Intelligent Simulation of the Epidemic Process of Diphtheria Infection

Dmytro Chumachenko
National Aerospace University “Kharkiv Aviation Institute”, Kharkiv, Ukraine

***Abstract* – The aim of the study is to construct an intelligent agent-based model of the dynamics of the spread of morbidity by infectious diseases by the example of diphtheria infection. The proposed model allows taking into account heterogeneity of the population, knowledge base of agents, as well as intellectual communications of the modeled population. The intelligent agent-based approach to simulation allows increasing the reliability of the model. This will allow epidemiological experts to take timely and effective anti-epidemic measures to reduce morbidity, which has a high social and economic importance for society.**

***Index Terms* – artificial intelligence, agent-based simulation, epidemic process, epidemic modeling, fuzzy logic**

I. INTRODUCTION

Implementation of epidemiological surveillance of infectious diseases is impossible without studying the dynamics and manifestations of the epidemic process. Correct forecast of its development allows to develop effective and rational measures. Taking into account the fact that it is impossible to carry out experiments on the distribution of pathogens among the population on bioethical items, it is important to develop adequate mathematical models for predicting the epidemic process of morbidity.

To date, a significant number of such theoretically valid models of population dynamics have been created. They rely on the mathematical apparatus of statistics and probability theory. A common drawback of existing models is the low accuracy of forecasting, as well as its short-term. One of the main problems of the epidemic process in the systems of population dynamics is the stochastic nature of its behavior. Also, existing models do not take into account the peculiarities of the internal behavior of the population, the assessment of the external environment by objects, the logical behavior of the specimens of the population. When analyzing the epidemic process, in contrast to the behavior of the population dynamics systems, the researcher is only interested in one “epidemic-recession” cycle, because the further development of dynamics can vary considerably depending on the consequences of epidemic behavior, as well as the external influences taken.

The aim of given investigation is to develop intelligent agent-based model of epidemic process of infectious disease using the example of diphtheria infection, which will solve the deficiencies of existing approaches and improve the accuracy of the simulation.

II. PROBLEM OF DIPHTHERIA INFECTION

Diphtheria is an infectious disease transmitted by airborne droplets. It is characterized by inflammation of the mucous membranes of the mouth and nasopharynx, as well as by the phenomena of general intoxication, by the defeat of the cardiovascular, nervous and excretory systems. It is accompanied by high lethality and serious complications, resulting in disability.

At the beginning of the 20th century, the incidence of diphtheria in the countries of the Soviet Union was about 1,000 per 100,000 people. Thanks to mass immunization since 1932, a sharp decrease in the incidence was noted, a low rate was registered in 1976 - 0.02 per 100,000. However, parents' refusals to vaccinate children, unreasonable expansion of contraindications to routine immunization, use of immunopreparations with a lower antigen load led To a gradual decrease in the tension of collective immunity against diphtheria, which, combined with the ongoing circulation of the pathogen (carrier), contributed to the epidemic in the East Europe, including Ukraine and Georgia, since 1991.

III. INTELLIGENT AGENT-BASED MODEL OF EPIDEMIC PROCESS

Modeling is one of the ways to solve problems that arise in the real world. It is used in case if experiments with real objects/systems or their prototyping is impossible or too expensive and allows optimizing the system before its implementation. Simulation involves mapping the problem from the real world to the world of models, analyzing and optimizing the model, finding a solution, and mapping the solution back to the real world.

One of the most universal approaches in modeling is imitation agent-based modeling, as it makes it possible to take into account any complex structures and behaviors, and also maximally reflects the real processes taking place in nature and society. The main advantage of agent-based systems is the construction of the model of each agent with the definition of its individual parameters [1].

To achieve the research goal, an agent-based model in the NetLogo environment, which allows to simulate the interaction of up to 100,000 particles (agents) has been developed. This size of the population is sufficient to transfer the rules of its dynamics and interaction to any number of individuals.

The main tasks of the agent-based system are to determine the percentage of the population subject to compulsory immunization in order to avoid the epidemic of diphtheria, to predict the development of the disease, to study the significance of the influence of various factors, both medical and social, on reducing the number of patients, managing the epidemic process of diphtheria infection, and optimizing the results and achieving their maximum compliance with the real situation.

To create the model, three sets of agents were defined: healthy people, carriers and sick. Set of healthy people was divided into two subsets: immune (immuned = true) and susceptible (immuned = false). Set of sick, in turn, was divided into isolated (isolated = true) and non-isolated subsets (isolated = false). Visually, these categories are distinguished by shapes and colors. Before starting the program, the input parameters of the model are set: Q_h – the number of healthy, Q_s – the number of sick agents, Q_c – the number of carriers, V – the speed of movement of agents (km per day) and I_l – the immune layer.

