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Predicting the Spread of Infectious Diseases in a Closed System Based on Cellular Automata and SIRS Model

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Abstract: For the existence of a closed system in a public place, the transmission of infectious diseases changes under different initial conditions. When the initial susceptible person is a staff member, the change in the number of sick people over 100 days is simulated using a cellular automata model. The transformation of the number of susceptible, sick, and recovered persons was simulated. When the initial incubators were other persons, a differential equation was developed using the model to study the change in the number of affected persons. Finally, compare the two conditions and analyze the process of growth and decrease.

1. Introduction

During the COVID-19 epidemic, Wuhan decided to close the city to prevent the further spread of the epidemic and reduce the transmission rate of infectious diseases through a series of protective measures and finally achieved zero growth of patients.

Suppose there are two types of people in a closed system with a public place, one can move freely and the other is a staff member fixed at a location in the public place and all people in the system may go to the public place. In this closed system, there is some kind of infectious disease that is not immune for life spread and can be transmitted during the incubation period, assuming that there is an initial incubator.

Firstly, we study the change in the total number of incubators and morbidities in a closed system when the initial incubator is a worker in a public place (with a certain space of activity, in a specific location in a public place).

Then, we study the change in the total number of incubators and morbidities in a closed system when the initial incubators are free agents (the activity space is within the closed system).

2. Predicting the spread of infectious diseases in a closed system

2.1 The infectious disease transmission model when the sick person is a worker

2.1.1 Establish an infectious disease transmission model based on cellular automata

A closed environment with a population of one million is set up with a common area in the center, and those whose activities are within the common area are staff members. Let a particular staff

member in the common area under the initial conditions be the carrier of virus number 0 and the coordinates are located in the center of the common area, and all other people are susceptible. The probability that a susceptible person will become infected and become a carrier of the virus is λ. The mortality rate of the sick is f=0, and the cure rate is μ. The probability of a recovered person losing immunity and becoming re-infected with the disease is γ.

An optimized forest annealing model is constructed to model the spread of infectious diseases within the period [0, T] to explore the changes in the number of sick people in the system. The specific modeling is as follows.

(1) Cell: All people in the closed system.

(2) Cell space: The two-dimensional space of $N=n*n$.

(3) Neighbor form: Moore type with a neighbor radius of 1.

(4) Cell state space: Let the state variable of each cell be $S_{\{i,j\}}^{t}$, indicating the state of the cell at the moment t with coordinates (i, j). The state space is set to 0, 1, and 2 states respectively. $S_{\{i,j\}}^{t}=0$ means that the cell is in a susceptible state, i.e., not infected and not immune. $S_{\{i,j\}}^{t}=1$ means that the cell is in a diseased state, i.e., infected and infectious. $S_{\{i,j\}}^{t}=2$ means that the cell is in a cured state, i.e., cured and temporarily immune.

(5) Study time: Defined T as the study time of the spread of infectious diseases, Δ as the period of the first order of the spread of infectious diseases, every 10 cycles for one day (t), to study the daily change in the number of sick people.

(6) Simulate the virus transmission process: Initially, there is a virus carrier, and the 3*3 matrix is constructed with the virus carrier. When the coordinates of the susceptible person are positioned in the matrix, the virus carrier has the probability equals λ to infect the susceptible person located in the neighboring position, and if one of the neighboring positions in the matrix is constructed with the susceptible person as the center is a virus carrier, the susceptible person has the probability equals λ to be infected as a virus carrier. After every ten cycles, there is a probability equals μ that a carrier will be cured and become a recovered person or the probability equals λ to die, and a probability γ that a recovered person will be reinfected and become a carrier.

2.1.2 Model solution

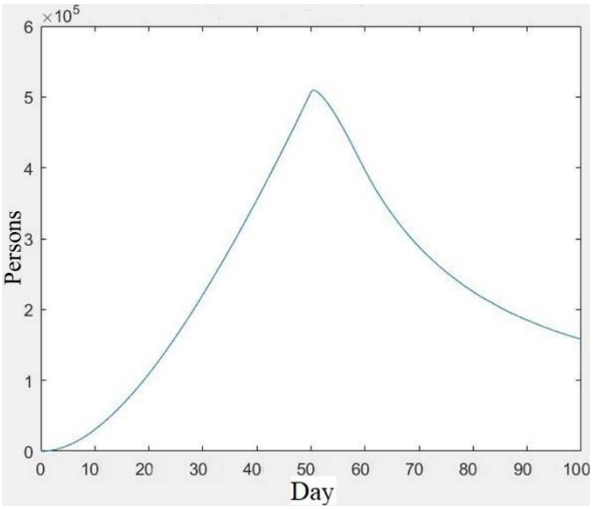

Figure 1: The change in the total number of sick people within 100 days

Red indicates virus carriers, i.e., S=2. Green indicates recovered and susceptible people i.e., S=1. The probabilities are taken as λ=60%, μ=5%, and γ=0.6%. The probability of a person being infected

