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Mathematical Model of COVID-19 Pandemic and Related Analysis

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Abstract

The respiratory illness COVID-19 originates from the novel coronavirus SARS-CoV-2. Following its initial identification in Wuhan, China, in December 2019, this virus rapidly disseminated worldwide, resulting in a widespread global pandemic. On the world's economy, daily life, and public health, COVID-19 has had a huge impact. In order to comprehend the dynamics of the pandemic and to direct public health strategies, mathematical models have shown to be helpful. This manuscript presents a Susceptible-Infected-Quarantine-Recovered (SIQR) model to simulate the progression of the COVID-19 pandemic in Beijing, China. The model incorporates five distinct compartments, namely Susceptible (S), Infected (I), Recovered (R), Quarantined (Q), and Death (D). This model is solved by Euler's Method and get the formulations of the classes. Numerical simulations are employed to complement the mathematical analysis of the model. The findings of our study indicate that the widespread and effective utilization of masks significantly impedes the progression of the COVID-19 pandemic.

Keywords: COVID-19, health policy, infectious diseases, quarantine, optimal control, mask-wearing, social distancing, lock down

1. Introduction

1.1 Background

COVID-19 is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. It was initially discovered, isolated, and characterized in December 2019 in Wuhan, Hubei Province, China. (Zhu N, Zhang DY, & Wang WL, 2020). Globally, it has affected over 507 million individuals and resulted in more than 6 million deaths as of April 2022 (World Health Organization [WHO], 2022). The pandemic has negatively affected the global economy and other aspects. For instance, Brazil's SoPaulo stock market experienced a 15% decline from March 9 to March 13, marking the most significant weekly decrease since the 2008 financial crisis. Moreover, the country's GDP dropped by 11.4% in the second quarter of 2020 compared to the same period in 2019 (C. M. L. D. Melo, G. A. S. Silva & A. R. S. Melo, 2020). This ongoing situation presents an unprecedented challenge, impacting people's daily lives and the healthcare sector. Although it remains uncertain how long this situation will persist and when the spread of COVID-19 will gradually stabilize, its effects continue to be felt worldwide.

The novel coronavirus can be transmitted through air droplets and close contact, and is highly contagious. (Chu Jiang, 2020). In order to manage the transmission of the COVID-19 virus, government has adopted many effective intervention measures such as mandatory lockdown, large-scale nucleic acid testing and strict isolation measures. (N. Ferguson, D. Laydon & G. Nedjati Gilani, 2020). In late December 2019, Wuhan City, located in Hubei Province, China, witnessed the emergence of numerous cases of pneumonia with an unidentified cause. (B. Tang, N. L. Bragazzi, Q. Li, S. Tang & Y. Xiao, 2020). After epidemiological investigation and laboratory testing, it was confirmed that the pathogen was a new type of coronavirus. In January 2020, the Chinese National Health Commission officially designated the emerging pneumonia cases in Wuhan City as statutory Class B infectious diseases, triggering the implementation of reporting and management protocols. Additionally, preventive measures typically reserved for Class A infectious diseases were adopted. As the Spring Festival approached, a period characterized by significant population movement, various provinces, municipalities, and autonomous regions in China began to report imported cases of COVID-19 originating from Wuhan. The first documented case of COVID-19 imported from Wuhan into Beijing was recorded on January 19, 2020 (Guo Deyin, Jiang Jiafu & Song Hongbin, 2020). To reveal the transmission of the COVID-19, we take Beijing as the research object and conduct mathematical modeling on the past real data.

