Scientific Research Publishing

Journal of Applied Mathematics and Physics, 2023, 11, 457-477
https://www.scirp.org/journal/jamp
ISSN Online: 2327-4379
ISSN Print: 2327-4352

Dynamic Modeling and Analysis of Occult Transmission of Omicron SARS-CoV-2 Epidemic

Kun Wang[1,2], Lu Wang[1,2], Linhua Zhou[1,2*]

[1]School of Mathematics and Statistics, Changchun University of Science and Technology, Changchun, China
[2]Provincial Demonstration Center for Experimental Mathematics (Changchun University of Science and Technology), Changchun, China
Email: 1051989905@qq.com, *chowlh1718@163.com

How to cite this paper: Wang, K., Wang, L. and Zhou, L.H. (2023) Dynamic Modeling and Analysis of Occult Transmission of Omicron SARS-CoV-2 Epidemic. *Journal of Applied Mathematics and Physics*, **11**, 457-477.
https://doi.org/10.4236/jamp.2023.112028

Received: January 11, 2023
Accepted: February 14, 2023
Published: February 17, 2023

Abstract

At present, the Omicron variant is still the dominant strain in the global novel coronavirus pneumonia pandemic, and has the characteristics of concealed transmission, which brings heavy pressure to the health systems of different countries. Omicron infections were first found in Chinese Mainland in Tianjin in December 2021, and Omicron epidemic broke out in many parts of China in 2022. In order to enable the country and government to make scientific and accurate decisions in the face of the epidemic, it is particularly important to predict and analyze the relevant factors of Omicron's covert transmission. In this paper, based on the official data of Jilin City and the improved SEIR dynamic model, through parameter estimation, the contact infection probability of symptomatic infected persons in Omicron infected patients is 0.4265, and the attenuation factor is 0.1440. Secondly, the influence of infectious duration in different incubation periods, asymptomatic infected persons and other factors on the epidemic situation in this area was compared. Finally, the scale of epidemic development was predicted and analyzed.

Keywords

Omicron Epidemic, Epidemic Dynamics Model, Hidden Transmission, Numerical Simulation

1. Introduction

The COVID-19 Omicron variant ("Omicron") is the main epidemic strain in most countries in the world. Compared with the earlier variants such as Alpha and Delta, Omicron has the characteristics of higher, faster and more hidden transmission [1] [2] [3]. On March 3, 2022, 8 local cases were reported in Jilin City, and then the epidemic spread throughout the city. In the face of the sudden

Omicron epidemic, Jilin City announced on March 9 that the whole city was "closed down", temporarily closed the traffic infrastructure, built a shelter hospital, and took several rounds of "large-scale nucleic acid detection", "tracking and isolation" and other gradually upgraded non-drug interventions. The current round of epidemic was basically controlled on May 11, and 27,498 cases were finally infected.

The incubation period of infectious diseases refers to the time interval from the invasion of pathogens to the earliest appearance of clinical symptoms or signs [4]. Since the outbreak of COVID-19 in 2019, most studies have shown that COVID-19 infected people are infectious in the incubation period through retrospective review of patients with COVID-19 in the incubation period. Based on the data of Wuhan City and the whole country in 2020, considering that the patients in the incubation period are infectious, Zhu Wenwen *et al.* [5] established a mathematical model to estimate the number of infected people in the incubation period that are not under control, and accurately predicted that the epidemic situation in the whole country will basically end on the 70th day after January 23. Rothe C *et al.* [6] made a follow-up survey on the contact of several patients and their contacts in Germany, and found that the susceptible healthy individuals contacted patients in the incubation period, and the healthy individuals became infected. Su Wating *et al.* [7] selected 14 COVID-19 patients in the incubation period who were treated in the operating room of the hospital as the research objects, investigated the contact infection between the operating room medical staff and patients, and found that 3 of the 42 medical staff were finally diagnosed with infection. Relevant research shows that [8], the incubation period of Omicron mutant is about 2 - 4 days, which is significantly shorter than the previous COVID-19 mutant. Compared with other mutant strains, Omicron mutant strains have stronger infectivity, immune escape ability and faster transmission speed due to more mutations [9]. The rapid transmission of Omicron infected persons in the incubation period is an important factor that causes the occult transmission of Omicron virus.

