

# Mathematical Model for COVID-19

Lingfei Kong \*

University of Rochester, USA

\* Corresponding Author Email: Konglingfei2023@163.com

**Abstract.** Since the end of 2019, novel coronavirus has started to spread around the world and continue to mutate. From the initial Alpha to Delta and Omicron, it continues to affect our economic, social and spiritual life. In the process of prevention and control of COVID-19, many people are constantly questioning the prevention and control measures taken in China, such as wearing masks when going in and out of public places, washing hands frequently when going out and back home, regular disinfection in public places, the necessity of building large-scale shelter hospitals, fixed-point isolation of close contacts and infected persons, and universal vaccination. In this paper, the mathematical models, Si, Sir, SEIR, SEIRD, are used to scientifically reveal the transmission link and future development trend of novel coronavirus; At the same time, through mathematical analysis, the necessity of the above new crown epidemic prevention measures is explained in detail.

**Keywords:** Model SI; Model SIR; Model SEIR; Model SEIRD.

## 1. Background

Since the end of 2019, a novel coronavirus known as "corona" has rapidly spread across the globe, culminating in a worldwide pandemic. This pandemic represents one of the most significant challenges humanities has faced in the last century, posing a grave threat to human safety and health. As of May 13, 2022, according to official data from the World Health Organization, there have been 517,648,631 confirmed COVID-19 cases and 6,261,708 deaths worldwide, with case numbers still on the rise.

The novel coronavirus continues to evolve, with recent months witnessing the emergence of more contagious variants like Delta and Omicron, impacting major Chinese cities like Shanghai. These mutations have profound repercussions on economic, social, and spiritual aspects of life, severely affecting various industries such as tourism, catering, commerce, transportation, conventions, and exhibitions.

In response, countries worldwide have implemented effective measures to combat the virus. China, in particular, has taken comprehensive and rigorous steps to control the epidemic, including mask-wearing, hand hygiene, disinfection, the construction of makeshift hospitals, isolation of close contacts, and widespread vaccination.

This paper, authored by a mathematical modeling enthusiast rather than an epidemiologist, aims to gain a precise understanding of classical epidemic transmission models by studying global literature. It employs mathematical modeling to analyze different stages of COVID-19 prevention, elucidating transmission dynamics. The objective is to use mathematical models to predict epidemic development, peak times, and key statistics. By analyzing model parameters, the significance of various preventive measures can be evaluated, assisting decision-makers in crafting effective strategies, including healthcare investments, mobility restrictions, and personal protection recommendations. The research seeks to provide a clear direction for COVID-19 prevention and control efforts.

## 2. Problem statement & Assumption

### 2.1. Problem statement

During the prevention and control of COVID-19, many people have been questioning the developing trend and the measures taken in China.

- How to analyze and predict the future development trend of COVID-19 and when it will reach the peak and inflection point?
- How to evaluate the infectivity of novel coronavirus?
- Why should we isolate infected people and people in incubation period?
- How to evaluate the importance of shelter construction, universal vaccination and regular nucleic acid testing?
- The necessity of flow restriction in public places, wearing masks when going out, washing hands frequently at home and other protective measures for the prevention and control of COVID-19?

This paper hopes to use a mathematical model to clearly reveal the transmission link of COVID-19 from the initial outbreak to the overall prevention and control process, and the necessity of scientifically quantifying the epidemic prevention and control.

## 2.2. Assumption

In order to study the transmission process of novel coronavirus more clearly, before the mathematical model is established, we peel off some interfering factors and assume that we live in an ideal environment. The environment meets the following conditions:

- Novel coronavirus has the same infectivity to all people, that is, all people are susceptible to infection and have the same infection probability.
- The total number of subjects is  $N$  that remains unchanged, regardless of natural life and death and immigration.
- Those who are not infected by the virus are called susceptible, which is represented by set  $s$  (susceptible).
- Infected people who are not cured are called infected people. They have the ability to transmit the virus to others, which is expressed by set  $I$  (infective).
- After the infected person is cured, the antibody will not be infected again. It is called the remover, which is represented by set  $R$  (removal). It includes people who are cured and immunized or effectively isolated or dead, who will neither infect others nor be infected.
- At a certain time  $t$ , the proportion of infected persons is  $i(t)$ , then the number of infected persons is  $N \cdot i(t)$ ; If the proportion of susceptible persons is  $s(t)$ , the number of susceptible persons is  $N \cdot s(t)$ ; If the proportion of people who move out is  $r(t)$ , the number of people who move out is  $N \cdot r(t)$ . At the same time, we can get:

$$r(t) + i(t) + s(t) = 1 \quad (1)$$

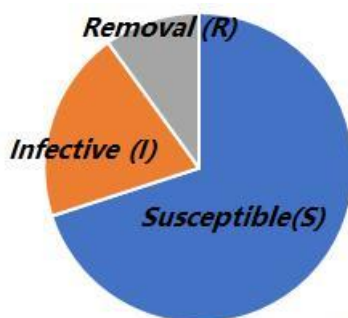


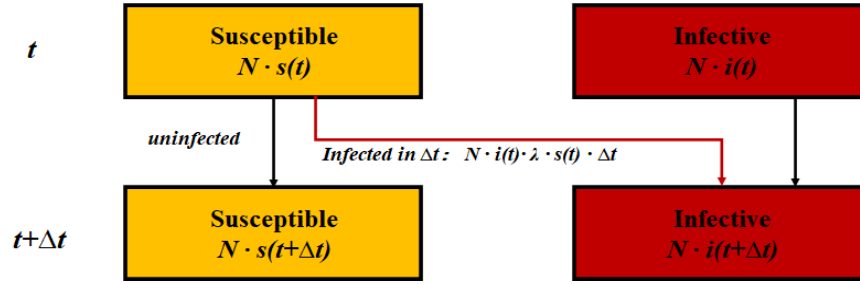
Fig. 1 Subject pie chart

## 3. Mathematical model establishment

### 3.1. Model Si of the initial outbreak of COVID-19

At the initial stage of the outbreak of the COVID-19, everyone did not know and understand the virus. Medical institutions and epidemic prevention departments did not take any measures. The virus spread silently and freely among people.

