

A Health Policy Simulation Model of Ebola Haemorrhagic Fever and Zika Fever

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Abstract This study proposes a simulation model of a new type of infectious disease based on Ebola haemorrhagic fever and Zika fever. SIR (Susceptible, Infected, Recovered) model has been widely used to analyse infectious diseases such as influenza, smallpox, bioterrorism, to name a few. On the other hand, Agent-based model begins to spread in recent years. The model enables to represent behaviour of each person in the computer. It also reveals the spread of an infection by simulation of the contact process among people in the model. The study designs a model based on Epstein's model in which several health policies are decided such as vaccine stocks, antiviral medicine stocks, the number of medical staff to infection control measures and so on. Furthermore, infectious simulation of Ebola haemorrhagic fever and Zika fever, which have not yet any effective vaccine, is also implemented in the model. As results of experiments using the model, it has been found that preventive vaccine, antiviral medicine stocks and the number of medical staff are crucial factors to prevent the spread. In addition, a modern city is vulnerable to Zika fever due to commuting by train.

Keywords Infectious disease · Ebola haemorrhagic fever · Zika fever

1 Introduction

Infectious diseases have been serious risk factors in human societies for centuries. Smallpox has been recorded in human history since more than B.C 1100. People have also been suffering from many other infectious diseases such as malaria, cholera, tuberculosis, typhus, AIDS, influenza, etc. Although people have tried to prevent and

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hopefully eradicate them, a risk of unknown infectious diseases including SARS, a new type of infectious diseases, as well as Ebola haemorrhagic fever and Zika fever have appeared on the scene.

A model of infectious disease has been studied for years. SIR (Susceptible, Infected, Recovered) model has been widely used to analyse such diseases based on a mathematical model. After an outbreak of SARS, the first SIR model of SARS was published and many researchers studied the epidemic of the disease using this model. When an outbreak of a new type of influenza is first reported, the U.S. government immediately starts an emergency action plan to estimate parameters of its SIR model. Nevertheless the SIR model has difficulty to analyse which measures are effective because the model has only one parameter to represent infectiveness. For example, it is difficult for the SIR model to evaluate the effect of temporary closing of classes because of the influenza epidemic. The agent-based approach or the individual-based approach has been adopted to conquer these problems in recent years [1–4]. The model enables to represent behaviour of each person. It also reveals the spread of an infection by simulation of the contact process among people in the model.

In this study, we developed a model to simulate smallpox and Ebola haemorrhagic fever and Zika fever based on the infectious disease studies using agent-based modelling. What we want to know is how to prevent an epidemic of infectious diseases not only using mechanisms of the epidemic but also decision making of health policy [5]. Most importantly, we should make a decision in our modern society where people are on the move frequently world wide, so we can minimise the economic and human loss caused by the epidemic.

2 Cases of Infectious Disease

2.1 *Smallpox*

The smallpox virus affects the throat where it invades into the blood and hides in the body for about 12 days. Patients developed a high fever after that, but rashes do not appear until about 15 days after the infection. While not developing rashes, smallpox virus is able to infect others. After 15 days, red rashes break out on the face, arms and legs, and subsequently they spread over the entire body. When all rashes generate pus, patients suffer great pains; finally 30 % of patients succumb to the disease. For thousands of years, smallpox was a deadly disease that resulted in thousands of deaths.

2.2 Ebola Haemorrhagic Fever

A source of Ebola infection is allegedly by eating a bat or a monkey, but it is unknown whether the eating these animals is a source of the infection. The current epidemic, which began in Guinea in Dec. 2013, 23 people have died. The authorities of Guinea, Liberia and Sierra Leone have each launched a state committee of emergency and have taken measures to cope with the situation. The prohibition of entry over the boundary of Guinea is included in these measures.

There is a risk that a cough and a sneeze includes the virus, so the infection risk is high within 1 m in length of the cough or sneeze. The incubation period is normally 7 days, and then the person gets infected after showing the symptoms. The symptoms in the early stage are similar to influenza. They are fever, a headache, muscular pain, vomiting, diarrhoea, and a stomachache. The fatality rate is very high; 50 to 90 % There is no effective medical treatment medicine confirmed officially and several medicines are currently being tested. According to a guideline of WHO, the serum of a recovered patient is one of most effective treatments.

