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Equal Distribution Model of Epidemic Drugs Based on a Cellular Automata Model

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Abstract. The epidemic spreading of infectious disease is a process of evolution over time. Based on the cellular automata model[1], this paper analyzes the epidemic spreading rules, and establishes an efficient equal distribution model of drugs in a broad sense. For multiple regions, in case of demand of drugs exceeding supply, the drugs shall be distributed according to the proportion of a total number of people in each region, the number of patients, the number of the isolated, and the number of deaths. It is necessary to simulate based on these four schemes to obtain simulation results. The results show that, when the drugs are distributed by the proportion of the number of deaths, it is optimal for controlling over epidemic situations.

Keywords. Ebola virus, cellular automaton model, equal distribution model, multiple regions

1 Introduction

Ebola virus is also translated as Iborra virus, which is a kind of very rare virus. Ebola virus can cause severe Ebola hemorrhagic fever in humans and non-human primates, which is a serious and fatal disease with the mortality rate of 90%. Currently, there is no effective vaccine or treatment means against Ebola virus. The prevention of Ebola virus is mainly from drug development and vaccine research and development. Now, there are not effective drugs and vaccines. Available data indicates that such virus may be spread in a very short time. When Ebola virus spread in West Africa in August 2014, it now has caused infection and death to a large number of people, and caused panic in the world. Therefore, for the current spreading of the Ebola virus, this paper establishes a cellular automaton model[2] in combination with the epidemic spread rules, adds a random mobility model with Poisson distribution, and creatively adds a quantity of state to present terrain. Based on the above virus spread model and combined with the distribution, spreading and pathogenicity of this epidemic and its other characteristics, this paper creatively proposes an equal distribution model of drugs. The equal distribution of drugs refers to the delivery of the drugs to different regions based on a certain quantity index in disease spreading regions and different quantity indexes corresponding to different distribution schemes. To fix other conditions,

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this paper simulates different distribution schemes according to the cellular automaton model. The merits and demerits of the scheme will be determined by the simulation results. Under the premise of the limited existing drug production capacity, this paper establishes an effective drug distribution scheme, so as to reduce the morbidity and mortality of people in epidemic area.

2 Model and analysis

2.1 Equal distribution model of drugs in a broad sense.

2.1.1 Multi-objective delivery model based on goods and materials [3]

Based on existing therapeutic drugs, the control of epidemic spreading largely depends on the drug production speed, drug storage and transport capacity, setting of transfer station, drug delivery and distribution model and so on. The drug production speed is limited to existing medical production capacity, which is considered to be limited and unchanged. With the progress of science and technology and the development of transport tools, the transport capacity is very strong. Time costs and expense costs considered in transport are insignificant for life. Therefore, to reduce the morbidity and mortality of people in stricken area is a goal considered.

1) Ebola virus has spread in the locality. For different epidemics in different locations of different countries, different locations have demand on the drugs, but the demand on quantity will differ according to the severity of the epidemic situation. Therefore, it is a multi-objective delivery model of medical drugs.

In the research of goods and materials in the supply chain of Ebola epidemic, the modes of transport involved are mainly aircraft and ship. Meanwhile, due to restrictions of objective circumstances, it is inevitable involved in the drug transport, loading and unloading, and temporary transfer during the drug delivery process. In most cases, the supply of drugs is less than the demand for drugs. At this time, we are faced with the problem of demand and distribution of drugs.

The design of multi-objective delivery model, location planning of the transfer station, selection of transportation route, combination of transport drugs, and acceptance or rejection of meeting the needs become a key to decision-making issues.

Based on such scheme, this paper researches a drug distribution scheme involved in multi-objective delivery location.

2) Time costs and expense costs considered in transport are insignificant for life. Therefore, to reduce the morbidity and mortality of people in the stricken area is a goal considered. This paper creatively proposes an equal distribution model of drugs. The general equal distribution model of drugs refers to the delivery of the drugs by the proportion to different regions based on a certain quantity index in disease spreading regions and different quantity indexes corresponding to different distribution schemes. It specifically includes the following four distribution schemes:

A. The drug distribution based on the proportion of a total number of people in different regions.
B. The drug distribution based on the proportion of the number of the infected in different regions.
C. The drug distribution based on the proportion of the number of the isolated in different regions.
D. The drug distribution based on the proportion of the number of death in different regions.

The implementation process of four different solutions: The update of cellular status at each time step depends on the statistical results of the previous time step. The actual implementation based on this program is intuitive, simple and efficient.

2.1.2 Assumptions

According to the research methods of epidemic disease, we decide to establish an epidemic model by two-dimensional random mobility cellular automata. Combined with multi-connectivity and mono-connectivity results of Ebola virus and the actual situation, we adopt multiple regions as a research base.