At this stage, there is no remover set R without healers and dead. So, we can get  $r(t)=0$ ,  $i(t) + s(t) = 1$ .



**Fig. 2** Model Si of the initial outbreak of COVID-19

We set:

- The starting time of the epidemic is  $t$ , the number of susceptible persons at that time is  $N \cdot s(t)$ , and the number of infected persons is  $N \cdot i(t)$ .
- After a short period of time  $\Delta t$ , at  $t + \Delta t$  the number of susceptible persons is  $N \cdot s(t + \Delta t)$ , the number of infected persons was  $N \cdot I(t + \Delta t)$ .
- In unit time, the average effective contact times of each infected person with susceptible persons are  $\lambda$  (daily exposure rate), the number of new infections caused is  $\lambda s(t)$ . During the period of  $\Delta t$ , we get the number of infected persons increased to:

$$\underbrace{N \cdot i(t)}_{\text{Infected}} \cdot \underbrace{\lambda \cdot s(t)}_{\substack{\text{Average number of} \\ \text{persons per unit} \\ \text{time exposed to} \\ \text{susceptible}}} \cdot \underbrace{\Delta t}_{\substack{\text{Propagation} \\ \text{duration}}} \quad (2)$$

From the above process, it can be deduced that:

$$\frac{N \cdot i(t + \Delta t) - N \cdot i(t)}{\Delta t} = N \cdot i(t) \cdot \lambda \cdot s(t) \quad (3)$$

Thus, the change rate of infected persons can be obtained:

$$\frac{di(t)}{dt} = \lambda \cdot s(t) \cdot i(t) \quad (4)$$

And then:

$$\frac{di(t)}{dt} = \lambda \cdot s(t) \cdot i(t) = \lambda \cdot i(t) \cdot (1 - i(t)) \quad (s(t) + i(t) = 1, r(t) = 0) \quad (5)$$

According to the logistic differential equation, the above implicit function can be integrated to obtain:

$$i(t) = \frac{1}{1 + (1/i_0 - 1) \cdot e^{-\lambda t}} \quad (t = 0, i(0) = i_0) \quad (6)$$

This is the SI model for the early outbreak of the COVID-19. According to the SI model, at the initial stage of the outbreak of COVID-19, without considering cure and death, the total number of samples  $n$  can be divided into  $S$  and  $I$ . if there is no treatment and epidemic prevention, all people will eventually be infected by the virus.

So, for the SI model at the early stage of the outbreak of COVID-19, if no treatment and epidemic prevention is done, at what time will the epidemic spread growth rate be the largest?

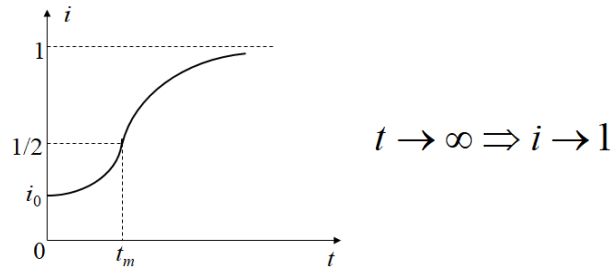
We can do the second derivative of the infected function  $i(t)$ , and the results are as follows:

$$\frac{di^2(t)}{dt^2} = \lambda^2 \cdot i(t) \cdot (1 - i(t))(1 - 2 \cdot i(t)) \quad 0 < i(t) < 1 \quad (7)$$

When  $di^2(t)/dt^2 = 0$  and  $i(t) = 1/2$ , the growth rate of epidemic infection is the largest, and the corresponding time  $t_m$  is shown in the following formula:

$$t_m = \lambda^{-1} \ln \left( \frac{1}{i_0} - 1 \right) \quad (8)$$

Thus, the infected function  $i(t)$  of SI model image can be drawn as follows.

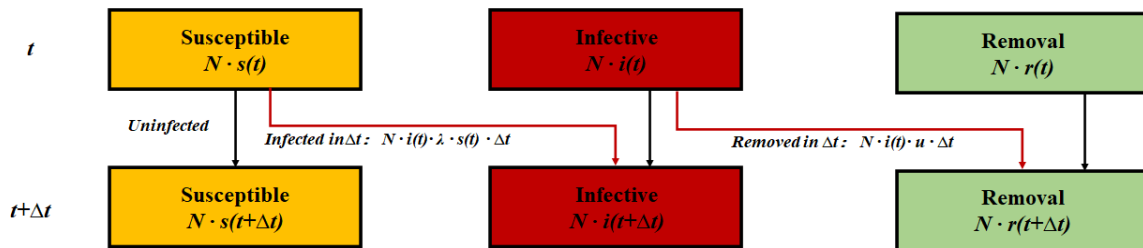


**Fig. 3** SI model image

Si model is only applicable to the initial stage of infectious diseases and can be used to predict the peak arrival time of the increase rate of infectious cases.

