Dynamical Analysis for the Control of COVID-19: A Modified SEIR Model

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Abstract: Objective: The paper of this research is to establish a new infectious disease dynamics model, which can be used to evaluate the epidemic situation of covid-19 in 2019, and to evaluate the epidemic situation of covid-19 in Hubei Province based on the SEIR model. Methods: Considering that covid-19 patients with latent period have strong infectious ability, and the epidemic prevention information of the media has a positive impact on mass epidemic prevention, an optimized SEIR epidemic dynamics model considering latent period transmission ability, tracking and isolation intervention measures and mass disease awareness was established. Referring to the official epidemic data of Hubei Province from January 23 to February 24, 2020 as the initial value of the dynamic system, the paper analyzes the epidemic situation in Hubei Province based on the modified SEIR model to evaluate the impact of various measures and policies on the epidemic transmission trend. Results: The theoretical analysis of the model shows that measures such as quarantine and medical tracking can effectively inhibit the large-scale spread of the epidemic; centralized reception, layered treatment and other important measures have played a key role in the rapid decline of the peak number of infected people. Improving personal prevention awareness can curb the increase of infected people. In addition, the publicity of news media can greatly increase people's disease awareness, so as to control the development trend of epidemic situation and effectively reduce the peak number of infected people. Conclusion: the modified SEIR model can be used for theoretical analyzing of covid-19 transmission and help the government to formulate epidemic prevention policies.

1 INTRODUCTION

In recent decades, many infectious diseases are constantly erupting, such as Ebora, swine flu, and Chaga virus. At the end of 2019, an infectious disease called New Coronavirus pneumonia (COVID 19) was first launched in the world. The virus was highly infectious and no vaccine was available at that time.

The COVID-19 has been responded very quickly by China's government. In Hubei Province, where the epidemic first broke out, the first level response to major public health emergencies has been launched since January 24, 2020. In order to control the spread of the epidemic, the government has adopted isolation measures based on past experience, such as stopping performances and other activities, closing cinemas, KTVs, schools and some workplaces to reduce crowd gathering. In addition, the government has also introduced policies to restrict the movement of people to prevent the large-scale spread of the virus from person to person. Hubei Province has also implemented strict medical follow-up isolation, such as a 14 day isolation observation of the people who have been in contact with the infected people.

From the experience of China and other countries in dealing with the epidemic situation, it can be found that isolation measures are a very effective and feasible anti-epidemic policy which has become the first choice of many countries in facing the epidemic situation. However, in the early stage of the epidemic, some scholars did not consider the isolation factor in the research on the development trend of covid-19 epidemic through dynamic model. For example, according to the estimate results of the number of infections by Jonathan et al. (Jonathan, 2020) on January 24, 2020, as of February 4, the number of COVID-19 infection cases in Wuhan will reach 190,000, far exceeding the actual number of infections.

Also, with the development of technology, communication software and news media, people have more and more ways to obtain disease information, which is conducive to timely taking

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protective measures to reduce the occurrence of diseases. Especially, how the behavior of people with strong awareness of disease and the government quarantine methods affect the spread of infectious diseases is worthy of targeted research. Over the years, many mathematical models have been proposed to study the impact of disease awareness on infectious diseases. These models can be divided into two categories: Network model and mean field model

There are two ways about the influence of disease awareness on infectious diseases: 1) The first way is to reduce the contact infection rate and take preventive measures. 2) The media area m of independent storehouse is introduced to represent the change of disease information

As for the second mode of influence, most of the relevant studies did not consider the constant input rate of media coverage. For example, The SIS model established by Basir et al. (Basir, 2018) In 2018 studied the impact of disease awareness and time lag on infectious disease control. In 2020, Kumar et al. (Kumar, 2020) established a SVIR model based on an independent rate equation, taking into account the impact of vaccination coverage information. These studies consider the second mode of disease awareness, but the growth of media coverage is only related to the infected people.

In addition, recent conditions have shown that carriers of the virus in the incubation period have a strong risk of virus transmission because they have not yet shown symptoms. However, the dynamic model of the epidemic spread established by researchers previously ignored this risk. At the same time, in previous studies, isolation and prevention have not been considered as factors influencing the spread of epidemics. Therefore, this paper studies the effect of disease awareness, virus latency, and quarantine measures on the dynamic model of infectious diseases. Under the above assumptions, an infectious disease model with certain rationality and research value is established, which provides theoretical support for the prevention and control of the current COVID-19 and some other infectious diseases in the future.

