# TJHSST Computer Systems Lab Senior Research Project
# Simulation of the Spread of a Virus Throughout Interacting Populations with Varying Degrees and Methods of Vaccination 2008-2009

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**Abstract**

This project is designed to expand upon the common agent-based simulation of a virus infecting a very generic population. Factors such as multiple populations, different forms of transportation, and social interactions will be accounted for. Different maps with different types of pseudo-random populations will be created and different types of existing and fictional viruses will be simulated. Once working models are finished, the effects of vaccinating parts of the population can be modeled to determine the most effective methods and minimum percentages of vaccination needed to stop a viruses spread.

**Keywords:** herd immunity - type of immunity that occurs when the vaccination of a portion of the population (or herd) provides protection to unprotected individuals

basic reproduction number (R0)- the mean number of secondary cases a typical single infected case will cause in a population with no immunity to the disease in the absence of interventions to control the infection

# 1 Introduction - Elaboration on the problem statement, purpose, and project scope

## 1.1 Scope of Study

Because this project will be solely agent-based instead of incorporating system dynamics, the scope of the simulation will be limited by the processing power of the computer. There is also a limit to how detailed each agent can be. The theorertically ideal simulation would have to incorporate an actual population, factoring in every detail. Obviously this is not a realistic goal to expect of any simulation. There will be classes of people to simulate different things like people who travel, people who work, etc. Professions also play a large part in how a person is affected by the spread of a virus. A doctor working in a hospital is much more likely to become infected as he helps his patients who are likely there to be treated because of the viral infection. On the other hand someone going to work might not have nearly as much interaction with other people, let alone those who are infected, expecially since people in the workplace environment will likely not show up to work once they begin to show symptoms. In terms of buildings, an important feature that will have to be included is hospitals because of their significant influence on the spread of disease as mentioned before with doctors. Schools are frequently called a "cesspool" for disease, and with good reason. Children are less likely to take the appropriate measures to limit their exposure to viral infection, and thus will quickly spread it among their peers. The variables for vaccination will include effectiveness, chance of causing the infection itself, percentages of the population vaccinated, and some form of trace vaccination.

## 1.2 Expected results

This project is an attempt to determine the most effective methods of vaccinating a population, considering the factors of the type of population and what virus is infecting it. Different methods of vaccination will be used to see if vaccinating certain subsets of the population makes a difference, what the herd immunity is, and how extensive trace vaccinations need to be in order to effectively stop the virus' spread.

In the process of programming this simulation, I hope to learn about the spread of viruses among populations and how to model not only this spread,

but the movements and interactions within basic human populations over the span of several days to weeks.

### 1.3 Type of research

Because of the nature of this project, it will be for the most part pure applied research, because it will attempt to apply current knowledge of viruses and vaccination to determine efficient methods of vaccination different populations. There is some use-inspired basic research, as viruses that have not been modeled can theoretically be used in this program.

## 2 Background and review of current literature and research

Virus simulation is by no means a new technology or study, and thus material on the subject is plentiful. Using vaccination is also a popular model to simulate, and in one paper by Bret D. Elderd, Vanja M. Dukic, and Greg Dwyer the differences in efficiency between trace vaccination and mass vaccination were studied. Other papers describe the mathematics behind various models and the variables used, such as R0 or Pr for probability of recovery. While much of this research focuses on system dynamics, it still has material covering agent-based modeling. The article on spatial simulation gives great insight into how to approach the modeling of an environment as it factors in locations such as schools, dorms, homes, work places, and hospitals, much like I intend my own simulation to use. The MIT paper compares agent-based mods to differential equation models to determine the advantages and disadvantages of both, and how they can be combined to reduce the inaccuracy inherit in both. Because I am not including any significant degree of system dynamics in my simulation, the mathematical models will not be particularly useful and have thus been merely touched upon here, rather than having formulas listed and going in depth on how they work.