### 3.2. Mathematic Model SIR

In the process of prevention and control of COVID-19, medical institutions and epidemic prevention departments in various countries have taken various epidemic prevention measures, such as: building large shelter hospitals to treat patients with COVID infection; Through universal vaccine popularization, people's probability of getting COVID will be reduced. Therefore, in this stage, the total number of samples is  $N$ , which will be composed of susceptible person set  $S$ , infected person set  $I$  and removed person set  $R$ . And we get  $r(t)+i(t) +s(t)=1$ .



**Fig. 4** Mathematic Model SIR

We set:

- The starting time of the epidemic is  $t$ , the number of susceptible persons at that time is  $N \cdot s(t)$ , the number of infected persons is  $N \cdot i(t)$ , and the number of displaced persons is  $N \cdot r(t)$ .
- After a short period of time  $\Delta t$ , at  $t + \Delta t$ , the number of susceptible persons is  $N \cdot s(t + \Delta t)$ , the number of infected persons was  $N \cdot I(t + \Delta t)$ , the number of people who move out is  $N \cdot R(t + \Delta t)$ .

In the same way as the derivation method of model SI, the following differential equations can be obtained:

$$\frac{ds(t)}{dt} = -\lambda \cdot s(t) \cdot i(t) \quad (9)$$

$$\frac{di(t)}{dt} = \lambda \cdot s(t) \cdot i(t) - u \cdot i(t) \quad (10)$$

$$\frac{dr(t)}{dt} = u \cdot i(t) \quad (11)$$

In the equation above, constant  $\lambda$  is the daily contact rate of infected persons (the average number of effective contacts per patient per day), constant  $u$  is the daily cure rate (the proportion of patients cured every day in the total number of patients). Here we introduce a variable  $\sigma$  equals to the daily exposure rate of infected persons  $\lambda$  Ratio to daily cure rate  $u$ .

$$\sigma = \lambda / \mu \quad (12)$$

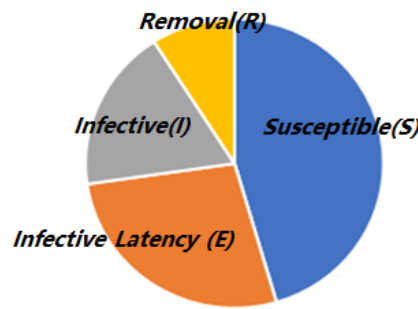
The practical significance of  $\sigma$  can describe the effective contact number of each patient in an infection period.

### 3.3. Optimistic mathematic model SEIR

In the actual process of epidemic prevention and control, since patients infected with novel coronavirus are not infectious at the initial stage, and do not cause contact infection to others, we call this period the incubation period. Therefore, by optimizing the SIR model mentioned in the previous section, we can get the mathematical model SEIR that is more in line with the epidemic prevention and control process.

The model assumes that the total number of samples is  $N$ , which is composed of susceptible person set  $S$ , infection latency set  $E$ , infected person set  $I$  and removed person set  $R$ .

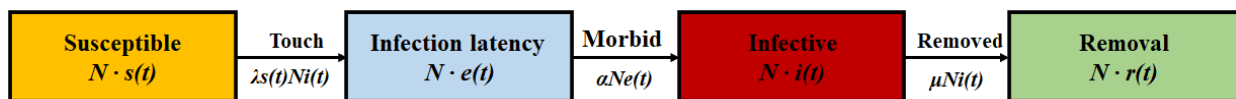
$$s(t) + e(t) + r(t) + i(t) = 1 \quad (13)$$



**Fig. 5** The mathematical model SEIR assumes a pie chart of the sample.

We make some assumptions as following,

- When the initial time  $t = 0$ , the initial ratio of the number of various types of people is  $s_0, e_0, i_0, r_0$ .
- Daily exposure  $\lambda$ . That is, the average number of susceptible persons effectively contacted by each sick person every day.
- Daily incidence rate  $\alpha$ . That is, the ratio of latent patients who become infected every day to the total number of latent patients.
- Daily removal rate  $\mu$ , that is, the ratio of the number of infected people cured or died every day to the total number of infected people.
- Average cure days  $1/\mu$ . Also known as the average infection period, that is, the number of days from illness to cure.
- Number of contacts in infectious period  $\sigma = \lambda/\mu$ . That is, the number of susceptible persons effectively contacted by each patient within  $1/\mu$  days of the whole infection period.



**Fig. 6** Optimistic mathematic model SEIR

As shown, each infected person can make  $\lambda \cdot s(t)$  susceptible persons become latent patients, and the number of infected persons is  $N \cdot i(t)$ , so there are patients every day  $\lambda \cdot s(t) \cdot n \cdot i(t)$  susceptible patients became latent patients.

In  $N \cdot e(t)$  of patients with daily incubation period, there are  $\alpha \cdot N \cdot e(t)$  became infected.

Among the infected  $N \cdot i(t)$ , every day there are  $\mu \cdot N \cdot i(t)$  is cured or dies and becomes the remover.

