Research Paper

Study on the Effectiveness of Prevention Strategies for the COVID-19 Pandemic: A Case Study in Ezhou, China

Wang Qian[1*], Zhuang Yue[1]

1. School of Safety Science and Emergency Management ,Wuhan University of Technology, China.

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ABSTRACT

Background: Today, with the coronavirus disease 2019 (COVID-19) pandemic, the governments and international institutions are taking various approaches to control the infections. This study aims to propose an improved susceptible-exposed-infectious-removed (SEIR) model to predict the future trend of pandemic and assess the effectiveness of prevention and control strategies.

Materials and Methods: A new SEIR model was developed by adding two Q_1 and Q_2 isolation parameters (at home and hospital) named "SEIR-Q_1Q_2" to predict the future trend of pandemic, and assess the effectiveness of prevention and control strategies in Ezhou, Hubei province, China. The stimulation was conducted in Python by evaluating the effects of pandemic knowledge dissemination, medical supply, and both.

Results: due to the lack of knowledge of the disease risk, there was no strong tendency towards self-isolation, and the outbreak time coincided with the start of the Spring Festival, China's major holiday, when many Chinse people are gathered and have close contact with each other. Therefore, it was not possible to disseminate the knowledge of pandemic, which let the virus kill many people.

Conclusion: The SEIR-Q_1Q_2 model can be used to predict the future trend of the COVID-19 pandemic by proposing the dissemination of the pandemic knowledge and increasing the supply of medical resources.

*** Corresponding Author:**
Wang Qian, PhD.
Address: *School of Safety Science and Emergency Management ,Wuhan University of Technology, China.*
E-mail: *wangqian570719@163.com*

1. Introduction

Since the outbreak of the novel coronavirus disease in early 2020, the pandemic has gone through three different stages of evolution: Incubation period, spread period, and recovery period. The outbreak of infectious diseases has been effectively controlled by the concerted efforts of the whole society. In various countries, governments have taken multiple preventive and control measures such as the dissemination of disease-related information, extending holidays, isolation at home, setting up makeshift hospitals to treat confirmed patients, and ensuring the supply of medical supplies, which have led to remarkable results.

Despite the various techniques, job safety analysis can be the preferred option for hazard identification and control in health centers. In order to accurately control the diseases, there is a need to accurately analyze the effects of various preventive measures on the spread of disease and put forward a variety of infectious disease and system dynamics modeling methods based on differential equations. However, these models mostly analyze the effectiveness of a single strategy and there is a lack quantitative research on the effectiveness of combined prevention and control strategies. i.e., non-pharmaceutical interventions for infectious diseases through personal protection, quarantine, isolation, and foci elimination [1]. Therefore, this paper aims to study the spread trend and control strategy of COVID-19 by proposing a mathematical prediction model reflecting the dynamic characteristics of infectious diseases. The changes in the number of infected people were analyzed under the intervention conditions, including the dissemination of information and the increase of supplies to predict the spread trend of COVID-19 in urban areas under precise controlled conditions, provide scientific basis for local governments and medical centers to formulate reasonable policies for resuming work and production, and ensure social stability and economic development.

Prediction models of risk for infectious diseases

In 1926, Kermack and McKendrick proposed the famous susceptible-infectious-removed (SIR) model of infectious diseases [2] when they studying the plague epidemic in Mumbai. In 1932, the susceptible-infectious- susceptible (SIS) model was developed for assessing the re-infection of recovered patients [3]; the basic regeneration number indicator was proposed for transmissibility of diseases; and the "threshold theory" was established to distinguish the prevalence of diseases. Later, there were more complex models such as Susceptible-Exposed-Infectious-Removed (SEIR) model, which takes into account the incubation period of the disease to establish dynamic equations and study the transmissibility of diseases.

By comparing the differences between SIS, SIR and SEIR models, it is believed that the spread of COVID-19 is more suitable for SEIR model, and two conditions of with or without infection during the incubation period were studied [4]. By fitting the epidemiological curve and calculating the basic regeneration number, Wu deduced the infection intensity and peak time, and the epidemiological end time for COVID-19 [5]. Based on the changes in the transmission time, infectious disease models can be used to predict the inflection points of the epidemic in order to take timely and effective preventive measures [6]. Althaus added the variable "D" to the SEIR model which represents infected people who died, and the model quantified the impact of early preventive measures on transmission and calculated the risk of a new outbreak caused by a single undetected case [7]. Naz and Al-Raeei added the variable "A" which represent the isolated patients, to develop the SEIAR model and verify the optimal value of fitted parameters under preventive measures [8]. The SEIR model was used in another study by evaluating the effects of different non-pharmaceutical interventions to provide reference for other countries to formulate prevention policies [9]. Based on the above mentioned studies, we proposed a nonlinear SEIR-Q_1Q_2 model in this study by adding isolation parameters Q_1 and Q_2 for suspected and confirmed cases, respectively, based on the SEIR model and the precursory signals of COVID-19 outbreak.