After the large-scale vaccination of the novel coronavirus vaccine, the severe rate and mortality rate of human infection decreased significantly [10]. Bozwana reported that 85% of the new Omicron infections were asymptomatic [11]. The number of asymptomatic infected persons in Omicron epidemic further increased. Although many asymptomatic infected people have no obvious clinical manifestations, Omicron virus can be transmitted to others due to its presence in the body, thus accelerating the epidemic [12]. Sun Tingzhe *et al.* [13] studied the influence of asymptomatic infected people on the transmission of COVID-19 based on SCIRA differential equation model. The results show that even if the confirmed cases are cleared, strict prevention and control measures should be continuously implemented, otherwise potential asymptomatic infected people may have a second outbreak. Dan Weng *et al.* [14] confirmed by mathematical model that compared with imported cases, the COVID-19 epidemic caused by asymptomatic infected persons broke out faster and on a larger scale. Rahul Subramanian *et al.* [15] used the SEPIAR model to quantitatively analyze the asymptomatic infection and transmission dynamics of COVID-19 in New York City, indicating that the control of asymptomatic infection is the key to avoid community transmission of COVID-19. The sharp increase in the number of asymptomatic infections has posed a major challenge to the epidemic prevention and control. This round of Omicron epidemic in Jilin City reported 13,451 asymptomatic infections, accounting for about 49% of the total number of infections.

The emergence of COVID-19 variants, such as Omicron, has brought many challenges to global public health security. Therefore, it is necessary to discuss and analyze the key factors that cause the occult transmission of Omicron epidemic, so as to provide a reference for formulating disease prevention and control measures in the future. In this study, based on the epidemic data of Omicron in Jilin City from March 3, 2022 to May 11, 2022, the Omicron transmission model was established, the contact infection rate, attenuation factor and other key parameters of Omicron were estimated, and the infection in the incubation period and the impact of asymptomatic infected persons on the epidemic spread were evaluated.

The rest of this paper is structured as follows. Section 2 analyzed the epidemic data of Jilin City, corrected the data, and processed the data in sections according to the characteristics of epidemic prevention and control in Jilin City; in section 3, based on the dynamic zoning model of infectious diseases, the Omicron transmission model of novel coronavirus pneumonia in Jilin City is established. The values of parameters in each stage are adjusted appropriately, and the key parameters are estimated using the least square method; In Section 4, numerical simulation experiments are conducted to evaluate the influencing factors of covert transmission; a conclusion is provided in Section 5.

2. Data

2.1. Research Data

The research data is taken from the official report of Jilin Municipal Health Commission, mainly including newly confirmed cases and newly asymptomatic cases in Jilin City (**Figure 1**). On March 3, Jilin reported the first confirmed case of Omicron. After about a week, the number of confirmed cases in the whole city increased significantly on March 9. In order to control the spread of Omicron as soon as possible, Jilin City announced on the 9th that the whole city was closed down, gradually closing the expressway and urban public transport system; implement the “dynamic zero COVID policy”, that is, carry out multiple rounds of large-scale nucleic acid testing throughout the city, treat infected patients with integrated traditional Chinese and western medicine, transport and isolate close contacts, manage and control by regions and levels, and constantly strengthen the implementation of control measures until the end of the epidemic.

Since the outbreak of Omicron epidemic in Jilin City, with the arrival of aid resources and medical personnel from other regions of the country, the detection capacity of Jilin City has been continuously improved. The use of mobile cabin hospitals has effectively improved the efficiency of patient transport, and the implementation of the "dynamic zero COVID policy" has been increasing. The development process of the epidemic can be divided into the following six stages.