The following differential equations can be obtained by the same derivation method as Si and SIR models:

$$\frac{ds(t)}{dt} = -\lambda \cdot s(t) \cdot i(t) \quad (14)$$

$$\frac{de(t)}{dt} = \lambda \cdot s(t) \cdot i(t) - \alpha \cdot e(t) \quad (15)$$

$$\frac{di(t)}{dt} = \alpha \cdot e(t) - u \cdot i(t) \quad (16)$$

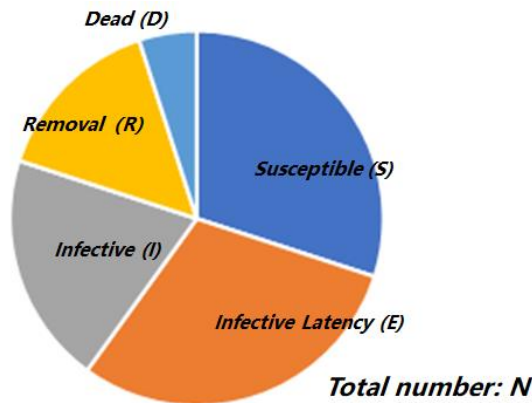
$$\frac{dr(t)}{dt} = u \cdot i(t) \quad (17)$$

### 3.4. Optimistic mathematic model SEIRD

In the process of actual epidemic prevention and control, it is necessary to separately count the number of deaths caused by novel coronavirus infection to more accurately assess the harm of COVID-19. Therefore, by further modifying model SEIR mentioned in the previous section, we can get a mathematical model SEIRD that is more in line with the epidemic prevention and control process.

The model assumes that the total number of samples is  $N$ , which is composed of susceptible person set  $S$ , infection latency set  $E$ , infected person set  $I$ , rehabilitated person set  $R$  and dead person set  $D$ .

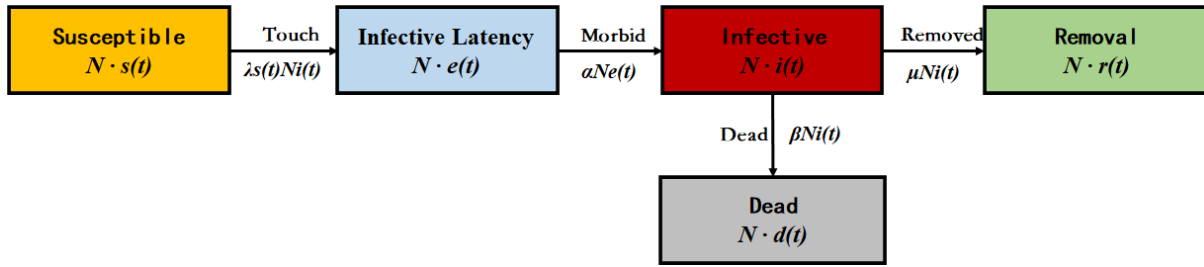
$$s(t) + e(t) + r(t) + i(t) + d(t) = 1 \quad (18)$$



**Fig. 7** SEIRD optimization mathematical model assumes sample pie charts.

We make some assumptions as following,

- When the initial time  $t = 0$ , the initial ratio of the number of various types of people is  $s_0, e_0, i_0, r_0$ .
- Daily exposure  $\lambda$ . That is, the average number of susceptible persons effectively contacted by each sick person every day.
- Daily incidence rate  $\alpha$ . That is, the ratio of latent patients who become infected every day to the total number of latent patients.
- Daily removal rate  $\mu$ . That is, the ratio of the number of infected people cured or died every day to the total number of infected people.
- Average cure days  $1/\mu$ . Also known as the average infection period, that is, the number of days from illness to cure.
- Number of contacts in infectious period  $\sigma = \lambda/\mu$ . That is, the number of susceptible persons effectively contacted by each patient within  $1/\mu$  days of the whole infection period.
- Daily death rate  $\beta$ . That is the proportion of infected persons to total deaths per day.



**Fig. 8** Optimistic mathematic model SEIRD

As shown, each infected person can make  $\lambda \cdot s(t)$  susceptible persons become latent patients, and the number of infected persons is  $N \cdot i(t)$ , so there are patients every day  $\lambda \cdot s(t) \cdot n \cdot i(t)$  susceptible patients became latent patients, and among the  $N \cdot i(t)$  infected persons every day  $\mu \cdot N \cdot i(t)$  becomes the removals and  $\beta \cdot N \cdot i(t)$  persons are dead.

In  $N \cdot e(t)$  of patients with daily incubation period, there are  $\alpha \cdot N \cdot e(t)$  became infected.

Among the infected  $N \cdot i(t)$ , every day there are  $\mu \cdot N \cdot i(t)$  is cured or dies and becomes the remover.

Among the infected  $N \cdot i(t)$ , every day, there are  $\beta \cdot N \cdot i(t)$  becomes the death.

The following differential equations can be obtained by the same derivation method as Si and SIR models:

$$\frac{ds(t)}{dt} = -\lambda \cdot s(t) \cdot i(t) \quad (19)$$

$$\frac{de(t)}{dt} = \lambda \cdot s(t) \cdot i(t) - \alpha \cdot e(t) \quad (20)$$

$$\frac{di(t)}{dt} = \alpha \cdot e(t) - u \cdot i(t) - \beta Ni(t) \quad (21)$$

$$\frac{dr(t)}{dt} = u \cdot i(t) \quad (22)$$

$$\frac{dd(t)}{dt} = \beta \cdot i(t) \quad (23)$$

## 4. The role of math model in COVID-19

### 4.1. The role of model SI

According to the SI model, at the initial stage of the outbreak of COVID-19, without considering cure and death, the total number of samples  $n$  can be divided into  $S$  and  $I$ . if there is no treatment and epidemic prevention, all people will eventually be infected by the virus.

For the SI model at the early stage of the outbreak of COVID-19, if no treatment and epidemic prevention is done, at what time will the epidemic spread growth rate be the largest?