Measures for infectious disease control

Since infectious diseases have a complex way of transmission, it is believed that its morbidity and mortality can be reduced through inoculation, vaccine, and effective drug therapy. With epidemiological studies and the improvement of human capacity to respond to public health emergencies, non-pharmaceutical measures including personal protection, quarantine, social distancing, traffic control, and foci elimination became more important. These measures are considered direct interventions. At the same time, it is of great significance to explore how to promote social organizations and the public to implement such interventions. To this end, indirect measures related to the attitudes towards personal protection and public health behaviors should be developed. For example, media can change the people's understanding of the epidemic which can change the public attitudes and behaviors [10].

Prem et al. evaluated the impact of physical distancing measures on the progression of the COVID-19 and simulated the ongoing trajectory of an outbreak in Wuhan using the SEIR model [1]. Raveendran proposed reverse quarantine, which separates the population with severe disease (vulnerable population) from the general population at risk of disease to reduce epidemic-related mortality and morbidity [11]. Shen et al. indicated that through strict quarantine and non-pharmaceutical interventions, social distancing measures can reduce the daily social contacts in public places [12]. Based on a sensitivity analysis, Biao et al. reported that interventions such as contact tracing followed by quarantine can effectively reduce the number of infected population and transmission risk [13]. After taking strict prevention and control measures, the contact rate can be reduced and the maximum number of infected cases during the incubation and infection periods can be significantly decreased. Devrim conducted a review study using daily practice combined with the latest guidelines and empirical information to identify infection control measures during the COVID-19 pandemic [14]. Náraigh proposed an optimal control strategy to minimize the cost of non-pharmaceutical interventions, considering that the number of inpatients should not exceed the health service capacity of the hospital [15]. Liu et al. shared the experience of COVID-19 prevention and control in Wuhan, including sealing off the cities and constructing Fangcang hospitals. According to them, the SEIR model was effective in controlling the number of infected people [16].

Epidemic prevention and control measures with multiple social factors are summarized in Table 1. In order to verify the effectiveness of these measures, there are two types of methods. In the early stage of the outbreak, improving the knowledge of epidemic prevention and control strategies can quickly reduce the number of infected cases. In the later stage, the supply of medical resources can reduce the spread of infection and increase the treatment rate among confirmed patient which can lead to decreased death rate up to zero and the complete control of the pandemic [17].

2. Materials and Methods

SEIR-Q_1Q_2 model

In order to assess the effectiveness of multiple prevention and control strategies in reducing the spread of COVID-19, the participants were divided into four groups based on the SEIR model including Susceptible, Exposed, Infectious, and Recovered. The development of the pandemic was modeled by evaluating the multiple isolation strategies for susceptible and infectious groups. In this model, the parameter Q_1 was introduced to represent the susceptible cases isolated at home, and Q_2 was introduced to represent the infectious cases isolated at hospital. In the susceptible group (S), the probability of effective isolation at home is shown by φ1, while in the infectious group (I), the probability of effective isolation at hospital is shown by φ_2. The parameter Q_2 is transformed into convalescences with a probability of ω, and κ is the probability of death.

The first phase is the early stages of the outbreak when it was not effectively controlled. It is assumed that exposed patients (E) become infectious with the probability of α every day, and the remaining exposed patients recover from the infection on that day. The susceptible person was considered to have daily contact with n_1 person, and the recovered person had a daily contact with n_2 person. Among them, β_2 is the probability of susceptible patients' contact with exposed patients, and β_1 is the probability of susceptible patients' contact with infectious patients. Due to the limited resources of the hospital, it is assumed that some infectious patients are not effectively treated; therefore, there is a probability of death κ.

In the next stages, the government and hospitals began to control the pandemic. Based on the first phase, the government increases the knowledge of prevention strategies among susceptible groups and effectively treats and isolates the infectious groups to reduce the spread of the disease. Due to the strict isolation at the hospital, it is assumed that Q_2 will not be infectious; hence, the state-transition diagram of the proposed model based on the SEIR model is shown in Figure 1.

