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Information Technologies for Assessing the Effectiveness of the Quarantine Measures

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Abstract. The paper proposes to use information technology for modeling and assessing the effectiveness of alternative quarantine measures to prevent the spread of viral infections (for example, COVID 19). A software tool was developed to simulate the spread of a virus infection, the protection effectiveness and quarantine measures based on the Unity3D engine. The modeling process is accompanied by a visual display of the interaction of observation objects. Statistics are displayed dynamically and are presented both a statistical data and a graph. The simulation system is flexible and adaptive, allowing you to customize a number of parameters. Among which should be noted the following: observation parameters (up to 1000 elements, with an increase at startup on computers with high performance); selection of protection means with a percentage of the number of objects that use the protection type; behavioral scenarios of observed objects. This allows you to check the effectiveness of quarantine measures, to assess the effectiveness of protecting the population from viral infections. The paper also demonstrates a comparison of the obtained simulation results.

Keywords: Information Technologies, Modeling, Quarantine Measures, Evaluation, Efficiency, Viral Infections, Covid-19.

1 Importance of Quarantine Measures

Applying restrictive measures helps to slow down the spread of viral infections and to win valuable time to prepare hospitals and medical staff for the increased number of hospital admissions. This is the stance taken by the WHO [1].

Restrictive measures, quarantine measures or quarantine is a set of restrictive and regular anti-epidemic measures aimed at limiting contact with an infected or supposedly infected person, animal, good, product, vehicle, locality, territory, district, region, etc. In some cases, quarantine implies a complete isolation of the outbreak area with the use of armed forces [2]. One of the primary objectives of quarantine is breaking the mechanism of transmission and localising outbreaks of the disease.

Pandemics have occurred regularly throughout history and have resulted in enormous casualties. Some of the most illustrative examples list [3-7]: the Antonine Plague (165-180 AD) with the death toll reaching about 5 million people; the Justinianic Plague (541-542 AD) – 30-50 million; the smallpox epidemic in Japan (735-737 AD)

– 1 million; the Black Death (bubonic plague) (1347-1351) – 200 million; smallpox (1520) – 56 million; plague pandemic in Europe (seventeenth century) – 3 million; plague pandemic in Europe (eighteenth century) – 600,000; 6 cholera pandemics (1817-1923) – 1 million; plague pandemic in Europe (1855) – 12 million; yellow fever (late 1800) – 100-150 thousand; Spanish flu (1918-1919) – 40-50 million; Russian flu – 1 million 1889-1890 (despite their names, both Spanish and Russian flu outbreaks originated outside these countries); Asian flu (1957-1958) – 1,1 million; Hong Kong flu (1968-1970) – 1 million; Swine flu (2009-2010) – 200,000; Ebola (2014-2016) – 1,000; COVID-19 infections, 2019-present.

The world community with the help of international organisations such as the WHO puts in enormous effort to prevent the spread of diseases, introduces population vaccination policies, etc. However, despite some obvious success, the risk of global pandemic outbreaks remains high enough, the situation with COVID-19 is a good example of it.

It is important to understand that pandemics are usually accompanied by panic and aggression among the population. Restrictive measures (quarantine) are meant not only to protect healthy people and hold back the spread of the disease, but also to protect infected or supposedly infected people from possible outbreaks of physical harm or violence against them.

Isolation of the infected people as well as observation of those who have been in contact with them are both an integral part of quarantine measures. The duration of contact is considered one maximum incubation period of the given disease since the last contact with the infected person or since exiting the epidemic area [2]. Furthermore, quarantine measures also include protection of the state territory from external infectious diseases.

Colloquially, the word “quarantine” may be used to describe restrictive, isolating and observational anti-epidemic measures in childcare institutions and hospitals taken against rapidly spreading infectious diseases such as chickenpox, scarlet fever, diphtheria, influenza, etc. In these cases, however, it is rarely spoken of the full range of measures predefined by a quarantine.

On 10 March 2020 the World Health Organization announced that the COVID-19 virus epidemic, which was first recorded in Wuhan, China, in December 2019, had reached pandemic levels [8]. Having emphasised the “alarming levels of spread and severity” the WHO urged the countries to take immediate and decisive measures to stop the spread of the Coronavirus disease.

