Teaching Health Care Management with Simulation Games

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Abstract - Usage of simulation games in education is constantly growing, due to their significant benefits, such as interactivity in a risk free environment. Simulation games are a pedagogical tool which allows development and knowledge simultaneously with the development of experience, in controlled environment. Areas of education in which simulation games are used are broad and they range from engineering to business and management. Simulation games are also used in health care management, with range of interesting applications. System dynamics is a simulation method that is often used for the development of simulation games, since it allows an observance of long-term dynamic phenomena. The goal of the paper is to provide an overview of simulation games usage in education, with the focus to health care management. A simulation game, developed with the usage of system dynamics is presented, with the focus to epidemic investigation and management. Graphic user interface of the game, as well as several simulation runs are presented.

I. INTRODUCTION

Simulation models presents a powerful tool that can be used to model and present the real world. Among numerous methods, such as discrete simulation [1] and agent based modelling [2], system dynamics models offer increased understanding of complex social and physical systems over time using feedback loop structures. System dynamics modelling enable users to simulate business processes. In other words, users learn how to develop and understand “What if” scenarios in dynamic world and how to manage complex systems such as company, competition and market [3]. Simulations enable users to improve decision making skills, make experiments and play.

Simulation games provide experiential learning and allow users to conduct experiments in predefined time period without any risk [4]. Simulation games present an effective tool which allows users to make decisions in safe environment and to analyze all steps they have made. Consequences of given actions are visible during simulation period compared with consequences in the real world which can be seen after longer time period. In other words, during simulation game, users practice their knowledge while solving real problems. Therefore, simulation games can be defined as pedagogical tool which enable users to practice their knowledge and gain business experience in controlled and risk free environment.

There is wide range of areas where simulation games can be used, from engineering, transport, and supply to health care management and business. However, in order to have good feedback and results from using simulation games and to acquire knowledge that can be applied in real business situation, several assumptions should be satisfied: cleared learning objectives, prepared learning materials, applied other teaching methods, adequate technology support, detailed analysis of results, well trained teachers, enough time preparation and financial resources [5]. Homer et al. [6] list the number areas of the application of system dynamics in health care, and here we shall mention those related to this research: (i) disease epidemiology (e.g. Homer et al. [7]), HIV/AIDS (Roberts et al, [8]), chlamydia infection (Royston et al., [9]), dengue fever (Ritchie-Dunham et al, [10]) and drug-resistant pneumococcal infections (Homer et al., [11]). The goal of the paper is to provide an overview of yellow fever system dynamics simulation model, that is used for the development of the simulation games used for the teaching of health care management at Faculty for Dental Medicine & Health, University of Osijek.

II. MODEL DESCRIPTION

A. Model structure

Simulation game is developed based on the model of the epidemic spreading of yellow fever among humans over the mosquito bite, which is based on the description of yellow-fever in Study Notes in System Dynamics by Michael Goodman [12]. Model focuses to the situation in the hypothetical city, in which yellow fever is spreading. At first there is small # of contagious humans in the city that have been bitten and have the yellow fever virus incubating inside them. When there are many contagious humans, there are many incubating mosquitoes that become infectious and bites more vulnerable humans that become contagious and generate even more infectious mosquitoes, and so on. After humans are sick they either die or become immune. When person survives yellow fever it cannot get sick any more. In other words, human population that can get sick of yellow fever is limited.

Model is based on the presumption that number of mosquitoes is constant, because yellow fever does not influence mortality and fertility patterns of mosquitoes. In addition, model presumes that mosquitoes hatch rate is constant. Every day equal number of mosquitoes are born. Mosquitoes are potentially dangerous only for three days. Therefore, if mosquito does not bite contagious human during the first three days, it is considered safe and is removed from Potentially dangerous population. If mosquito bites contagious human during the first three days of its life it becomes incubating and is also removed from the Potentially dangerous population.

Figure 1 presents the model of spreading yellow fever. Model is developed using Vensim, the specialized software for system dynamics modelling, that can be also used for game development. Model consists of stocks, flows, and constants.

