Application of Agent-Based Modelling in Learning Process

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With advances in information and communication technologies and rapid computing and technological progress, modelling, and simulation of real problems, has become the most important teaching and learning method in educational process. Representing and explaining processes through simulations can enable students to easier understand these processes and discover the essential properties of a system. In many situations, in learning different subjects it is not possible to experiment with real objects to find the right solutions, therefore modelling and simulation can be used to build models that represent the real systems. Agent-based modelling (ABM) is a powerful simulation modelling technique, that can be easily incorporated in learning and teaching processes. Agent based modelling (ABM) is a relatively new method compared to system dynamics and discrete event modelling. In ABM a system is modelled as a collection of autonomous decision-making entities called agents, that can interact among each other's. In this paper, the agent-based modelling simulation is considered as a tool in educational process for learning and teaching different subjects. Anylogic software is used for some simulation examples of agent-based modelling that can be used in educational process.

Povzetek: Programska oprema Anylogic se uporablja za nekatere simulacijske primere modeliranja na podlagi agentov, ki se lahko uporabljajo v izobraževalnem procesu.

1 Introduction

Simulation is an imitation of the operations of real-world processes or a system over time. The behaviour of the system over time is studied by developing a simulation model. It is common for models to be represented as a set of assumptions about the system itself. These assumptions are expressed through mathematical logical or symbolic relations between entities that are objects of interest in the system. Simulations can be used at the design's stage before the system is built but also on existing systems to determine whether potential changes will have an impact on system performance. Therefore, simulations can be used either as a tool to predict how changes will affect an existing system or as a tool to predict the performance of a new system under a different set of conditions. Sometimes the evolving model can be solved mathematically. Then, the solution can be obtained by using differential equations, probability theory, algebraic models, or other mathematical techniques. This solution usually consists of one or more numeric parameters called the system performance measure. However, most real systems cannot be solved mathematically because they are too complex. In this system, numerically based simulations can be used to imitate system's behaviour over time. The simulation data are collected through system monitoring. The data generated during the simulation is used to evaluate the performance of the system [1-4]. For simulation, there are three main methods: Discrete Event Simulation, System Dynamics, and Agent Based Simulation.

The Discrete Event Simulation (DES) models a process as a series of discrete events. Each event occurs at a particular point in time and represent a change of state in the system. Discrete event simulations are entity driven. The entities represent customers arriving in the system for servicing [5,6].

System dynamics (SD) are used to understand the nonlinear behaviour of complex systems over time. In SD three main objects are considered; stocks, flows and delays. Stocks are basic stores of objects; flows define the movement of items between different stocks in the system and delays are the delay between the system measuring something and then acting upon that measurement [5,6].

Agent based simulation (ABS) is a relatively new method compared to system dynamics and discrete event modelling. With agent-based modelling, the entities known as agents must be identified and their behaviour defined. The agents may be people, cells, households, vehicles etc [5-10].

In this paper, agent-based modelling and simulations and their application in the educational process is considered. It is shown how the agent-based simulation methods can help for easily and better understanding the basics of some processes, that otherwise are difficult to imagine and understand.

Also, it is shown that this type of simulation can be used in education process, especially in learning math's subjects for math students and students of computer science also for learning and teaching science for medical students, or subjects connected to business and organization sciences and students learning that problematics.

In the paper are described models which are implemented in AnyLogic Simulation and Modelling Software. We choose this simulation software because of is its availability and its simplicity for use because it is free simulation software originally intended for educational process.

First, we describe epidemiological model SEIR-D and its usefulness for learning and understanding to the medical students, math students and students of computer science. The next model considered, is a model of Hospital Emergency Department. This model is important for the business students, medical students, and math students. And at the end, we consider example from a real world, that also can be used for easily understanding of different subjects used for math students, computer science students and business students. Precisely, we describe model of market that starts selling a new consumer product.

With considering of these simple models, the students can easily understand the basic concepts of subjects connected to this simulation and can visually and dynamically present something that can be difficult to present or imagine otherwise.

