# An Agent-Based Model for Containing a Virus Outbreak

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**Abstract:** Devising control strategies during a viral outbreak via military and medical interventions is significant to minimize the casualties brought by the disease. Moreover, finding the cure at a proper time is as important before the situation becomes pandemic. This study determined the time needed for the military to intervene and the time should a cure be found during a viral outbreak in an isolated population to at least save half of the population. This study uses an agent based model following the epidemic phases set by World Health Organization. For phase 3 where a patient zero is introduced, the infection rates were compared for systems with and without asymptomatic carriers. For phase 4 where the objective is to control the outbreak, the critical number of infected agent was varied by 10%, 30%, and 50% of the population before introducing military and medical interventions. The simulation started when patient zero was introduced to a population of 1000 with 10% of the population with high immunity and the rest with low immunity. The set limit for the simulation for each scenario is a year which is equal to 3,000 ticks, having represented 8 ticks per day. Results showed that the infection rate caused by asymptomatic carriers is twice greater than the infection rate caused by symptomatic agents. Based on the simulation, only one way was seen to be effective in saving half of the population, providing 10% or more of each military and medical forces, assuming the available resources can be mustered in time and providing the military and medical intervention with not more than 50 % of the known infection in the initial population and not more than two months since the start of the outbreak.

*Key words: asymptomatic carrier; agent-based model; disease-control; infectious diseases; epidemic*

## 1. INTRODUCTION

Infectious diseases represent an ongoing threat to the health and livelihoods of people everywhere. Over the course of our history the summation of deaths caused by pandemics may actually be greater than the summation of deaths caused by wars. About 10 million people around the world died of communicable diseases in 2010 (Institute for Health Metrics and Evaluation, 2010). From the 1918 Spanish flu that killed 75 million people and the 1981 discovery of Human immunodeficiency virus (HIV) to the latest scare, Ebola which death toll nears 5,000 out of more than 10,000 cases all over the world that still remains uncontained as of writing this paper (World Health Organization, 2014), one could safely assume that infectious diseases remain a leading cause of morbidity and mortality worldwide.

In 2009 the World Health Organization released its six phases of pandemic alert, describing the evolution of the disease from a virus found in animals to its spread in human population, evolving from an epidemic scale to pandemic level until its post pandemic recovery activities. The six-phased approach also includes global policies and response plans per phase. The phase 1 occurs when there is no virus circulating among animals has been reported to cause infection in humans. Phase 2 is declared when an animal influenza virus is circulating in domesticated or wild animals is known to have caused infection in humans and is therefore considered a specific potential pandemic threat. Phase 3 is declared when a animal or human-animal influenza reasserting virus has caused sporadic cases or small clusters of disease in people, but has not resulted in human-to-human transmission sufficient to sustain community-level outbreaks. Phase 4 is declared when it is already epidemic. A combination of military and medical interventions were then introduced for varying percentage of known infection in the population. This was done to device control strategies in containing the outbreak through aggressive quarantine and health care response plans. It is a common knowledge, that a greater military and medical forces and abrupt action can only be the solution for a successful outbreak control. However given the circumstances for limited resources, especially in impoverished nations, the researchers aimed to determine the longest time possible before a medical intervention starts with the assurance of still saving half of the population. Uncontrolled epidemic leads to pandemic which is Phase 5. Phase 6 is the termination of the human civilization.

In order to aid in the decision making of the government, mathematical models were created to analyze the spread of infectious diseases, and create control strategies via simulated scenarios and soft computing (Brauer & Castillo-Chavez, 2001). The ability to make predictions about diseases could enable scientists to evaluate inoculation or isolation plans that may have a significant effect on the mortality rate of a particular epidemic (Daley & Gani, 2005). Thus, this study aims to determine the effects of the intervention of military and medical forces at different rates of infected population. This study provides the critical percent of infected population should the society finds the cure or vaccine in order to save half of the population.

## 2. METHODOLOGY

The simulation was done using Netlogo, a multi-agent programmable modelling environment. The graphical user interface (GUI) of the model is shown in figure 1. This model simulates an isolated system of interacting agents (persons) without any barrier with an initial population density of 0.1. Births and migration were not considered in this model.

The agents in this model has been profiled into three immunity levels. Their immunity profile decides their role or change of role as the infection spreads. Immunity is given to the militaries and doctors. High and low immunity was then distributed randomly in the profile of the susceptible.