2 Variety of Quarantine Measures

Restrictive measures are actions that prescribe special behaviour procedures for a group of people restricting their movement with the aim of the epidemiological protection of the population. There are three different categories of restrictive measures that vary in scope and severity: intensified medical surveillance, observation and quarantine.

Medical surveillance aims at active identification of the infected individuals among the population as well as their consequent isolation and hospitalisation. It is as a rule

carried out by means of questioning the complaints, physical examination, thermometry and laboratory analyses.

Observation encompasses intensified medical supervision, as well as restriction of movements, however, it allows for a minimal interaction with the society. At the same time, contacts between those, who are under observation and those, who are not under observation, are not allowed.

Quarantine entails a complete isolation assured by special guards. Interaction with the society takes place only via representatives of medical services who usually use special protective equipment and have to undergo certain cleaning procedures after visiting quarantine areas.

Anti-epidemic measures are normally carried out by specialists from healthcare and treatment facilities. Specialist teams are formed to provide isolation, treatment, disinfection, laboratory and vaccination services.

The following restrictive measures should also be mentioned: self-isolation – is a modern term used to describe a set of measures taken by the population itself in order to organise the quarantine, this term spread out during the COVID-19 pandemic; face mask regime, which means the compulsory wearing of hygiene masks and other respiratory protection items.

3 Application of Restrictive Measures and the Need to Assess their Efficiency

International human rights norms guarantee every individual the right to the highest attainable standard of health. Consequently, states are obliged to take measures to prevent the threats to public health and to provide medical assistance to those who need it. International human rights standards also permit limitation of certain rights and freedoms in situations of serious threats to public health and emergencies that threaten the life of a nation. Such limitations shall be lawful, limited in time and respectful of human dignity, subject to control and proportionate to the aim pursued.

The scale and severity of the COVID-19 pandemic is clearly reaching such a level of public health threat that it may justify restriction of certain rights and freedoms, as, for instance, restriction of the freedom of movement under the conditions of quarantine or isolation.

Any quarantine measures may result in restriction of human rights, it is, however, a compulsory measure aimed at protecting the health of citizens and, in some cases, their survival. The extent and severity of the restrictive measures, as well as their duration, have to be proved by medical and epidemiological experts on the basis of modelling results, analysis of statistical data and clinical analyses. As can be seen, model synthesis, as well as further modelling and their trials help to assess various developmental scenarios related to the spread of infection. This also helps to answer the question of the effectiveness of certain measures under certain environmental influences.

The unjustified imposition of restrictive measures may cause the destruction of economic relations, resulting in famine and other disasters. On the other hand, an overly liberal approach may lead to the uncontrolled spread of infections, the collapse of the

health system and death of numerous people. As can be seen, decisions that are made may have drastic consequences both for a separate region and for the country as a whole. That is why it is utterly important to conduct scientific research, collect statistical data and carry out modelling of the consequences of various restrictive measures. Rarely do researchers have sufficient data in order to conduct a holistic mathematical modelling, instead they often apply simulation modelling.

4 Selection of Modelling Approach for Quarantine Measure Efficiency

Mathematical models are traditionally divided into analytical and simulation models [9-11].

Analytical models are equations or systems of equations written in the form of algebraic, integral, differential, finite-difference and other relations and logical conditions. An analytical model is usually static. The analytical representation is only suitable for very simple and highly idealised tasks and objects, which as a rule have little in common with the real (complicated) world but are highly generalised. This type of model is usually used to describe fundamental properties of objects.

Complicated objects are rarely described analytically. Simulation models (dynamic) are an alternative to analytical models. Simulation models, in contrast to analytical ones, presuppose the construction of an algorithm representing the sequence of processes within the analyzed object. Then the behaviour of the given object is 'played' on a computer. Simulation models are used when the modelling object is so complex that it is impossible or highly difficult to adequately describe its behaviour with mathematical equations.

Simulation modelling allows a large model to be divided into parts (objects, "pieces"), which can be used separately, creating other, simpler or, conversely, more complex models. Thus, the main advantage of simulation modelling in comparison to analytical modelling is the opportunity to solve more complex problems. Simulation models can be gradually made more sophisticated without losing their efficiency. This reproduces the functioning algorithm of the system over time – the behaviour of the system, thereby imitating the elementary phenomena that make up the process, retaining their logical structure and sequence. This allows the initial data to provide information on the current state of the process at certain points in time, making it possible to estimate the characteristics of the system. Simulation models make it relatively easy to take such factors into account as the presence of discrete and continuous elements, non-linear characteristics of system elements, multiple random interactions, etc. which often cause difficulties in analytical analyses [12].