Stage I: From March 3 to March 9, 2022, Jilin City reported the confirmed case of Omicron for the first time on March 4. The epidemic situation has been in the hidden development stage until March 9.

Stage II: From March 10 to March 14, 2022. On March 10, Jilin entered the "lockdown" state: zoning and hierarchical management and control, suspension of public transport operations, and large-scale nucleic acid testing, that is, the beginning stage of "dynamic zero COVID".

Stage III: From March 15 to March 25, 2022. On March 20, Jilin City announced a new round of large-scale nucleic acid testing, upgraded the city's management and control measures, and implemented global static control, that is, the enhanced phase of "dynamic zero COVID".

Stage IV: From March 26 to March 30, 2022, Jilin City will conduct large-scale nucleic acid testing again on March 26, that is, the critical stage of "dynamic zero COVID".

Stage V: March 31 to April 7, 2022. Jilin City carried out nucleic acid testing in the whole city, launched the general attack of social clearance, and completed the social clearance on April 7, that is, the "dynamic zero COVID" stage.

Stage VI: From April 8 to May 11, 2022. Since April 8, the confirmed cases in Jilin City have been found in the closed control area and transported for isolation treatment "point-to-point". On May 11, only one new asymptomatic infection case was added, and then there were no new cases for two consecutive weeks, which is the deepening stage of "dynamic zero COVID".

2.2. Data Correction

Because some confirmed cases were changed from asymptomatic to confirmed cases, such cases appeared cough, fever, fatigue and other symptoms after a period of observation after nucleic acid test result was positive; or after a period of time, although there are no clinical symptoms, there are lesions in the lung CT examination, they will be diagnosed as confirmed cases [16]. The incubation period of Omicron in this paper is set as 3 days [17]. We take the number of asymptomatic confirmed cases on one day as a part of the cumulative number of confirmed cases on that day, and the cumulative number of asymptomatic cases three days ago is reduced accordingly. For example, the cumulative number of confirmed cases on March 31 (excluding the asymptomatic cases transferred to confirmed cases on that day) is n_1, the number of confirmed cases without