2 Agent based modelling

There are many definitions from different experts about what agents in systems are, but all agree that agents are a software component that is autonomous and aims to act as a human agent (collect data, process data, and interpret data) [6].

Agent - based modelling (ABM) is one of the newer approaches in computer simulation. This type of simulation is mainly used to model complex system, and it is based on autonomous agents and their interactions.

Agent-based models (ABMs) are computational structures where system-level behaviour can be obtained by the behaviour of individual agents. ABM basically contains three elements: agents, an environment, and rules governing each agent's behaviour and its local interactions with other agents and with the environment.

Agents have their own characteristics, rules of making decision, ability to interact with other agents in the system and environment based on which they can change and adjust their behaviour [6, 7].

This method of modelling must identify active entities, or agents and their behaviour must be defined. Agents can be people, households, vehicles, equipment, products, or companies, more precisely anything, that is related to the system [7].

In recent years, ABM has been used in various branches of science, and the largest application they found in the social sciences. It is often used to simulate the phenomenon in economic and technical sciences. Until the appearance of these models, modelling of phenomena in society were most often reduced to a simplified presentation of social phenomena, and very often they were only verbal models.

In ABM models, which models social phenomena and processes; agents represent people, and through their mutual communication and rules of conduct are modelled social processes and social communication. The main assumption is that people and their social skills can be realistically modelled.

Agent-based modelling and simulations provide more realistic models and lead to new possibilities in modelling and simulations. Agents used in these simulation models originate from the fields of robotics and artificial intelligence. Today, ABM agents are not more related to the design and understanding of artificial intelligence. The basic application is in modelling of human social behaviour, social phenomena and individual decision making.

With the obvious benefits that agent-based modelling and simulations bring, the number of simulation models of different social behaviours are increased. Today, it can be done many micro simulations that could not be done before a few years.

We are using ABM for modelling different models that can help students to easily learn and teachers to better teach different natural, social and math subjects.

3 Agent based modelling in education process

Knowledge application in realistic situations has been shown to be verry important in the process in developing complex skills. Students can acquire high level of expertise in complex real problem-solving tasks if they have enough previous knowledge and enough practice. Practice can be obtained with facing real problems which correspond to a professional field. In educational programs, the opportunity to engage in real-life problem solving is very limited. These limitations make practice in real-life situations often inaccessible especially for novice learners. Therefore, simulations can often be used in education settings. In STEM (science, technology, engineering, and mathematics) education, modelling and simulation can be used to facilitate a deeper understanding of concepts and relationships between objects and problems, easily problem solving, and decision making. Agent based modelling and simulation can be used in medical education, where simulations are used to enhance diagnostics competence, technical skills for future doctors and nurses. Agent based simulation can also be used in other fields, such as teaching education, engineering, and management, also can be used by the students of economic, biology, political science [11 -18].

Some of the most used simulation software in education are: EcoBeaker, SimBio, NetLogo, MIMOSE, AgentScript, Swarm, JAS-mine and Anylogic.

NetLogo is a multi-agent programmable modelling environment for simulating natural and social phenomena.

It is especially well suited for modelling systems that are developing over the time. NetLogo allows sophisticated modelling and allows the experienced programmers to add their own Java extensions. This software is used by many hundreds of thousands of students, teachers, and researchers from whole world [19].

MIMOSE consists of a model description language and an experimental frame for simulation of the described models. The main purpose of MIMOSE simulation software was the development of a modelling language that considers special demands of modelling in social science, especially the description of nonlinear quantitative and qualitative relations, stochastic influences, birth and death processes, and micro and multilevel models [20].

EcoBeaker is an ecological simulation program. This program is designed primarily for education goal but can be used and for research models. EcoBeaker gives a two-dimensional computer world into which agents are placed and their behaviours are designed [21].

Swarm is a simulation software package for multi-agent simulation of complex systems developed at the Santa Fe Institute. It is made to be a useful tool for researchers and students in many disciplines. The basic architecture of Swarm is the simulation of collections of concurrently interacting agents: with this architecture, a large variety of agent-based models can be implemented [22].