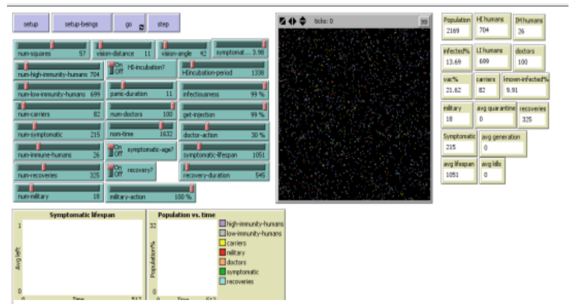

Figure 1. Graphical User Interface

There are nine (9) types of agents in this model. The (a) symptomatic (green) – infected agents showing symptoms of the disease, has the ability to infect susceptible agents upon contact. It is subjected to a specific lifespan, dies if not cured. The (b) symptomatic carriers (yellow) - infected agents with high immunity that undergoes the latent phase of the virus before becoming symptomatic, has the ability to infect susceptible agents upon contact. The (c) doctors (orange) - vaccinated humans that are totally immune to the virus. Has the ability to cure carriers and symptomatic agents, introduce immunity among the susceptible agents. The (e) militaries (red) – considered immune and move as regular humans do, unless they see a symptomatic or panicked human, which they will run towards. A member of the military will quarantine any symptomatic on a patch they walk into. (f) The High-immunity-humans (light violet - HI) - walk five times as fast as symptomatic. If it sees a symptomatic in front of them, it turns around and panic. It becomes an asymptomatic carrier when infected and only after the latent period has elapse shall it become symptomatic. (g) Low-immunity-humans (light gray - LI) - walk five times as fast as symptomatic. If it sees a symptomatic in front of them, it turns around and panic. It becomes a symptomatic upon infection. (h) Immune-humans (blue) – either naturally immune, an agent that is immune in the virus even in the start of the outbreak or asymptomatic carriers and ordinary agents that became immune by vaccination. (i) The recoveries (cyan) - vaccinated infected agents that becomes totally immune of the virus but remains infectious for some time until such time that its recovery duration period elapses.

A susceptible with a low immunity upon infection would become symptomatic however if it has high immunity, upon infection the agent shall acquire the characteristics of an asymptomatic carrier and only after the time dictated by the virus latent period elapses shall it became symptomatic. All symptomatic agents shall be given a specific lifespan for which it will die if not vaccinated with the cure. Despite the symptomatic acquiring immunity and recovery upon vaccination, its period of infectiousness would still continue and will only stop after the recovery duration period elapses.

Moreover, the virus infects susceptible agents through direct contact transmission. It exhibits the ability to remain latent for some time assuming the host has high immunity. However it still remains infectious despite its latency and continues shedding thus its host assumes the role of an asymptomatic carrier. Only after which its latency period elapse shall its host become symptomatic. The virus shall continue shedding for some time even after a vaccine was introduced in its host. Only non-vaccinated humans and non-immune can be infected by the virus. The virus' latent period lasted for 41 days or equivalent to 328 ticks while the symptomatic agent's lifespan assigned is 31 days or equivalent to 246 ticks, for which the agent shall die after the assigned ticks in the symptomatic lifespan, expires.

The methodology for simulating the spread of virus was implemented by introducing patient zero to an initial population of 1000. A baseline data was simulated where there is no intervention by the military and there is no vaccine or cure found, and thus the military and doctors are not immuned. This is compared to a series of data when interventions occurred at different critical percent (10%, 30% and 50% of the population) are infected before the interventions of the military (10% of the population) and/or a vaccine or cure is found given by the doctors (10% of the population). The simulation will stop either when all agents are deceased or when all living agents are vaccinated. The number of ticks and the statistics of agents were recorded and compared.

The model created in this study attempted to realistically represent the behavior of individuals during an outbreak as well as characterize the natural biological process of the virus spreading among individuals. Important roles such as militaries and doctors are also equally represented in the model, the initial population used was 1000 and all sliders remained constant in all simulated situations. The simulation was set to run up to 3,000 ticks which are set to be equivalent to a year or 365 days, having 8 ticks per day. Actions taken would be considered a failure if the virus was still not eliminated by the 3,000$^{th}$ tick or half of the initial population was not saved despite introducing the force of military and doctors.

## 3. RESULTS AND DISCUSSION

The infection rate is shown in figure 2.

