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Research on the spread of infectious diseases in closed systems based on SIR and SEIRD models

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ABSTRACT. *Aiming at the problem of the spread of infectious diseases in a closed system, this paper uses the Runge-Kutta method to construct a prediction model based on improved SIR infectious disease infection and a SEIRD model based on causality, and comprehensively use MATLAB and other software programming to solve the problem. The number of people infected with infectious diseases increased first and then decreased and eventually tended to zero, and the number of people infected with infectious diseases was related to the daily contact rate between the latent and the population. After the staff took preventive and control measures, the rate of transmission of infectious diseases decreased and the number of people transmitted decreased.*

KEYWORDS: *improved SIR, Runge-Kutta method, causality analysis, SEIRD model*

1. Instruction

Infectious disease refers to a type of infectious disease that occurs after pathogenic microorganisms infect the human body. Infectious diseases are infectious diseases, and infectious diseases are not necessarily infectious. The occurrence of infectious diseases should have three links, namely the source of infection, the route of transmission, and the susceptible population. As long as one of the links is cut off, the occurrence and development of infectious diseases can be treated or prevented. The emergence of vaccines is to prevent infectious diseases. Paying attention to personal hygiene and environmental hygiene is the way to cut off the source of infection.

In 2020, facing the new crown pneumonia epidemic that swept the world and the National Health Commission issued the "Infectious Disease Prevention and Control Law" on October 2, 2020, it has attracted great attention from the whole society. The prevention and treatment of infectious diseases is a major issue to ensure the health and safety of the people, and is a fundamental element for ensuring social stability and building a harmonious society.

2. Summary of research status

In reference to the spread of the new crown pneumonia epidemic, the literature [1] predicts the spread of the new crown pneumonia epidemic by considering the factors of deaths of infectious diseases, and compares the predicted results with the actual number of infected, cured, and dead people. When the daily contact rate is set at a fixed value, the maximum value of the proportion of infected persons and the time to reach the maximum value, the limit value of the proportion of cured and dead persons are calculated; the conditions for the non-spreading of the new crown pneumonia epidemic are derived, and the most effective prevention The control method is to reduce the daily contact rate. The disadvantage is that only general research ideas are put forward, without computer simulation, and no changes in the number of patients in the system are obtained.

Literature [2] studied the spread of the pneumonia epidemic in Xinguan from the perspective of computer simulation, and finally verified that the community selected by the case can be opened to traffic, and proposed planning suggestions for community opening. The disadvantage is that it has not further studied whether urban public transport can be introduced into residential communities.

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Literature [3] theoretically introduced in detail three methods for calculating the traffic capacity of signal-controlled intersections, namely saturation rate method, stop line method and conflict point method, and then selected a signal-controlled cross For intersections, the capacity of the intersection was calculated separately and compared with the actual observed capacity to explore the calculation method of the intersection capacity suitable for my country's traffic conditions. The disadvantage is that it does not consider urban traffic as a whole, such as the impact of intersections on road capacity.

All in all, the existing literature more or less has its shortcomings and needs to be improved.

This article is to study the spread of infectious diseases in a closed system. In view of this problem, we divide it into four small problems to study. First: select Runge-Kutta method to establish SIR model, and predict the change in the number of patients in the system according to the different daily contact rates of infected persons when we agree that the staff and other personnel are infected; second: build based on SEIRD The model analyzes the protective effect after adding protective measures and the impact on infectious diseases.

3. Model of infectious disease transmission in a closed environment

3.1 Model principle

The Runge-Kutta method is a high-precision single-step algorithm widely used in engineering, including the famous Euler method, which is used to numerically solve differential equations. Due to the high precision of this algorithm and measures to suppress errors, its implementation principle is also more complicated.

The classic SIR model divides the population into three categories, namely, infected, uninfected, and cured. In this article, in view of the status of infectious diseases, considering the death factors of patients, the classic SIR model is improved, and the population is divided into uninfected, infected, cured, dead, uninfected, infected, cured, and dead. The ratios are respectively$s(t)$, $y(t)$, $r(t)$, $q(t)$, and $s(t)+y(t)+r(t)+q(t)=1$. But it does not consider birth and natural death factors.