SimBio is a simulation software for teaching biology. The software can be used for biological systems such as cardiac cells, epithelial cells, and pancreatic β cells. With this software can be simulated experiments in evolution, cell biology, genetics, and neurobiology. SimBio is written in Java, uses XML and can solve ordinary differential equations [23].

AgentScript is a minimalist agent- based modelling framework. This tool is based on NetLogo agents' semantics. Its goal is to promote an agent-oriented programming model in a deployable CoffeeScript /JavaScript implementation [24].

JAS-mine is a Java-based computational platform that features tools to support the development of large-scale, data-driven, discrete-event simulations. JAS-mine is specifically designed for both agent-based and microsimulation modelling, anticipating a convergence between the two approaches [25].

AnyLogic is a multimode simulation modelling tool developed by AnyLogic (formerly XJ Technologies). Supports simulation methodologies based on agents, discrete events, and system dynamics. AnyLogic is a cross-platform simulation software running on Windows, macOS and Linux.

AnyLogic is used to simulate markets and competition, healthcare, manufacturing, supply chain and logistics, retail, business processes, social and ecosystem dynamics, defense, asset management, pedestrian dynamics, and road traffic.

AnyLogic models can be based on any of the three methods in simulation modelling: discrete events, system dynamics or agent-based systems [26].

The comparison of different simulation software used in education, mentioned before, and their main features are given in Table 1 .

Table 1: Comparation of different simulation software used in education

	Operating system	**Programming language**	**User support and License**	**Model development effort**	**Models' scalability level**	**Subjects covered**	**User friendliness**
EcoBeaker	Windows and Mac	No programming skills required	CD with tutorial/ Proprietary, not free for use	Simple, easy	Small scale	Ecology, conservation biology, and evolution	high
SimBio	Windows and Mac.	Java	Tutorials, Interactive Chapters, Workbook Labs, Frequently Asked Questions / General Public Licence, free for use	Moderate	Medium scale	Ecology, Evolution, Env Science, Cell Biology. Genetics, Conservation, Biology, Physiology	Medium to high
NetLogo	Cross-platform: JVM, (difficult to install on Windows)	NetLogo	Documentation; FAQ; selected references; tutorials; third party extensions; defect list; mailing lists /General Public License, free for use	Simple, easy to moderate	Medium to high scale	Different natural and social sciences	medium

MIMOSE	Linux, Windows (difficult to install on Windows)	Java	Tutorial for installation and use/ Open sourced, free for use	Moderate	Small scale	Social science	poor
AgentScript	All OS with Browsers	Javascript, NetLogo	Tutorials, Example Models /Open source free for use, GPLv3 license	Simple, easy	Small scale	Primary for social sciences but usable for natural sciences too.	medium
Swarm	Cross-platform	Java; Objective-C	Wiki; tutorials; examples; documentation; FAQ; selected publications; mailing lists/ General Public License, free for use	Hard, Complex	Extreme scale	Primary for social sciences .	poor
JAS-mine	Cross-platform: JVM	Java	Tutorials, presentations, videos/ Eclipse plugin, free for use	Simple, easy to moderate	Medium scale	Social and natural sciences, primary social, discrete-event simulations, including agent-based and microsimulation models	medium
Anylogic	Linux, macOS, Windows	Java	Demos; training; online community; ask a question; online help; tutorials; consulting services/ Free Personal Learning Edition available	Moderate	High scale	Different natural and social sciences, discrete events, system dynamics or agent-based systems	medium to high

In continuation in this paper, we give examples of the use of agent-based modelling and simulations in different areas to facilitate the study and understanding of certain problematics. We used AnyLogic as a software for implementing these examples.

We chose AnyLogic because as mentioned above and as given in Table 1, AnyLogic compared to other tools has the best features in terms of ease of use, free to use, use in multiple areas, adaptability, utility in natural and social sciences and user friendliness. And considering all these features, we decided to use AnyLogic for agent-based modelling in education. We have selected three models that can be used by students of social and natural sciences, or more specifically, medical students, biology students, mathematics and computer science students, economics and business students.