The World Health Organization (WHO) emphasizes the critical role of timely developed mathematical models in furnishing public health decision-makers and policymakers with empirically substantiated statistics. These models are crucial for informing and guiding effective public health decisions and policies (M. Egger, 2017). And it is proved that mathematical models is useful to investigate infectious diseases and create practical methods for effectively eradicating infection (W. O. Kermack & A. G. McKendrick, 2020). Researchers have recently employed mathematical modeling techniques to investigate the intricate transmission dynamics and distinctive epidemiological characteristics of COVID-19, yielding notable findings. A sophisticated mathematical model was constructed to analyze the transmission patterns of the COVID-19 pandemic, employing a system of fractional differential equations. Additionally, the model incorporated the examination of the effects of lockdown measures on disease transmission dynamics (Atangana, 2020). In addition, considering constructing a mathematical model with quarantine policy as one of the coefficients can provide us with real information more effectively, such as using ordinary differential equations (E. A. Iboi & O. O. Sharomi, 2020). The objective of this paper is to propose a SIQR model by considering the quarantine policy and mask wearing rate based on datasets we collected. In our research, we endeavor to investigate significant concerns on the COVID-19 pandemic, explicitly focusing on the relationship between public mask-wearing behavior and the progression of the outbreak. Using computed numerical outcomes, we aim to assess the effectiveness of epidemic prevention policies and provide valuable recommendations based on our evaluations. By analyzing mask usage’s impact on the pandemic’s development, our study aims to contribute valuable insights for public health policymakers and decision-makers.

1.2 Objectives and Significance

The primary objective of this article is to construct an advanced mathematical model of the COVID-19 pandemic by incorporating the latest advancements and cutting-edge techniques in the field. With the help of a mathematical model, we will implement numerical analysis and discuss potential features which could affect the spread of COVID-19 pandemic. This model will give a more detailed description. Additionally, this study aims to analyze the mask-wearing that can affect virus transmission. The potential significance of this research is to develop a deeper understanding of the COVID-19 pandemic, which has profoundly impacted the world. By providing a more accurate analysis of transmission patterns, this model can inform public health policies, guide vaccination strategies, and ultimately help minimize the pandemic’s negative consequences.

Moreover, this study can contribute to the broader scientific community’ s understanding of the epidemiology of infectious diseases, particularly in the context of emerging infectious diseases like COVID-19. Overall, the objectives of this study are both timely and critical for addressing the ongoing public health crisis and informing future pandemic preparedness efforts. To achieve the goal, the manuscript is structured as follows: we have developed the model and described the methodology used in the article. To get numerical solutions, the algorithm schemes are developed to support them. The numerical results and related analysis are presented in Section 3. We also fit the mathematical model with accurate data and determine the value of parameters. Finally, we summarized some conclusions in Section 4.

2. Methodology

In Section 2, we formulate the SIQR model based on the virus’s transmission properties and devise an algorithmic approach to obtain numerical outcomes. By leveraging the collected data, we fine-tune the model parameters to optimize the fitting accuracy.

2.1 Mathematical Model

The mathematical model in this article is divided into five classes. The whole human population to be taken into account is designated by N(t), and it consists of the following categories: susceptible(S), infected(I), recovery(R), quarantined(Q), and death(D) at any time. We assume that patients with new coronary pneumonia are equally contagious during incubation and onset periods. The contagiousness of patients after isolation is almost zero, and this study divides all infection cases into infected patients I and quarantined patients Q. Infected patients are those who are contagious after infection (whether they develop symptoms or not). The quarantined patients are those who have been quarantined after the onset of illness and those in the incubation period who have been quarantined in advance. Except for the infected cases, those who were not infected but had the possibility of being infected were the susceptible S. The people who recover after infection and will not be infected again are recovered persons R. Individuals who have tested positive for COVID-19 are classified as part of the “I” category in the study. The dataset utilized in this research comprises daily epidemic data in Beijing, sourced from the National Health

Commission of China (NHC), spanning the period from January 20, 2020, to March 10, 2020.

According to Beijing's pandemic prevention and control policy, a mathematical model is constructed at that time. Following the widespread pandemic breakout in Wuhan, Beijing conducted extensive and frequent nucleic acid testing daily to establish a solid preventive and control strategy so no one would be left behind. As soon as an infected person is found within the healthy population, appropriate action should be taken. Considering the initial phase of the pandemic and the general lack of awareness regarding preventive measures among the population, the virus spread quickly. Since there is no effective therapy for COVID-19, the development of self-immunity stands as a fundamental approach for healing, making it essential to provide a supportive system for individuals who are infected, particularly in critical circumstances.

In the scenario where a significant number of individuals become contagious within a short timeframe, providing comprehensive care to all affected becomes challenging due to the limited capacity of medical support system providers. However, if many individuals become contagious quickly, medical support system providers cannot adequately care for all infectious people. As a result, three scenarios may be used to describe the infected population. Immediately after the pandemic is discovered, some of the infected population will be placed in quarantine; however, another portion of the infected population may recover on its own as a result of a robust immune system and other factors; for the rest of the infected person, imminent death is possible. Patients who are isolated after infection because they do not have the conditions to contact the outside world during the isolation period and even use better medical resources, some isolated patients have a distinct possibility of recovery. Assuming that the total population of Beijing on day t is N(t).