2.3 Zika Fever

Zika fever is an illness caused by Zika virus via the bite of mosquitoes. It can also be potentially spread by sex according to recent report [6, 7]. Most cases have no symptoms and present are usually mild including fever, red eyes, joint pain and a rash [8], but it is believed that the Zika fever may cause microcephaly which severely affects babies by a small head circumference.

3 Related Work

3.1 Smallpox and Bioterrorism Simulation

Epstein [9, 10] made a smallpox model based on 49 epidemics in Europe from 1950 to 1971. In the model, 100 families from two towns were surveyed. The family includes two parents and two children thus the population is each 400 from each town. All parents go to work in their town during the day except 10 % of adults who go to another town. All children attend school. There is a communal hospital serving the two towns in which each 5 people from each town work. This model was designed as an agent-based model, and then simulation of infectious disease was conducted using the model. As results of experiments showed that (1) in a base model in which any infectious disease measures were not taken, the epidemic spread within 82 days and 30 % of people died, (2) a trace vaccination measure was effective but it was difficult to trace all contacts to patients in an underground railway or an airport, (3)

a mass vaccination measure was effective, but the number of vaccinations would be huge so it was not realistic, (4) epidemic quenching was also effective, and reactive household trace vaccination along with pre-emptive vaccination of hospital workers showed a dramatic effect.

3.2 Individual-Based Model for Infectious Diseases

Ohkusa [11] evaluated smallpox measures using an individual-based model of infectious diseases. The model supposed a town including 10,000 habitants and a public health centre. In the model, one person was infected with smallpox virus at a shopping mall. They compared between a trace vaccination measure and a mass vaccination measure. As a result of simulation, it was found that the effect of trace vaccination dropped if the early stage of infection was high and the number of medical staff is small, while the effect of mass vaccination was stable. Therefore timely and concentrate mass vaccination is required when virus starts spreading. The estimation about the number, place and time of infection is needed quickly and the preparation of an emergency medical treatment and estimation system is required for such occasions.

Summary of related work From these studies, the effectiveness of an agent-based model has been revealed, yet these are not sufficient models to consider a relationship between vaccination and antiviral medicine stocks, and the number of support medical staff and medicine from other countries. In addition, authorities need to make a decision regarding blockade, restrictions on outings including cars and railways while considering economic loss of the policy. This study takes into account these extensions.

4 A Health Policy Simulation Model of Infectious Disease

We designed a health policy simulation model of infectious disease based on Epstein's smallpox model. The model includes smallpox and Ebola haemorrhagic fever.

4.1 A Base Model of Smallpox

We assume all individuals to be susceptible which means no background of immunity. 100 families live in two towns.

The family includes two parents and two children. Therefore the population is each 400 in each town. All parents go to work in their town during the day except 10% of adults commute to another town. All children attend school. There is a communal

hospital serving two towns in which 5 people from each town work. Each round consists of an interaction through the entire agent population. The call order is randomised each round and agents are processed or activated, serially. On each round, when an agent is activated, she identifies her immediate neighbours for interaction. Each interaction results in a contact. In turn, that contact results in a transmission of the infection from the contacted agent to the active agent with probability.

The probability of contact at an interaction is 0.3 at a workplace and a school, while 1.0 at a home and a hospital. The probability of infection at a contact is 0.3 at a workplace and a school, while 1.0 at a home and a hospital. In the event the active agent contracts the disease, she turns blue to green and her own internal clock of disease progression begins. After twelve days, she will turn yellow and begins infecting others. Length of noncontagious period is 12 days, and early rash contagious period is 3 days. Unless the infected individual is vaccinated within four days of exposure, the vaccine is ineffective. At the end of day 15, smallpox rash is finally evident. Next day, individuals are assumed to hospitalize. After eight more days, during which they have a cumulative 30 % probability of mortality, surviving individuals recover and return to circulation permanently immune to further infection. Dead individuals are coloured black and placed in the morgue. Immune individuals are coloured white. Individuals are assumed to be twice as infectious during days 1 through 19 as during days 12 through 15.