The total number of people in the whole model is N, forming a dynamic equilibrium. Thus, differential equations of SEIR-Q_1Q_2 model can be obtained as follows (Equation 1):

$$1.\ \frac{dS}{dt}=-\frac{n_1\beta_1S(t)I(t)}{N}-\frac{n_2\beta_2S(t)E(t)}{N}-\varphi 1S(t)$$

$$\frac{dE}{dt}=\frac{n_1\beta_1S(t)I(t)}{N}+\frac{n_2\beta_2S(t)E(t)}{N}-\alpha E(t)$$

$$\frac{dI}{dt}=\alpha E(t)-(\gamma+k)I(t)-\varphi_2I(t)$$

$$\frac{dR}{dt}=\gamma I(t)\omega Q_2$$

$$\frac{dQ_1}{dt}=\varphi_1S(t)$$

$$\frac{dQ_2}{dt}=\varphi_2I(t)-\omega Q_2(t)$$

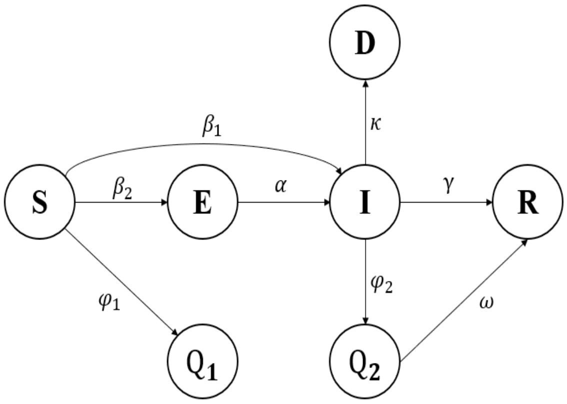

Figure 1. State-transition diagram of SEIR-Q_1Q_2 model

Parameter estimation

According to the report of the National Health Commission, the incubation period of the COVID-19 is 7-14 days, and its average is about 7 days. Therefore, α=1/7, which is about 0.14. the n_1 and n_2 values were determined as the average daily contact of 10 susceptible patients and 30 exposed patients, respectively. Parameter definition and values in the SEIR model are shown in Table 2.

The definition and values of parameters in the proposed SEIR-Q_1Q_2 model are presented in Table 3. The simulation was performed in Python software, and the time was set at 60 days. The actual progression trend of each study group regarding the transmission of the disease is illustrated in Figure 2. Under the condition of effective isolation, the number of susceptible people (S) showed a downward trend in the early stage of outbreak. The number of exposed (E) and infectious (I) people showed an upward trend. As it took 7-14 days for the exposed person to be diagnosed, the upward trend for them was greater than that for infectious people. The intersection of E and I in the figure was recorded as the highest number of infectious people, providing a starting point for further analysis and research.

Data sources

The study area was Ezhou City of Hubei Province in China. Ezhou is a city that connects Wuhan subway networks and has the highest degree of integration with Wuhan, which is the largest city in Wuhan metropolitan area. Ezhou has a small area of 1,594 square kilometers but a large population (1,059,700 people). Considering the proportion of infected people, the severity of the pandemic in Ezhou is at the highest level after Wuhan, and the health level in Ezhou is far lower than that in Wuhan. For nearly 60 days from January 31 to March 31, 2020, the ratio of the number of infected people in Hubei province to the total population was calculated to obtain the infection ratio. As can be seen in Table 4, Ezhou had the highest infection ratio after Wuhan among the cities of Hubei province.

Table 1. Epidemic prevention and control measures for infectious diseases

Classifications	Measures	Implementation Plans
Pharmaceutical interventions	Drug therapy	Research and development of prophylactic drugs
Non-pharmaceutical interventions	Social distancing	Reduce the daily presence in public places
	Quarantine	Follow-up and identification of close contacts, entry-exit screening
	Isolation and avoiding close contact	Home isolation and daily sanitizing
	Foci elimination	Disinfection of air or large areas of environmental surfaces
	Traffic control	Closing schools and places with high population density

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Table 2. Parameter definition and values in the SEIR model

Parameters	Definitions	Values
N	Total number of people in an area	10000
β_1	Disease transmission coefficient between infectious and susceptible people	0.14
β_2	Disease transmission coefficient between exposed and susceptible people	0.1
α	The probability that a exposed person turn into an infectious person	0.14
γ	The probability that an infectious person recovers from the disease	0.056
k	The probability that an infectious person dies	0.02
n_1	Average daily contact with others for susceptible people	10
n_2	Average daily contact with others for exposed people	30

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Table 3. Definition and values of parameters in the SEIR-Q_1Q_2 model

Parameters	Definitions	Value
φ_1	The probability of effective isolation at home for susceptible people	0.01
φ_2	The probability of effective isolation at Fangcang hospital for infectious people	0.01
ω	The probability of isolation at hospital	0.20

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The official data about daily confirmed cases, recovered cases, and deaths in Ezhou City from January 30 to March 31, 2020 were obtained according to the National Health Commission report. As shown in Figure 3, the abscissa indicates that the outbreak period from January 30 to March 31 was 60 days, and the ordinate indicates the number of people. The solid line indicates the number of people according to official data, and the dotted line indicates the number of infected people.