$N(t)=S(t)+I(t)+Q(t)+R(t)-D(t)$, where $S(t)$, $I(t)$, $Q(t)$, $R(t)$, $D(t)$ are susceptible, infectious, quarantined, recovered, death on the day t.

In this article, one important point we must consider is that the effective use of masks significantly affects the spread of COVID-19. ϕ is the proportion of community members who appropriately use face masks. Individuals in the vulnerable compartment have a lower risk of infection because they use the preventative strategy of wearing masks, using ζ to denote the reduction in infection risk owing to the usage of face masks. Individuals are transferred to the recovery compartment after being released from the quarantined and infectious compartments, defined by γ and κ, respectively. The coefficient β refers to the transmission rate. q denotes the isolation rate, and we assume the sum death rate is $\mu+\mu(\alpha)$, where μ is the death rate without the pandemic, and $\mu(\alpha)$ describes the death rate caused by COVID-19. The flow diagram of the model with all the above coefficients and variables is given in Figure 1. Additionally, Tables 1 and 2 contain descriptions of each parameter and all variables with their definitions.

Table 1.

Parameter in the model	Meaning
β	Transmission rate
ϕ	The proportion of susceptible population who use face masks
ζ	Reduction factor
γ	Recovery rate
q	Isolation rate
κ	Recovery rate of isolated individuals
μ	Normal death rate
α	Death rate due to the COVID-19

Based on the assumptions and variables, mathematical formulation is given below:

$$\frac{dS}{dt} = -(1-\phi)SI\beta - \phi SI\beta(1-\zeta) - \mu S$$

$$\frac{dI}{dt} = (1-\phi)SI\beta + \phi SI\beta(1-\zeta) - (\mu+\mu(\alpha))I$$

$$\frac{dQ}{dt} = qI - \mu Q - \kappa Q$$

$$\frac{dR}{dt} = \gamma I + \kappa Q - \mu S$$

$$\frac{dD}{dt} = \mu S + (\mu+\mu(\alpha))I + \mu Q + \mu S$$

The model is initiated with initial conditions where $S(0)>0$, $I(0)>0$, $Q(0)\geqq 0$, $R(0)\geqq 0$, $D(0)\geqq 0$.

Table 2.

Variables	Meaning
S	Susceptible compartment
I	Infected compartment
R	Recovered compartment
Q	Quarantined compartment
D	Death compartment

Table 3.

Parameter	Meaning
β	Transmission rate
ϕ	Proportion of susceptible population who use face masks
ζ	Reduction factor
ɣ	Recovery rate
q	Isolation rate
κ	Recovery rate of isolated individuals
μ	Normal death rate
α	Death rate due to COVID-19