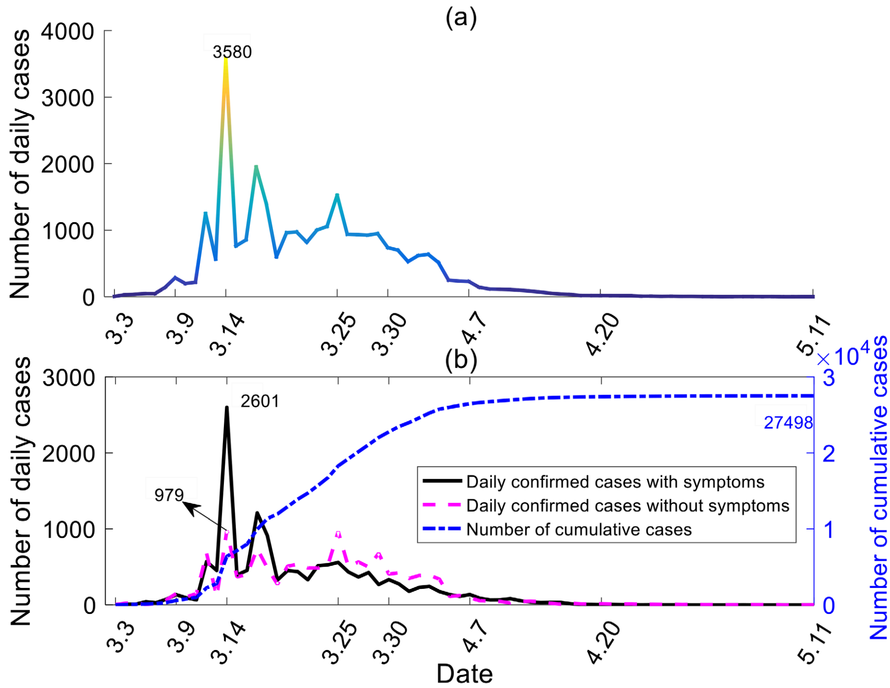

Figure 1. Cases in Jilin City from March 3 to May 11, 2022. The data were obtained from the official website of Jilin Municipal Health Commission, (a) the number of new cases per day; (b) Figure, where the blue dotted line represents the cumulative confirmed cases (including asymptomatic infections), the black solid line represents the newly confirmed cases every day, and the purple dotted line represents the newly added asymptomatic cases every day.

symptoms on that day is l, and the cumulative number of asymptomatic cases on March 28 is n_2. After data correction, the cumulative number of confirmed cases on March 31 is $n_1 + l$, the cumulative number of asymptomatic cases on March 28 is $n_2 - l$, and the cumulative number of confirmed cases on March 28 did not change.

3. Model

3.1. Model Establishment

Based on the dynamic zoning model of infectious diseases, the transmission characteristics of Omicron, and the effect of dynamic zero clearing prevention and control measures in Jilin, we divide the population in this city into the following 12 zones: susceptible population ($S(t)$), vaccinated population ($V(t)$), isolated susceptible population ($Q_1(t)$), inoculated and isolated population ($Q_2(t)$), non-infectious exposed population ($E_1(t)$), infectious exposed population ($E_2(t)$), symptomatic infected people ($I(t)$), asymptomatic infected population ($A(t)$), exposed isolated population ($Q_E(t)$), symptomatic infected people being treated in hospital ($H_I(t)$), asymptomatic infected people being treated in hospitals ($H_A(t)$) and recovering population ($R(t)$). The model flow chart is shown in Figure 2.

The following dynamic model is established according to flow chart 2:

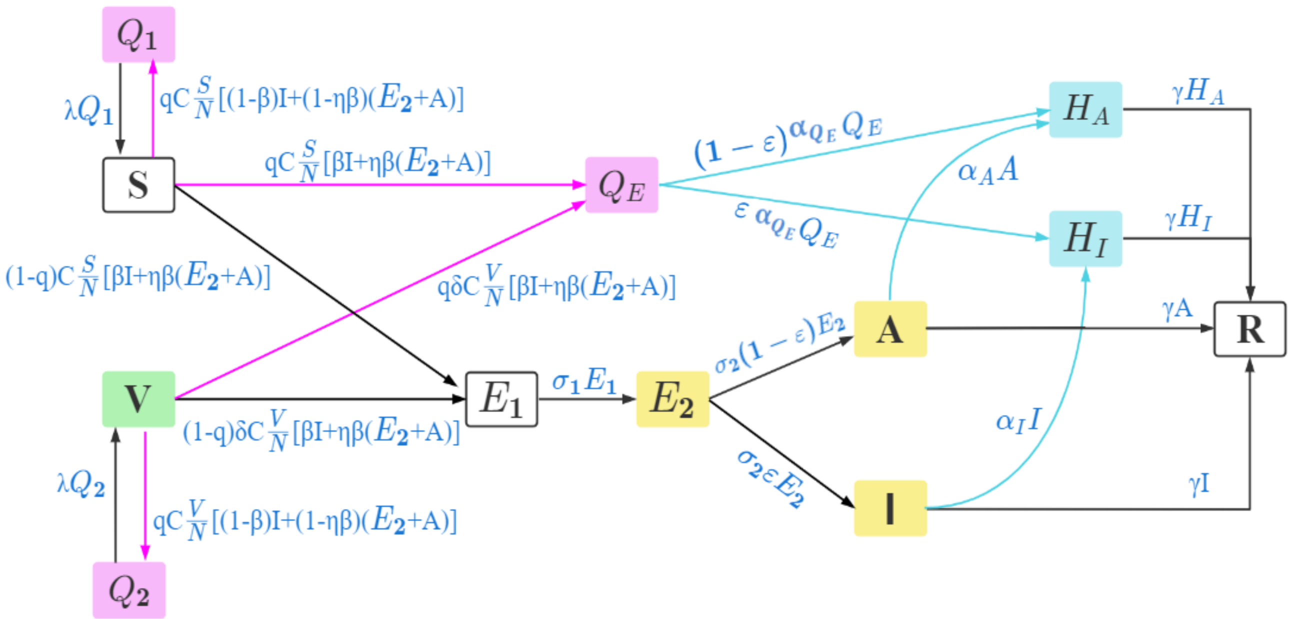

Figure 2. Flow Chart of CODID-19 Epidemic.

$$\begin{cases}
\dfrac{\mathrm{d}S}{\mathrm{d}t}=-qC\dfrac{S}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]-\left(1-q\right)C\dfrac{S}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]\\
\qquad -qC\dfrac{S}{N}\left[\left(1-\beta\right)I+\left(1-\eta\beta\right)\left(E_2+A\right)\right]+\lambda Q_1\\
\dfrac{\mathrm{d}V}{\mathrm{d}t}=-q\delta C\dfrac{V}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]-\left(1-q\right)\delta C\dfrac{V}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]\\
\qquad -qC\dfrac{V}{N}\left[\left(1-\beta\right)I+\left(1-\eta\beta\right)\left(E_2+A\right)\right]+\lambda Q_2\\
\dfrac{\mathrm{d}Q_1}{\mathrm{d}t}=qC\dfrac{S}{N}\left[\left(1-\beta\right)I+\left(1-\eta\beta\right)\left(E_2+A\right)\right]-\lambda Q_1\\
\dfrac{\mathrm{d}Q_2}{\mathrm{d}t}=qC\dfrac{V}{N}\left[\left(1-\beta\right)I+\left(1-\eta\beta\right)\left(E_2+A\right)\right]-\lambda Q_2\\
\dfrac{\mathrm{d}E_1}{\mathrm{d}t}=\left(1-q\right)\delta C\dfrac{V}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]+\left(1-q\right)C\dfrac{S}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]-\sigma_1 E_1\\
\dfrac{\mathrm{d}E_2}{\mathrm{d}t}=\sigma_1 E_1-\sigma_2\left(1-\varepsilon\right)E_2-\sigma_2\varepsilon E_2\\
\dfrac{\mathrm{d}I}{\mathrm{d}t}=\sigma_2\varepsilon E_2-\alpha_I I-\gamma I\\
\dfrac{\mathrm{d}A}{\mathrm{d}t}=\sigma_2\left(1-\varepsilon\right)E_2-\alpha_A A-\gamma A\\
\dfrac{\mathrm{d}Q_E}{\mathrm{d}t}=qC\dfrac{S}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]+q\delta C\dfrac{V}{N}\left[\beta I+\eta\beta\left(E_2+A\right)\right]-\alpha_{Q_E}Q_E\\
\dfrac{\mathrm{d}H_I}{\mathrm{d}t}=\alpha_I I+\varepsilon\alpha_{Q_E}Q_E-\gamma H_I\\
\dfrac{\mathrm{d}H_A}{\mathrm{d}t}=\alpha_A A+\left(1-\varepsilon\right)\alpha_{Q_E}Q_E-\gamma H_A\\
\dfrac{\mathrm{d}R}{\mathrm{d}t}=\gamma A+\gamma I+\gamma H_I+\gamma H_A
\end{cases} \tag{3-1}$$