3.2 Model establishment

Suppose the initial time is after elapsed, consider the decrease in the number of uninfected people, the increase in the number of patients, dead and cured in the time period.

Number of patients increased within

$$N[y(t+\Delta t)-y(t)]=\lambda Ny(t)s(t)\Delta t-\mu Ny(t)\Delta t-Nmy(t)\Delta t$$

Number of uninfected people reduced in

$$N[s(t+\Delta t)-s(t)]=-\lambda Ny(t)s(t)\Delta t+\mu Ny(t)\Delta t$$

Increased number of healers in

$$N[r(t+\Delta t)-r(t)]=\mu Ny(t)\Delta t$$

Increase in the number of dead in

$$N[q(t+\Delta t)-q(t)]=mNy(t)\Delta t$$

Divide both ends of the formula ①~④ by at the same time, and eliminate the limit to get

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$$\begin{cases} \dfrac{dy}{dt} = \lambda sy - \mu y - my \\ \dfrac{ds}{dt} = -\lambda sy + \mu y \\ \dfrac{dr}{dt} = \mu y \\ \dfrac{dq}{dt} = my \end{cases}$$

Initial time $y(0) = y_0$, $s(0) = s_0$, $r(0) = r_0$, $q(0) = q_0$, $y_0 + s_0 \approx 1$, The solution of model ⑤ cannot be obtained. So analyze $s(t)$, $q(t)$, $r(t)$ Relationship with t.

3.3 Model solution

The contact rate of the day was 0.3, that is, the staff used MATLAB software to program the latent person (see Appendix: Procedure 1), and the prediction results of the number of patients were shown in Figure 1.

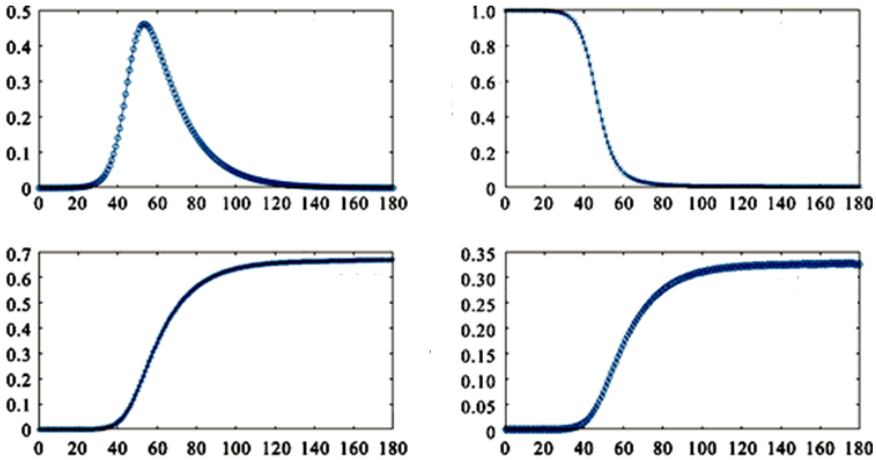

Figure. 1 Changes in the proportions of the four groups of people within 180 days when the daily contact rate is 0.3

The contact rate of the day was 0.2, that is, the staff used MATLAB software to program the latent person and the prediction result of the number of patients was shown in Figure 1.

