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On intelligent agent-based simulation of COVID-19 epidemic process in Ukraine

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Abstract

COVID-19 has impacted all areas of human activity around the world. Modern society has not faced such a challenge. Affordable travel and flights between continents allowed the virus to rapidly spread to all corners of the world. An effective tool for the development of anti-epidemic measures is mathematical modeling. The paper proposes a simulation model of COVID-19 propagation based on an agent-based approach. The case of the spread of the epidemic process before vaccination is considered. To verify the model, we used the data of official statistics on the incidence of COVID-19 in Ukraine, provided by the Center for Public Health of the Ministry of Health of Ukraine. The constructed model makes it possible to identify the factors influencing the development of the COVID-19 epidemic in a certain area.

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Keywords: Agent-based simulation; epidemic process; COVID-19; epidemic model; compartement model.

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1. Introduction

Over the past decades, significant changes have occurred in epidemiological science: epidemiology is considered not only as a doctrine of the epidemic process, but as a science that studies the patterns of the occurrence and spread of any pathological conditions among the population [1]. Modern medical science makes extensive use of epidemiological research methods.

Mathematical modeling is a powerful enough tool for studying complex objects and processes in the real world. It is especially irreplaceable in those areas of research where real experiments on objects are complicated or simply impossible. Epidemiology and data-driven medicine are examples of one such area [2].

The mathematical models of epidemic processes developed to date are mainly systems of differential equations [3]. This type of model has several disadvantages, namely:

- the models are discrete, while the spread of infection is continuous;
- individual properties of objects are not taken into account;
- the models contain "averaged" parameters that are not related to the physical properties of objects;
- the value of some parameters is very difficult or impossible to determine based on statistical data;
- models have high computational complexity and difficulties in changing the rules for the incidence of disease.

Simulation modeling using the agent-based approach is supposed to be the most suitable apparatus for modeling processes in epidemiology [4]. It allows, by setting the initial parameters for each type of object, as well as the rules of the system according to which objects interact with each other and the environment, to calculate the dynamic patterns of the development of infection and to identify the most significant properties of agents that contribute to a change in the rate of spread [5]. The advantage of this approach is that it takes into account the individual properties of each object, which makes up a complex system [6]. The dynamics of a complex process is the result of the functioning and interaction of relatively simple objects. The main task of analytics is to formulate interaction rules.

The **aim** of given research is to develop an agent-based model of COVID-19 epidemic process in certain area.

This research is part of a comprehensive epidemic forecasting and epidemic containment decision-making model development study, which concept is presented in [7].

2. COVID-19 epidemic process in Ukraine analysis

The COVID-19 pandemic is a pandemic, also known as the coronavirus pandemic, caused by Coronavirus Severe Acute Respiratory Syndrome 2 (SARS-COV-2). The virus was first detected in December 2019 in Wuhan, China. The current scientific consensus is that the virus is most likely zoonotic in origin from bats or another closely related mammal [8].

The virus is transmitted mainly by the respiratory route, when people inhale droplets and particles that infected people excrete when breathing, talking, coughing, sneezing. People are at their peak of infectiousness when their symptoms begin to show, but they are already infectious 1-3 days before. Their infectiousness declines after the first week, but they remain infectious for up to 20 days and can spread the virus even if they have never had any symptoms.

The symptoms of COVID-19 vary greatly, from nil to life-threatening. COVID-19 is transmitted when people breathe in air contaminated with droplets and small airborne particles. Transmission can also occur by splashing or spraying contaminated liquids into the nose, mouth, or eyes, and rarely over contaminated surfaces [9].

The spread of coronavirus disease in Ukraine was recorded on March 3, 2020, when the first case of the disease was confirmed in the Chernivtsi region. In the country COVID-19 is manifested by three types of tests - laboratory (polymerase chain reaction and enzyme-linked immunosorbent assay) and "rapid" (express test), which can be carried out outside the laboratory [10].

