaches 60 at the same time in the hospital, in this case the chances of getting sick are very high, about as evidenced by the graph of the number of infected in the system, it shows that each patient in the system is sick, the time that patients spend in the system is equal to 700 units of model in Yemeni, and the value of the queue more than 30 people in the model, ie, half of the patients in the model stand in line.

Fig. 13. Non-optimized patient flow

Figure 13 shows the result of the functioning of the model on the plan of the medical organization. Map showing the result of a model with an unoptimized patient flow. The red zone is the site of congestion and the spread of infection. The main MO problem is visible on the map: the lines for an appointment with the therapist and in the treatment room block the rest of the clinic's patients because of this, a flea market is formed. To solve this problem, it is proposed to implement the following solutions:

1) Move the therapist's room into the interior of the medical institution (1) in this way, even if there is a queue, it will not prevent people from going to the clinic;

2) Transfer the other most popular cabinet (procedural) to the right side of the medical organization (2);

3) Make changes to the patient schedule.

From the obtained simulation results, it can be assumed that the main problem of this medical organization is too close to the registry of the offices of the therapist and pediatric doctor. Because of this, in the process of waiting for reception and receipt of cards, the flows of emergency and planned patients merge into an insurmountable barrier. In order to avoid the situation in Figure 14, you should move these rooms to different parts of the building and increase the number of services in the registry. The changes made are presented in Figure 15.

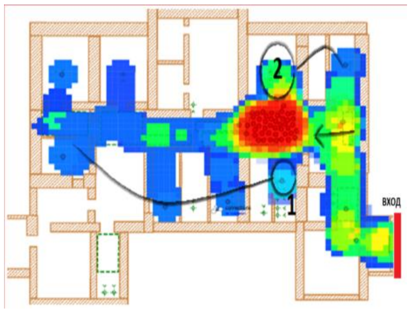

Fig. 14. Changes in job postings

As a result, the result was obtained, shown in Figure 15. The green color on the map indicates a good separation of patient flows on the map. It means streams are well optimized.

As you can see, the maximum number of simultaneous patients in the system fell from 60 to 10, the number of infected in the system decreased to 6, the time in the system became 200 units of model time, and the queue in the system was no more than two people. This indicates a good separation of patient flows, as well as the fact that the clinic has enough doctors to serve patients and changes in their number are not required.

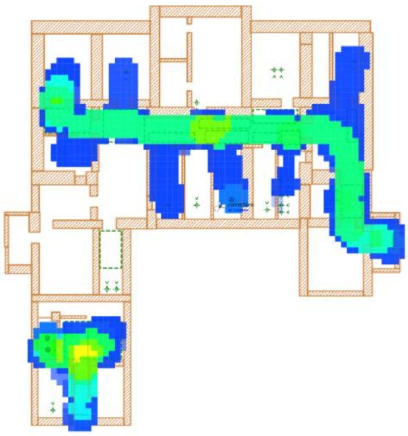

Fig. 15. Optimized patient flow

Based on the results of the experiments, we can conclude that the main drawback of planning the activities of a medical organization was purely organizational and the queue was accumulated not because of time and discipline of service, but because of the difficulty of going through a medical organization. As soon as this problem was eliminated, the number of patients simultaneously in the model fell by 75%, the time spent in the system decreased by 50%, the number of infected people fell by 40%, and the queue size decreased by 70%. Summarizing the above, the use of simulation allows not only to evaluate the effectiveness of the medical organization, but also to find solutions to improve the separation of patient flows.

VI. CONCLUSION

As a result of our studies, we performed several experiments that allowed us to evaluate:

– the effect of the number of emergency patients on the dynamics of patient flow;

– the effect of changes in patient flows on the spread of viral infection.

Based on the obtained simulation results, it can be assumed that each medical organization has an optimal set of parameters for itself, for example, the considered version of the building layout has difficulties in sharing patient flows due to its too complicated structure, unsuccessful location of rooms, and overloaded specialists.

The experiments performed allowed us to simulate the results of decisions to improve the separation of patient flows. At the same time, the best effect was obtained as a result of changing the position of jobs in order to unload the main rooms, which as a result allowed to achieve an acceptable result in the separation of patient flows.

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