4 Examples of agent-based modelling in anylogic used for education

A. Epidemiological models

Epidemics of infectious diseases are triggering interest in predicting epidemic dynamics. Agent-based simulations can be used for education process for the medical students involved in public health and epidemiology. For this goal, universities and research centres are using simulations as teaching tools for these students.

Simulation of spread on infectious disease is playing a central role in controlling spread of infection and making prediction that can help monitoring of epidemic [27]. Some of important epidemiologic models are SI, SIS, SIR, SIRS, and SEIR, SEIR -D model without vital dynamics and with vital dynamics.

Here is given an example, where SEIR-D model without vital dynamics is explained.

In the SEIR-D model, the total population of N individuals are divided in 5 categories: susceptible (S), exposed (E), infected (I), recovered (R), and death (D).

- Susceptible – the started population people who are not infected by the virus.
- Exposed - people who are infected but who can’t infect others
- Infectious - people who are infected and who can infect others
- Recovered – people who have recovered from the virus.
- Death – people who death as consequence from infectious disease.

This model relies on the assumption of a totally susceptible population at time t0 as a starting point of the pandemic.

The goal of considering of SEIR-D is to explain the variation of S(t), E(t), I(t), R(t), D(t). This model can help medical students in public health and epidemiology, for easy understanding of a spread of the any infectious disease.

The SEIRS-D model in Anylogic simulation software is represented in Fig 1.

In Anylogic, stocks are used to represent real-world processes (material, knowledge, people, money, etc) and it define static part of the system. Flows define their rate of change - how stock values change in the time, and it define the dynamics of the system.

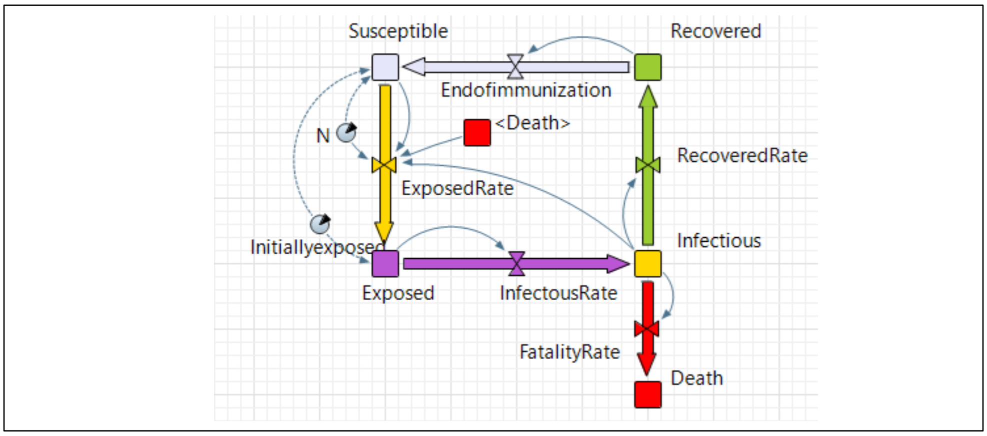

Figure 1: SEIR-D model in AnyLogic

AnyLogic automatically generates a stock's formula according to the user's stock-and-flow diagram. AnyLogic automatically created these formulas when the flow is added. This process can be easily done by students or teachers to visually represent real situation of spreading the disease.

Next step is defining the parameters and dependencies. Seven Parameters are defined: Total Population, Infectivity, ContactRate, AverageIncubationTime, AverageIllnessDuration, AverageImmunizationperiod, FalalityRate, with their default values (As shown in Fig. 2).

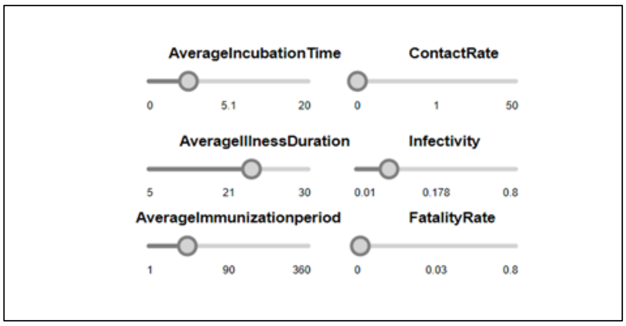

Figure 2: Parameters in the model

- Total Population=2000000
- Infectivity=0.01
- ContactRateInfectious=1
- AverageIncubationTime= 5.1 days
- AverageIllnessDuration= 21 days
- AverageImmunizationperiod = 90 days
- FatalityRate = 0.03

Initially, the number of infected persons is 1. I(0) = 1, and the number of the exposed persons E (0) = 20. The output of the model run, is given in Fig 3.