I have done a lot of research on how different viruses work in order to figure out how to set the variables for each type of virus. Smallpox for instance has a high rate of infection and can be airborne. It has an incubation period of roughly 12 to 14 days, but can be between 7 and 17. This range can be modeled in my software with dynamic variables and will account for 12 to 14 days being more common by assigning this range a higher probability.

During the first 2 to 4 days, symptoms begin, but the infected person is not very contagious. After this a rash begins to appear, and the person become highly infectious - this lasts for about four days. The next five days are characterized by the formation of pustles and a slight drop in the extreme level of contagiousness. Over the following five days the pustles begin to scab over, then for the last six days the scabs fall off leaving scars. After all of the scabs have resolved (fallen off), the person is no longer contagious. Methods will be created to model this change in how contagious a person is, but right now there is only a constant rate of infection.

# 3 Development

After doing some research into other virus simulation programs, I found Jill Dunham's program which serves as a good base for my own simulation. While I began this quarter working on my original simulation from scratch, I moved to doing research on how other researchers worked with different variables and the differences between dynamic and agent-based modeling. It was during this research that I came upon Mrs. Dunham's model and began learning how the software works. Because of the proximity of this discovery to the end of the quarter, I have not made drastic changes to the program in terms of the code itself, but I continued my research of how to change aspects of the program. The program initially contained a basic flu virus, but I have implemented my own smallpox model and done some tweaking of her pre-done viruses.

## 3.1 Requirements

The broad requirements of the project are to be able to realistically simulate the spread of a virus throughout a population, this population being one that can be easily modified and the virus being one that can likewise be easily modified. The program must also be able to show the effects of vaccination in prevention of the virus spread.

## 3.2 Overview

Using the software created by Jill Dunham, based off of the MASON platform, I will implement additional variables, such as buildings, types of people,

viruses, etc. in order to test vaccination methods. The software creates people, randomly assigning a type (i.e. profession and age group) and a home. In the case of a student, a school will be assigned, in the case of a doctor, a hospital will be assigned, and so on.

## 3.3 Restrictions

While the processing power of the computer environment is of course a limitation to any such virus model, I will more likely run into the problem of time restrictions. Having only started using this piece of software during the second interim period of the second quarter, I will not have as much time as originally planned. On the flip side, I have already done some work that goes beyond what was done by Mrs. Dunhamssoftware, so it will not take much longer to finish implementing the work I already did into te new software.

## 3.4 Research

Conducting research filled a significant portion of my time this quarter, and even lead me to scrap my original project in favor of simulation model already created, allowing me to spend more time on research and working on my actual project. I did a lot of research on different types of viruses  mostly smallpox and the flu. I also did some on the common cold, which differs from influenza in that the symptoms are not as severe and the chance of death is virtually zero. The CDC provided most of the data on the viruses I tested. I also did some research on Ebola, but have not yet implemented it in my program. The interesting aspect of Ebola will be watching the effects of Reston Ebola, because while it is currently only able to infect non-human primates, it is an extremely infectious diseasebecause it is airborne. The only thing that would stop a rampage of this virus if it were to cross over the species boundary is the fact that it kills its host very rapidly. My model would be able to model this and see what type of population would be most vulnerable, ergo which population would be least in need for vaccination.

## 3.5 Testing and Analysis

My model testing consists primarily of comparing the results to the research I have done. By tweaking the variables of rate of infection and probability of infection and using the research to program the progress of the disease (i.e.

when symptoms appear, when death occurs), I am able to create a working model of each virus. While the rate of death for any given virus can vary by country because the conditions of the hospitals and the ability to treat patients varies by country, I am only using the rates of death from the US in order to create models that are primarily useable in developed countries, as this will be the most vulnerable type of area to rapid spread of viral infection and the most able to respond in the appropriate way. Some of the work I have done this quarter involves tweaking the probability of a person staying home from work when sick, and this becoming a dynamic variable based on how sick the person is, or what virus they have.