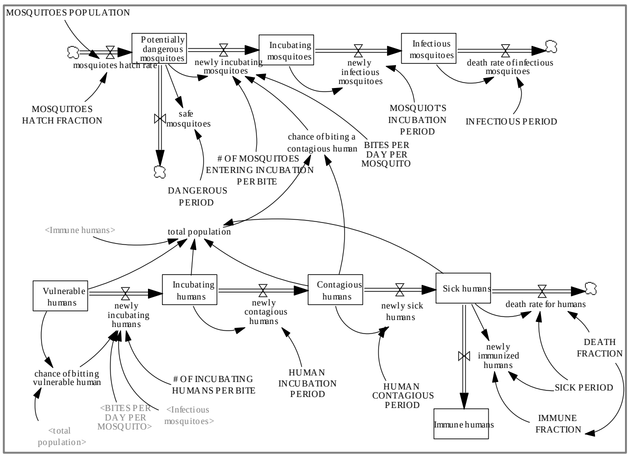


Figure 1 System dynamics model of yellow fever (Source: Authors, based on [12])

B. Feedback loops in the model

There are two feedback loops in the model, that will be briefly elaborated. At first there is small number of contagious humans in the city that have been bitten and have the yellow fever virus incubating inside them. Positive feedback loop is driving the number of newly incubating mosquitoes up during the first 120 days. When there are many contagious humans, there are many incubating mosquitoes that become infectious and bites more vulnerable humans that become contagious and generate even more infectious mosquitoes, and so on.

Model focuses only on the situation in the city. Also, after humans are sick they either die or become immune. When person survives yellow fever it cannot get sick any more. In other words, human population that can get sick of yellow fever is limited, which is the result of the negative feedback loop.

C. Model equations

Vensim notations for the model elements are used. The stocks are written with the first capital letter, flows and auxiliary variables in small caps, and constants in all caps. The stocks in the system dynamics model are the following: potentially dangerous mosquitoes, incubating mosquitoes, infectious mosquitoes, vulnerable humans, incubating humans, contagious humans, sick humans, and, immune humans. Stocks are indicated with the first capital letter.

The flows in the system dynamics model are as following: mosquitoes hatch rate, newly incubated mosquitoes, newly infectious mosquitoes, death rate of infectious mosquitoes, safe mosquitoes, newly incubating humans, newly contagious humans, newly sick humans, newly immunized humans, death rate of humans. Flows are indicated with small caps.

The constants in the system are as following: mosquitoes' population, mosquitoes hatch fraction, dangerous period, # of mosquitoes entering incubation per bite, bites per day per mosquitoes, mosquitoes incubating period, infectious period, # of incubating humans per bite, human incubation period, human contagious period, death fraction, sick period, and immune fraction. Constants are indicated by all caps. The model equations are as following:

"# OF INCUBATING HUMANS PER BITE"=1
Units: humans/bites; # of incubating people resulting from an infectious mosquito's biting one vulnerable person. (1)

"# OF MOSQUITOES ENTERING INCUBATION PER BITE"=1
Units: mosquitoes/bites; # of mosquitos that enter incubation. (2)

BITES PER DAY PER MOSQUITO=0.22222
Units: bites/day/mosquitoes; # of times a day each mosquito bites. (3)

chance of biting a contagious human=Contagious humans/total population
Units: dmnl; Chance that potentially dangerous mosquito will bite a contagious human is ratio of # of contagious humans to the total population in the city. (4)

chance of biting vulnerable human=Vulnerable humans/total population
Units: dmnl; Ratio of # of vulnerable humans to the total city's population. (5)

Contagious humans= INTEG (newly contagious humans-newly sick humans,100)
Units: humans; Current # of contagious humans. (6)

DANGEROUS PERIOD=3
Units: day; If mosquito bites a contagious person in the first three days it will become incubating&infectious. (7)

DEATH FRACTION=0.2
Units: dmnl; # of humans that die per 1 sick human. (8)

death rate for humans=Sick humans*DEATH FRACTION/SICK PERIOD
Units: humans/day; # of sick humans die per day. (9)

death rate of infectious mosquitoes=Infectious mosquitoes/INFECTIOUS PERIOD
Units: mosquitoes/day; # of mosq. die per day. (10)

HUMAN CONTAGIOUS PERIOD=4.5
Units: day; Time needed for humans to become sick. (11)