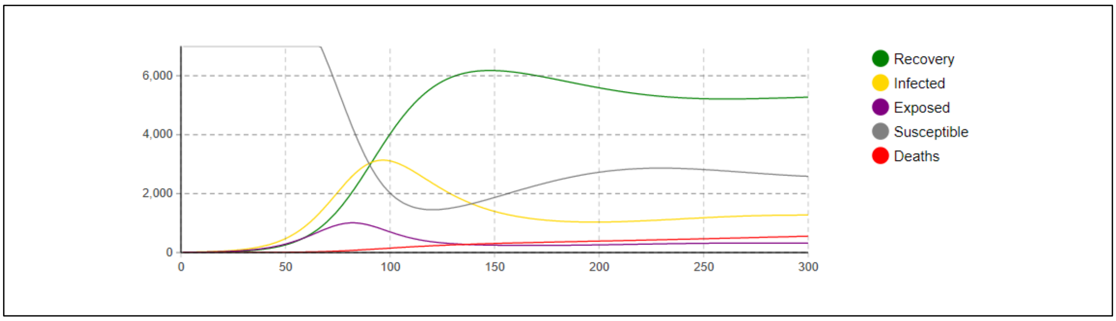

Figure 3: Output from SEIR-D model

The medical student, using this model, has powerful tools for prediction of the spread of the infectious disease. This model can be modified by students to track some epidemic spread (for example COVID-19 pandemic) [28]. After discussing death rates, prevention and treatment options and genetic and age-related variation in host susceptibility, the students can decide to focus on transmission into their model. Through discussion with the professors, they can realize how the transmission of infection disease can occur. This exercise with extending a model to reflect specific biological assumptions helps students understand the iterative process by which models are developed. Also, students can understand the utility of simpler models to understanding key features of the system's behaviour [29].

On the other hand, this model can be important for math and computer science students, because the model is given by the system of the following differential equations:

$$\frac{dS(t)}{dt} = \xi R(t) - \frac{\beta}{N-D} I(t)S(t)$$

$$\frac{dE(t)}{dt} = \frac{\beta}{N-D(t)} I(t)S(t) - \alpha E(t)$$

$$\frac{dI(t)}{dt} = \alpha E(t) - \gamma I(t) - \Delta I(t)$$

$$\frac{dR(t)}{dt} = \gamma I(t) - \xi R(t)$$

$$\frac{dD(t)}{dt} = \Delta I(t)$$

This model can be used as a good example of how differential equations can be implemented in epidemiological models.

Advantages of using agent - based simulation in epidemiology are in the fact that the mathematical representation of processes enables transparency and accuracy regarding the epidemiological assumptions. This allows students with their professors to test understanding of the epidemiology disease by comparing model results and results obtained from observation. Also, mathematical models can help predicting outcomes and adjustment of measures for stopping the spread of infections, as well as taking new appropriate measures.

B. *Hospital emergency department simulation*

This model is important and can be applied in process of education for the business students, and for a math and computer science's students.

For business students, the model can be used for well organizing of the healthcare systems. For the math and computer science's students is good example for hybrid model that integrates methods of discrete event simulation and agent-based simulation.

Overcrowding in the Emergency Department (ED) is one of the most important issues in healthcare systems. This situation leads to an increase in length of stay, a decrease in the quality of care and the burnout of nursing staff.