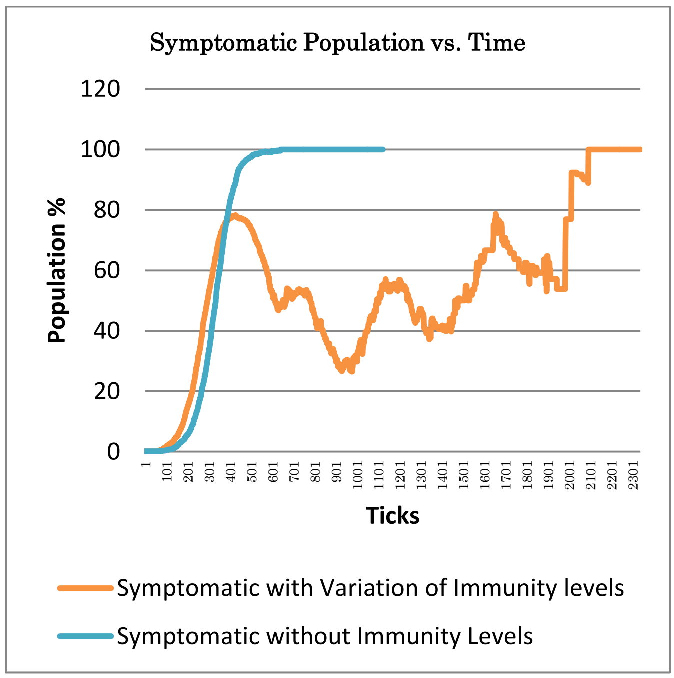


Figure 2. Symptomatic Population vs. Time

Infection rate is the rate at which a disease is spread among people. Knowing just the numbers of cases of infection identified by surveillance activities is not sufficient to identify the risk (probability) of infection occurring in the facility residents; rates must be used (Utah Department of Health, 2011).

Comparing the two graphs as seen above, Fig. 2B representing the second simulation had the first prominent peak, this shows that the infection spreads at a faster rate among the population of the susceptible in the population. The results of the simulation showed that in the course of the first 30 days or 240 ticks, the rate of infection in the second simulation is twice greater than the rate of infection in the first simulation.

This occurred due to the presence of an asymptomatic carrier, a person or other organism that has contracted an infectious disease, but who displays no symptoms (Mosby, 2011). It is common mistake for humans to not take precautions against humans not exhibiting symptoms of the disease thus unknowingly engages in physical contact that might cause the spread of the disease in case that the other person is infected yet asymptomatic.

Calculation of the infection rate: (Eq. 1)

$$\frac{Number\ of\ infectious}{Number\ of\ susceptible} \times 100 = Rate\ of\ Infection$$

Table 1A. Infection rate caused by symptomatic beings

| No. of Infectious | No. of Susceptible | No. of Days | Rate of Infection |
|---|---|---|---|
| 123 | 1000 | 30 | 12.3 % |
| 990 | 1000 | 71 | 99 % |

Table 2A. Infection rate caused by asymptomatic carriers and symptomatic beings

| No. of Infectious | No. of Susceptible | No. of Days | Rate of Infection |
|---|---|---|---|
| 263 | 1000 | 30 | 26.3 % |
| 990 | 1000 | 71 | 99 % |

However as the outbreak continues and as time passes, the rate of infection for the second simulation slows down such that the two simulation reaches 99% infection at the same time which is the 71$^{st}$ day.

*B. Mortality Rate*

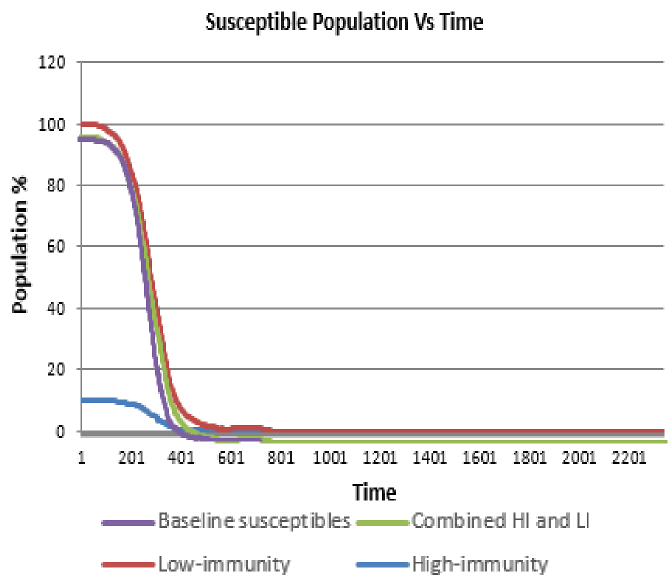


Fig. 3. Susceptible Population vs. Time Plot with variation in immunity levels and carriers are taken into account.