HUMAN INCUBATION PERIOD=4.5
Units: day; Time needed for humans to become contagious. (12)

IMMUNE FRACTION=1-DEATH FRACTION
Units: dmnl; # of humans that become immune per sick human. (13)

Immune humans= INTEG (newly immunized humans,0)
Units: humans; Current # of immune hum. in city. (14)

Incubating humans= INTEG (+newly incubating humans-newly contagious humans, 0)
Units: humans; Current # of incubating hum. in city. (15)

Incubating mosquitoes= INTEG (newly incubating mosquitoes-newly infectious mosquitoes,0)
Units: mosquitoes; Current # of incub. mosq. (16)

Infectious mosquitoes= INTEG (+newly infectious mosquitoes-death rate of infectious mosquitoes,0)
Units: mosquitoes; Current # of infect. mosq. (17)

INFECTIOUS PERIOD=3
Units: day; # of days remaining for an inf. mosq. until it dies. (18)

MOSQUIOT'S INCUBATION PERIOD=12
Units: day; Time needed for mosquitoes to become infectious. (19)

mosquiotes hatch rate=MOSQUITOES POPULATION*MOSQUITOES HATCH FRACTION
Units: mosquitoes/day; # of mosq. hatched per day. (20)

MOSQUITOES HATCH FRACTION=0.05555
Units: 1/day; # of mosquitoes hatched per one mosquito per day. (21)

MOSQUITOES POPULATION=500000
Units: mosquitoes;
Total mosquito population is constant and remains in equilibrium throughout the simulation. (22)

newly contagious humans=Incubating humans/HUMAN INCUBATION PERIOD
Units: humans/day
# of humans that become contagious per day. (23)

newly immunized humans=
Sick humans*IMMUNE FRACTION/SICK PERIOD
Units: humans/day
# of humans that are immunized per day. (24)

SICK PERIOD=2.5
Units: day;
Time for sick person to either die or to recover. (25)

newly incubating humans=chance of bitting vulnerable human*BITES PER DAY PER MOSQUITO*Infectious mosquitoes*"# OF INCUBATING HUMANS PER BITE"
Units: humans/day;
# of humans entering incubation per day. (26)

newly incubating mosquitoes=Potentially dangerous mosquitoes*chance of biting a contagious human*BITES PER DAY PER MOSQUITO*"# OF MOSQUITOES ENTERING INCUBATION PER BITE"
Units: mosquitoes/day
# of mosquitoes per day that have bitten contagious person during the first 3 days and enters incubation. (27)

newly infectious mosquitoes=
Incubating mosquitoes/MOSQUIOT'S INCUBATION PERIOD
Units: mosquitoes/day
# of newly infectious mosquitoes per day. (28)

newly sick humans=Contagious humans/HUMAN CONTAGIOUS PERIOD
Units: humans/day
# of humans that become sick per day. (29)

Potentially dangerous mosquitoes= INTEG (mosquitoes hatch rate-newly incubating mosquitoes-safe mosquitoes,0)
Units: mosquitoes
# of potentially dangerous mosquitoes in the area. (30)

safe mosquitoes= Potentially dangerous mosquitoes/DANGEROUS PERIOD
Units: mosquitoes/day
# of mosquitoes that are safe. They have not bitten a contagious person. (31)

Sick humans= INTEG (+newly sick humans-death rate for humans-newly immunized humans,0)
Units: humans
Current # of sick humans in the city. (32)

total population=Contagious humans+Immune humans+Incubating humans+Sick humans+Vulnerable humans
Units: humans
Current total city's population. (33)

Vulnerable humans= INTEG (-newly incubating humans,19910)
Units: humans
# of humans in city that are vulnerable to disease. (34)

III. MODEL BEHAVIOUR

A. *Impact of "chance of biting contagious human"*

Figure 2 presents a Change of total population of humans, contagious humans, and chance of biting a contagious human.