Two major causes of this congestion are identified, the first one is unjustified Emergency Department visits and the second one a lack of downstream beds. An unjustified emergency visit concerns a patient who have no health problem or a non-emergency health problem. This situation creates a work overload for the medical staff. The lack of downstream beds increases the length of stay in the Emergency Department because patients must wait for a bed in a relevant medical unit. Sometimes patients are admitted to a medical unit that is not adapted to their pathology to decrease the ED congestion. This situation is problematic because it reduces the quality of care.

First the patients come to the emergency department of the hospital, in the department they are checked whether they are emergency cases or not. In case of an emergency and in relation to the condition of the patient with an emergency, some mandatory medical tests are performed, such as different X-rays of certain parts of the body or other diagnostics tests.

For the emergencies, there must always be beds available in the hospital and after the medical tests are performed, it is decided whether to keep the patient and to determine his diagnosis or just to determine the diagnosis and patient can leave the hospital.

If the case is not urgent, the patient's vital signs such as pulse, temperature, blood pressure and respiratory rate are checked. After checking patient's vital signs, his treatment is determined. Because these patients are not urgent from high degree, additional medical tests may not be needed, therefore they can only be diagnosed if necessary and discharged from the hospital, but still, some can leave without the need for a diagnosis.

For the successful development of this simulation, a Discrete event simulation model and agent-based simulation model in Any Logic program is used. In classic discrete event tools, the entities are passive and can only have attributes that affect the way they are handled. In AnyLogic multimethod simulation software, entities and resources can be modelled as agents with individual behaviour and state changes.

In this simulation triangular distribution is used because the exact rate of patient arrival is not known, therefore, a minimum, a most probable, and a maximum value for a triangular distribution are set.

The model in Anylogic is presented in Fig 4.

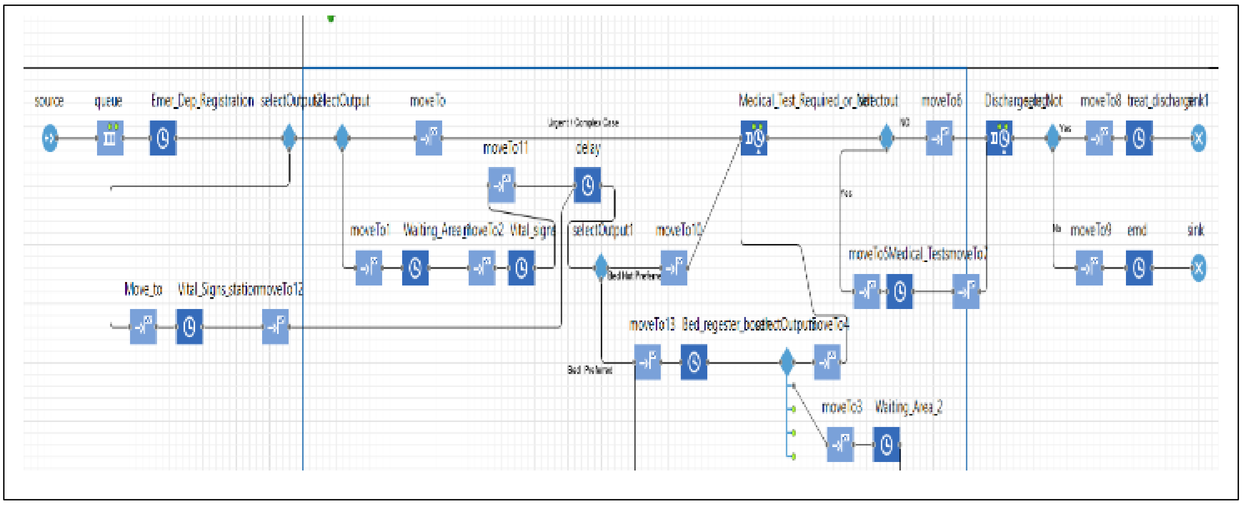

Figure 4: Emergency department model in anylogic

The result of simulation is given in Fig 5.