4.2 A Base Model of Ebola Hemorrhagic Fever

In the event the active agent contracts the disease, she turns blue to green and her own internal clock of disease progression begins. After seven days, she will turn yellow and begins infecting others. However, her disease is not specified in this stage. After three days, she begins to have vomiting and diarrhoea and the disease is specified as Ebola. Unless the infected individual is dosed with antiviral medicine within three days of exposure, the medicine is ineffective. This is an imaginary medicine to play the policy game. At the end of day 12, individuals are assumed to hospitalize. After four more days, during which they have a cumulative 90 % probability of mortality, surviving individuals recover and return to circulation permanently immune to further infection. Dead individuals are coloured black and placed in the morgue. Immune individuals are coloured white. Other settings are the same as smallpox.

4.3 A Base Model of Zika Fever

About 80 % of cases have no symptoms which is called latent infection, but the latent patients can transmit Zika virus to other mosquitoes. The incubation period of Zika virus disease is not clear, which is likely to be 3 to 9 days. After the incubation period, the symptoms including fever, skin rashes, conjunctivitis, muscle and

joint pain, malaise, and headache occur and last for 6 days. Zika virus disease is relatively mild and requires no specific treatment, so any strategies are not selected in the model.

Zika virus is transmitted to people through the bite of an infected mosquito from the *Aedes* genus. This is the same mosquito that transmits dengue. Therefore, the model of Zika fever is based on the life and habits of mosquitoes that transmit dengue. Mosquitoes bite and thus spread infection at any time of day. Humans are the primary host of the virus, but it also circulates in mosquitoes. An infection can be acquired via a single bite. A mosquito that takes a blood meal from a person infected with Zika fever, becomes itself infected with the virus in the cells lining its gut. About 10 days later, the virus can be spread to other human. An adult mosquito can live for 30 days with the virus.

Mosquitoes live around each town, office, school in Zika fever model. The areas they live overlap with human areas. Therefore the Zika virus can be transmitted between mosquitoes and human. Additionally, mosquitoes also live around a rail station in another Zika fever model where people use a train to commute their offices every day. A mosquito bite human once per four days. An infection rate from a mosquito to human is set at 0.5 and from human to a mosquito is set at 1.0. Figure 1 shows Interface view of a simulation model of Zika fever.

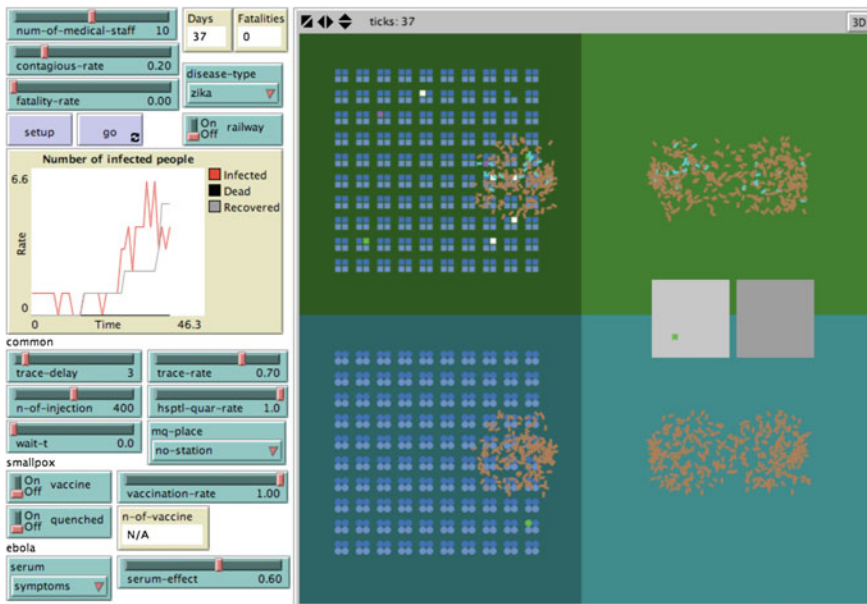


Fig. 1 Interface view of a health policy simulation model of Zika fever

4.4 Vaccination Strategies for Smallpox and Ebola Hemorrhagic Fever

The vaccination strategies we can select in the model are mass vaccination and trace vaccination. Each of them has advantages and disadvantages.