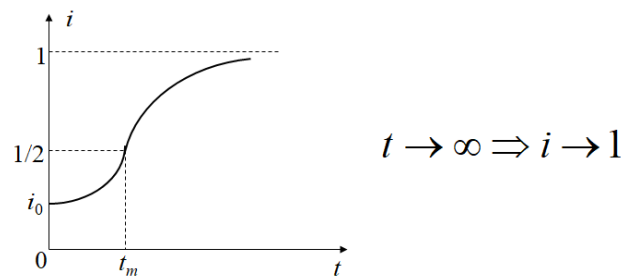
$$\frac{di^2(t)}{dt^2} = \lambda^2 \cdot i(t) \cdot (1 - i(t))(1 - 2 \cdot i(t)) \quad 0 < i(t) < 1 \quad (24)$$

We can do the second derivative of the infected function  $i(t)$ , and the results are as follows.

When  $di^2(t)/dt^2 = 0$  and  $i(t) = 1/2$ , the growth rate of epidemic infection is the largest, and the corresponding time  $t_m$  is shown in the following formula.

$$t_m = \lambda^{-1} \ln \left( \frac{1}{i_0} - 1 \right) \quad (25)$$

**5. Thus, infected function  $i(t)$  in the SI model can be drawn as follows:**



**Fig. 9** SI model

SI model is only applicable to the initial stage of infectious diseases and can be used to predict the peak arrival time of the increase rate of infectious cases.

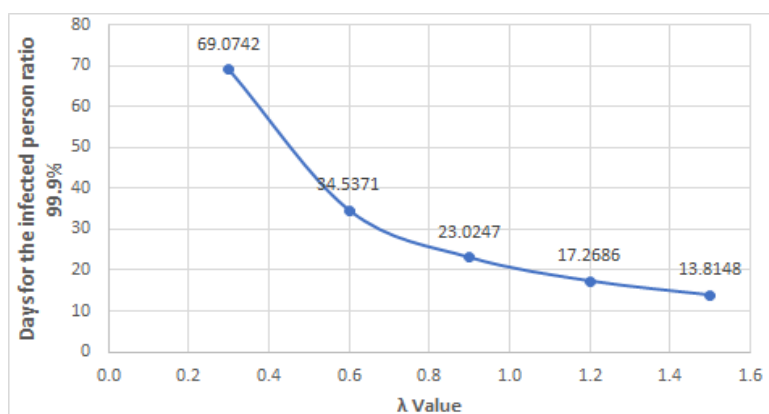
In the process of establishing the model in the previous chapter, we can clearly see through the SI model how to avoid any epidemic prevention intervention. when the number of infected people is 50% ( $i(t) = 1/2$ ), the infection rate is the highest, and eventually all people will be infected with COVID-19.

Here we quantify the relationship between the daily infection rate  $\lambda$  and epidemic infection intensity. Assuming that the total number of samples takes a city with a population of 1 million as an example, on the first day, there is a sudden infection of new crown for unknown reasons, then:  $N=106$ ,  $s_0 = 1$ ,  $i_0 = 10^{-6}$ . We can set different  $\lambda$  and calculate the time about the infection ratio 99.9%. The data are shown in the table below:

**Tab. 1** Schedule of 99.9% urban infection rate with a population of one million

| $\lambda$ | Days about the infection ratio 99.9% |
|-----------|--------------------------------------|
| 0.3       | 69.0742                              |
| 0.6       | 34.5371                              |
| 0.9       | 23.0247                              |
| 1.2       | 17.2686                              |
| 1.5       | 13.8148                              |

Based on the data above, we can draw the graph.



**Fig. 10** Days for the infected person ratio 99.9%

Through the derivation of the above data model, we can conclude that the time that the total sample population tends to be infected is shorter when the value  $\lambda$  is greater.

The main vector of novel coronavirus is droplet infection. Through wearing masks, washing hands frequently, regular disinfection in public places and other protective measures, the probability of single contact infection can be greatly reduced, even the daily infection rate  $\lambda$  decreases significantly. If we assume the value  $\lambda$  is 0.6 without protection and the probability of single contact infection can be reduced by 70%, the result is  $\lambda$  should decrease to  $0.6 * (1-70\%) = 0.18$ . Similarly, using the above Si model ( $n = 106$ ,  $s_0 = 106$ ,  $i_0 = 10^{-6}$ ), we can get:

**Tab. 2** The daily infection rate after taking protective measures.

| $\lambda$ | Days about the infection ratio 99.9% |
|-----------|--------------------------------------|
| 0.6       | 34.5371                              |
| 0.18      | 115.124                              |

From the above analysis, it can be seen that through the mathematical model SI, mining  $\lambda$  which is the influencing factors is very important for epidemic prevention. It can clearly reveal the importance of effectively blocking the transmission of novel coronavirus. That is, by improving people's living habits, such as wearing masks when going out, not having to party, washing hands frequently and so on, it can be decrease  $\lambda$  values to reduce the transmission speed of COVID-19. It is effective way to block the transmission route of the epidemic.

### 5.1. The role of model SIR

The differential equations in model SIR can be obtained.

$$\frac{ds(t)}{dt} = -\lambda \cdot s(t) \cdot i(t) \quad (26)$$

$$\frac{di(t)}{dt} = \lambda \cdot s(t) \cdot i(t) - u \cdot i(t) \quad (27)$$

$$\frac{dr(t)}{dt} = u \cdot i(t) \quad (28)$$

Where, constant  $\lambda$  is the daily contact rate of infected persons (the average number of effective contacts per patient per day), constant  $u$  is the daily cure rate (the proportion of patients cured every day in the total number of patients). Thus, the variable  $\sigma$  (number of effective contacts per patient in an infection period) is obtained.