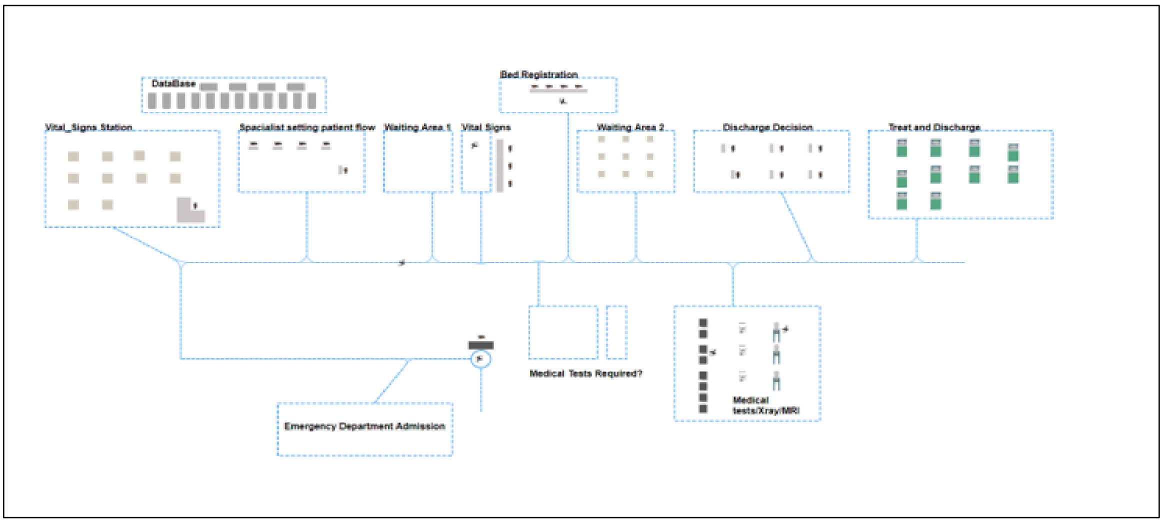

Figure 5: Output from simulation

This simulation can be helpful for the students of business and other organization sciences, managing and logistics, also and computer science students. The model can be helpful in the process of improving organization on the Hospital Emergency Department, to obtain optimal number of rooms, beds, and some other things for each sub-department of the ED, as well as have an estimated price for the ED, to optimally serve patients entering the ED with a known arrival rate.

This simulation can be useful because students can experiment on the simulation model instead of real Hospital Emergency Department.

The students can modify appropriate parameters and estimate output results from these parameters. Therefore, using this model students can easily manage with real problems like this one.

C. Market models

An agent-based model of a costumer cinema is considered for this example. In this model each costumer is an agent. The model includes 5000 people who have not seen the movie in the cinema, but a combination of advertising will eventually lead them to purchase the ticket to watch it. Also, advertising's influence on consumer demand is considered, by allowing a specific percentage of them to become interested in purchasing the ticket during a given day. Advertising effectiveness = 0.1 determines the percentage of potential users that become ready to buy the product during a given day. In Fig 6 is presented diagram of Cinema model presented in AnyLogic.

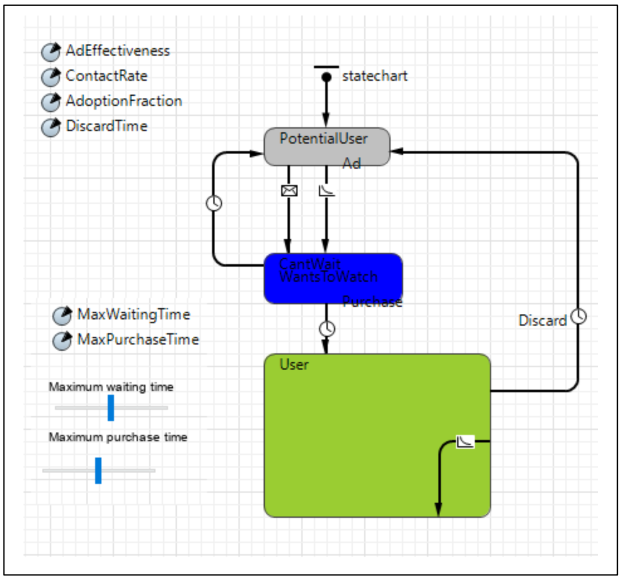

Figure 6: Cinema model

The parameters that are used represent several functions. The first parameter AdEffectiveness defines the percentage of potential users who become ready to buy the ticked and watch the movie during a given day. The second ContactRate represent how many contacts a person has per day with other PotentialUsers. The third AdoptionFraction is used to show us how much the ContactRate (the contact between two PotentialUsers) has affection. The last parameter, DiscardTime, represents how much time will the User wait to become PotentialUser again.