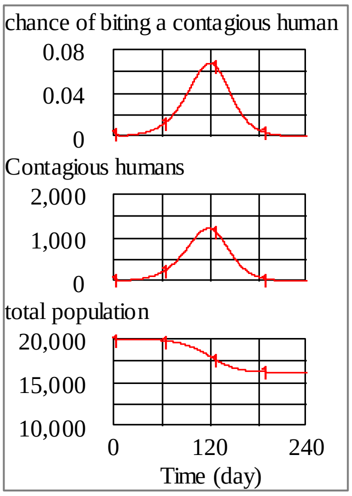


Figure 2 Change of total population of humans, contagious humans, and chance of biting a contagious humans (Source: Authors' work)

Connection between human sector and mosquito sector is "chance of biting contagious human". First there are only 100 sick humans. Compared to 20,000 people that live in the city, 100 sick people is very small number and chance for mosquito to bite sick human is very small. (For few days it even decreases because some of those sick humans died or became immune and the disease is not yet widely spread.) Therefore, yellow fever spreads very slowly for the first 30 days. But, still few mosquitoes succeed to bite sick humans. After 12 days that mosquitoes become Infectious and they succeed to bite healthy humans that becomes contagious and then sick. Positive feedback loop that consists on number of contagious people and infectious mosquitoes increase number of sick people in the city.

The number of sick humans, contagious humans and infectious mosquitoes is rising exponentially. But, not every human that has yellow fever die. Only 20% of humans die and 80% survive and become immune. As many humans get sick, stock of Vulnerable humans decreases. Therefore, after the period of 120 days, the chance for biting vulnerable human (which is ratio of vulnerable humans to total population) decreases. Fewer humans get sick and chance of biting a contagious human also decreases.

B. *Changes in human population*

Figure 3 presents the change of total population of humans, population of vulnerable humans, death rate for humans, and number of immune humans. In the same time number of immune human increases. The disease theoretically disappears from the city when everyone in the city got sick and either died or became immune. This is what happens at the end of simulation. Chance for sick person to die is 20%, and to get immune is 80%. Therefore, after the epidemic 4,000 people died and 16,000 survived. number of immune people is equal to the total population at the end of epidemic and vulnerable humans do not exist in the city any more (stock approaches to zero).

Number of immune humans, number of vulnerable humans, sick humans and total population exhibit S-shaped growth. Equilibrium value for immune humans is 16,000 because there are at the beginning 20,000 humans in the city that all become sick and the chance to become immune is 80%. Therefore, equilibrium value for total population is also 16,000. Equilibrium value for vulnerable humans is 0 because everybody in the city will eventually get sick and model does not include birth rate in the city because it's purpose is only short term analysis. Equilibrium value for sick humans is 4,000 because chance to become sick is 20%.

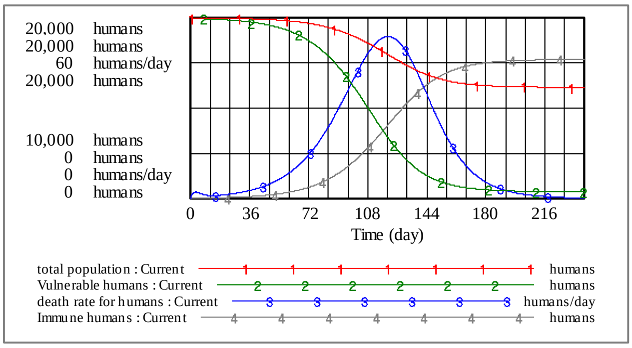


Figure 3 Change of total population of humans, population of vulnerable humans, death rate for humans, and number of immune humans (Source: Authors' work)

For the first 120 days Vulnerable humans and Immune humans exhibit either exponential growth or exponential decay because their net flows are increasing. Inflection point is at the 120th simulation day because net flows reach their maximum values and start to decrease. After that time stocks exhibit either asymptotic growth or asymptotic decay. I shall explain S-shaped decay of stock of vulnerable humans.

Figure 4 presents the change of number of incubating human, infectious mosquitoes, and chance of biting vulnerable human. Stocks and flows in the mosquito sector depend on the spread of the yellow fever in the city.