Simulation modelling is close to an object-oriented representation, which describes the natural way of objects, their state, behaviour, and interactions between these objects. Simulation modelling is currently the most efficient method of system analysis, it is often the only practically available method of obtaining information on system behaviour, especially at its design stage. A simulation model, unlike an analytical model, is

not a complete system of equations, but a carefully defined scheme with a detailed description of the structure and behaviour of the analysed object. Simulation modelling is characterised by the reproduction of the phenomena described by the model, while maintaining their logical structure, sequence of alternation in time, the interconnection between the parameters and variables of the analysed system.

A large variety of mathematical methods can be used in analytical models, often resulting in an optimal solution and sometimes enabling a sensitivity analysis. Unfortunately, however, analytical solutions do not always exist, whereas the existing ones are not always easy to find. As far as simulation models are concerned, the optimality of the solution is not guaranteed, and it is often difficult to obtain a solution that is at least somewhat close to optimal. Sometimes numerous simulation model trails are required in order to obtain an acceptable confidence in the "goodness" of any solution. Still, simulation modelling can be used to gather the data that is difficult or impossible to obtain with the help of analytical models. For instance, determining the influence of model parameters variability, or determining the behaviour of the model before it reaches a steady state, etc.

Simulation models are considered among the most promising when managing the economic objects. Generally speaking, for complex problems where time and dynamics are important, simulation models are considered one of the most popular and useful methods for quantitative analysis [13].

As a result, some peculiarities of the analytical modelling and simulation which are base of the selection of modelling approach may be formulated.

Specifics of Analytical Modelling:

1. Analytical models may be used to determine an optimal solution.
2. Analytical models tend to be difficult to formalise and formulate, sometimes they are impossible to formulate at all. Any analytical model has its own "complicating" factors, which depend on the specifics of the given model.
3. Analytical models usually offer average or stationary (long-term) solutions. In practice, it is often the non-stationary behaviour of the system or its characteristics over a short period of time that are important, making it impossible to obtain 'average' values.

Specifics of Stimulation Modelling:

1. Simulation modelling requires a large number of trials.
2. It requires assessment of a large number of possible alternative solutions.
3. It allows for multiple alteration of the model parameters.
4. It gives an opportunity to analyse complex behaviour scenarios of the system.
5. Simulation modelling can be run on a wide range of software specifically developed for it.

Having analysed the requirements, possibilities, advantages and disadvantages of both analytical and simulation modelling, one may conclude that it is the simulation modelling that should be used in order to assess the efficiency of applying restrictive

measures. This approach enables one to collect the data given different specific conditions and varying restrictive measures.

5 Overview of Epidemiology Models

Many scientists have tackled the task of modelling the spread of epidemics. One of the first references to the construction of mathematical models goes back to the publication titled ‘Mathematical Methods for Evaluating the Effectiveness of Smallpox Vaccination Methods’ by D. Bernoulli in 1760 [14]. However, the most active development of mathematical models of epidemic spread took place in the twentieth century. The following works are worth mentioning: Brownlee (1906) [15] – he applied a statistical approach to predict the immune protection: epidemic theory (Pearson’s distribution); W.O. Kermack, A.G. McKendrick (1927) [16] – the ‘law of mass action’ was applied for the first time, according to it, the number of new infections within the population is directly proportional to the product of the current number of the susceptible and infected individuals. Elaboration of the differential SIR model (Susceptible - Infected - Recovered); L. Reed, W.H. Frost (1931) [17] – used chains of binomial distributions to describe the number of infected individuals at each time interval. Noble (1974), Bailey (1975), Murray, Staley & Brown (1986) worked on spatial SIR model [14].

Unfortunately, the twenty-first century did not see the victory over diseases and epidemics, so consequently, numerous research carried on: model of the spread of tuberculosis – A.A. Romanjuha (2004), model of the outbreak of the Severe Acute Respiratory Syndrome (SARS) in China in 2003 – J. Zhang (2005) [18], mathematical model of the spread of COVID-19 coronavirus from the source of infection (bats) to humans in Wuhan Province – J. Chen (01.2020) [19]. Modelling is often based on machine learning approach. [20].