On March 11, 2020, the Cabinet of Ministers adopted a resolution on preventing the spread of COVID-19 coronavirus in Ukraine, which is quarantined on the territory of Ukraine from March 12 to April 3, 2020 and is prohibited:

- visits to educational institutions by its applicants;
- holding all mass events in which more than 200 people take part, except for the events necessary to ensure the work of state authorities and local authorities, sports events are allowed to be held without the participation of spectators;
- kindergartens and educational institutions were closed.

Quarantine was introduced in all areas, in addition, of the 219 checkpoints, 49 were left open. On March 25, 2020, the Cabinet of Ministers decided to introduce an emergency regime throughout Ukraine for a period of 30 days, until April 24, 2020, through the spread of coronavirus disease in 13 regions. The Ministry of Health of Ukraine announced the criteria for easing quarantine and other restrictions related to anti-epidemic measures against COVID-19 [11].

Indicators of readiness for the transition of areas to the 2nd stage of quarantine, which provides for the relaxation of quarantine:

- incidence (the number of new cases of COVID-19 in the last 7 days per 100,000 population) must be less than 12;
- the occupancy of places in healthcare institutions designated for hospitalization of patients with a confirmed case of COVID-19 should be no more than 50%;
- the number of tests (PCR testing together with IFA testing) for 7 days in 100,000 population should be at least the incidence rate - that is, more than 12;
- R-indicator (Reproduction indicator) should be at the level of 0.9 – 1.0 – calculated on the basis of the number of new cases in the last 7 days prior to 7 days. It characterizes the number of new infections from one patient. If “R” is greater than one, it means that the infection in the population is increasing, if it is less than one, it is dying out.

These criteria were broadly in line with the general criteria for easing quarantine measures previously developed by the European Union. On May 23, 2020, the Ministry of Health published on the website a table of readiness for the second stage of quarantine exemptions by region. On July 22, the Cabinet of Ministers of Ukraine extended the adaptive quarantine in Ukraine until August 31, 2020, introducing the division of Ukraine into 4 “zones” from August 1.

According to the Ministry of Health and the National Security and Defense Council, as of June, 2021, 2235801 cases of SARS-CoV-2 infection were confirmed in Ukraine, of which 52391 people died, 2168387 recovered.

3. COVID-19 agent-based model

As a structure of the developed model, it is proposed to divide the population into four states: S – susceptible, E – exposed, I – infected, R – recovered. Such conditions can be used to model the spread of the epidemic process before the introduction of vaccination of the population. Population agents interact with each other and with the modeling environment. The transmission of morbidity and the transitions of agents between states occur on the basis of probabilistic coefficients, which are determined experimentally on the basis of statics on the incidence of COVID-19 in the selected area. We used data from the official statistics of COVID-19 in Ukraine provided by the Public Health Center of the Ministry of Health of Ukraine.

The structure of agent states is shown in Figure 1.

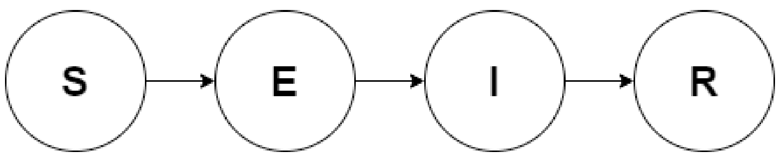

Fig. 1. Structure of agent’s states

Transitions between the states of agents can be described by the following system of differential equations:

$$\begin{cases} \frac{dS}{dt} = \mu N - vS - \frac{\beta SI}{N} \\ \frac{dE}{dt} = \frac{\beta SI}{N} - vS - \sigma E \\ \frac{dI}{dt} = \sigma E - \gamma I - vI \\ \frac{dR}{dt} = \gamma I - vR \end{cases}, \quad (1)$$

where S is number of agents in Susceptible state, E is number of agents in Exposed state, I is number of agents in Infected state, R is number of agents in Recovered state, μ is birth coefficient, ν is death coefficient, β is transition rate, γ is recovery rate, σ is contact rate.

Agents can be in different states and have different characteristics, which allows modeling the heterogeneity of the population. The UML-diagram of agent classes is shown in Figure 2.