### 3.6 Part 2

For second semester, now that I have been able to study a lot of the code for the new software, I will be able to continue implementing the new elements of hospitals and schools as well as various vaccinations. My primary goal for third quarter is to create a working method of producing graphs because as of yet I do not have any real output method to create visuals besides the simple screenshot of what the program is displaying.

Implementing the vaccination will be the most difficult part of the project because I am no longer using my own software, where I not only knew how to implement such an element, but I had already done so. This part of the project will begin in third quarter and its perfection so to speak will carry on to fourth quarter where I will conduct extensive testing and optimization of vaccination methods.

## 4 Results and Discussion

My project in the beginning of the year was a somewhat basic virus model, but could easily implement various viruses and populations, albeit not through the use of a GUI. After working on it for the first and part of the second quarter, I abandoned it for the MASON software. I again began some work on the virus model, but after a few weeks discovered virus software based of the MASON platform and sent a request to use this software for my project. After receiving the code, which was sparsely commented, I began the tedious process of going through the bulk of the code that I would need to modify in order to implement my own goals. Because of the flexibility of my pro-

gram, it has a wide array of possible uses. The ability to optimize the use of vaccination techniques will prove to be of a significant advantage in fighting off the widespread effects of a highly infectious agent within a population, whether it be because of natural causes or bioterrorism. In the latter case, the model proves highly useful because it will be able to easily implement the new disease by changing some variables and if necessary hard-coding some of its behavior within a single host.

# 5 Conclusion

Expectations for my program include working models of past epidemics and the capability to models possible future epidemics to a fair degree of accuracy. This type of model is especially useful in today's world, where the threat of bio-terror attacks is a real fear, and precautions must be made to react to such an event.

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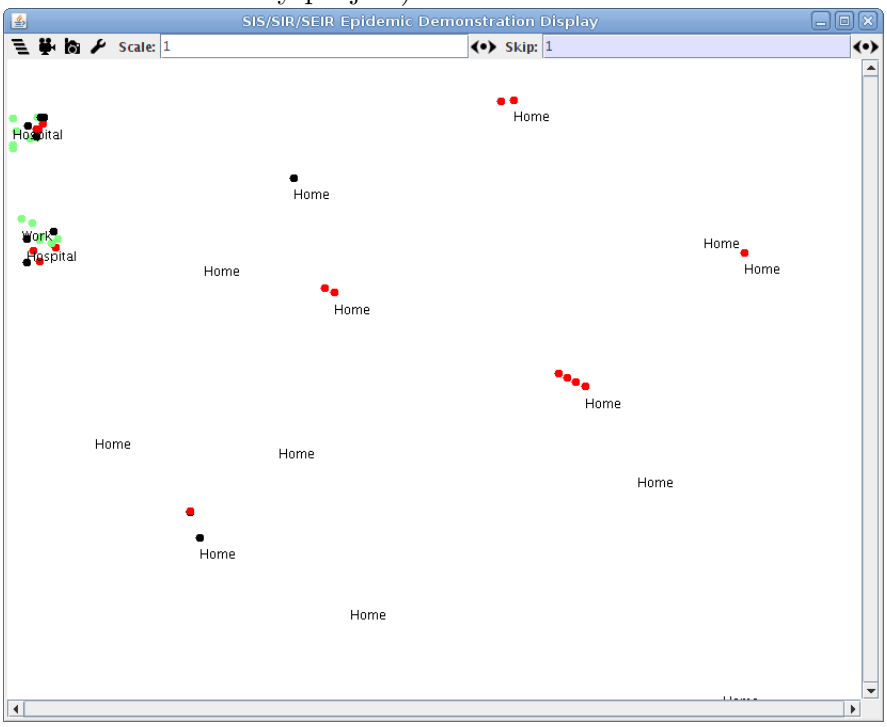
# 7 Appendix

Example run (Note that it appears almost identical to the original software. This is because most of my changes are not changes to the display code, as that is not a focus of my project).




# 8 Acknowledgements

I am basing my program off of Jill Dunham's An Agent-Based Spatially Explicit Epidemiological Model in MASON, which uses the MASON software platform.