Mass vaccination As preemptive vaccination, the mass vaccination strategy adopts an indiscriminate approach. First all of the medical staff is vaccinated to prevent infection. When the first infected person is recognised, certain per cent of individuals in both towns will be vaccinated immediately. The vaccination rate and the upper limit number of vaccination per day are set on the model for the strategy.

Trace vaccination All of the medical staff is vaccinated as pre-emptive vaccination. Given a confirmed smallpox case, medical staff traces every contact of the infected person and vaccinates that group. In addition of the mass vaccination strategy, the trace rate and the delay days of contact tracing are able to be set according to the model for the trace vaccination strategy.

Trace serum or antiviral medicine dosing All of the medical staff is given serum or antiviral medicine as TAP (Target antivirus prophylaxis). Given a confirmed Ebola hemorrhagic fever case, medical staff traces every contact of the infected person and provides the medicine to that group. In addition to the mass vaccination strategy, the trace rate and the delay days of contact tracing are set according to the model.

5 Experimental Results

5.1 A Base Model of Ebola Hemorrhagic Fever

The process of infection in an Ebola hemorrhagic model is plotted in Fig. 2. The model employs non-intervention to the disease. A solid line, a dotted line and a line with marker indicate the number of infected, dead and people who have recovered respectively. When a player adopts non-intervention, it takes approximately 231 days until convergence of the outbreak and more than 716 people have died.

Figure 3 shows the results of 100 experiments. The number of fatalities under 20 people was 59 times out of 100 experiments, but the number of fatalities over 700 people in 800 inhabitants recorded 39 times. The result indicates that the infection phenomenon is not based on the normal distribution. It means we need to carefully consider all possibility and risk beyond the scope of the assumption regarding infection spread.