6 Model Description and Development of Software

Simulation software architecture may be presented in the form of four separate modules (Fig.1).

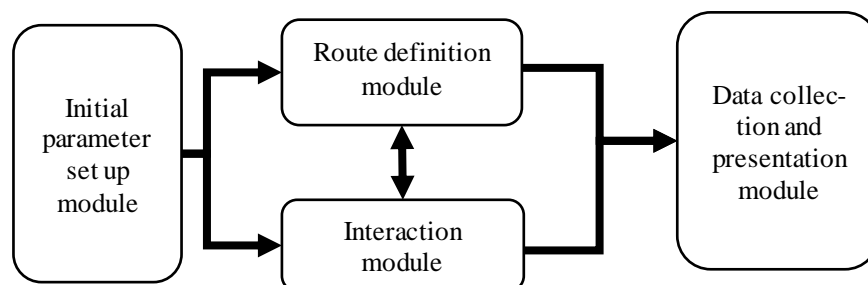


Fig. 1. – Scheme of a software modular architecture.

Initial parameter set up module – is an interface element enabling the user to specify parameters and ensuring a flexible and user-friendly tool to manage route defining models, setting up the principles and nature of virus spread, and the availability of defence mechanisms. Unfortunately, at the moment, the software tool is still under development, therefore, its interface allows one to specify the size of the test group, to select the available personal protective measures, including the percentage of the test group members who will be using it, to select the simulation scenario, and to specify whether the place is forbidden to visit. Most of the route definition parameters, maintenance of social distancing or viral infection behaviour have to be set in the programming code;

Route definition module – a wide range of strategies may be implemented thanks to route definition methods. For example, defining a route to visit an accommodation (a private house or a multi-storey building), an office, a shop, a school, a mass event. Moreover, the test group will not be homogeneous, its members will stick to the behavioural strategy given to them at the beginning of the simulation. For instance, 10% should head towards a school facility, hence 10% of the test group will try to enter a facility associated with the school. A visit schedule can also be specified, but there is no differentiation between classroom distribution. In the school facility itself, members of the test group move chaotically, if current facility is forbidden to visit, they will move evenly around the allowed facilities or walk around the city;

Interaction module – specific interactions between the members of the test group as well as with the source of infection. This module manages the principles of infection and consequently patterns of the viral disease spread. Furthermore, the software scripts may contain the principles of immunity build up, characteristics of the nature of the disease, availability of protective measures and their effectiveness, presented in terms of the likelihood of infection;

Data collection and presentation module – is used to gather and visualise the information on the process of simulation.

7 Model description and software development

Main chain algorithm may be described as follows:

Step 1. Setting up the parameters of simulation, namely type of protection measures, size of the test group, type of scenario, location, route definition algorithms for the test group, parameters of interaction and infection spread;

Step 2. Note the information on simulation in the databank;

Step 3. Placing the test group onto the location;

Step 4. Moving the test group around the location according to the scenario;

Step 5. Fulfilling the requirements for the “Encounter” script launch. If there are no members of the test group within the infected area, go to Step 4, otherwise, go to Step 6;

Step 6. If the first member of the test group is infected, go to Step 9, otherwise, go to Step 7;

Step 7. If there are more members of the test group infected, go to Step 11, otherwise, go to Step 8;

Step 8. Running the “Encounter of the Healthy” script, move to Step 15;

Step 9. If there are more infected members of the test group, go to Step 10, otherwise, go to Step 11;

Step 10. Running the “Encounter of the Infected” script, move to Step 15;

Step 11. Calculation of the infection parameters. The probability of infection is determined according to the set up parameters and the availability of personal protective measures;

Step 12. If members of the test group are infected, go to Step 13, otherwise, go to Step 15;

Step 13. Running the “Infection” script, move to Step 15;

Step 14. Running the script “Suspected Infection”, go to Step 15;

Step 15. Collection, processing and saving the statistical data, creating diagrams;

Step 16. If conditions for simulation continuation are met, it means that there are still some infected members of the test group, go to Step 4, otherwise, go to Step 17;

Step 17. End of simulation.