At the beginning of the outbreak, the first confirmed case was reported in January 24, 2020, after climbing fast start showing a Wuhan imported cases. On February 13, 2020, new cases were reported which reached its peak in

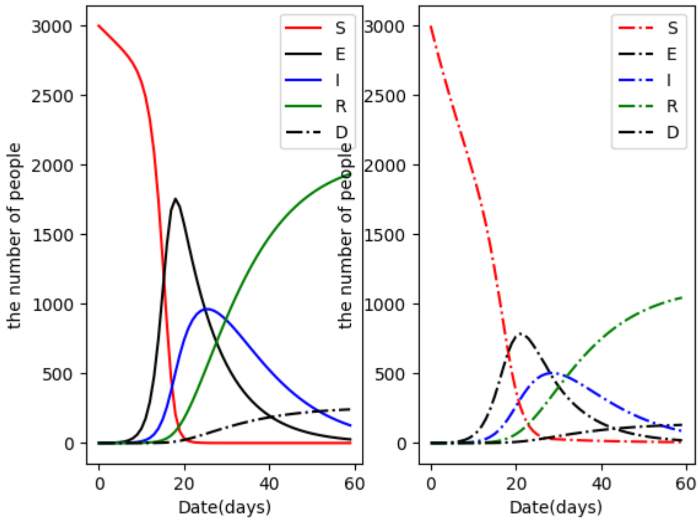

Figure 2. Propagation time curve (φ_1=0.01, φ_2=0.01) for Ezhou City

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Table 4. The infection rates at different cities of Hubei Province, China

City	Number of Infected Cased	Population (ten thousand)	Infection Rate
Wuhan	2639	1100	2.400
Ezhou	189	107	1.766
Xiaogan	541	492	1.100
Suizhou	228	221	1.032
Huanggang	573	693	0.827
Jingmen	227	289	0.785
Xianning	166	254	0.653
Xiangyang	286	566	0.505
Jingzhou	221	599	0.369

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mid-February; fitting out the inflection point on February 19. In late February 21, the outbreak wave started again. In the period around the predicted transmission points, the prevention and control strategies could be more effective in curbing the spread of the virus. The five-day period from February 13 to February 18 is considered as phase I and the five-day period from February 19 to February 24 is considered as phase II. Taking timely and effective measures in these two phases can reduce the peak of the predicted transmission points and further curb the development of the pandemic.

3. Results

Warehouse model analysis of pandemic information dissemination

In the early stage of the COVID-19 outbreak, due to the lack of knowledge of the disease risk, there was no strong tendency towards self-isolation, and the outbreak time coincided with the start of the Spring Festival, China's major holiday, when many Chinse people are gathered and have close contact with each other. Therefore, it was not possible to disseminate the knowledge of pandemic, which let the virus kill many people. By broadcasting the videos about how to fight the pandemic through the media, the public awareness of the pandemic and personal hygiene can be improved, which block the transmission of the virus and reduce the probability of infection among susceptible groups. Reducing exposure is the most important way to avoid the pandemic getting out of control. Although most prevention and control strategies have certain theoretical basis and feasibility, no prevention and control measures are universal. The effectiveness of these measures depends on many factors, including the disease itself, communication ability, the outbreak development, mutation in pathogen evolution, and resistance to the disease as well as the peoples'