2 METHODS

2.1 Improvement of SEIR Model

In the traditional SEIR model, S stands for the susceptible population, I stands for the infected population, E stands for the exposed population and R stands for the recovered population. The model also assumes because the infected individual will produce antibodies after recovery. However, considering the quarantine measures, quarantine susceptible [S_q], quarantine exposed [E_q] and quarantine infected [I_q] are taken into consideration. When it comes to the impact of the disease awareness, a new population group which stands for the awared susceptible [S_a] should also be added into the model. So that it will be possible to estimate the impacts of both the disease awareness and the quarantine measures on the spread of a certain epidemic. In view of the fact that the isolated infected people will beput into quarantine treatment as soon as possible, all these people will become hospitalized patients in this model [H]. Therefore, in the revised model [S], [I] and [E] respectively refer to the susceptible, infected and exposed persons who escape from the isolation measures. In this way, the improved SEIR model in this paper can be represented by figure 1.

2.2 Establishment of New Model

[q] is defined as isolation proportion, [β] is defined as infection probability, [c] is defined as contact rate, [ρ] is defined as effective contact coefficient (1 for reference), Therefore, [ρc] refers to the effective contact rate. Then we can give out the transmissive relationship between susceptible people and other

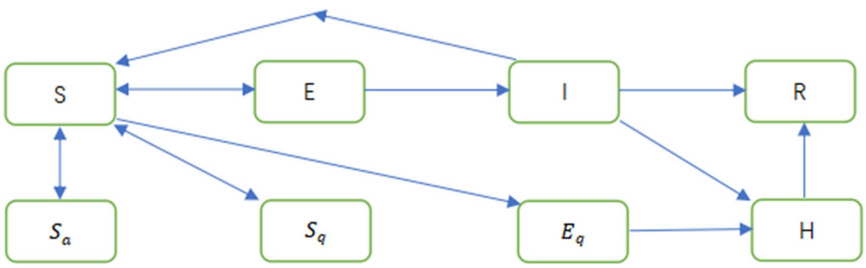

Figure 1: The improved SEIR model.

groups of people:

- The conversion rate from susceptible population to quarantine susceptible population is $\rho c q(1-\beta)$
- The conversion rate of susceptible population to isolated latent population is $\rho c q \beta$
- The conversion rate from susceptible population to exposed population is $\rho c \beta(1-q)$

The effective information density [M(t)] adopted in the model is a time dependent function and includes the following three terms:

- The input value of disease awareness [o], a constant in the whole model which reprents the publicity efforts of government officials and other news media for epidemic prevention and control
- The generation rate of autonomous disease awareness [η], reporting how people's disease awareness develop naturely through the spread of disease
- The disease awareness decay rate [θ], modeling how people's disease awareness decay over time

In this case the effective information density [M(t)] can be written ito the following expression:

$$\frac{dM}{dt} = o + \eta I - \theta M \qquad (1)$$

At the same time, the influence of non quarantine infected person and exposed person on the susceptible population should be taken into consideration, and the susceptible person whose quarantine has been removed is changed into susceptible person again. In addition, it is reasonable to assume that patients during latent period has the same ability of infection as that of patients with symptoms.

Therefore, the equation of the number of the susceptible is:

$$\frac{dS}{dt} = -[\rho c\beta + \rho c q(1-\beta)]S(I+E) + \lambda S_q - MS + \omega S_a \qquad (2)$$

In equation (2), λ stands for the quarantine release rate. Since the quarantine time in China is 14 days, the value of λ can be taken as $1/14$.

The equation of the number of the exposed is:

$$\frac{dE}{dt} = \rho c\beta(1-q)S(I+E) - \sigma E \qquad (3)$$

In equation (3), σ stands for the transformation rate from exposed to infected. Since the average latent period is about seven days according to the China Health Inspection Commission,the value of σ can be taken as $1/7$.

The equation of the number of the infected is:

$$\frac{dI}{dt} = \sigma E - (\delta_I + \alpha + \gamma_I)I \qquad (4)$$

In equation (4), $\delta_I, \alpha, \gamma_I$ respectively represent the quarantine rate, the fatality rate and the recovery rate of the infected.

The initial values of the dynamic system refer to the official data (State Health Commission of the people's Republic of China) of Hubei Province. The specific parameters and their values are described in Table 1.