This paper does not consider vaccination and population inflow and outflow during Omicron epidemic; Assume that the immune escape rate of Omicron virus against the existing vaccine protective barrier is δ, *i.e.*, in addition to susceptible individuals S, some individuals vaccinated δV may also be infected with Omicron virus. In this paper, it is considered that the exposed population in the late incubation period is infectious, that is, the exposed infectious individuals E_2, infected but undiagnosed individuals I and A are the source of the whole infectious epidemic. Assume that the average number of contacts per person in a unit time is C, the tracking rate of individuals in close contact with infected cases is q, the probability of close contact with symptomatic case I and infection is β, the possibility of contacting infectious exposed individuals E_2 or asymptomatic case A and getting infected is $\eta\beta$. η is the attenuation factor, then the number of people exposed to infection without infectivity within a unit time is $E_1 = (1-q)C\frac{S}{N}\left[\beta I + \eta\beta(E_2 + A)\right] + (1-q)\delta C\frac{V}{N}\left[\beta I + \eta\beta(E_2 + A)\right]$. After $1/\sigma_1$ days, they have developed into infectious exposed individuals E_2, and the number of isolated exposed individuals is $Q_E = qC\frac{S}{N}\left[\beta I + \eta\beta(E_2 + A)\right] + q\delta C\frac{V}{N}\left[\beta I + \eta\beta(E_2 + A)\right]$. In addition, the susceptible individuals S within an unit time are isolated at the quarantine room Q_1 at a rate of $qC\frac{S}{N}\left[(1-\beta)I + (1-\eta\beta)(E_2 + A)\right]$, because they are close contacts. Besides, among the vaccinated population V, $qC\frac{V}{N}\left[(1-\beta)I + (1-\eta\beta)(E_2 + A)\right]$ individuals are isolated at the quarantine room Q_2 for $1/\lambda$ days. For isolated exposed individuals Q_E, after $1/\alpha_{Q_E}$ days (slightly shorter than the days of exposure), they are diagnosed. And they are transferred to rooms H_I and H_A to receive treatment at a rate of $\varepsilon\alpha_{Q_E}Q_E$ and $(1-\varepsilon)\alpha_{Q_E}Q_E$. The incubation period is $\frac{1}{\sigma}$ days (*i.e.*, $\frac{1}{\sigma} = \frac{1}{\sigma_1} + \frac{1}{\sigma_2}$). Within an unit time, the untracked exposed infected individuals $\sigma_2\varepsilon E_2$ and $\sigma_2(1-\varepsilon)E_2$ become symptomatic infector I and asymptomatic infector A after being exposed for $1/\sigma_2$ days. Symptomatic case I and asymptomatic case A not identified and isolated in the city I α_I and α_A (at different stages α (different values) were confirmed by nucleic acid screening and transferred to rooms H_I and H_A. Finally, the symptomatic infector I, asymptomatic infector A and confirmed cases H_I and H_A who are receiving treatment at hospital get recovered at a rate of γI, γA, γH_I and γH_A, and they are transferred to room R.

Based on the Next-Generation method [18], the matrixes $\mathbb{F}$ and $\mathbb{V}$ are defined as follows:

$$\mathbb{F} = \begin{bmatrix} 0 & (1-q)C\frac{\eta\beta}{N}(S+\delta V) & (1-q)C\frac{\beta}{N}(S+\delta V) & (1-q)C\frac{\eta\beta}{N}(S+\delta V) \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{3-2}$$

$$\mathbb{V} = \begin{bmatrix} \frac{1}{\sigma_1} & 0 & 0 & 0 \\ \frac{1}{\sigma_2} & \frac{1}{\sigma_2} & 0 & 0 \\ \frac{1-\varepsilon}{\alpha_I+\gamma} & \frac{\varepsilon}{\alpha_I+\gamma} & \frac{1}{\alpha_I+\gamma} & 0 \\ \frac{1-\varepsilon}{\alpha_A+\gamma} & \frac{1-\varepsilon}{\alpha_A+\gamma} & 0 & \frac{1}{\alpha_A+\gamma} \end{bmatrix} \tag{3-3}$$