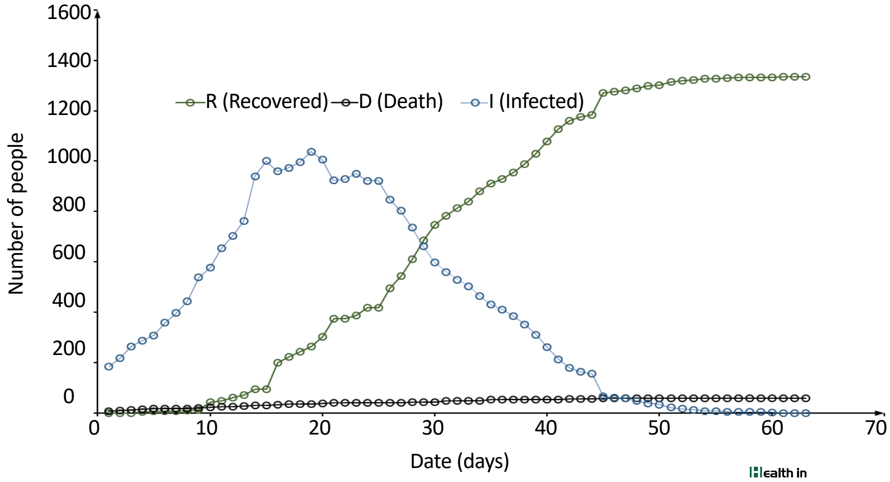

Figure 3. Transmission time curve for Ezhou City

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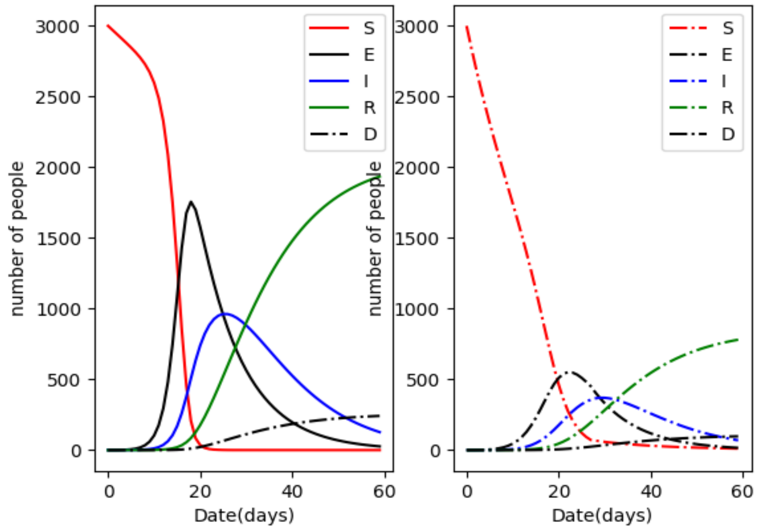

Figure 4 . Propagation time curve (φ_1=0.04, φ_2=0.01)

immunity and susceptibility, social structure, education, economic conditions, and so on. The effectiveness of a control measure against the infectious diseases in different times and places can be greatly different.

It is assumed that the probability of isolation effectiveness φ_1 in the SEIR-Q_1Q_2 model increases from 0.01 to 0.04, while the φ_2 (effectiveness of isolation at hospital) remains unchanged. After simulation in Python, as shown in Figure 4, the number of infectious cases decreased from 1000 to 400, and the number of exposed cases decreased from 1700 to 600. Therefore, by disseminating the knowledge of pandemic prevention and control measures for susceptible people isolated at home, the risk of transmission can be reduced more dramatically. For example, during influenza epidemics, public health authorities advised people to reduce the chance of infection or transmission by paying attention to personal hygiene, use of cough etiquette, wearing masks, and staying at home after the onset of symptoms. When the transmissibility and pathogenicity of the virus are enhanced and the epidemic situation becomes more serious, other measures such as closing the schools and offices and restricting the public gatherings are often taken. However, when measures such as school or workplace closures and traveling restrictions are taken, they are often difficult to be implemented or are unacceptable to the public because of creating social and economic problems.

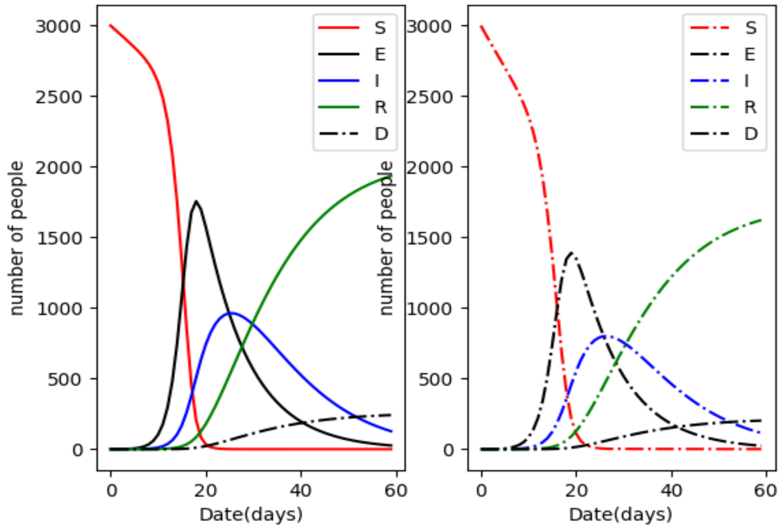

Figure 5. Propagation time curve (φ_1=0.01, φ_2=0.04)