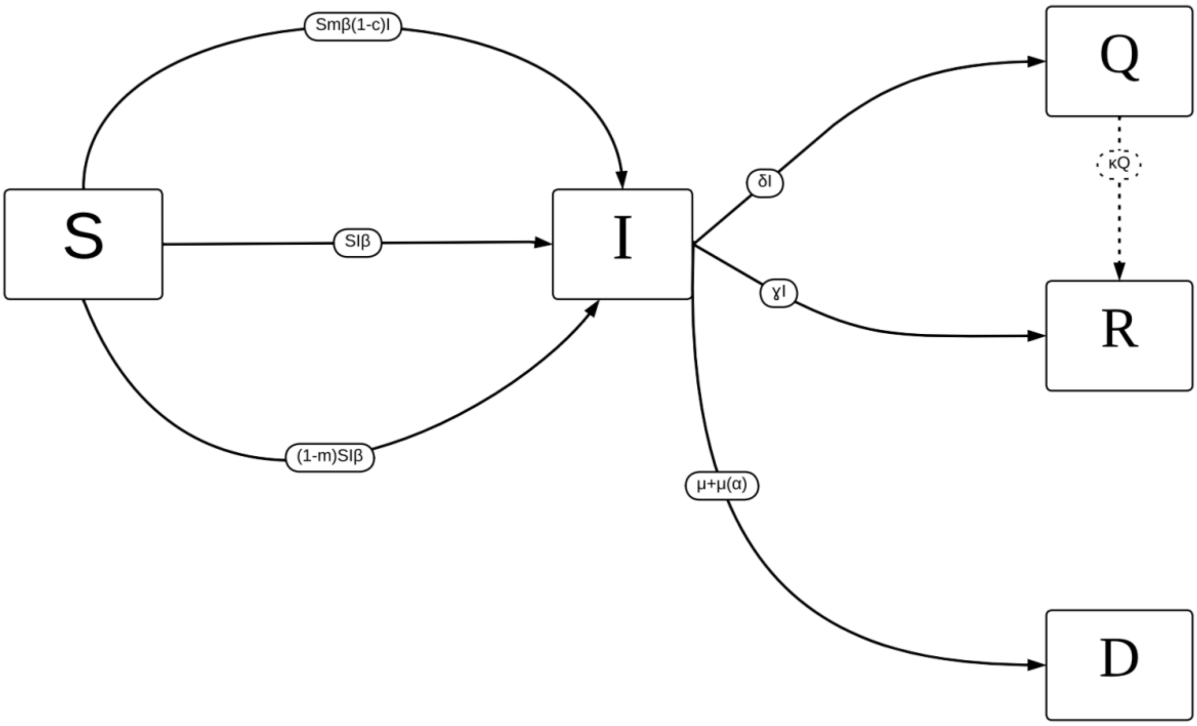


Figure 1.

2.2 Numerical Scheme

The simplest numerical method for solving above equations is Euler’s method. We begin by considering a general first-order differential equation.

$$\frac{dy}{dx} = f(x, y)\,, y(x_0) = y_0,$$

where $f(t, y)$ is a known function and the values in the initial condition are also known numbers. After discretizing the equation, defining the discrete points is $x_n = x_0 + nh, n = 0,1,2,\ldots$, where $h = x_{n+1} - x_n$ is equidistant step size. The exact solution of the differential equation is obtained by numerical method, denoted as $y(x_i), i = 1,2,\ldots, n, n+1$. Approximations at discrete points$x_1, x_2, \ldots, x_n, x_{n+1}$are denoted as $y_i, i = 1,2,\ldots, n, n+1$. The numerical integration method realizes the discretization process for the initial value solution of ordinary differential equations when applied to the Euler method. By employing mean differences, we can approximate the derivatives of ordinary differential equations, then we get: $\frac{y(x_{n+1})-y(x_n)}{h}=y'(x_n)=f(x_n,y(x_n)),n=0,1,2,...$, and get the following formulation of Euler's method: $y_{n+1}=y_n+hf(x_n,y_n),n=0,1,2,...,\ y(x_0)=y_0$. We can also deduce the formulations of mathematical model by the Euler method:

$$dS_{n+1}=-(1-\phi)S_nI_n\beta - \phi S_nI_n\beta(1-\zeta) - \mu S_n$$

$$dI_{n+1}=(1-\phi)S_nI_n\beta+\phi S_nI_n\beta(1-\zeta)-(\mu+\alpha)I_n$$

$$dQ_{n+1}=qI_n - \mu Q_n - \kappa Q_n$$

$$dR_{n+1}=\gamma I_n + \kappa Q_n - \mu S_n$$

$$dD_{n+1}=\mu S_n + (\mu+\alpha)I_n + \mu Q_n + \mu S_n$$

Next, we know that$\frac{S_{n+1}}{\Delta t} - \frac{S_n}{\Delta t} = f_n$, and then $S_{n+1} = S_n + f_n\Delta t = S_n + dS_{n+1}$. By applying this technique, the iteration formulations of other variables can be solved:

$$I_{n+1} = I_n + dI_{n+1}$$

$$Q_{n+1} = Q_n + dQ_{n+1}$$

$$R_{n+1} = R_n + dR_{n+1}$$

$$D_{n+1} = D_n + dD_{n+1}$$

The numerical simulations are run using the Matlab with Euler method in programming software version R2023a to assist the mathematical study of the model. The numerical simulations take into account the following initial conditions:

S_0=21843000,
I_0=3,
Q_0=0,
R_0=0,
D_0=0.