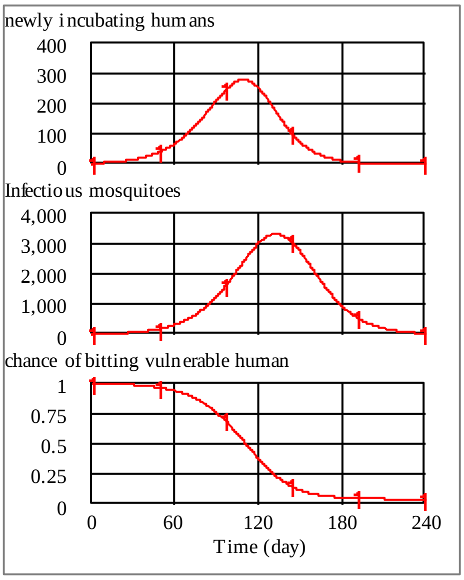


Figure 4 Change of number of incubating human, infectious mosquitoes, and chance of biting vulnerable human (Source: Authors' work)

Net flow into stock of vulnerable humans is equal to number of newly incubating humans. It depends on number of infectious mosquitoes and chance for biting vulnerable humans. As number of infectious mosquito's increase, chance of biting vulnerable human decreases because number of vulnerable human decreases. But, stock of vulnerable humans is limited and soon chance for biting vulnerable human gets smaller than 50%. This is about 120th simulation day which is inflection point for all stocks that exhibit S-shaped growth. As more and more people get sick, number of vulnerable humans decreases and chance for biting vulnerable human also decreases. In the same time number of contagious human decreases because there is less vulnerable humans to become contagious and there are many sick people that was already contagious. Therefore, number of infectious mosquito decreases.

Stock of vulnerable humans exhibits S-shaped growth because there are two feedback loops that drives its behavior. Critical variable is chance of biting contagious human. First, there is positive feedback loop that consists on number of contagious people and infectious mosquitoes. As more mosquitoes are infectious they bite healthier people that become contagious and chance of biting contagious human increases and even more mosquitoes become infectious that bite even more healthy people and so on.

On the other hand, there is negative feedback loop. As number of infectious mosquitoes increases more people get contagious and number of vulnerable humans decreases. Therefore, chance for mosquito to bite a contagious human decreases and number of infectious mosquitoes finally decreases.

C. Changes in mosquito population

Figure 5 presents the change of newly incubating mosquitoes, number of potentially dangerous mosquitoes, and chance of biting vulnerable human (Source: Authors' work).

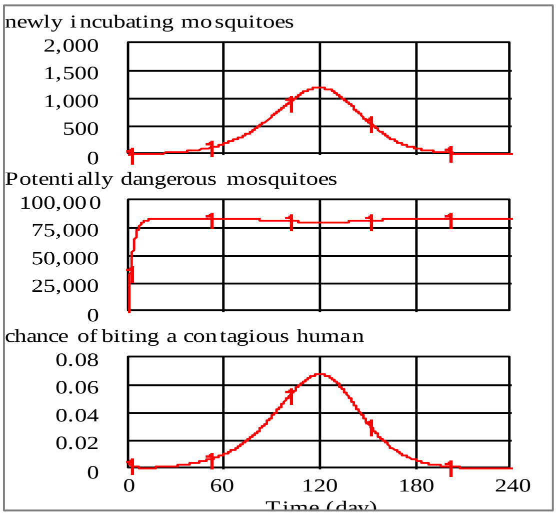


Figure 5 Change of newly incubating mosquitoes, number of potentially dangerous mosquitoes, and chance of biting vulnerable human (Source: Authors' work)

At first number of contagious humans is too small to affect to a great extent population of Potentially vulnerable mosquitoes. Therefore, after ten days population of Potentially vulnerable mosquitoes almost reaches its equilibrium value that would exist if there were no contagious humans in the city. But, because of positive feedback loop (more infectious mosquitoes – more contagious humans – more infectious mosquitoes) number of newly incubating mosquitoes is rising and it reaches maximum value of 1,194 newly incubating mosquitoes per day at 119th day of simulation.

Positive feedback loop also influences potentially vulnerable mosquitoes and safe mosquitoes. From 70th and 150th simulation day number of Potentially vulnerable mosquitoes and number of safe mosquitoes have decreased bellow their equilibrium values. This is the period when yellow fever peaks in the city and chance of biting contagious human is larger than 2%. After 150th simulation day chance of biting contagious human has decreased enough, and number of newly incubating mosquitoes is small enough for Potentially vulnerable mosquitoes and safe mosquitoes to reach their equilibrium values again.