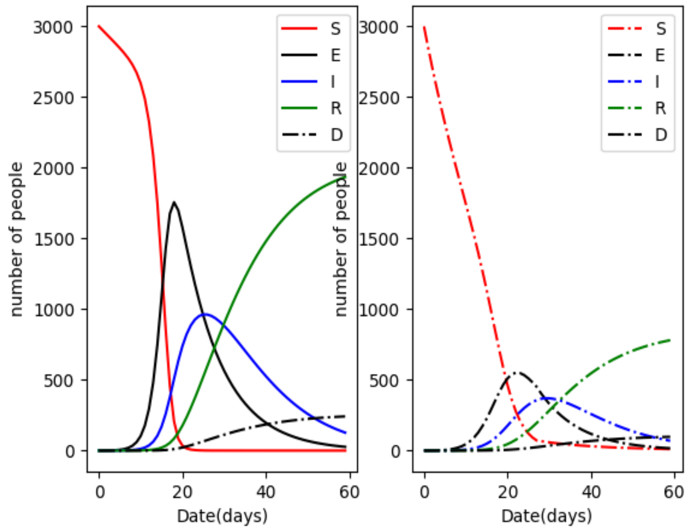

Figure 6. Propagation time curve (φ_1=0.05, φ_2=0.05)

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Warehouse model analysis of medical supply

In the middle of the COVID-19 outbreak, a decision was made by the government to build the Huoshenshan Hospital in Ezhou on January 26 due to the surge in the number of confirmed cases. In addition, the Hospital of Traditional Chinese Medicine and the Hospital of Integrated Traditional Chinese and Western Medicine, which were under construction in Ezhou, transformed into infectious disease control hospitals. The total number of hospital beds in the city was more than 2,300. Because of the shortage of resources in general hospitals, Fangcang Hospital in Wuhan became an important site for treating patients with mild COVID-19. The flexible temporary hospital building is also an important measure to compensate for the lack of general hospitals during major disasters. At the same time, the use of cloud platform technology and remote video conference system can help real-time doctor-patient communication inside and outside the hospital and building a proper place for keeping patients and establishing a business platform integrating information about the patients and diagnosis can help medical staff to quickly and comprehensively receive the information of confirmed cases and formulate treatment plans more accurately.

It is assumed that the probability of φ_2 in the SEIR-Q_1Q_2 model increases from 0.01 to 0.04, while the φ_1 remains unchanged. After simulation in Python, as shown in Figure 5, the number of infectious people decreased from 1000 to 800, and the number of exposed cases decreased from 1700 to 1400. Therefore, by increasing the supply of medical resources, building quarantine tents, isolating patients for treatment can play an important role in reducing the risk of the pandemic development.

Warehouse model analysis of pandemic information dissemination and medical supply

In the early stage of the pandemic, the dissemination of pandemic prevention knowledge during isolation at home can reduce the infection rate β, while the supply of medical resources during isolation at hospital can shorten the average infection time 1/γ. It is often thought that the best way to control an outbreak is to activate all preventions measures as soon as possible, but it is difficult to identify them early.

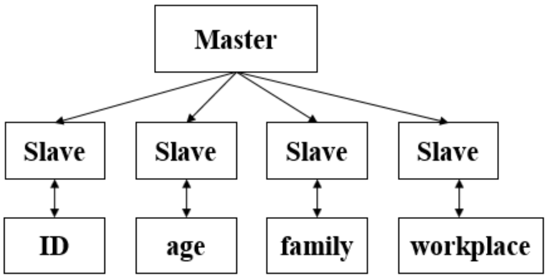

Figure 7. Master/slave model of the network

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Table 5. Agent parameters in the ABM

Parameters	Definitions
ID	Agent's identity
Body type	Agent's physical fitness (related to age)
Age	Agent's age (subject to the population law)
Family	Agent's family
Usual location	Agent's regular activity place
Profession	Agent's occupation and workplace
Vehicle	Have transportation
Vaccine	Vaccination times

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It is assumed that in the SEIR-Q_1Q_2 model, the φ_1 increases from φ_1=0.01 to φ_1=0.05, and the φ_2 increases from φ_2=0.01 to φ_2=0.03. After simulation in Python, as shown in Figure 6, the number of infectious people decreased from 1000 to 350, and the number of exposed cases decreased from 1700 to 500. Therefore, when the dissemination of pandemic prevention knowledge and medical supply are taken place together, the effectiveness of prevention and control strategies can be maximized. Precision epidemic prevention and control scientific nature, the feasibility of fully considering measures, using the model to simulate all kinds of effect of prevention and control measures, in the model design as much as possible close to the actual situation, especially in recent years, there will be mapped to the spread of infectious diseases kinetics of crowd interaction contact on complex networks, for us to achieve accurate prediction, disease control and prevention and control measures evaluation provides an important method. Accumulate necessary data base and quantitative evaluation results for future scientific prevention and control.

