2020 International Conference on Artificial Intelligence and Computer Engineering (ICAICE) | 978-1-7281-9146-1/20/$31.00 ©2020 IEEE | DOI: 10.1109/ICAICE51518.2020.00104

Transmission mechanism of Novel coronavirus based on SIR model and emergency supplies network's relation

Zhang Shuo[1st]
School of Economic And Management
Beijing Information Science & Technology University
Beijing, China
e-mail: chinazqz@126.com

An Xuejiao[2nd]
School of Economic And Management
Beijing Information Science & Technology University
Beijing, China
e-mail: anxuejiao798@163.com

Qi Lin[3rd*]
School of Economic And Management
Beijing Information Science & Technology University
Beijing, China
*Corresponding author: e-mail： qilin@bistu.edu.cn

Zhou Wei[4th]
School of Economic And Management
Beijing Information Science & Technology University
Beijing, China
e-mail: zhouweizzzzz@163.com

Abstract—The outbreak of novel coronavirus pneumonia has caused great potential problems to the lives and property of people around the world. The novel coronavirus pneumonia has the characteristics of strong transmission and wide influence.In order to better explore the transmission mechanism of novel coronavirus pneumonia, and realize the detection and early warning of the spread of novel coronavirus pneumonia;this article uses the SIR model to explore the mechanism of the spread of the Novel coronavirus. Finally, the network relationship of emergency supplies during the novel coronavirus pneumonia epidemic situation was analyzed.

Keywords- SIR model; novel coronavirus pneumonia; mechanism

I. INTRODUCTION

The Novel coronavirus pneumonia(COVID-19) began to break out in Wuhan City of Hubei Province in China, and quickly spread to the whole China. At present, the epidemic is breaking out in many places around the world and showing a rapid trend, which has become a global epidemic.[1] Compared with traditional infectious diseases, the prevention and control of Novel coronavirus pneumonia is more limited due to the unknown pathogen, transmission route and exact treatment method.[2] Therefore, if the Novel coronavirus pneumonia is not detected and prevented early, it will not only affect the regional changes in the healthy environment but also affect global health environment. Due to the characteristics of transmission and spread of Novel coronavirus, it is easy to infect other people in a short time, so it is very important for the prevention and control of Novel coronavirus pneumonia.[3]

In the standard epidemiological SIR model, all individuals in the population can be roughly divided into a limited number of states, including susceptible individuals, infected individuals, and removed individuals.[4] The traditional SIR model can not only be applied to the study of the spread and spread of infectious diseases, such as the application in the SARS epidemic, the prediction of the spread of Ebola virus, but also many other fields. The SIR model has a wide range of applications, while the Novel coronavirus pneumonia has the characteristics of a general infectious disease.[5]

Using the different infection status of infectious disease groups, the law of the spread of the Novel coronavirus can be explored.

II. ASSUMPTIONS OF SIR MODEL

In order to simplify the model and get a reasonable solution, we make the following assumptions:

Assume that the population in the studying area is a constant N, not because of the change of time change. Namely, we do not consider the natural birth rate and death rate.

With considering the serious situation of the Novel coronavirus pneumonia, we found the cure is few, namely, most of the number of the cure is zero. So people can be divided into three kinds: class S is the susceptible, class I is the people who have been infected, class R is the remove, this class includes the cure who recover from Novel coronavirus pneumonia and the death because of the Novel coronavirus pneumonia (the cure and the death have two characteristics in common: 1. Won't be infected, 2. Under the premise of making carcass process, they will not be infected, based on this, the two class merge into one class). The proportions of this three kinds of people in the total number N respectively is $s(t)$, $i(t)$ and $r(t)$, that is $s(t)+i(t)+r(t)=1$.

Because of the effect of infectious diseases, the number of the susceptible changes over time. Its change rate and the product of the number of the susceptible at that time and the number of the infected people at that time is become direct ratio.

DOI 10.1109/ICAICE51518.2020.00104

The speed of the infected to the remove and the number the infected at that time is become direct ratio.