There are two more parameters to test the impatience of the customers. MaxWaitingTime, which is the maximum time a user will wait for the product (in this case, seven days), and MaxDeliveryTime, which is the maximum time for delivery a product (in this case, 20 days).

When the program is run, the 5000 population that are previously selected are obtained. Mostly there are gray Potential Users because the patience is very low and the max waiting time in this case is 7 days. The yellowGreen which are the Users are less and when they are done with watching the movie, they cannot go back for another 6 months.

This Cinema model simulates how 5000 people will react if they all are PotentialUsers and waiting to purchase one ticked for the one movie in the Cinema. From this model it can be concluded that 5000 people is a lot for just one selling counter and the waiting line is too long, which means that the customers will have high impatience and most of them won't wait, eventually quit, and go back to PotentialUsers. Therefore, if the purpose of the model is to sell tickets to 5000 people there must be more than one selling counter, therefore the waiting line won't be too long.

The output from simulation in given in Fig 7.

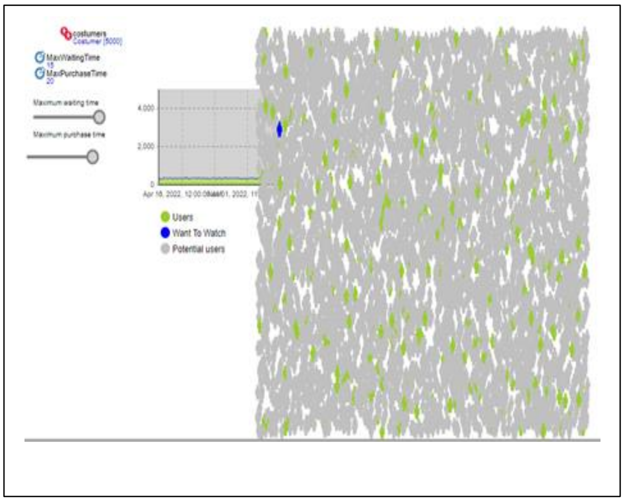

Figure 7: Output from Cinema model

This model can be good example for computer science students, economics, and business students. With making different adjustments of the parameters, students can watch changes of the behaviour of the model and can easily understand how appropriate changes reflected in consumer behaviours and whole system dynamics and can improve customer satisfaction. This model can help students to make market predictions. Students can easily apply and extend this obtained knowledge to real problems like this.

5 Conclusion

Rapid advances in computing power and increasing use of ICT in all aspects of life have made agent-based modelling and simulation (ABMS) feasible and appealing tool for easily studding teaching and understanding different subjects. Simulation-based learning can offer learning with approximation of practice, overcoming limitations of learning in real-life situations. Performing modelling and simulation activities in educational environments can be an effective tool for learning complex and dynamic systems. Students using simulation can be more motivated for learning, gaining new skills, easily understanding subjects, gaining intuition, and making generalization. The opportunity to alter and adjust real life aspects and situations, in a way that facilitates learning and practicing makes simulation an effective educational tool. Simulation-based learning can start early in study programs because it can be effective for beginners and advanced learners too. Simulation models could be used as a tool in education system, from primary and secondary school and for higher education in learning and teaching subjects in undergraduate curriculums.

Agent-based modelling and simulation (ABMS) is a powerful technique in simulating and exploring phenomena that includes a large set of active components represented by agents.

Also, agent-based models offer an extensible way to model different systems consisting of autonomous and interacting agents which perform their actions and adapt their behaviours.

In this paper are given some agent-based simulations examples that can be used by math and computer science students, medical students and business and management students, for easily understanding of learned material and gaining skills for facing with real problems.

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