Agent-based modeling

Vaccination and social distancing can help reduce the transmission of disease. The spatio-temporal distribution of infectious diseases have shown that the crowd flow and social relations are complex; hence, it is difficult to use traditional mathematical methods to model the infectious disease transmission. Therefore, a "top-down" approach for agent-based modeling (ABM) was used to conduct computerized simulation of the disease transmission process and the virus diffusion process and speed in urban areas in a more detailed way. When modeling the effects of various prevention and control measures, the designed model should be close to the reality as much as possible. In recent years, the dynamic process of disease transmission has mapped into the complex network of population interaction, which provides an important method for accurate prediction and control of disease and evaluation of prevention and control measures. It is necessary to collect data on the epidemic process to clearly identify the contact history of infected cases and the social contact of the population. Therefore, we adopted the method of complex network simulation to evaluate the effectiveness of prevention and control strategies in a complex network as close as possible to the actual social contact characteristics of the population.

The social contact network is the network formed by daily contact of individuals with others, denoted as G_t= (V, E, W), where V is the set nodes (individuals in the crowd), E is the set of edges formed by individual contact, and W is the weight set of the edges in the network. The prevention and control measures can be generally divided into two categories of pharmaceutical and non-pharmaceutical measures or non-adaptive and adaptive measures. Non-adaptive measures are usually started before the outbreak (such as vaccination, mass immunization, etc.) and do not change the individuals' daily activities as the epidemic progresses, while adaptive measures cause a changes in the individuals' daily activities (e.g., closing schools and restriction of social activities).

The artificial data of Ezhou population was generated by iterative proportional fitting method. The data set assigns basic information such as identity (ID), age, gender, workplace (school) ID, and family ID to each individual (Figure 7). Assume that individuals with the same family create a fully connected network and individuals in the same school or workplace create a small network. Using small-world network generation algorithm, a contact network for the school or workplace was generated, and finally a contact network data for the whole city was built.

Determining the behavioral characteristics of agents

From a macro point of view, the daily activities of many people in cities are similar, but the daily activities of people of the same type are different. Classifying "people" in cities and modeling their behaviors can simulate their daily activities during pandemics. After the onset of the COVID-19 outbreak, the people's daily behaviors changed in the form of isolation after infection. After recovery, they can no longer moves freely in the city. After getting the pandemic-related information, they restrict themselves or reduce outdoor activities and take preventive measures such as wearing a mask when going out. They also change their transportation mode and witness that many areas such as schools are closed.

Design of parameters and attributes for agents in urban areas

Considering that a pandemic simulation may involve millions or more individuals and the ABM method itself has a high demand for computing resources, it is necessary to parallelize the simulation parameters. In the simulation of disease transmission based on the social contact network, the first problem of parallelization is the network segmentation. The parameters of agents refer to some information of the agents that do not change with the simulation. These parameters affect the agent behaviors and interactions. For example, in the short-term simulation, the age of agent is a parameter, which does not change with the progress of simulation, but it is related to the constitution of agent, which affects the risk of infection in agent. The other parameters of agent are shown in Table 5.

Google Map was used for obtaining location data and the disease-specific parameters such as duration of incubation and infection were obtained according to the centers for disease control and prevention (CDC). Observational data included demographic and behavioral information collected using field notes. The propagation of the social contact network was analyzed, and the squared coefficient of variation for the network (CV^2) was finally obtained CV^2. According to this, the contact propagation rate was defined as $\beta=\sigma R_0/k\,(1+CV^2)$, where K is the average degree of the network.

4. Discussion

Based on the scenario analysis of COVID-19 pandemic situation in Ezhou City, the warehouse model and ABM were used to analyze the prediction of the pandemic situation. In the warehouse model, there was no correlation between population size and $\beta=\sigma R_0$; therefore, the epidemic curves of the two were approximately consistent.

5. Conclusions

By improving the SEIR model based on the simulation conducted in Python, various warehouse room changes with time, the number of key parameters spread and popular trend at present stage has carried on the estimation and prediction, starting from the basic reproductive number, reduce virus infection rate of beta $1/\gamma$ and shorten the average infection time, the most basic means to prevent the outbreak of the out of control is to reduce contact. The second is to strengthen the carrying capacity of hospital isolation. The SEIR-Q_1Q_2 model can be used to predict the future trend of the COVID-19 pandemic by proposing the dissemination of the pandemic knowledge and increasing the supply of medical resources. In order to improve the effectiveness of prevention, the dynamic process of disease transmission can be mapped to the complex network of population interactions. To simulate the spread of COVID-19 in cities, a simulation system should be established according to the characteristics of people in cities which are the carriers of the diseases. The simulation system can reflect the transmission process and speed in real time and predict the development of COVID-19. It can reflect the influence of different prevention and control measures on the spatio-temporal spread of the disease.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Both authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Prem K, Liu Y, Russell TW, Kucharski AJ, Eggo RM, Davies N, et al. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: A modelling study. The Lancet Public Health. 2020; 5(5):e261-70. [DOI:10.1016/S2468-2667(20)30073-6] [PMID] [PMCID]