III. The Establishment of SIR Model

An epidemiological model is the SIR model shown in the figure 3. This model is the same as the SIS model except that once a person has recovered from the disease, they would receive lifelong immunity. The SIR model, which computes the theoretical number of individuals infected with a contagious illness in a closed population over time, was proposed by Kermack and McKendrick (1927).[6] The SIR model is appropriate for viral diseases such as measles, mumps and rubella.

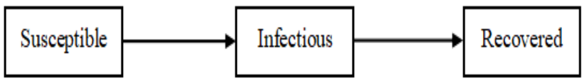

Figure 1. SIR model

The method use dynamics to build SIR model and study disease's diffusion law and trend. In addition, the model is suitable for strong immunity after curing infectious diseases which can't be infected again. The differential equation model:

$$\begin{cases} \dfrac{ds}{dt} = -\beta si, & s(0) = s_0 > 0 \\ \dfrac{di}{dt} = \beta si - ri, & i(0) = i_0 > 0 \\ \dfrac{dr}{dt} = ri, & r(0) = r_0 \geq 0 \end{cases} \tag{1}$$

where $\beta > 0$ is the infection rate and $\gamma > 0$ is the remove rate. $1/\gamma$ is the average infective period. $\rho = \gamma/\beta$ is relative remove rate. The differential equation's the last two equations based on the last two assumptions.

No matter how the initial condition s_0, i_0, the patient will eventually disappear, namely $\lim_{t\to\infty} i(t) = 0$.[7]

If $s_0 < \rho$,when t increases and $t \to +\infty$,the number of the infected $i(t)$ monotone decreasing tends to zero, the number of the susceptible $s(t)$ monotone decreasing tend to s_∞ .If $s_0 > \rho$, when t increases, the number of the infected $i(t)$ increases first and reach maximum when $s = \rho$, then $i(t)$ diminishes and tend to zero, $s(t)$ monotonic decreasing and reduce tend to s_∞ ,where $s_\infty = \lim_{t\to\infty} s(t)$, s_∞ is the only positive root of transcendental equation as follow:

$$s_0 = \exp[-\frac{1}{\rho}(1-s)] - s = 0 \tag{2}$$

IV. Novel coronavirus of SIR Diffusion Prediction and Solving Model

The outbreak and diffusion of the Novel coronavirus bring great impact to the epidemic area of economic development and people's life. We learned a lot of important experience and lesson from this Novel coronavirus diffusion, especially to realize quantitative prediction spread and diffusion of this infectious disease. The experience provides important reference basis to control the spread of the Novel coronavirus virus.[8]

In the differential equation model β, γ changes over time. β, γ can be seen as a function of time t . According to the model assumptions, each patient can make healthy people become infected every day which the number of the healthy people is $\beta(t)s(t)$, therefore,

$$\lambda(t) = \beta(t)s(t) = \frac{\text{the number of new infection in } t \text{ days}}{(\text{the cumulative infections} - \text{the total cures}) \text{ in } (t-1)\text{days}} \tag{3}$$

where $\gamma(t)$ is the remove rate, namely, the cure rate, and therefore,

$$\gamma(t) = \frac{\text{new cure patients in } t \text{ days}}{(\text{the cumulative infections} - \text{total the cures}) \text{ in } (t-1) \text{ days}} \tag{4}$$

According to the historical data, we can obtain $\lambda(t)$ and $\gamma(t)$ equation by curve fitting. We can build dynamic prediction system of disease's diffusion by using this model; its basic steps are as follows:

Step 1: Based on the data some time ago, we can obtain $\lambda(t)$ and $\gamma(t)$ equation by curve fitting;

Step 2: Use the fitting out of $\lambda(t)$ and $\gamma(t)$ equation and differential equation to predict the next cycle of the disease spread situation;

Step 3: After reaching a new cycle, we can return to Step 1 and use more data for parameter fitting (this choice is depends on the actual situation).

Proceeding in this fashion, we can establish a dynamic forecast system of spreading the disease.

As the SIR model says, i is the number of patients have been infected. Given initial value of s , i and r , we can obtain i value at some point by solving differential equation group. For this model, we expect i can stay at a lower level, which means that the spread of infectious disease has been effectively controlled. Analyzing the model, in order to carry out effective control of i , we should decrease the propagate coefficient disease and improve the recovery rate of infectious diseases. From the perspective of emergency rescue, we should ensure rescue medication enough for emergency treatment of patients and increase the probability of restore it, thereby more effectively control the number of i .