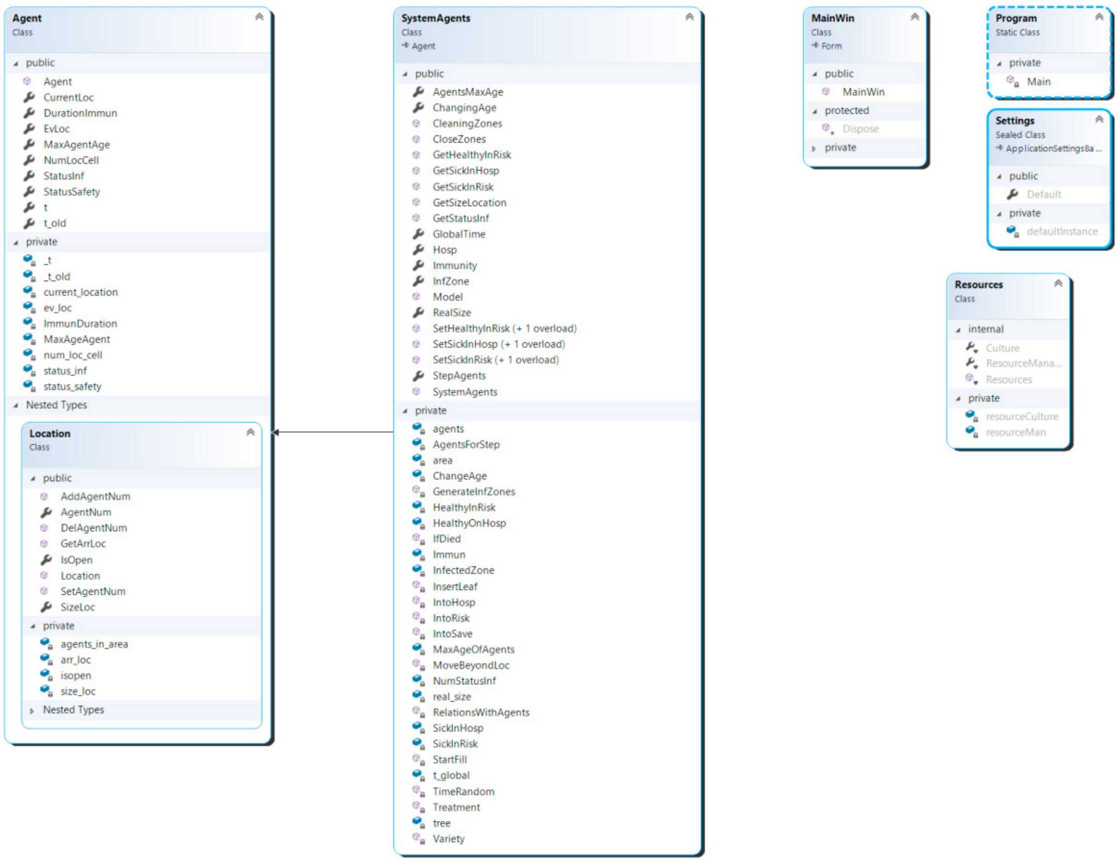

Fig. 2. Diagram of classes

The developed model is implemented in the AnyLogic environment.

4. Results

The results of the model built in the AnyLogic environment are shown in Figure 3.