Table 1: Parameters used in the system and their values.

parameter	description	default value	Reference
q	isolation proportion	1×10^{-6}	(Wang, 2020)
β	infection probability	2.05×10^{-9}	(Wang, 2020)
c	contact rate	3	
ρ	effective contact coefficient	1	
o	disease awareness value	0.1	(Liu, 2018)
η	autonomous disease awareness rate	0.01	(Gani, 2018)
θ	disease awareness decay rate	0.06	(Gani, 2018)
λ	quarantine release rate	$\frac{1}{14}$	
ω	disease awareness loss rate	0.2	(Gani, 2018)
σ	transformation rate	$\frac{1}{7}$	
δ_I	quarantine rate of the infected	0.13	(Wang, 2020)
α	fatality rate	2.7×10^{-4}	(Wang, 2020)
γ_I	recovery rate of the infected	0.007	(Wang, 2020)

3 RESULTS

Based on the SEIR model, this paper makes a retrospective study on the epidemic situation in Hubei Province. Furthermore, the author analyzes the development law of the epidemic under the impact of different control measures as well as media publicity.

3.1 Estimation of The Impact Quarantine on Epidemic Situation

In the numerical simulation analysis, it is assumed that the initial contact rate under the current prevention and control measures is 2. By increasing the exposure rate to simulate the development trend of people infected with covid-19 under the condition of ineffective prevention and control measures, the effect of different prevention and control measures can be evaluated. Figure 2 shows the epidemic simulation under higher exposure probability of susceptible persons (the exposure rates under three kinds of poor management and control are 3, 4 and 6 respectively). The analysis found that strict prevention and control measures can effectively contain the large-scale spread of the epidemic. It is estimated that if the government does not issue strict quarantine measures on January 23, 2020, the number of infections in Hubei Province may reach more than twice the actual number of infections. In addition, if measures are not taken to control the epidemic, the virus will spread faster, which will cause greater loss of life and property, and cause serious social panic. In particular, in the extreme cases of ineffective prevention and control (i.e. 2 and 3), the number of people infected with the epidemic will drop very slowly after reaching the peak, and the duration of the epidemic will be very long.

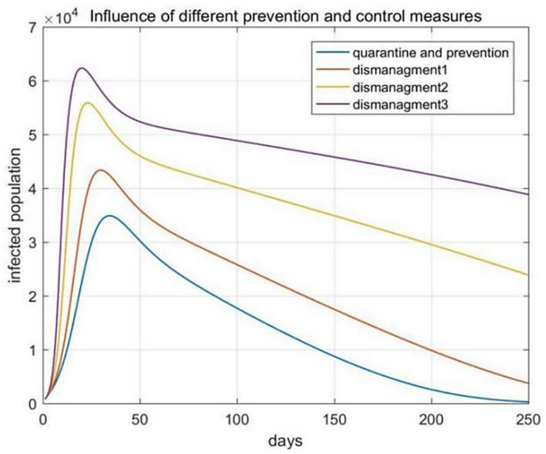

Figure 2: Influence of different prevention and control measures.

In this paper, the author simulated the effect of tracking and isolation measures, that is, the decrease of tracking and isolation ratio. As shown in the figure 3, the isolation ratio decreases to 0.9, 0.8 and 0.6 times in case of lack of quarantine1, 2and 3. The peak number of infected people and the rising rate largely increased. Especially when the isolation rate was taken as 0.6q, the peak number of the infected nearly doubles. In the numerical simulation, the overall trend of the epidemic development is basically consistent, and the number of infected people drops to 0 in about 250 days, which means that the epidemic is basically over. Therefore, strict medical tracking and isolation is an effective means to control the development of the epidemic.

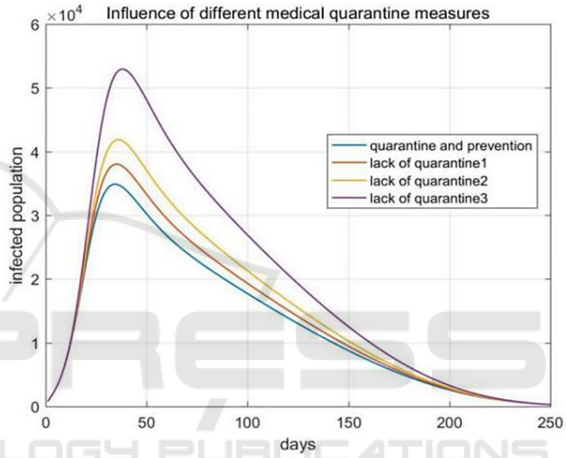

Figure 3: Influence of different medical quarantine measures.