In the early period of epidemic situation of infectious diseases, populations were inoculated on cycle pulsed T. The below figure is SIR infectious disease model and broadcast model represented by the formula:

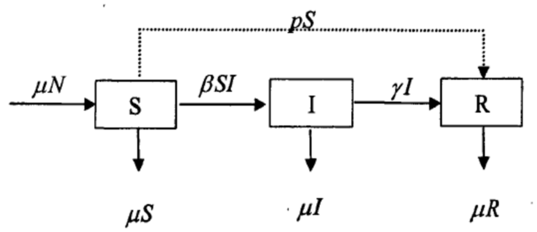

Figure 2. SIR model with pulse vaccination

$$\begin{cases} \dfrac{ds}{dt} = -\beta si, & s(0) = s_0 > 0 \\ \dfrac{di}{dt} = \beta si - ri, & i(0) = i_0 > 0 \\ \dfrac{dr}{dt} = ri, & r(0) = r_0 \geq 0 \end{cases} \tag{5}$$

$$\begin{cases} s(t) = (1-p)s(t^-) \\ i(t) = i(t^-) \quad t = t_n \quad n = 0,1,2\ldots \\ r(t) = r(t^-) + ps(t^-) \end{cases} \tag{6}$$

From above figure, we can see the method of the pulse vaccination is effective for the patients.

Unlike traditional mass one-time vaccination, the pulse vaccination method can guarantee at a relatively low coverage of effective control of the spread of the population. We assume that $i(t)$ is a function of a decreasing over time and μ is natural birth rate and natural population mortality, then the population of infected people will eventually tend to zero. Assuming that under the condition of $\frac{di}{dt} < 0$, then we can conclude that the critical value of s_c:

$$s_c = \frac{u+r}{\beta} > \frac{(ut-p)(e^{ut}-1)+upt}{ut(p-1+e^{ut})} \tag{7}$$

So the critical value of p_c is

$$p_c = \frac{ut(u+r-\beta)(e^{ut}-1)}{ut(\beta-u-r)+\beta(1-e^{ut})} \tag{8}$$

If vaccination coverage rate $p > p_c$, we can know that the system can get a stability of the disease-free periodic solution.

As described by the model of infectious disease outbreak in a certain region, before the affected populations were inoculated, the first thing needs to know is that the demand for the vaccine of the epidemic area at the rescue period. Based on the SIR model with pulse vaccination represented by the law of infectious disease diffusion, we use the following form of demand predict the change of $D_k = ps(t_k^-)$ over time.

V. Novel coronavirus Diffusion and Emergency Supplies Network's Relation

The ability of sudden public health incident warning defense system shows the system response to sudden public health incident readiness, namely, the ability to meet the demand of emergency logistics in the limited time and space constraints. In important infectious disease events, the relationship between the emergency logistics supply capacity and emergency logistics demand mainly shows the collaborative of the spread of infectious diseases network and the emergency logistics distribution network. On the one hand, if a city suffers a big infectious disease attack, the city will form a people-oriented node of the dangerous source diffusion network, which has two characteristics of fast and jumping, and the flow with infected people can spread from one city to another city. Emergency supplies distribution system of emergency relief supplies with the spread of the hazards will form a emergency logistics network as the node of cities, therefore, spread of infectious diseases network is driven by emergency supplies in emergency logistics network of distribution. According to the area, on the other hand, the demand for change over time is satisfied, the infected people constantly reduce, immune population rapidly increase, the spread of infectious diseases in the area will also get effective control, namely the emergency supplies distribution network inverse control the spread of the infectious diseases.

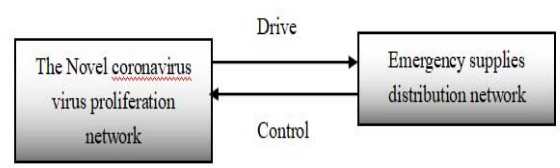

Figure 3. the relation of Novel coronavirus diffusion and emergency supplies network

The Novel coronavirus virus spread the relationship between the network and the emergency logistics network is shown in Figure 3.