Mortality rate or death rate is a measure of the number of deaths (in general, or due to a specific cause) in a particular population, scaled to the size of that population, per unit of time (Porta, 2014). Getting the mortality rate in the simulation as stated in by Greenwood (1948) proved highly useful in controlling the plague and other major epidemics. Public health in industrialized countries was transformed when mortality rate as a function of age, sex and socioeconomic status emerged in the late 19th and 20th centuries (Jha, 2002). This track record has led to the argument that inexpensive recording of vital statistics in developing countries may become the most effective means to improve global health (Jha, 2012).

Varying levels of immunity showed a faster spread of infection in the first 30 days of the outbreak as discussed above, this may seem to be a negative effect due to the asymptomatic carriers, however it has also its positive side, as shown in Fig. 3B, the calculated mortality rate per no. of days for varying levels of immunity is actually lesser than the calculated mortality rate per no. of days for consistent immunity level among susceptible agents. A longer time till compete annihilation was measured for the second simulation than the first simulation. This means that varying level of immunity would help in slowing down the fatality rate of the outbreak.

Calculation of the mortality rate: (Eq. 1)

$$\frac{No. of\ deaths}{No.\ of\ susceptible} \times 100 = Rate\ of\ Mortality$$

Calculation of the mortality rate caused by symptomatic beings:

$$\frac{1000}{1000} \times 100 = 100\ \%\ \text{in 111 days}$$

Calculation of the mortality rate caused by asymptomatic carriers and symptomatic beings:

$$\frac{1000}{1000} \times 100 = 100\ \%\ in\ 292\ days$$

The comparison of the simulation resulted that adding carriers and varying the levels of immunity of humans would help in decreasing the death rate. Furthermore the time it takes to completely annihilate the entire population is twice longer than the first simulation. Given this data means that humanity has a bigger fighting chance with a susceptible population having varying levels of immunity or a virus that assumes a latent period. Time is an important factor in controlling an outbreak. A faster infection rate could mean a total annihilation however a longer latent period of the virus and the varying immunity levels could mean a time to expense for finding a cure or developing strategic measures to control the outbreak.

Table 2. Military and Medical Intervention

Phase 4- Human-to-human transmission of an animal or human-animal influenza reasserting virus able to sustain community-level outbreaks has been verified. A disease outbreak happens when a disease occurs in greater numbers than expected in a community or region or during a season. An outbreak may occur in one community or even extend to several countries. It can last from days to years. Sometimes a single case of a contagious disease is considered an outbreak. This may be true if it is an unknown disease, is new to a community, or has been absent from a population for a long time.

## *1.2 Containing the outbreak through Military and Medical forces*

The virus cannot be contained with the force of military alone unlike the first situation in which carriers do not exist. With the presence of carriers, military would only be able to quarantine symptomatic agents but not carriers since they don't exhibit the symptoms and identifying them would be difficult. This would just result to a continual spread of infection. Adding medical forces would help in totally eradicating the virus since the vaccine aims to give immunity to the susceptible, carriers and symptomatic agents. However unlike the carriers and susceptible, the symptomatic agents would undergo a recovery period for which they are cured of the disease but continuously shedding the virus thus assuming the same characteristics as of an asymptomatic carrier, and only after 31 days or 246 ticks would the agents be totally free of the disease and its infectious period shall end. Ten simulated trials was done to determine the time till complete annihilation of the population with only the military intervention, the measured time till intervention for the most number of initial population saved, and longest time possible before a medical intervention and military intervention starts with the assurance of still saving half of the population.

Military and medical intervention only started upon reaching the stated percentage for known infection among the population, known infection pertains only to the percentage of symptomatic beings among the initial population and therefore this does not include asymptomatic carriers. The initial population used in the simulation is 1000, including the 100 militaries and 100 doctors assuming they are totally immune of the disease, this would be kept constant all throughout the ten simulations.

| Percentage of Known Infection till Military Intervention | Percentage of Known Infection till Medical Intervention | Number of people saved | Time ended |
|---|---|---|---|
| 10 % | No Medical Intervention | 0 | 361 days |
| 10 % | 10 % | 802 | 175 days |
| 10 % | 30 % | 768 | 171 days |
| 10 % | 50 % | 641 | 175 days |
| 30 % | 10 % | 788 | 207 days |
| 30 % | 30 % | 747 | 159 days |
| 30 % | 50 % | 669 | 186 days |
| 50 % | 10 % | 771 | 195 days |
| 50 % | 30 % | 747 | 159 days |
| 50 % | 50 % | 617 | 192 days |

As shown on the table above, with the military intervention alone, the time till complete annihilation of the population was extended up to 361 days which is longer by 69 days compared to the simulated outbreak without any military and medical intervention which ended by 292 days. This means that that quarantine helps in slowing down the outbreak.