The chart outlines the variables used to represent different aspects of a population in Beijing. S(0) represents the initial population, I(0) represents the initial number of infected individuals, Q(0) represents the initial number of people in quarantine, R(0) represents the initial number of recovered individuals, and D(0) represents the initial number of deceased individuals.

Next step is to create arrays and store initial value in the first element of the corresponding array.

S(1)=S_0
I(1)=I_0
Q(1)=Q_0
R(1)=R_0
D(1)=D_0
DI(1)=I_0
ACCases(1)=I_0

In order to better fit the actual data, set different infection rate values according to the policies in Beijing. We use the letter a to represent the infection rate of individuals in the susceptible. t_1 and t_2 are turning points when the epidemic infection rate changes. When $t_i<t_1$,a=a_0; $t_i<t_2$, a=a_c; $t_i>t_2$, a=a_{c2}. In order to solve problems and run the program, we write the program algorithm as shown below according to the theoretical guidance of the above formulas.

$$t(t_{i+1})=t(t_i)+dt$$
$$dS=-a(1-gh)S_{ti}I_{ti}$$
$$dI=a(1-gh)S_{ti}I_{ti}-(b+c+d)I_{ti}$$
$$dQ=bI_{ti}-(d+f)Q_{ti}$$
$$dR=cI_{ti}+fQ_{ti}$$
$$dD=dI_{ti}+dQ_{ti}$$

Then, we deduce:

$$S_{(ti+1)}=S_{ti}+dSdt$$
$$I_{(ti+1)}=I_{ti}+dIdt$$
$$Q_{(ti+1)}=Q_{ti}+dQdt$$
$$R_{(ti+1)}=R_{ti}+dRdt$$
$$D_{ti+1}=D_{ti}+dDdt$$
$$DI_{ti+1}=-dS$$
$$ACCases(t_{i+1})=ACCases(t_i)-dS$$

2.3 Parameter Determination

In this section, we will determine the value of parameters. We consider coronavirus cases in Beijing to determine the best-fitted model parameters to achieve this goal. In section 2.2, algorithm equations are constructed by six compartments.

The chart provides the definitions for the compartments as follows:

(a) Represents the rate at which susceptible individuals become infected.

(b) Indicates the rate at which infected individuals are isolated.

(c) Represents the rate at which infected individuals recover.

(d) Indicates the mortality rate among individuals in the infected and quarantined compartments due to COVID-19.

(f) Represents the rate at which individuals in quarantine recover.

(g) Indicates the proportion of individuals who use face masks.

The values obtained for numerical simulation are listed following:

Table 4.

Parameters	Parameters Value	Source
a	0.19/10000000*4.291	Assumed
b	0.7	(World Health Organization, 2020)
c	0.1	(World Health Organization, 2023)
d	0.0035	(Worldometer, 2022)
f	0.29	(Zhu, Na, Dingyu Zhang, Wenling Wang, Xingwang Li, Bo Yang, Jingdong Song, Xiang Zhao, et al, 2020)
g	0.5	(Zhu, Na, Dingyu Zhang, Wenling Wang, Xingwang Li, Bo Yang, Jingdong Song, Xiang Zhao, et al, 2020)

The parameter of the infection rate of individuals in the susceptible is the value estimated to achieve the best fit by image fitting between actual data and predicted values. The values of other parameters were obtained by consulting the relevant literature. Detailed literature information is listed in the reference section at the end of the article.

3. Results

In this section, we will use actual data to evaluate the COVID-19 model. This section are divided into three subsections. The first part is to present the model fitting real data. Part 2 aims to demonstrate the impact of face mask usage.

3.1 Model Fit

In this section, the actual data presented in the subsequent table are monthly aggregates obtained from the Department of Disease Control in China. The statistics are for the period of 12 January 2020 to 14 March 2020. To make it simple to match the real data with the simulated data, we first preprocessed the data and removed the newly added asymptomatic infection column provided by the original data table. Since the table lacks the current infected cases data, in order to obtain this part of the data, we use the excel table to perform column-to-column calculations. The calculation method involves adding the cumulative number of infected cases on the initial day of statistical data to the number of new cases daily. This sum is then adjusted by subtracting the daily count of newly recovered cases and new deaths.

The result of this calculation is the current infected cases. Figure 2 illustrates the outcome of fitting the model to real data.