VI. Conclusions

First of all, in order to better explor the transmission mechanism of Novel coronavirus and solve the current tense situation, this paper establishes SIR model to explore the transmission process of Novel coronavirus pneumonia and predict the development trend of Novel coronavirus pneumonia.[9] In this paper, the transmission mechanism and transmission process of infectious diseases, combined with the development characteristics of the new epidemic situation, the prediction model of the number of Novel coronavirus pneumonia infections provides accurate decision support for the control of the new epidemic situation.[10] Secondly, considering the possibility of the Novel coronavirus pneumonia vaccine coming out soon, we improved the SIR model.[11] The improved

SIR model can fully consider the relationship between the demand of vaccine in the epidemic area and the infected population.[12] Finally, the supply of emergency supplies during the outbreak of Novel coronavirus pneumonia was explored.[13,14] In this paper, the establishment and development of Novel coronavirus pneumonia control mechanism were fully explored, and the decision-making suggestions for the control of Novel coronavirus pneumonia situation were put forward.

ACKNOWLEDGMENTS

This research is supported by the promoting efficient connotative development construction project of Beijing Information Science and Technology University (521201090A, 5026010961).

REFERENCES

[1] Mareev V Yu, Orlova Ya A, Pavlikova E P, et al. [Steroid pulse -therapy in patients With coronAvirus Pneumonia (COVID-19), sYstemic inFlammation And Risk of vEnous thRombosis and thromboembolism (WAYFARER Study)].. 2020, 60(6):15-29.

[2] Lin Wang, Ruiying Huang, Zhili Chen, et al. The Application of "Internet Plus Nursing Service" Mode under the Epidemic of Novel Coronavirus Pneumonia. 2020, 08(05):255-264.

[3] Shao Shen, Zhou Zichen, Li Yue, et al. Experiences and practices in the current prevention and control of the novel coronavirus pneumonia in China.. 2020, :1-19.

[4] Bruce Mca. Sayers, Juan J. Angulo. A new explanatory model of an SIR disease epidemic: A knowledge-based, probabilistic approach to epidemic analysis. 2005, 37(1):55-60.

[5] Joel C. Miller. Mathematical models of SIR disease spread with combined non-sexual and sexual transmission routes. 2017, 2(1):35-55.

[6] Julie C. Blackwood, Lauren M. Childs. An introduction to compartmental modeling for the budding infectious disease modeler. 2018, 5(1):195-221.

[7] Luca Bolzoni, Elena Bonacini, Cinzia Soresina, et al. Time-optimal control strategies in SIR epidemic models. 2017, 292:86-96.

[8] Sarbaz H. A. Khoshnaw, Najem A. Mohammad, Rizgar H. Salih. Identifying Critical Parameters in SIR Model for Spread of Disease. 2017, 5(1):32-46.

[9] F. Umer, Z. Haji, K. Zafar. Role of respirators in controlling the spread of novel coronavirus (COVID‐19) amongst dental healthcare providers: a review. 2020, 53(8):1062-1067.

[10] Chladná Zuzana, Kopfová Jana, Rachinskii Dmitrii, et al. Global dynamics of SIR model with switched transmission rate.. 2020, 80(4):1209-1233.

[11] F.A. Rihan, Q.M. Al-Mdallal, H.J. AlSakaji, et al. A fractional-order epidemic model with time-delay and nonlinear incidence rate. 2019, 126:97-105.

[12] Kanica Goel, Nilam. A mathematical and numerical study of a SIR epidemic model with time delay, nonlinear incidence and treatment rates. 2019, 138(2):203-213.

[13] A George Maria Selvam, D Abraham Vianny, Mary Jacintha. Stability in a fractional order SIR epidemic model of childhood diseases with discretization. 2018, 1139(1)

[14] Xiaobin Rui, Fanrong Meng, Zhixiao Wang, et al. SPIR: The potential spreaders involved SIR model for information diffusion in social networks. 2018, 506:254-269.