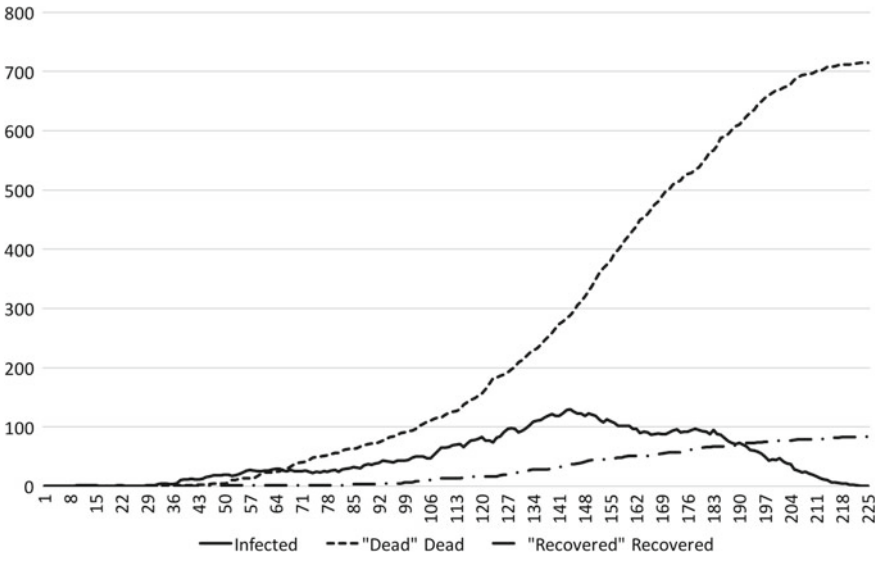


Fig. 2 The experimental result of the Ebola base model: non-intervention

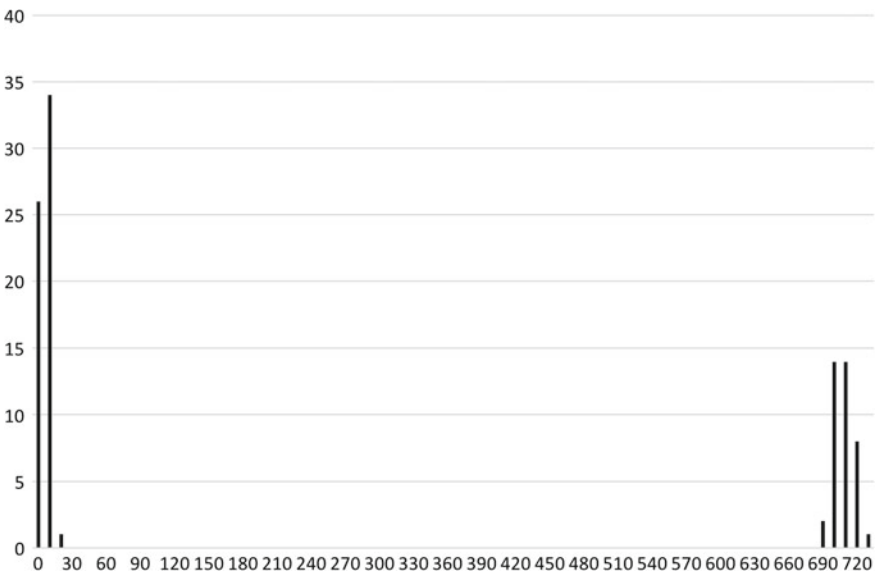


Fig. 3 The frequency chart of the Ebola base model: non-intervention

5.2 Mass Vaccination Model

The process of infection is plotted with the mass vaccination strategy in which individuals are vaccinated randomly after three days when given a confirmed smallpox case. The policy succeeds to prevent the outbreak because the number of vaccination per day is 600 and three fourths of inhabitants are vaccinated per day. On the other hand, the short ability of vaccination ends in failure because the number of vaccination per day is 400 and a half of inhabitants are vaccinated. The ability of vaccination per day bifurcates the results.

5.3 Trace Vaccination Strategy

It was found that the ability of more than 50 vaccinations per day was able to control an epidemic in most cases. In the case of using a public transportation to commute, however, it makes a substantial difference. 400 vaccinations per day could not prevent the outbreak, while 600 vaccinations per day succeeded to prevent it. Trace vaccination strategy is one of the most effective policies in a town where people commute by car, but a large number of vaccinations per day, at least a half of people, is required if most of people use public transportation systems like a railway and a bus.