[2] Foppa IM. 4 - W.O. Kermack and A.G. McKendrick: A seminal contribution to the mathematical theory of epidemics (1927). A Historical Introduction to Mathematical Modeling of Infectious Diseases. 2017:59-87. [DOI:10.1016/B978-0-12-802260-3.00004-3]

[3] Kermack WO, Mckendrick A G. Contributions to the mathematical theory of epidemics-II. the problem of endemicity. Bulletin of Mathematical Biology. 1991: 53(1-2):57-87. [DOI:10.1016/S0092-8240(05)80041-2]

[4] Huang B, Zhu Y, Gao Y, Zeng G, Zhang J, Liu J, et al. The analysis of isolation measures for epidemic control of COVID-19. Applied Intelligence. 2021; 51(5):3074-85. [DOI:10.1007/s10489-021-02239-z] [PMID] [PMCID]

[5] Wu S, Sun P, Li R, Zhao L, Wang Y, Jiang L, et al. Epidemiological development of novel coronavirus pneumonia in china and its forecast. medRxiv. 2020. [DOI:10.1101/2020.02.21.20026229]

[6] Ma R, Zheng X, Wang P, Liu H, Zhang C. The prediction and analysis of COVID-19 epidemic trend by combining LSTM and Markov method. Scientific Reports. 2021; 11(1):17421. [DOI:10.1038/s41598-021-97037-5] [PMID] [PMCID]

[7] Althaus CL, Low N, Musa EO, Shuaib F, Gsteiger S. Ebola virus disease outbreak in Nigeria: Transmission dynamics and rapid control. Epidemics. 2015; 11:80-4. [DOI:10.1016/j.epidem.2015.03.001] [PMID]

[8] Naz R, Al-Raeei M. Analysis of transmission dynamics of COVID-19 via closed-form solutions of a susceptible-infectious-quarantined-diseased model with a quarantine-adjusted incidence function. Mathematical Methods in the Applied Sciences. 2021; 44(14):11196-210. [DOI:10.1002/mma.7481] [PMID] [PMCID]

[9] Shou MH, Wang ZX, Lou WQ. Effect evaluation of non-pharmaceutical interventions taken in China to contain the COVID-19 epidemic based on the susceptible-exposed-infected-recovered model. Technological Forecasting and Social Change. 2021; 171:120987. [DOI:10.1016/j.techfore.2021.120987] [PMID] [PMCID]

[10] Yan Q, Tang Y, Yan D, Wang J, Yang L, Yang X, et al. Impact of media reports on the early spread of COVID-19 epidemic. Journal of Theoretical Biology. 2020; 502:110385. [DOI:10.1016/j.jtbi.2020.110385] [PMID] [PMCID]

[11] Raveendran AV, Jayadevan R. Reverse quarantine and COVID-19. diabetes & metabolic syndrome. Clinical Research & Reviews. 2020; 14(5):1323-5. [DOI:10.1016/j.dsx.2020.07.029] [PMID] [PMCID]

[12] Shen M, Peng Z, Xiao Y, Zhang L. Modeling the epidemic trend of the 2019 novel coronavirus outbreak in China. Innovation. 2020; 1(3):100048. [DOI:10.1016/j.xinn.2020.100048] [PMID] [PMCID]

[13] Tang B, Wang X, Li Q. Estimation of the transmission risk of 2019-nCov and its implication for public health interventions. Journal of Clinical Medicine. 2020; 9(2):462. [DOI:10.3390/jcm9020462] [PMID] [PMCID]

[14] Devrim İ, Bayram N. Infection control practices in children during COVID-19 pandemic: Differences from adults. American Journal of Infection Control. 2020; 48(8):933-9. [DOI:10.1016/j.ajic.2020.05.022] [PMID] [PMCID]

[15] Náraigh LÓ, Byrne Á. Piecewise-constant optimal control strategies for controlling the outbreak of COVID-19 in the Irish population. Mathematical Biosciences. 2020; 330:108496. [DOI:10.1016/j.mbs.2020.108496] [PMID] [PMCID]

[16] Liu M, Ning J, Du Y, Cao J, Zhang D, Wang J, et al. Modelling the evolution trajectory of covid-19 in Wuhan, China: Experience and suggestions. Public Health. 2020; 183:76-80. [DOI:10.1016/j.puhe.2020.05.001]

[17] Kermack WO, Mckendrick AG. Contributions to the mathematical theory of epidemics-I. Bulletin of Mathematical Biology. 1991; 53(1-2):33-55. [DOI:10.1007/BF02464423]

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