Figure 2 shows that the actual data's most outstanding values are found from days 20 to 28. Immediately afterward, the trend of the epidemic began to show a decreasing trend. Immediately afterward, the trend of the epidemic began to show a decreasing trend. This is due to the Beijing municipal government's announcement that all inter-provincial passenger transport and inter-provincial tourist chartered vehicles into and out of Beijing would cease on January 28, 2020, to restrict the epidemic's spread. Strict preventative and control measures have been implemented, including postponing the start of kindergartens and primary schools and stopping all off-campus training programs and offline test administration. Nearly simultaneously, the Palace Museum declared that it would close on January 26, 2020, to stop and contain the outbreak. Additionally, several art galleries and museums are closed. Therefore, limiting individuals' movement, gathering, and interaction can lessen the likelihood of viral transmission, obstruct the chain of an epidemic's progress, and lessen the danger of infection

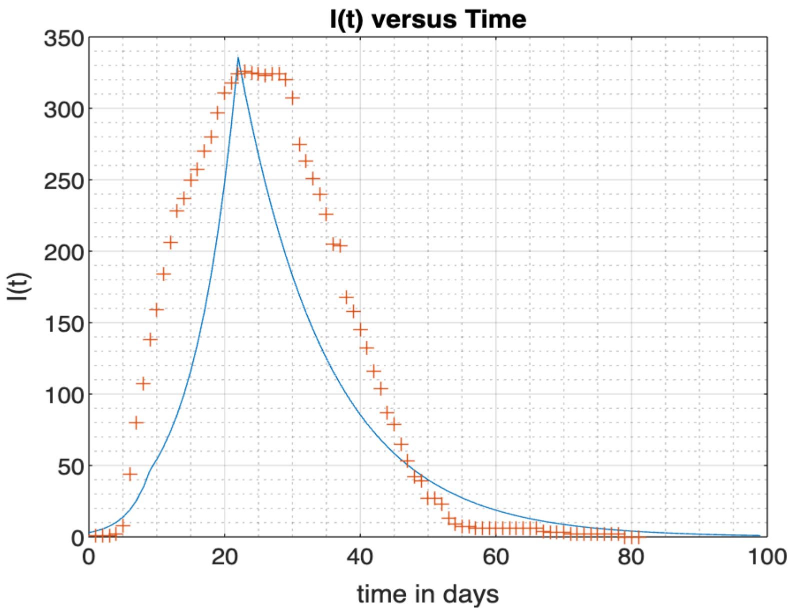


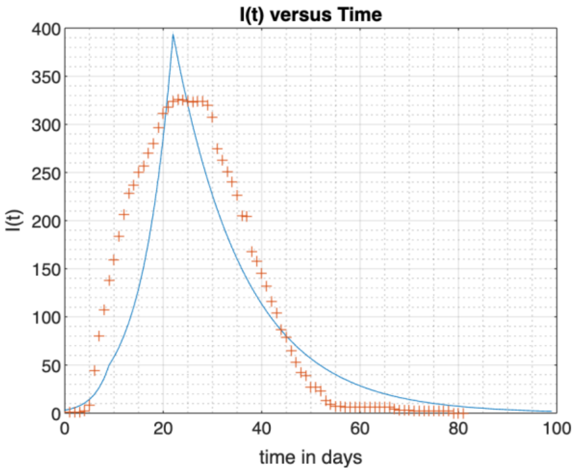
Figure 2.

Note: Red line represent real data, and blue line draws predicted data.