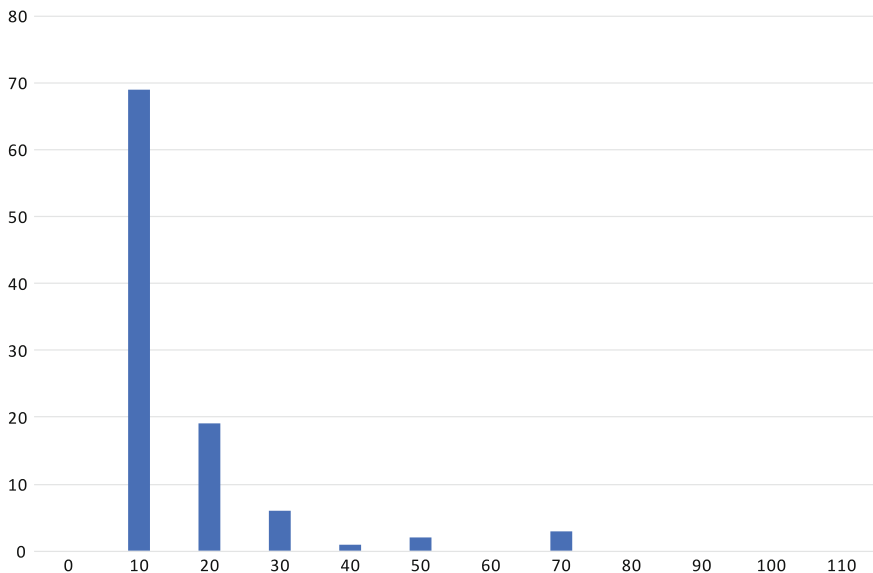


Fig. 4 The experimental result of Zika fever model without a railway

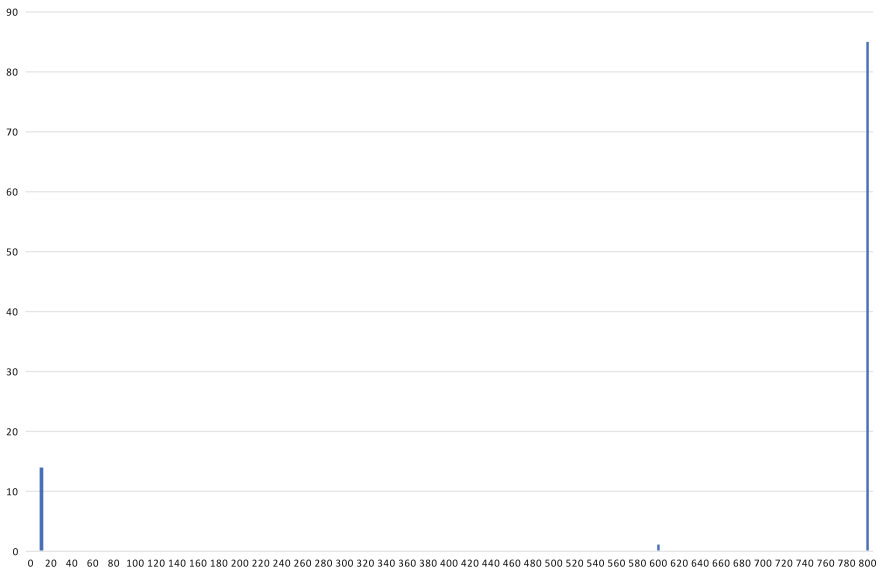


Fig. 5 The experimental result of Zika fever model with a railway

5.4 Isolated Town Model of Zika Fever With/Without a Rail Station

The process of infection in Zika model of an isolated town is plotted in Fig. 4. It was found that most cases are under 30 fatalities, but a few cases are over 70 fatalities. On the other hand, Fig. 5 shows that cases are polarised to different results in a modern city with a rail way for a commute. The case under 10 infected people is 15 times, and the case in which all people are infected by mosquitoes is 85 times.

6 Discussion

The results of these experiments are that (1) trace vaccination strategy is one of the most effective policies to Ebola hemorrhagic fever, but (2) both Ebola hemorrhagic fever and Zika fever can be affected seriously by the case of train commuters, even if the trace vaccination strategy is adopted for them. This result indicates that a blockade of railways is more effective alternative strategy in modern cities where most people commute by public transportation system such as train, subway, bus and so on.

7 Conclusion

This study proposes a simulation model of Ebola haemorrhagic fever and Zika fever. It also evaluates health policies to prevent an epidemic. As health policies, vaccine stocks, antiviral medicine stocks, the number of vaccinations per day by medical staff, mass vaccination, and trace vaccination are implemented in the model. As a result of experiments, it has been found that vaccination availability per day and the number of medical staff are crucial factors to prevent the spread for the mass vaccination strategy. On the other hand, small quantities of vaccination for approximately 10% of inhabitants are vaccinated per day are able to control an epidemic in most cases. In the case of using a public transportation to commute, however, even if half of inhabitants were vaccinated per day, it would not prevent the epidemic. Two thirds of vaccinations per day are required each day to prevent the epidemic.

In addition to that, this study also conducts the model of Zika fever to understand the mechanism of spreading Zika virus via mosquitoes. As a result of experiments, it is crucial for preventing a Zika epidemic to get rid of mosquitoes from a train station where people use it to commute to their office.

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