at that location is calculated by dividing the sum of the values of the 8 neighbors around the person by 2. The number of virus carriers is recorded cyclically for each cycle, and the final output *I*-*t* image is shown in Figure 1, where the number of virus carriers reaches a maximum of 509,423 on day 50.

2.2 The infectious disease transmission model when the diseased person is a free agent

2.2.1 SIRS infectious diseases model

The total number of people in the closed system is divided into three categories: susceptible (*S*), carriers (*I*) (incubators and onset), and recovered (*R*). The total number of people $N=S+I+R$ does not change so the infection is not fatal.

Susceptible individuals (*S*) have a probability β of becoming infected as carriers. Carriers have a probability γ of being cured as recovered individuals (*R*). Recovered persons (*R*) have a probability μ of losing immunity and a probability α of becoming infected again as carriers. The differential equation is obtained by analyzing the change in the number of susceptible persons (*S*), carriers (*I*), and recovered persons (*R*) in the period from t_0 to t_0+dt.

$$\begin{cases} \dfrac{\mathrm{d}S(t)}{\mathrm{d}t} = -\lambda I(t)S(t) + \alpha R(t) \\ \dfrac{\mathrm{d}I(t)}{\mathrm{d}t} = \lambda I(t)S(t) - \mu I(t) \\ \dfrac{\mathrm{d}R(t)}{\mathrm{d}t} = \mu I(t) - \alpha R(t) \end{cases}$$

2.2.2 Model solution

The initial conditions are listed as follows: $S(0)=999{,}999$, $I(0)=1$ and $R(0)=0$. Set $\lambda=60\%$, $\mu=5\%$ and $\alpha=1\%$. After solving, the number of persons as a function of time is obtained in Figure 2, where the number of carriers reached a maximum of 747,420 on day 36.

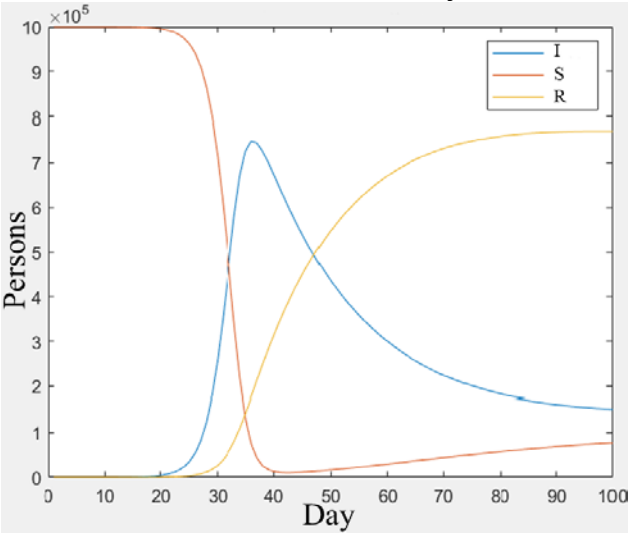

Figure 2: The change in the number of carried, susceptible, and recovered persons within 100 days

3. Conclusion

We analyzed the results in Figure 1 and Figure 2 to compare the transmission of infectious diseases when the initial incubators are staff and free people. In the pre-increase period, the total number of

patients increased at a faster rate when the initial latent was a free agent than when the initial latent was a staff member. The peak was first reached when the initial latent was a free agent during the study period and the peak number was also larger. Roughly at 90 days, the change in the number of illnesses when the initial incubator is a staff member and when the initial incubator is a free agent both tend to level off and have similar convergence values, so the two models can be considered reasonable and the conclusion is obtained.

Outbreaks, when the initial incubator is a worker, are easier to control than outbreaks when the initial incubator is a free agent.

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