Modeling is carried out on the basis of cyclic interrogation of all individuals and determination of their interaction in the event of a collision. Each simulation cycle corresponds to one day. The model takes into account the contagiousness of disease C, the incubation period for patients with IP_s and for IP_c carriers, the duration of disease T, the timing of isolation of patients with TI_s and other signs.

The proposed system belongs to the category of biomorfic agent-based systems and represents sets of agents with architecture (1):

$$Ag_i = <shm\ P_i,\ M_i>, \tag{1}$$

where $shm\ P_i$ is the agent schema defining its internal structure; M_i is the method of the agent that determines its behavior.

In this subject area, it is proposed to distinguish three breeds of agents (turtles): [healthy] for healthy, [carrier] for bacterial carriers and [sick] for patients with diphtheria.

The following is a description of the corresponding schemes:

```
breeds [healthy carrier sick]
turtles-own [age]
carrier-own [days]
healthy-own [immuned]
sick-own [days isolated],
```

where: [age] is the age, [days] is the time from the moment of infection, [immuned] is the indicator of immune protection, [isolated] is an indicator of the degree of isolation of the patient.

The method of agents functioning in the decision network includes three subfunctions: perception, decision and transformation.

Subfunction of perception (2)

$$Per: E \rightarrow A_{in} \tag{2}$$

provides selection of information from the environment and assignment of values to input attributes – [age], [days], [immuned].

Subfunction of solution (3)

$$Dec: A_{in} \rightarrow A_{out} \tag{3}$$

determines the values of the output variables (isolated) by the values of the input variables.

Subfunction of transformation (4)

$$Tran: A_{out} \rightarrow E' \tag{4}$$

changes the state of the environment, performing the operations of transferring the elements of sets from one to another in accordance with the rules given below, as well as removing elements of sets.

The overall structure of the system can be expressed by the following complex (5)

$$ABS = \{Ind, Prp, Atr, Inp, Out, Str\}, \tag{5}$$

where: *Ind* is the name of the system, *Prp* is system targets, *Atr* is system-wide characteristics, *Inp* is system input, *Out* is system output, *Str* is system structure. $Str = \{E, R\}$, *E* is the components of the system, *R* is the bond of the components.

The most progressive technology for implementing the method is the use of production knowledge bases in the form of fuzzy models.

Below are the fuzzy relationships that determine the realization of function (4) as the most significant from the point of view of interaction of agents:

$$\text{carrier: healthy} \rightarrow \text{sick}, \tag{6}$$

$$\text{carrier: healthy} \rightarrow \text{carrier}, \tag{7}$$

For example, the following fuzzy linguistic rules that implement the relations (6), (7) can be submitted:

If carrier catches healthy with immuned is Low
then healthy became carrier,
If carrier catches healthy with immuned is High
then healthy became sick,

where Low and High are linguistic variables.

IV. PROGRAM REALIZATION OF AGENT-BASED MODEL

The advantage of using this model is a simple interface, which makes it possible to use it by users who do not have a special mathematical preparation (Fig. 1) [2].

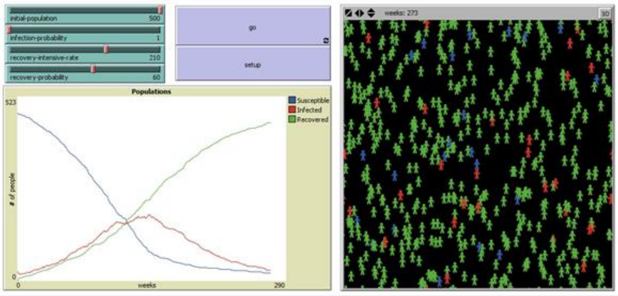
initial-population 500
infection-probability 1
recovery-intensive-rate 210
recovery-probability 60
weeks: 273

Figure 1. Interface of developed agent-based model

The user can specify the initial population, the number of sick individuals, the percentage of vaccination of the population. This makes it possible to carry out experiments on the dynamics of the incidence of diphtheria infection using both real statistics and the expected changes in the result of the measures taken.

V. RESULTS

The result of the simulation is a graph of the population change for the year, which makes it possible to predict the dynamics of the incidence of diphtheria infection, to determine the percentage of the population that must be vaccinated in order to preserve epidemic well-being and develop adequate and economically justified preventive and antiepidemic measures.