As expected given that the military and medical intervention occurred immediately at 10 % known infection and acted not more than a month since the start of the outbreak, it would save 80 % of the initial population.

Even with the delayed response of the military and medical intervention, the medics and militaries was still able to save more than half of the initial population given that it acts not more than two months since the start of the outbreak.

The simulated trials showed that a combination of military and medical forces is needed to completely eradicate the virus and saved at least half of the initial population. Aggressive actions must be taken immediately and a cure must be provided no more than two months since the initial outbreak.

Phase 5- The same identified virus has caused sustained community level outbreaks in two or more countries in one WHO region.

The virus if not contained within 3,000 ticks would be considered pandemic and quarantine on the town shall be lifted making the virus to spread easily.

## 4. CONCLUSIONS

In this simulation, an aggressive quarantine was done to eradicate the infection, for which the infected town is quarantined and no additional population was added all throughout the simulation. The outbreak was not contained by only having a force of military introduced since the carriers cannot be quarantined by the military, for asymptomatic carriers does not exhibit the symptoms of infected humans making them difficult to identify. The continual rise of symptomatic agents due to the population having greater humans with low-immunity and carriers continually infecting with no way to stop them resulted in overwhelming the military and infecting the entire population. With the factor of carrier being introduced a cure was the only solution to contain the outbreak. Based on the simulation, only one way was seen to be effective in saving half of the population, providing 20% or more of each military and medical forces, assuming the available resources can be mustered in time and providing the military and medical intervention with not more than 50 % of the known infection in the initial population and not more than two months since the start of the outbreak.

The model can be extended by simulating it in a case of pandemic. A pandemic covers a much wider geographical area, often worldwide. In the simulation, the infected region was put into quarantine for which the epidemic did not evolve to become pandemic. Adding a Geographic Information System map of the world for pandemic cases or an actual GIS map of a populated city could be done to simulate more realistic outbreaks and learn ways to control them.

In summary, asymptomatic carriers played a vital role in dramatically increasing the infection rate of the virus. However the varying levels of immunity in humans also helped in slowing the total eradication of the population. As advised by the World Health Organization (2009) it is imperative that the outbreak be dealt quickly, or else a greater loss of human life may occur.

## 5. REFERENCES

Bagnoli, F. Li`o, P. Sguanci, L. (2007). Risk perception in epidemic modeling. Quantitative Biology, 1, 5-6.

Brauer, F., Castillo-Chávez, C. (2001). Mathematical Models in Population Biology and Epidemiology. NY: Springer.

Daley, D. J. & Gani, J. (2005). Epidemic Modeling: An Introduction. NY: Cambridge University Press.

Greenwood M. Medical Statistics from Graunt to Farr. The Fitzpatrick Lectures for the Years 1941 to 1943. Cambridge: Cambridge University Press; 1948.

Jha P. (2002). Avoidable mortality in India: past progress and future prospects. Natl Med J India, 15, 32-36.

Jha, Prabhat (2012). Counting the dead is one of the world's best investments to reduce premature mortality. Hypothesis, 10, 254.

Porta, M (2014). A Dictionary of Epidemiology. Oxford: Oxford University Press. p. 69.

Utah Department of Health (2011). Calculation for Infection Rate and Mortality Rate. Retrieved October 27, 2014, from http://health.utah.gov/epi/diseases/HAI/resources/Cal_Inf_Rates.pdf

Vinson, B. (2012). Language Disorders Across the Lifespan. p. 94. Clifton Park, NY: Delma

World Health Organization. Pandemic Influenza Preparedness and Response. (2009). A WHO Guidance Document. World Health Organization Press, 50-55.

World Health Organization. (2012). HIV/AIDS. Retrieved on October 27, 2014, from http://www.who.int/gho/hiv/en/.

World Health Organization. (2014). Ebola: Updated personal protective equipment guidelines. Retrieved on October 27, 2014: http://www.who.int/csr/disease/ebola/en/.