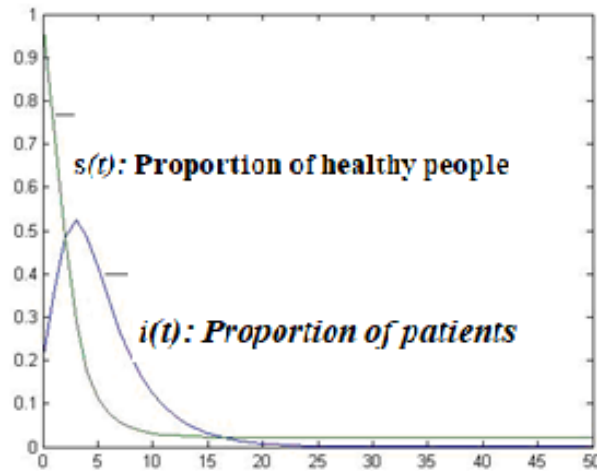
$$\sigma = \lambda / \mu \quad (29)$$

When  $\lambda=1$ ,  $\mu=0.3$ ,  $i_0= 0.02$ ,  $s_0=0.98$  and  $r_0 = 0$ , we can calculate the different values of  $i(t)$  and  $s(t)$  in the table below.

**Tab. 3** Time variation table of patient proportion and healthy person proportion

| $t(day)$ | $s(t)$ | $i(t)$ |
|----------|--------|--------|
| 0        | 0.9800 | 0.0200 |
| 1        | 0.9525 | 0.0390 |
| 2        | 0.9019 | 0.0732 |
| 3        | 0.8169 | 0.1285 |
| 4        | 0.6927 | 0.2033 |
| 5        | 0.5438 | 0.2795 |
| 6        | 0.3995 | 0.3312 |
| 7        | 0.2839 | 0.3444 |
| 8        | 0.2027 | 0.3247 |
| 9        | 0.1493 | 0.2863 |
| 10       | 0.1145 | 0.2418 |
| 15       | 0.0543 | 0.0787 |
| 20       | 0.0434 | 0.0223 |
| 25       | 0.0408 | 0.0061 |
| 30       | 0.0401 | 0.0017 |
| 35       | 0.0399 | 0.0005 |
| 40       | 0.0399 | 0.0001 |
| 45       | 0.0398 | 0      |

The corresponding graph of  $i(t)$  and  $s(t)$  is drawn below.



**Fig. 11** Graph of Proportion of patients and Proportion of healthy people

From the above figure, it can be seen that when the time increases from the initial value  $t = 0$  to the maximum value  $t = 7$ , the values of  $i(t)$  increases and the value reaches to maximum at  $t=7$ . Then it decreases with the increasement of  $t$  value and finally tends to 0. The graph of  $s(t)$  decreases monotonically with the increasement of  $t$  value and finally it tends to 0.

We divide the first derivative  $di(t)/dt$  by the derivative  $ds(t)/dt$  to get.

$$\frac{di}{ds} = \frac{1}{\sigma} - 1 \quad i|_{s=s_0} = i_0 \quad (30)$$

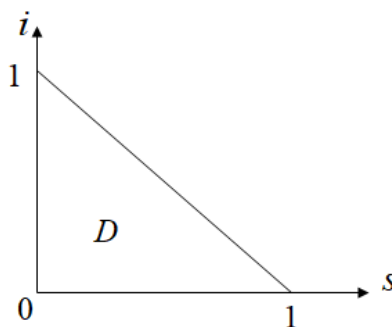
Do integration.

$$i(s) = (s_0 + i_0) - s + \frac{1}{\sigma} \ln \frac{s}{s_0} \quad (31)$$

Through the study of  $i(s)$ , we can get the range of its definition domain and value domain set  $D$  as follows:

$$D = \{(s, i) | s \geq 0, i \geq 0, s + i \leq 1\} \quad (32)$$

We draw the graph  $i(s)$  as below.



**Fig. 12** Graph  $i(s)$

By making the second derivative of  $i(s)$  and make it equal to 0, it can be obtained that when  $s=1/\sigma$ ,  $i(s)$  reaches the maximum value  $i_m$ .

$$i_m = s_0 + i_0 - \frac{1}{\sigma} (1 + \ln \sigma s_0) \quad (33)$$

When  $\lambda=1$ ,  $\mu=0.3$ ,  $i_0=0.02$  and  $s_0=0.98$ , we can get  $1/\sigma=0.3$  and draw  $i(s)$ .



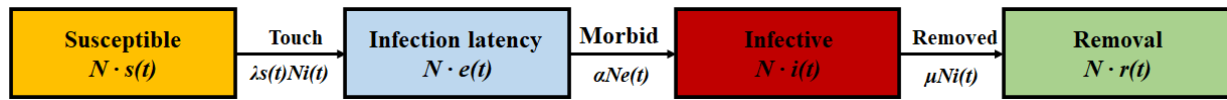
We can get the conclusion as below by graphic analysis of  $i(s)$ .

- From mathematical model SIR in the process of epidemic prevention and control, it is not difficult to see that  $s_0 < 1/\sigma$  is a sufficient condition for the non-spread of infectious diseases. Therefore, we can raise the threshold of  $1/\sigma$  to control the spread of the epidemic. The value  $\lambda$  reflects not only the infectivity of the epidemic, but also the health and epidemic prevention ability of the region, that is, the health level; The value  $\mu$  reflects the medical treatment level corresponding to the infectious disease, including treatment effect and medical resources. Therefore, from  $\sigma = \lambda / \mu$ , it can be concluded that in the actual epidemic prevention process, it is necessary to reduce the value  $\lambda$  as much as possible, increase value  $\mu$ .