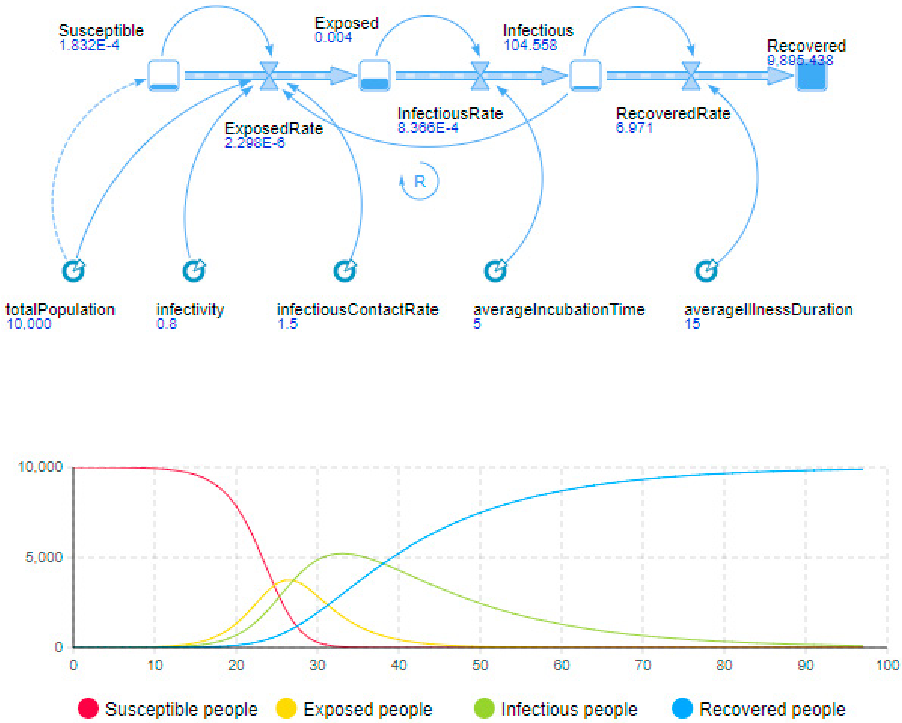

Fig. 3. COVID-19 model in AnyLogic environment

The graph shows the time course of the development of the epidemic process. The curve of the number of contacts begins to grow from about 14 days, which is equal to the incubation period of the disease. On the 32nd day, the number of infected individuals peaks and the number of susceptible individuals drops to zero - the entire population is now divided into the remaining three categories. Despite the reached peak in the number of infected, the epidemic persists for a relatively long time - it can be seen that the decrease in the number of infected is slower than their growth. After the 90th day, the number of infected is less than 1% of the population. Figure 4 shows the projections of the incidence of COVID-19 in Ukraine under various scenarios.

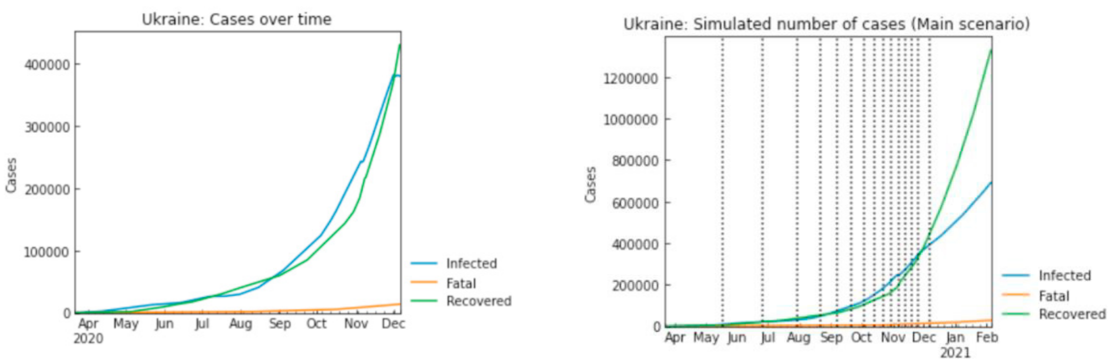

Fig. 4. Results of COVID-19 forecasting in Ukraine

5. Conclusions

The constructed model of the epidemic process of COVID-19 in Ukraine makes it possible to identify factors that affect the dynamics of morbidity in a certain area. Experimental research has shown that using more parameters does not interfere with the ease of use of the model, but, when combined with the use of real data as input, gives more reliable predictive results. The simulation results showed that the most effective measures to reduce epidemic dynamics are self-isolation of patients and tracking of contact individuals of the population. Moreover, the isolation of the entire population is not advisable, it is enough to isolate 80% of patients in the active phase. As a research perspective, it is planned to add additional parameters to the model as input data and see their impact on the output, which ultimately can be used as an assessment of the influence of various factors, which include vaccination of the population, which has recently begun.

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