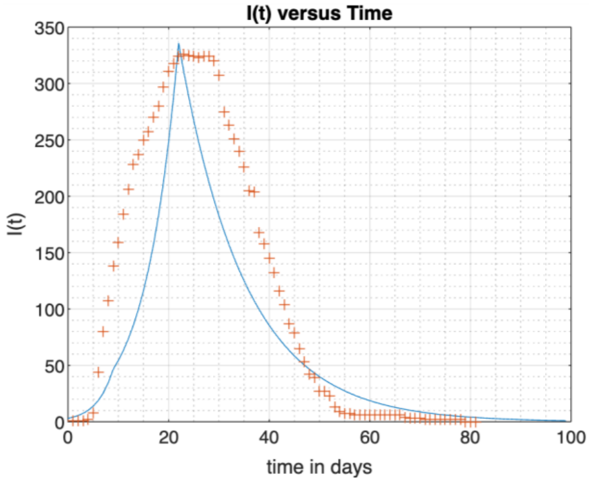
3.2 Implications of Face Mask Usage

In this section, the present study employs numerical simulation to investigate how altering the ϕ value influences the transmission dynamics of COVID-19 as computed in this research. We are aware that asymptomatic and exposed groups have the highest rate of illness transmission. (Jayanta Kumar Ghosh, Sudhanshu Kumar Biswas, Susmita Sarkar & Uttam Ghosh, 2020). Because I(t) and Q(t) classes can only infect medical personnel and those who look after them, they cannot transmit illnesses as far as asymptomatic and exposed individuals may, making it a realistic characteristic. As a result, if we raise the percentage of people who wear face masks, the transmission of the virus would be significantly curbed. Hence, our primary goal is to reduce interactions between vulnerable individuals and those who are exposed or asymptomatic in order to mitigate disease transmission. ϕ is the percentage of susceptible individuals who utilize face masks, as previously specified in Table 2. The influence of mask utilization on curtailing the dynamics of COVID-19 will now be examined. Initially, we merely modify the pace at which virus are transmitted while holding the values of other factors constant. We choose three different values for ϕ. However, three different values of ϕ (ϕ=0.49,0.5,0.53) are considered. The numerical results are presented in Figure 3.

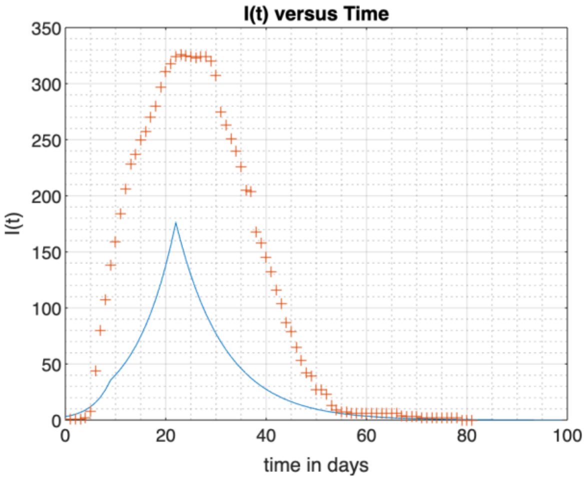
The presented numerical results make it simple to determine that the proportion of mask-wearing in susceptible populations is characterized by great sensitivity. The pandemic can be contained if more people regularly wear face masks in a community.



(ϕ=0.49)



(ϕ=0.5)



(ϕ=0.53)

Figure 3.

Note: Red line represent real data, and blue line draws predicted data.

3.3 Implications and Suggestions

In light of the successful fitting of the COVID-19 model for the Beijing region and the confirmed effectiveness of wearing masks in curbing the transmission of the virus, it is crucial to propose appropriate actions to respond to these findings. Based on the results obtained, the following ideas are presented:

Strengthened Public Health Campaigns: The findings underscore the importance of robust public health campaigns emphasizing the significance of wearing masks. Government agencies, health organizations, and community leaders should collaborate to develop and implement comprehensive campaigns that devocate for the adoption of masks as a crucial preventive measure in managing the dissemination of COVID-19. These campaigns should target various segments of the population and employ diverse communication channels to ensure widespread awareness and adherence.

Sustained Research and Surveillance: The findings emphasize the significance of continuous research and monitoring regarding the COVID-19 situation. Additional inquiries should be undertaken to assess the efficacy of various mask types, ideal mask-wearing protocols, and the enduring effects of mask usage on transmission reduction. Consistent data collection and analysis ought to be upheld to monitor the effectiveness of implemented measures and facilitate evidence-driven decision-making.