With the increase of daily contact rate between personnel, personal daily safety protection will be particularly important. The effective contact rate is $c' = \rho c$. Where c is the daily contact rate between daily personnel, ρ is the effective contact coefficient. Figure 4 reflects the impact of the reduction of effective contact coefficient on the development of the epidemic situation (assuming that the number of infected people does not jump), and sets the contact rate between personnel. When the effective contact coefficient is 0.5, 0.25 and 0.1 respectively. Personal daily protective measures will not only ensure personal safety, but also play a vital role in curbing the development of the epidemic. Strict daily safety protection helps advance the peak time of infection and reduce the peak number. Under strict personal protection measures, the peak number of infected people can be reduced by nearly 60%.

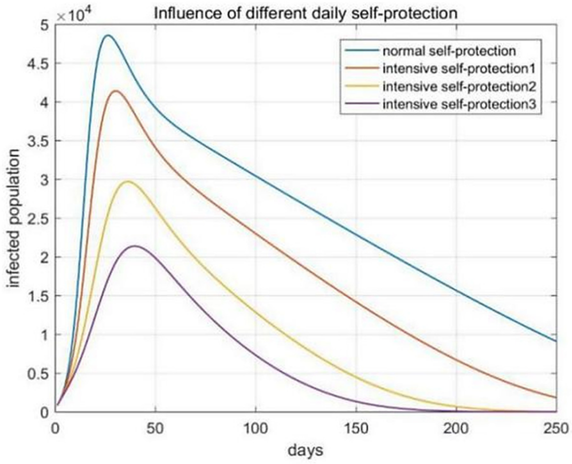

Figure 4: Influence of different daily self-protection.

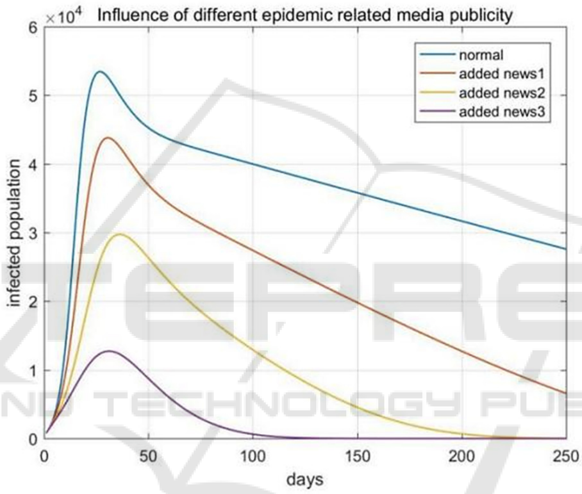

Figure 5: Influence of different epidemic related media publicity.

3.2 Estimation of The Impact of Disease Awareness on Epidemic Situation

The broadcast of epidemic situation by TV news media is one of the most important ways to obtain people's disease awareness. Figure 4 simulates the impact of different input rates of disease awareness on the spread of epidemic situation in the early stage of the epidemic when the media reports the epidemic related information to different degrees. As shown in figure 5, when the disease awareness input rate reaches 10 times, 20 times and 50 times of the initial value respectively, the rising rate of the number of infected people decreases rapidly, and the peak of infection also decreases greatly, and the number of infected people decreases rapidly after experiencing the peak, and soon reaches the disease-free equilibrium point. Especially when the input rate of disease awareness is 50, the peak number of infected people is only one third of the original, and nearly half of the time earlier to reach the disease-free equilibrium. It can be seen that information factors have a great impact on the prevention and control of the epidemic, and the improvement of people's disease awareness can effectively curb the development of the epidemic.

4 CONCLUSION

In summary, the research results of this article show that: First of all, prevention and control isolation and medical tracking isolation can effectively curb the spread of covid-19. Secondly, important measures such as centralized reception and graded treatment can enable the infected people to receive better treatment, and make the number of infected people drop rapidly. Third, self-protection measures, such as wearing a mask and paying attention to personal hygiene, can also effectively reduce the infection rate. Finally, when the epidemic just broke out, spreading knowledge about epidemic prevention through channels such as TV and the Internet can increase people's awareness of the disease and cultivate good hygiene habits for the public, thereby reducing the severity of the epidemic.

What is more, the results of the optimized SEIR model in this paper are in good agreement with the actual development trend of the epidemic situation in Hubei Province, thus confirming that the model is reliable in the analysis of infectious disease transmission situation. Furthermore, the result of this research can provide theoretical support for relavant policy making in the future.

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