Figure 6 presents the change of Incubating mosquitoes, infectious mosquitoes, and contagious humans. If there are more contagious humans in the city, chance for mosquito to become incubating is larger, and there will be also more infectious mosquitoes. number of contagious human peaks at 119th simulation day. Other stocks lag behind and number of incubating mosquito peaks at 130th day, and number of infectious mosquitoes peaks few days after.

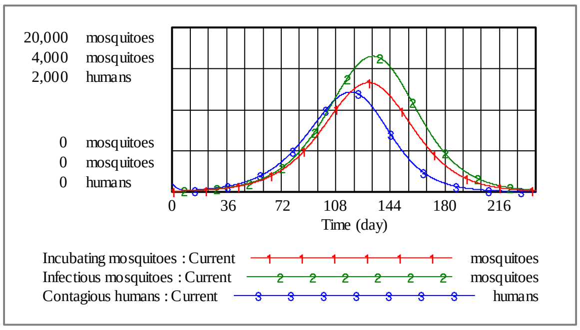
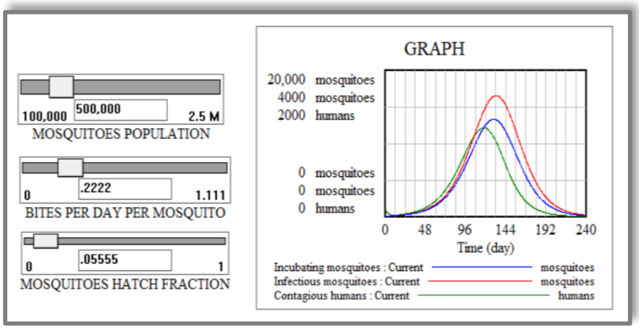


Figure 6 Change of Incubating mosquitoes, infectious mosquitoes, and contagious humans (Source: Authors' work)

IV. USAGE OF THE MODEL FOR TEACHING HEALTH CARE MANAGEMENT

Software Vensim allows conversion of the model to the game with the usage of sliders and output windows. Figure 7 presents the yellow fever game interface. Students can control size of the initial mosquitoes' population, number of bites per day per mosquito, and mosquitoes hatch fraction. The change of these values reflects the decisions related to mosquitoes' population that is significantly influencing yellow fever spreading. Size of the mosquito population is indicating the health care management actions before the disease spreads. On the other hand, sliders that can used for changes of bites per day per mosquito and mosquitoes hatch fraction reflect the actions that are done after the disease has already started to spread.



MOSQUITOES POPULATION 500,000

BITES PER DAY PER MOSQUITO .2222

MOSQUITOES HATCH FRACTION .05555

Figure 7 Yellow fever model interface (Source: Authors)

Model is used for teaching health care management at the Faculty for Dental Medicine & Health, University of Osijek. Model structure is presented to students, and game dashboard is discussed, which allows students to make experiments with the model. Before students play the game, the experiments with the model elaborated in this paper are presented to students. Graphic user interface of the game, as well as several simulation runs are presented, and students are encouraged to experiment with different values of sliders (Figure 7). Feedback from the students is positive, indicating that experimenting with the model allows more in-depth understanding of disease spreading. Experiment that is conducted using the model is presented in the following text, with the elaboration that is also discussed with the students. However, feedback from the students is not collected in formalized manner, which represents the limitation of the work.

V. CONCLUSION

Simulation games has become one of most used tools for enhancing teaching effectiveness in different fields of management, one of them being health care management. In this paper, we focus to teaching health care management using the simulation game developed with system dynamics approach. Our work has two contributions. First, we provide in-depth presentation of the yellow fever system dynamics model developed by the authors, based on the Goodman model [12], which consist of three elements: model description, model equations, and model behavior. Second, we propose the usage of the model as a simulation game for the purpose of teaching health care management. Future research directions should be oriented towards the testing of the model usage in comparison with traditional ex-cathedra teaching in order to assess the potential positive impact of simulation game to students' satisfaction and learning outcomes.

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