Thus, the number of controlled regeneration of model (3-1) is:

$$R_v = \rho\left(\mathbb{F}\mathbb{V}^{-1}\right) = \beta(1-q)\frac{C}{N}\left[\frac{\eta}{\sigma_2} + \frac{1-\varepsilon}{\alpha_I+\gamma} + \frac{\eta(1-\varepsilon)}{\alpha_A+\gamma}\right]\left[S(0)+\delta V(0)\right] \tag{3-4}$$

3.2. Parameter Estimation

Based on the model (3-1) and the data of confirmed cases in the first to fifth stages (March 3 to April 7) published by Jilin Municipal Health Commission [19], this study estimated the contact infection rate of Omicron symptomatic infected persons β, attenuation factor η, detection rate of symptoms α_{I1} at stage I (before blockade) and asymptomatic detection rate α_{A1} (that is, the proportion of symptomatic cases (asymptomatic cases) found in normal nucleic acid testing in unit time to the total infected population at the initial stage of Omicron's recessive transmission):

$$\alpha_{I1} \triangleq \alpha_I\big|_{\text{Stage I}}, \quad \alpha_{A1} \triangleq \alpha_A\big|_{\text{Stage I}}$$

And the initial value of non-infectious exposed population $E_1(0)$.

Some parameter values and initial values of state variables of model 3-1 are

Table 1. Variables and their description, initial value.

Symbol	Meaning	Initial Value	Source
$S(t)$	Susceptible population without vaccination	471,083	[20] [21]
$V(t)$	Vaccinated susceptible population	3,152,630	[20] [21]
$Q_1(t)$	Trace susceptible population without vaccination	0	[22]
$Q_2(t)$	Trace the susceptible population vaccinated	0	[22]
$E_1(t)$	No infectious exposed population	483.9378	Estimate
$E_2(t)$	Infectious exposed population	0	[22]
$I(t)$	Symptomatic infected population	1	[22]
$A(t)$	Asymptomatic infected population	7	[22]
$Q_E(t)$	Tracked isolated exposed people	0	[22]
$H_I(t)$	Symptomatic infected in-hospital patients	0	[22]
$H_A(t)$	Asymptomatic infected in-hospital patients	0	[22]
$R(t)$	Recovered population	0	[22]

shown in **Table 2**. According to the Communique of the Seventh National Population Census, the total population of Jilin City (N) is about 3623713 [20]. As of February 26, 2022, 87% of China's population has completed the whole process of vaccination [21], so it is assumed that $V(0)=87\%*N=3152630$, $S(0)=N-V(0)=471083$. The case reported by Jilin Municipal Health Committee on March 3 was taken as the initial value $I(0)$ of symptomatic infected persons and the initial value $A(0)$ of asymptomatic infected persons [22]. Constante Kuhlmann *et al.* [23] showed that the immune escape rate of Omicron for the protection of existing vaccines was $\delta=0.35$. Based on the studies of WU Y *et al.* [17], the incubation period of omicron is 3 days ($\frac{1}{\sigma}=\frac{1}{\sigma_1}+\frac{1}{\sigma_2}=3$). This papers assumes that the infectious days in the incubation period are 2 days (*i.e.*, $1/\sigma_2=2$). With reference to relevant research on social contact [24], the number of contacts before the blockade is assumed to be $C=14$. With the upgrading of control measures at each stage after the blockade, the number of contacts

Table 2. Parameters and their descriptions, value and sources.