The simulation results, presented in Fig. 2 – 4, are a study of time series for an agent-based system with the following parameters: population size – 100 000 people, carriers of diphtheria infection – 1, sick agents – 4, population transfer speed – 10 km per day. The graphs show the dynamics of changes in the total number of patients, as well as the number of patients isolated in the first thirty days, depending on the number of immunocompromised. X-axis is time in days, Y-axis is number of patients, blue graph is number of patients, red is number of isolated patients.

The adequacy of the proposed model for predicting the dynamics of the incidence of diphtheria was tested in a real epidemic situation in the diphtheria infection that has developed in the Kharkov region in the last 6 years.

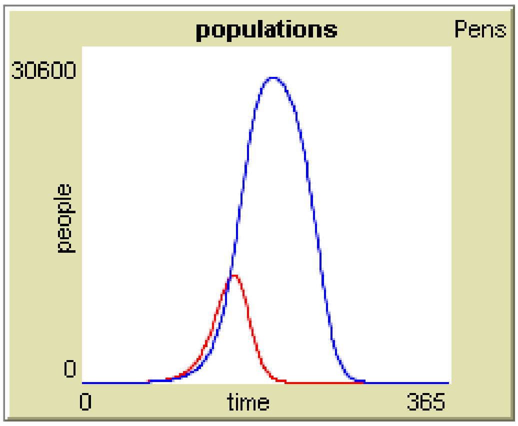

Figure 2. Simulation modeling of an agent-based system with 0% of immunocompromised

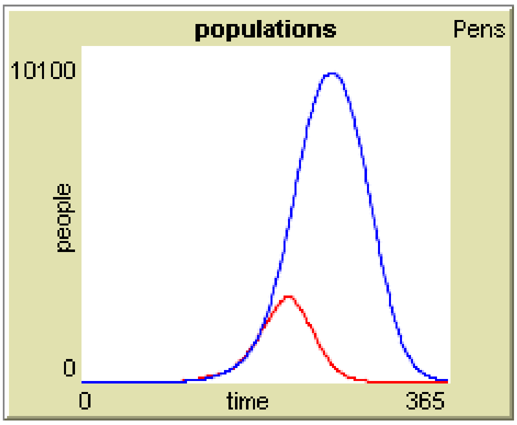

Figure 3. Simulation modeling of an agent-based system with 50% of immunocompromised

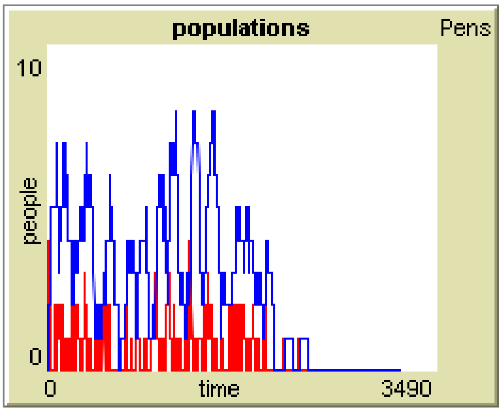

Figure 4. Simulation modeling of an agent-based system with 93% of immunocompromised

The results of modeling allow determining the percentage of the population subject to compulsory immunization to prevent the epidemic.

CONCLUSIONS

In the framework of this research, an intelligent agent-based model of the epidemic process of diphtheria infection has been developed. The developed model allows to take into account the individual characteristics of individuals of the population, the communications inherent in real processes, and also to solve the shortcomings of existing approaches.

The software complex was implemented in the city and district sanitary and epidemiological stations of the city of Kharkiv (Ukraine), which allowed conducting timely preventive measures and preventing the epidemic rise in the incidence rate in Kharkiv (Ukraine).

This investigation allows to propose a hypothesis that for the non-emergence of the epidemic, the time series corresponding to the number of patients should not exceed a certain threshold value. That is, the dynamic system describing the agent-based model must be a mapping of a finite set I into itself, $ABS: I \rightarrow I$, for nonlinear mappings, which include fuzzy models of the type (6), (7), is a sign of chaotic dynamics. Thus, the formation of conditions in the relations (2) – (4), which can be used to judge the stability of the dynamics of the agent-based system, seems to be relevant. This study is promising.

REFERENCES

[1]. T. Chumachenko, D. Chumachenko, and O. Sokolov, “Multiagent Simulation of the Hepatitis B Epidemic Process” *Online Journal of Public Health Informatics*, Vol 5, №1, pp. 178, 2013.

[2]. Комп’ютерна програма «Мультиагентная модель динамики заболеваемости дифтерией «DiphtheriaSim»» / Чумаченко Д. І.: Свід. Держ. реєстр. прав автора на твір №68482. – Зареєстр. 07.11.2016.