The simulation tool implies the possibility of using various models, however, the current version of the tool is based on the main probabilistic characteristics of the viral infection spread and the course of the disease taken from the WHO publications, as well as the article “Clinical characteristics of 1007 intensive care unit patients with SARS-CoV-2 pneumonia” by Glybochko P, Fomin V, Avdeev S, et al. [21]

The software tool is developed in the Unity environment, which enables visualisation of objects’ movements, selection of varying route definition algorithms and setting up rules for viral infection behaviour with the help of scripts. Furthermore, it makes it possible to select special algorithms for route definition and influence the likelihood of infection by introducing individual protection equipment. Altogether this enables simulation under varying conditions. Fig. 2 illustrates the development environment with the elaborated tool.

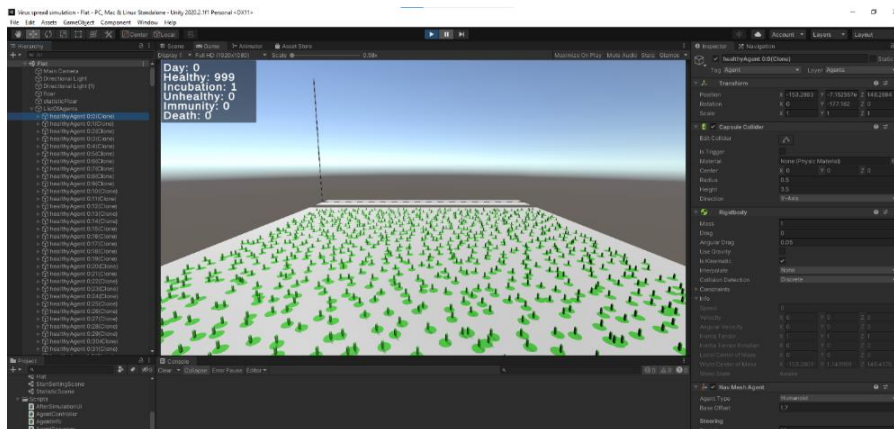


Fig. 2. Example of the development environment.

In order to start the simulation, one has to select and set up a range of initial data (Fig. 3):

- SelectMaskTypes – availability and type of individual protection equipment (masks and respirators);
- Select Population – sets up the size of the test group for the simulation;
- Select Scene – sets up the simulation scenario

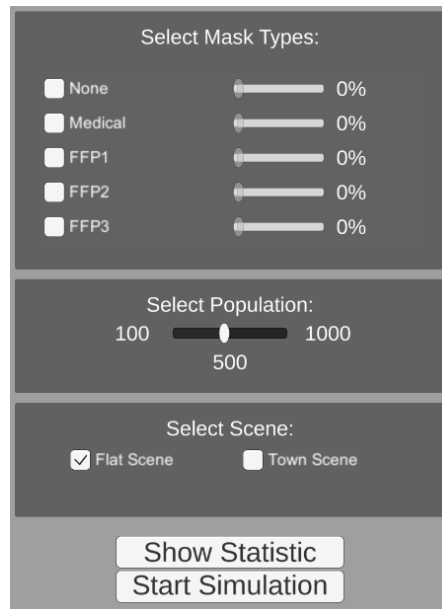


Fig. 3. Example of setting the initial conditions for the simulation.

8 Discussion of Modelling Results

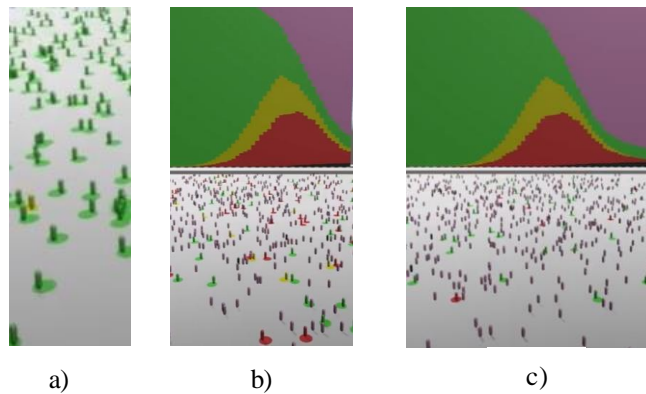


Fig. 4. Simulation results.