## 5.2. The role of model SEIR

52

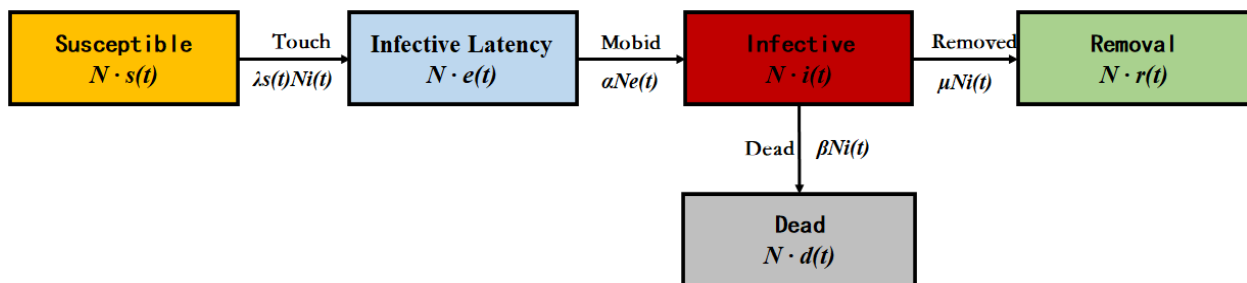
person and make it become a latent patient; Patients in the incubation period become infected; The infected person is cured or dies and becomes the remover. The whole process is as follows.



**Fig. 15** The role of model SEIR

However, if the coronavirus vaccine can be vaccinated for all, the susceptible population ( $s_0$ ) of sample population  $n$  in a short time can be greatly reduced and the population of migrants ( $r_0$ ) can be greatly increased at the lowest cost. At the same time, through the construction of shelter hospitals and other epidemic prevention means, the infected population will be effectively isolated and treated, which will greatly reduce the daily infection rate  $\lambda$ , and it is easy to concentrate excellent medical experts and a large number of medical staff, so as to improve the daily cure rate  $\mu$ .

### 5.3. The role of model SEIRD



**Fig. 16** The role of model SEIRD

According to the statistics of the World Health Organization, by the end of 2021, the total number of deaths from COVID-19 will be about 15,000,000. Through the COVID-19 modified model SEIRD, the mortality and change rate of COVID-19 can be clearly counted and calculated, and it can quantitatively evaluate the harm of COVID-19 to people's health.

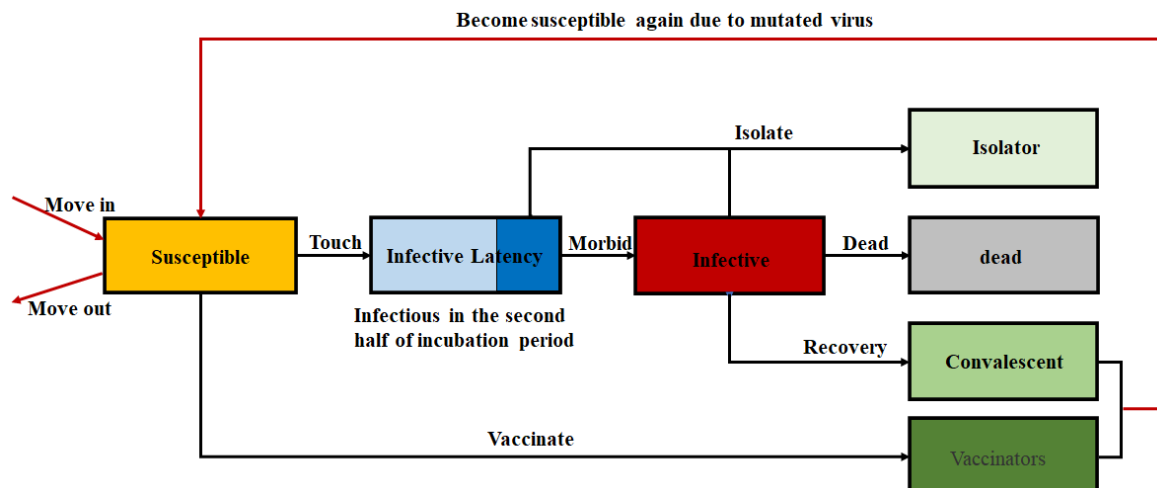
## 6. Deficiency and optimization of mathematical model

### 6.1. Deficiency of math model

When using the mathematical model to evaluate the development trend of the actual COVID-19 and guide the epidemic prevention work, it will be found that there is a difference between the results calculated by the mathematical model and the data of the occurrence results. This is because the actual development of the COVID-19 is affected by many factors. When establishing the mathematical model, in order to make the model research clearer, we make an ideal assumption for multiple influencing factors, such as the total number of samples is  $N$  and the number of daily exposures  $\lambda$ , daily incidence rate  $\alpha$ , daily recovery rate  $\mu$ , daily mortality  $\beta$ . They are constants in the model. However, the actual development of COVID-19 is always changing, which often leads to a certain gap between the mathematical results and the actual situation. However, as long as we constantly modify the influencing factors of the model and optimize the model, the results of the mathematical model will be closer to the actual development trend.