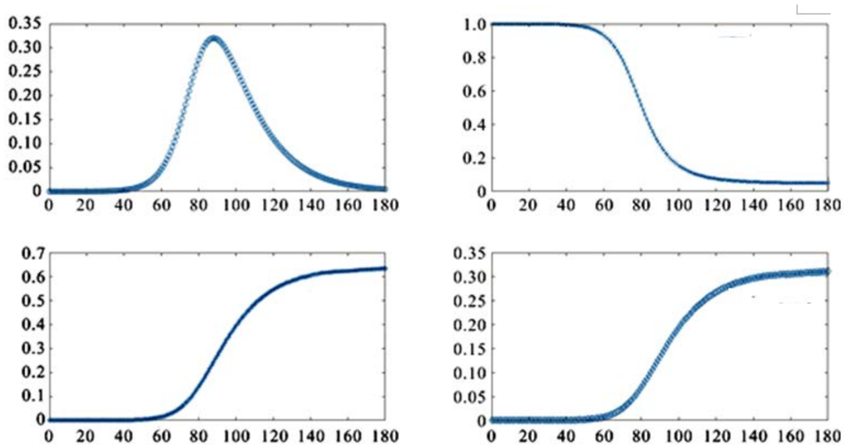

Figure. 2 When the daily contact rate is 0.2, the proportion of the four groups of people in 180 days

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Analyzing the changes in the number of infected people within 180 days, it can be seen that the number of infected people will not increase all the time. The number of infected people will increase first, and after a certain period of time, the number of infected people will usher in a peak, and then the number of infected people will gradually decrease, and eventually drop to 0.

4. SEIRD model based on causality

In summary, we have agreed that the incubation period of infectious diseases is 14 days.

The daily contact rate of latent persons is the same as that in question 1, and after contact, the probability of normal persons being infected with infectious diseases is 2.69%.

When an infected person becomes ill, isolation and testing are used for treatment.

The model adds the number of deaths D on the original basis, and the formula is as follows:

$$\begin{cases} \frac{ds(t)}{dt} = \frac{N(t)s(t)}{[s(t)+E(t)+y(t)]} - \frac{r_{is}p_{is}y(t)s(t)}{N(t)} - \frac{r_{es}p_{es}E(t)s(t)}{N(t)} \\ \frac{dE(t)}{dt} = -\frac{N(t)E(t)}{[s(t)+E(t)+y(t)]} + \frac{r_{is}p_{is}y(t)s(t)}{N(t)} + \frac{r_{es}p_{es}E(t)s(t)}{N(t)} - p_{ei}E(t) \\ \frac{dy(t)}{dt} = p_{ei}E(t) - (p_{ir} + p_{id})y(t) - \frac{N(t)y(t)}{[s(t)+E(t)+y(t)]} \\ \frac{dr(t)}{dt} = p_{ir}y(t) \\ \frac{dq(t)}{dt} = p_{id}y(t) \\ \frac{dN(t)}{dt} = N(t) - p_{id}y(t) \end{cases}$$

Assuming, analyze the law of change with. From formula the first two terms can be obtained,

$$\frac{dy}{ds} = -1 + \frac{m}{\lambda s + \mu}$$

$$y(s) = -s + \frac{\mu + m}{\lambda} ln\, s - \frac{\mu + m}{\lambda} ln s_0 + y_0 + s_0 = -s + \frac{\mu + m}{\lambda} ln \frac{s}{s_0} + y_0 + s_0$$

Since the staff have taken measures to prevent infectious diseases, when the latent person of the infectious disease comes into contact with people, the probability of infecting the staff will be reduced, and the daily contact rate of the staff with the crowd is higher than the daily contact rate of other people, which will cause infection The transmission rate of the disease decreases. When the latent infectious disease does not show clinical symptoms, normal contact, that is, although the number of people infected with the infectious disease will increase and then decrease, the time to reach the peak will be greatly increased. And at the same time, the number of people infected with infectious diseases will be less than those without protective measures.

5. Error Analysis

In the prediction model of the number of people infected with infectious diseases based on the SIR, the data used is approximated: the death rate and the cure rate of infectious diseases are approximated, which will cause certain errors in the model.

When the staff goes to get off work, they are equivalent to other staff, which will cause certain errors.

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6. Model evaluation and promotion

This article cleverly uses the flowchart to show the modeling ideas completely and clearly; Using matlab software to process data and make charts, which is fast, simple and intuitive; Question one, put the latent persons and the persons infected with infectious diseases in a group, reduce the variables and simplify the calculation process.

For some data, we have performed some necessary processing on it, which will bring certain errors;In order to make the calculation simple and to make the result more ideal, some secondary influencing factors are ignored.

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