A number of computational experiments with the elaborated tool were realized. Fig. 4 shows: a) start of the simulation with the test group interacting in the open air, b) and c) the simulation process at different stages. As can be seen, the software illustrates the process of simulation and presents the results and dynamics of statistical data collection. The full simulation process can be seen on <https://www.youtube.com/watch?v=abU-YzpcrsQ>.

Additionally, at the end of simulation one may obtain various numerical data, Fig. 5.

Day: 2 Healthy: 999 Incubation: 1 Unhealthy: 0 Immunity: 0 Death: 0	Day: 29 Healthy: 671 Incubation: 193 Unhealthy: 106 Immunity: 28 Death: 2	Day: 57 Healthy: 75 Incubation: 11 Unhealthy: 47 Immunity: 841 Death: 26
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Fig. 5. Example of obtaining numerical data at different simulation stages.

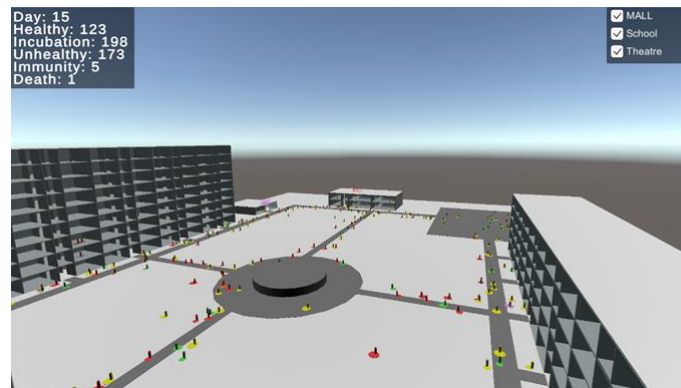


Fig. 6. – Example of a Town Scene.

Town Scene simulation (Fig.6). In the top right corner one can allow or block access to objects, simulating the introduction of restrictive measures, the results of access allowance or denial are shown in Fig. 7-8.

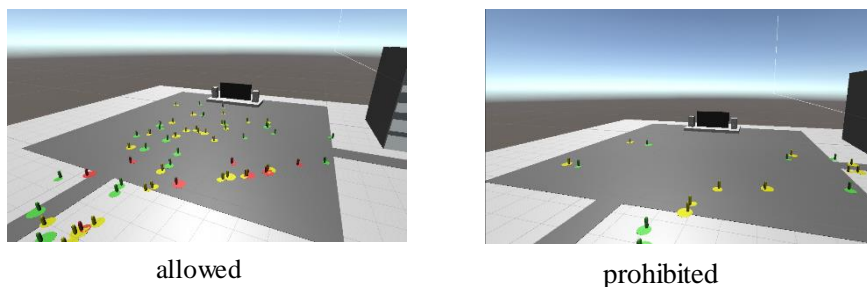


Fig. 7. – Example of ban on access to public events.

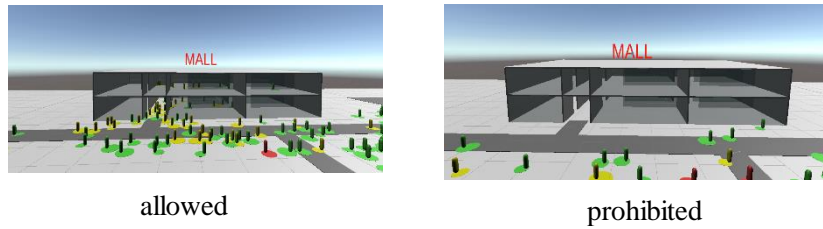


Fig. 8. – Example of ban on access to Mall.