4. Conclusion

This article presents a mathematical model aimed at examining and comprehending the dynamics of the COVID-19 pandemic specifically in the context of Beijing. We have considered five compartments, namely susceptible, infected, recovery, quarantined and death. Combined with the spread characteristics of the COVID-19, we formulate first-order differential equations. In order to obtain the numerical solutions, Euler's method was used to solve equations. Matlab also plays key role for numerical simulations. We use Matlab software to fit the model with real data. We examine the COVID-19 cases in Beijing between January 12th and March 14th, 2020, and stimate the optimal model parameters to validate the model and facilitate future predictions. According to the simulation's output, the real data were also modelled to anticipate the actual instances of the infected population. This study also explored the diverse implications of face mask usage. It revealed that consistent and rational utilization of face masks has the potential to effectively halt the spread of the COVID-19 pandemic. There are certain restrictions on the COVID-19 recommended model. The ongoing COVID-19 vaccine study is yielding promising outcomes, as Pfizer reports a vaccine efficacy rate of 95% against the pandemic. Despite the fact that the COVID-19 vaccinations have been administered to billions of individuals globally, our model did not incorporate the vaccination factor. However, we propose that future researchers employ the framework outlined in this study to evaluate the efficacy of current COVID-19 prevention strategies by applying it to assess the second wave of infected patients in Beijing.

References

Chu Jiang, Juguang Wang, Wei Cai, Shaobo Zhang, Huaqing Ying, Yan Xing, Haisheng Li, Yulian Li, Jiye Fu, (2020). Prevention on behalf of the COVID-19 response team of Haidian District Center for Disease Control and Epidemiological characteristics of confirmed coronavirus disease 2019 cases in Haidian district, Beijing. *Disease Surveillance, 35*(7), 602-607. doi: 10.3784/j.issn.1003-9961.2020.07.011.

Ferguson, N., D. Laydon, G. Nedjati Gilani, N. Imai, K. Ainslie, M. Baguelin, S. Bhatia, et al, (2020). Report 9: Impact of Non-Pharmaceutical Interventions (NPIs) to Reduce COVID19 Mortality and Healthcare Demand. Spiral.imperial.ac.uk. http://hdl.handle.net/10044/1/77482.

Ghosh, Jayanta Kumar, Sudhanshu Kumar Biswas, Susmita Sarkar, and Uttam Ghosh, (2022). "Mathematical Modelling of COVID-19: A Case Study of Italy." *Mathematics and Computers in Simulation, 194*(April), 1–18. https://doi.org/10.1016/j.matcom.2021.11.008.

Guo Deyin, Jiang Jiafu, Song Hongbin, Qin Tian, Li Zhenjun, Zhang Dingmei, Huang Senzhong, et al, (2020). Predictive Analysis and Countermeasures in Response to COVID-19 Epidemic in 2020–2021. *Disease Surveillance, 35*(12), 1068–72. https://doi.org/10.3784/j.issn.1003-9961.2020.12.005.

MELO, CRISTIANE M.L. DE, GUILHERME A.S. SILVA, ALANNE R.S. MELO, and ANTÔNIO C. DE FREITAS, (2020). COVID-19 Pandemic Outbreak: The Brazilian Reality from the First Case to the Collapse of Health Services. *Anais Da Academia Brasileira de Ciências, 92*(4). https://doi.org/10.1590/0001-3765202020200709.

National Health Commission of the People's Republic of China, (2020). Situation report of the pneumonia cases caused by the novel coronavirus, http://www.nhc.gov.cn/xcs/yqfkdt/202002/3db09278e3034f289841300ed09bd0e1.shtml.

Tang, Biao, Nicola Luigi Bragazzi, Qian Li, Sanyi Tang, Yanni Xiao, and Jianhong Wu, (2020). An Updated Estimation of the Risk of Transmission of the Novel Coronavirus (2019-NCov). *Infectious Disease Modelling, 5*, 248–55. https://doi.org/10.1016/j.idm.2020.02.001.

World Health Organization, (2020). Pneumonia of unknown cause-China. https://www.who.int/csr/don/05-january-2020-pneumonia-ofunkown-cause-china/en/.

World Health Organization, (2023). WHO COVID-19 Dashboard. World Health Organization. May 18, 2023. https://covid19.who.int/.

Worldometer, (2022). Worldometers - Real Time World Statistics. https://www.worldometers.info/.

Zhu, Na, Dingyu Zhang, Wenling Wang, Xingwang Li, Bo Yang, Jingdong Song, Xiang Zhao, et al, (2020). A Novel Coronavirus from Patients with Pneumonia in China, 2019. *New England Journal of Medicine, 382*(8). https://doi.org/10.1056/nejmoa2001017.