### 6.2. Optimization of math model

In order to reveal the transmission process of novel coronavirus, the interference factors were simplified more clearly before the mathematical model was established, and it was assumed that we lived in an ideal environment. However, the actual transmission of novel coronavirus is more complex, and more influencing factors can be added in the future mathematical model research, as shown in the following figure:



**Fig. 17** List of influencing factors that can be added to future mathematical model research.

As shown in the figure above:

- In real life, the total number of samples is  $N$ , which will change due to the flow of people in a city, which will cause great trouble to the epidemic prevention and control. In the epidemic prevention and control in Wuhan, the epidemic prevention measures of closing the city have been taken, that is, to control the total number of samples  $n$  unchanged to the greatest extent.
- Experts from the National Health Commission said that the incubation period of novel coronavirus is 7 - 10 days, and the latter half of the incubation period is infectious. Therefore, in the actual epidemic prevention work, we have taken home isolation measures for those close to COVID-19. At the same time, it can be optimized as an influencing factor in the future model revision.
- In the four models described above, no more thorough classification has been made for the migrants. In the future, model optimization can further divide the migrants into rehabilitation, vaccination, effective isolation, and death, and make statistics and predict the future change trend respectively.
- In the assumptions established in the previous model, it is clearly assumed that the transferor will neither infect others nor be infected. But in fact, because of the rapid mutation of novel coronavirus, the convalescent and vaccinated people may become susceptible again.

## 7. Conclusion

According to the characteristics of different stages of COVID-19 prevention and control, this paper expounds in detail the establishment process of the mathematical model and its theoretical basis for epidemic prevention and explains the future optimization direction of the data model.

Through the establishment and analysis of the whole mathematical model, we can draw the following conclusions.

- The epidemic prevention work of Xinguan is a national policy that benefits the country and the people. How to avoid any epidemic prevention intervention? When the number of infected people is 50% ( $i(t) = \frac{1}{2}$ ), the epidemic situation has the highest growth rate and eventually all people will be infected with COVID-19.
- It is very necessary to take personal protection measures, such as wearing masks and washing hands frequently when going out, as well as regular disinfection in public places. It can greatly reduce the probability of single contact infection by decreasing the daily infection rate  $\lambda$ .
- The construction of shelter hospital and effective isolation and treatment of incubation period and infected people are effective for Xinguan epidemic prevention, which will greatly reduce the daily infection rate  $\lambda$ . Also, it is easy to concentrate excellent medical experts and a large number of medical staff, so as to improve the daily cure rate  $\mu$ .

•The universal popularization of the new coronavirus vaccination can greatly reduce the susceptible population ( $s_0$ ) at the lowest cost, and greatly increase the population ( $r_0$ ). Finally, it can effectively control the spread of the epidemic.

## References

- [1] Andrew G. Atkeson, On Using SIR Models to Model Disease Scenarios for COVID19, June 2020
- [2] Alvarez, Fernando, David Argente, and Francesco Lippi. 2020. "A Simple Planning Problem for COVID-19 Lockdown." Working Paper 26981, NBER, April.
- [3] Atkeson, Andrew. 2020a. "How Deadly is COVID-19? Understanding the Difficulties with Estimation of its Fatality Rate." Staff Report 598, Federal Reserve Bank of Minneapolis, March.
- [4] Eichenbaum, Martin S., Sergio Rebelo, and Mathias Trabandt. 2020. "The Macroeconomics of Epidemics." Working Paper 26882, NBER, April.
- [5] Eksin, Ceyhan, Keith Paarporn, and Joshua S. Weitz. 2019. "Systematic biases in disease forecasting – The role of behavior change." *Epidemics* 27 (June): 96–105.
- [6] Farboodi, Maryam, Gregor Jarosch, and Robert Shimer. 2020. "Internal and External Effects of Social Distancing in a Pandemic." Working Paper 27059, NBER, April.
- [7] Fernandez-Villaverde, Jesus, and Charles I. Jones. 2020. "Estimating and Simulating a SIRD Model of COVID-19 for Many Countries, States, and Cities." Working Paper 27128, NBER, April.
- [8] McKibbin, Warwick, and Fernando Roshen. 2020. "The Global Macroeconomic Impacts of COVID-19: Seven Scenarios." Report. <https://www.brookings.edu/research/the-global-macroeconomic-impacts-of-covid-19-seven-scenarios/>. Brookings Institution, March.
- [9] Rachel, Lucasz. 2020. "An Analytical Model of COVID-19 Lockdowns." May.
- [10] Rowthorn, Robert, and Flavio Toxvaerd. 2015. "The Optimal Control of Infectious Diseases via Prevention and Treatment." Technical report, Cambridge-INET Working Paper Series.
- [11] Stock, James H. 2020. "Data Gaps and the Policy Response to the Novel Coronavirus." Working Paper 26902, NBER, March.
- [12] Rahim ud Din, Ebrahim A. Algehyne, Mathematical analysis of COVID-19 by using SIR model with convex incidence rate.
- [13] World Health Organization (WHO), Naming the coronavirus disease (COVID-19) and the virus that causes it, Archived from the original on 28 February 2020. Retrieved 28 February, (2020).
- [14] Hui DSI, Azhar E. Madani, T.A. Ntoumi, F. Kock, R. Dar, O. Ippolito, G. Mchugh, T. D. Memish, Z.A. Drosten, Christian, Zumla, A.; Petersen, E, The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health-The latest 2019 novel coronavirus outbreak in Wuhan, China, *Bulletin of Mathematical Biology*, 91(6) (2020) 264-66.
- [15] Zhao S, Lin Q, Ran J, Musa SS, Yang G, Wang W, et al. Preliminary estimation of the basic reproduction number of novel coronavirus (2019-nCoV) in China. *Int J Infectious Diseases* 2020; 92:214–7