Our goal of analysis is to control the disease as soon as possible, and we make the following assumptions:

- Analyze the development of medical conditions at the current stage and drug production conditions. We assume that drug production is in short supply, and the production capacity fails to be improved in a short term.
- In the initial period of drug production, the supply capacity is as follows:

$$F = \mu \times H \tag{1}$$

Where μ =0.5 is a proportionality coefficient, H is the peak number of the infected.

- According to the distribution characteristics of Ebola virus, we assume that the drug demand point is widely distributed in the region.
- The mortality rate of Ebola virus is up to 90%, so we think that there will be a demand for drugs in epidemic place.
- Analyze the treatment situation of the past large-scale influenza diseases, such as A/H1N1, SARS virus. We assume that there is a need of continuous drug supply, and the drug interruption will restore the status of the infected to the initial state of drug supply.
- Powerful transport capacity at the current stage and unity and cooperation effect in the world for large-scale viral prevalence. We think that drug production and transportation can be completed in a short term without significant effect on the experimental results.
- Drugs are only supplied for the isolated and the infected, so the drug supply can only affect the cure probability P_5 in Ebola virus spread model.

2.1.3 Distribution rules of equal distribution scheme of drugs

A. Equal distribution of drugs based on a total number of people in different regions

In Ebola virus infection model in multiple regions, the number of people in each region is W_i ($i = 1, 2, ..., N$), then the total quantity of drugs in each region is as follows:

$$Y_i = F \times W_i \bigg/ \sum_{i=1}^{N} W_i \tag{2}$$

B. Equal distribution of drugs based on the number of the infected in different regions

In Ebola virus infection model in multiple regions, the number of the infected in each region is R_i ($i = 1, 2, ..., N$), then the total quantity of drugs in each region is as follows:

$$Y_i = F \times R_i \bigg/ \sum_{i=1}^{N} R_i \tag{3}$$

C. Equal distribution of drugs based on the number of the isolated in different regions
In Ebola virus infection model in multiple regions, the number of the infected in each region is G_i ($i = 1, 2, ..., N$), then the total quantity of drugs in each region is as follows:

$$Y_i = G_i \Big/ \sum_{i=1}^{N} G_i \tag{4}$$

D. Equal distribution of drugs based on the number of death in different regions
In Ebola virus infection model in multiple regions, the number of death in each region is E_i ($i = 1, 2, ..., N$), then the total quantity of drugs in each region is as follows:

$$Y_i = E_i \Big/ \sum_{i=1}^{N} E_i \tag{5}$$

The cure probability of the isolated after update is as follows:

$$P_5 = \min(Y_i / G_i, 1) \tag{6}$$

2.1.4 Solution and results

According to the Ebola virus spreading characteristics, we simulate the Ebola virus spreading process by the use of cellular automata model, and update the cure rate of drugs on each iteration step by the use of four different schemes. The results are shown in the following figure:

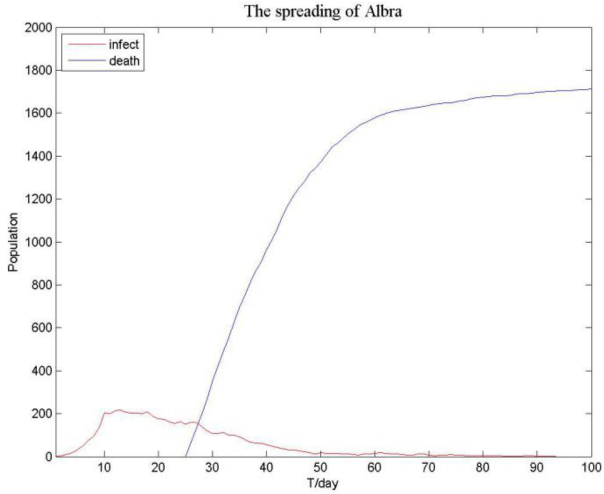

Figure 1. Variation diagram of the number of the infected and the death in Type A drug distribution scheme**.**

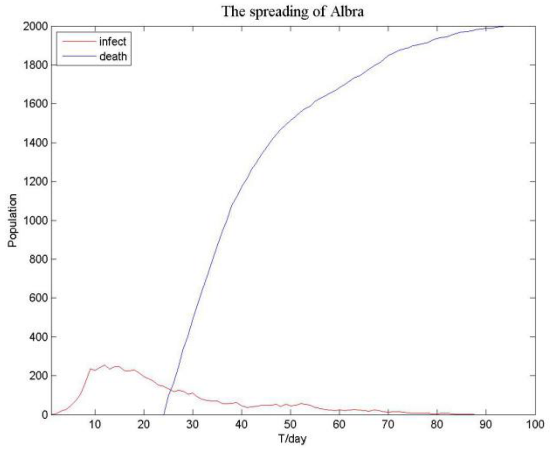

Figure 2. Variation diagram of the number of the infected and the death in Type B drug distribution scheme.