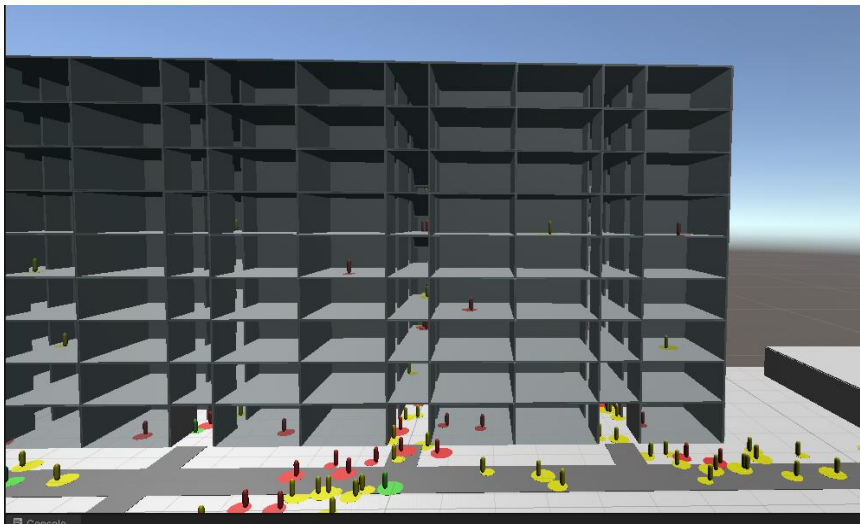


Fig. 9. – Example of enforcing quarantine or self-isolation.

Once a person has had contact with an infected individual, there is a certain likelihood that he or she will head ‘home’ (Fig.9). ‘Home’ is considered a multi-storey structure with numerous flats; the person occupies the nearest vacant flat and stays in it for the anticipated period of illness. Given a certain simplification, this behaviour algorithm can be perceived as hospitalisation. In this case, however, such factors as type and intensity of treatment, availability of medication and protective equipment, ways of patients transportation, as well as availability of a certain part of the test group, who will take on the role of medical staff, etc. all have to be taken into account. It will be implemented in the extended version of the software.

9 Scope of Application and Further Improvement of the Simulation Tool

Simulation results allows to compare different alternatives of the decision-making in order to choose the most efficient one. Furthermore, simulation results may be used to elaborate anti-epidemic measures, given the availability of the dynamics of the number

of the infected and those who need medical assistance, it is possible to prepare the infrastructure and reduce the negative impact on the region, population and economy in general.

Apart from the described application opportunities, the current version of the simulation model has a range of restrictions, which could be addressed by creating special scenarios. Namely, by introducing certain route definition algorithms for the test group and by adding the scripts that enable specification of a wide number of characteristics for every element of the test group:

- other parameters leading to changes in population are disregarded (natural death, effects of other diseases, migration, relocation, etc.);
- lack of age and sex differentiation;
- possibility of vaccination;
- availability of infrastructure objects and transportation hubs;
- hospitalisation;
- duration of stay in the area with the risk of infection.

The main restriction of the tool remains its performance. The software requires a lot of computing power given a large size of the test group (more than 10,000), especially in complex scenarios where it is necessary to run collision and route definition scripts for each item.

In closed rooms such as shops or schools, the number of test persons should not exceed 1,000. In addition, congestions in closed rooms are also not uncommon, this is due to the fact that the elements cannot pass through each other and have to keep social distancing.

The modeling process for human behavior inside buildings is described in «Distributed Simulation of Crowds with Groups in CrowdSim» [22].

Furthermore, simulation models have to take social and economic factors of the region into account [23]. Simulation results may be used for development of strategies to manage disasters [24 – 25], elaboration of infrastructure objects operation plan [26], reengineering and modernisation of public utility systems, including power sector [27].

10 Comparison of modeling results

Table 1. Comparing the results of the modelling.

Day	0			25			40			70		
	A	B	C	A	B	C	A	B	C	A	B	C
Healthy	999	999	999	819	824	819	179	174	173	74	71	67
Incubation	1	1	1	101	99	100	203	204	182	0	0	0
Un-healthy	0	0	0	69	68	70	327	329	329	1	0	1
Immunity	0	0	0	10	8	10	283	285	308	894	899	901
Death	0	0	0	1	1	1	8	8	8	31	30	31

In order to compare the ability of the application to achieve acceptable modelling results, we have implemented the same model in the NetLogo environment and using the GPSS language. A part of the results is shown in Table 1.