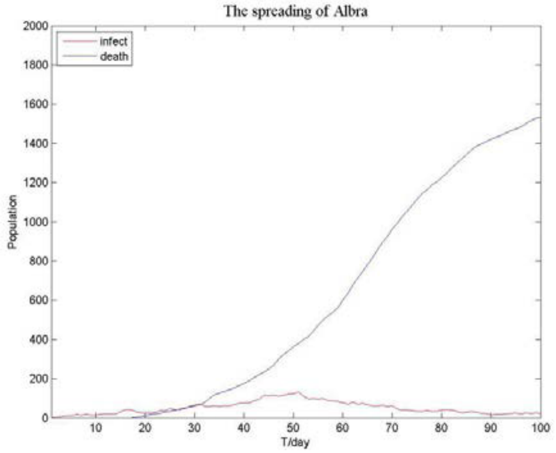

Figure 3. Variation diagram of the number of the infected and the death in Type C drug distribution scheme.

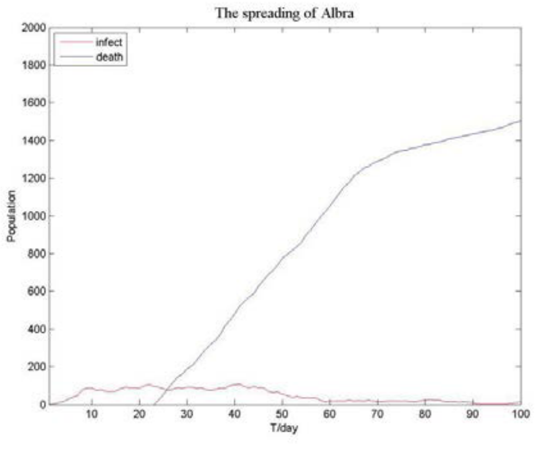

Figure 4. Variation diagram of the number of the infected and the death in Type D drug distribution scheme.

2.1.5 Analysis result

As shown in Figure 1 and Figure 2, the variation of the number of the infected in two schemes is almost the same with little difference in the peak value and the time step, which is in line with our expectations. To distribute drugs based on a total number of people in the region and the number of the infected in the region is basically a routine precaution for ordinary influenza. Here, the number of the infected is a simulated data in the model. In reality, the infected undetected is beyond our understanding, which has a certain proportion to the total number of people in the region, so the quantity of drug distributed has a little difference, and the effect of the epidemic control is similar.

As shown in Figure 3 and Figure 4, to distribute drugs based on the number of the isolated and the number of death has a very significant effect, and the variation of the number of the infected is almost the same with little difference in the peak value and the time step. The number of the isolated in the model is the number of the infected detected by us. To distribute drugs based on such value is also a measure usually adopted by the government for the treatment of large-scale influenza virus. The number of the isolated and the number of death have a certain proportion, so the quantity of drug has a little difference, and the effect of the epidemic control is similar.

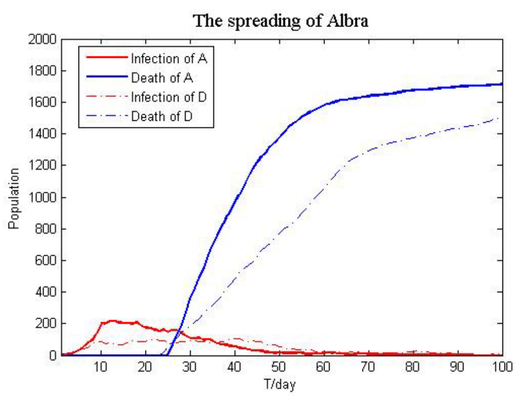

Figure 5. Comparison diagram of Type A and Type D scheme.

As shown in four diagrams in the analysis results, the effect of Type A and Type B drug distribution scheme is similar, while the effect of Type C and Type D drug distribution scheme is similar. Meanwhile, the effect of the former is significantly inferior to the latter. Through a comparison of Type A and Type D scheme in Figure 5, the peak of the number of the infected has a difference about double, and the former number of death is significantly higher than the latter. It indicates that the total number of people in the region fails to represent the epidemic spreading situation. The drug distribution scheme shall be done by the specific epidemic spreading situation. The number of death can directly and effectively reflect the epidemic spreading situation. Therefore, the number of death in each region can be a basis of drug distribution, so as to achieve the optimal epidemic control.

3 Conclusions

Based on the existing cellular automaton model[4], this paper adds a space terrain factor and a random mobility model with Poisson distribution. Considering the terrain factor, this paper divides the original region into 3×3 regions.

On this basis, this paper establishes four equal distribution schemes according to a total number of people in each region, the number of patients, the number of the isolated and the number of deaths. Through simulation of the results of four schemes, the results show that the number of death in each region can be a basis of drug distribution, so as to achieve the optimal epidemic control.

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