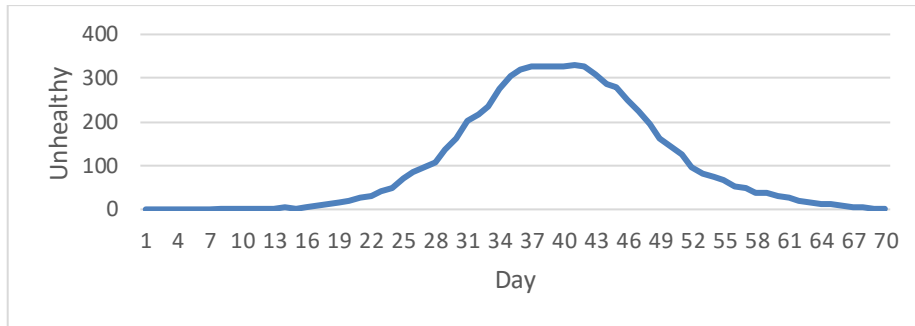


Fig. 10. Dynamics of the Unhealthy parameter when modelling in the developed application.

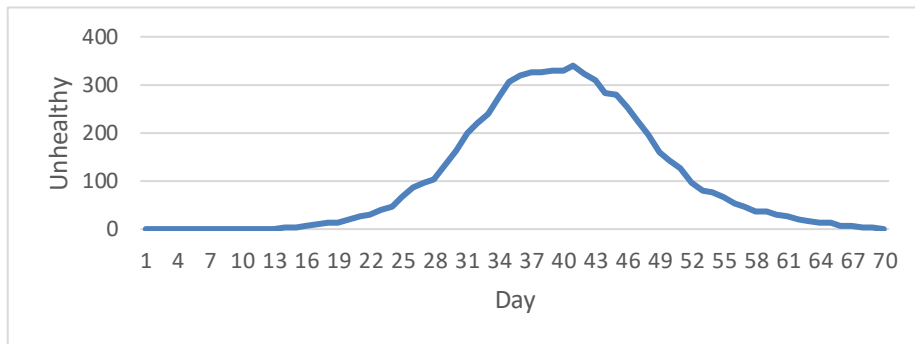


Fig. 11. Dynamics of the Unhealthy parameter when modelling in NetLogo.

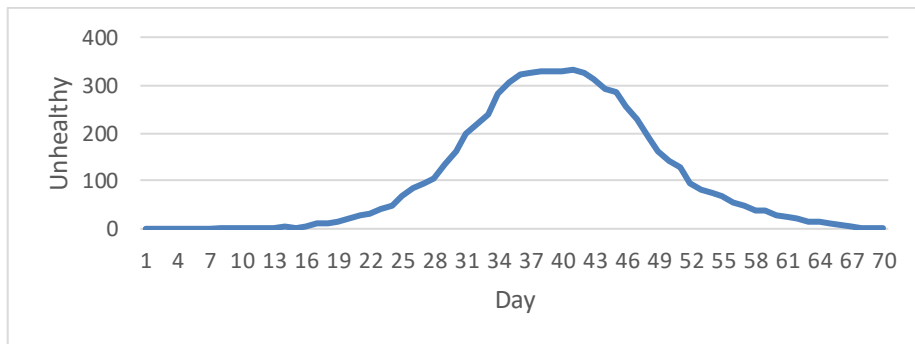


Fig. 12. Dynamics of the Unhealthy parameter when modelling using GPSS

In Table 1, column A is the result of the simulation with developed application, column B contains the NetLogo simulation results, and column C is the GPSS simulation result. As can be seen, the simulation results are quite similar, as confirmed by the graphs, which illustrate the dynamics of the simulation. The following graphs (Figures 10-12) illustrate the dynamics of "Unhealthy". Despite the slight local differences, the general dynamic is the same.

Conclusions

A software tool, enabling by means of simulation modelling to analyse the effectiveness of restrictive measures as well as the application of personal protective equipment, has been developed. The software was created in the Unity environment. The software allows the setting of the size of the test group, availability and type of individual protection equipment as well as varying simulation scenarios. As a result of the simulation, there is data available on the statistics and dynamics of the number of the infected, healthy, immunised and dead. Due to the possibility of creating scripts in the Unity environment, it is possible to recreate unique situations during the simulation and to evaluate the effectiveness of restrictive measures. The opportunity to simulate and evaluate the effectiveness of restrictive measures helps to justify the appropriateness of such restrictions and to choose the most efficient solution. This will minimise losses, both in terms of human casualties and economic indicators. The results of simulations carried out in different environments turned out similar. The dynamics of changes in key parameters differ by less than 3% on average and do not exceed 5% at each iteration step. Such modelling results suggest that the proposed simulation tool provides correct results and may be used for research, forecasting and decision-making.

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