Symbol	Meanings	Value at Different Stages						Source
		3.3 - 3.9	**3.10 - 3.14**	**3.15 - 3.25**	**3.26 - 3.30**	**3.31 - 4.7**	**4.8 - 5.11**	
N	Total population of Jilin	3623713						[20]
θ	Vaccine coverage rate	87%						[21]
δ	Immune escape rate of Omicron	0.35						[23]
C	Number of contacts	14	7	6	5	4	4	[24]
q	Track rate	0.25	0.25	0.25	0.55	0.65	0.7	[25]
$\frac{1}{\lambda}$ (days)	Time of isolation	14						[26]
$\frac{1}{\sigma_1}$ (days)	Time for group to stay at E_1	1						[17]
$\frac{1}{\sigma_2}$ (days)	Time for group to stay at E_2	2						[17]
ε	Proportion with symptoms	0.525						[27]
α_I	Detection rate with symptoms	0.2306	—	—	—	—	—	Estimate
		—	0.4	0.55	0.65	0.7	0.75	[28]
α_A	Detection rate without symptoms	3.5513e−14	—	—	—	—	—	Estimate
		—	0.4	0.5	0.65	0.7	0.75	[28]
α_{Q_E}	Tracking isolation detection rate	0.55						[28]
γ	Recovery rate	0.1						[29]
β	Contact infection rate of symptomatic infected persons	0.4265						Estimate
η	Attenuation factor	0.1440						Estimate

decreased accordingly (see Table 2). The gradual enhancement of the implementation of the "dynamic zero COVID-19" measures, the continuous improvement of the efficiency of large-scale nucleic acid detection and the transfer speed of confirmed cases, led to the continuous improvement of the detection rate in the city. Therefore, the detection rate in the city at each stage after the blockade is:

$$\alpha_{i2} \triangleq \alpha_i\big|_{\text{Stage II}},\ \alpha_{i3} \triangleq \alpha_i\big|_{\text{Stage III}},\ \alpha_{i4} \triangleq \alpha_i\big|_{\text{Stage IV}},$$
$$\alpha_{i5} \triangleq \alpha_i\big|_{\text{Stage V}},\ \alpha_{i6} \triangleq \alpha_i\big|_{\text{Stage VI}}\ \ (i = I, A)$$

See Table 2 for specific values of these parameters.

According to the data reported by Jilin Municipal Health Commission from March 3 to April 7, the contact infection rate of Omicron symptomatic infected persons was estimated based on the least square method β. Detection rate of symptomatic cases in stage I (before closure) $\alpha_{I1} \triangleq \alpha_I\big|_{\text{Stage I}}$, detection rate of asymptomatic cases $\alpha_{A1} \triangleq \alpha_A\big|_{\text{Stage I}}$ and the initial value of the exposed individual $E(0)$. The total amount of symptomatic cases (or asymptomatic cases) reported on day j ($j = 1, 2, \cdots, 36$) is recorded as $\widehat{M_I(j)}$ (or $\widehat{M_A(j)}$). The total amount of symptomatic cases (or asymptomatic cases) of day j ($j = 1, 2, \cdots, 36$) calculated from model is $M_I(j)$ (or $M_A(j)$):

$$M_I(j) = \sum_{k=j}^{j} \alpha_I I(k) + \varepsilon \alpha_{Q_E} Q_E(k),$$

$$M_A(j) = \sum_{k=j}^{j} \alpha_A A(k) + (1-\varepsilon) \alpha_{Q_E} Q_E(k).$$

Then the objective function of the least squares parameter estimation is obtained as follows:

$$\begin{aligned} &\min\left(\Gamma\left(\beta, \eta, \alpha_{I1}, \alpha_{A1}, E(0)\right)\right) \\ &= \min\left(\sum_{i=1}^{36}\left[M_I(j) - \widehat{M_I(j)}\right]^2 + \sum_{i=1}^{36}\left[M_A(j) - \widehat{M_A(j)}\right]^2\right) \end{aligned}$$

Wherein, $\Gamma\left(\beta, \eta, \alpha_{I1}, \alpha_{A1}, E(0)\right)$ is the error between model output and actual data. Furthermore, the estimated results were verified with the epidemic data of Stage VI.

4. Result and Numerical Simulation

4.1. Parameter Estimation and Predictions

The parameter estimation results are shown in Table 1 and Table 2. In Figure 3, the best fit curve and the reported data fit well (see black dotted line curve and red asterisk), showing the good fit effect between the dynamic model (3-1) and the actual data of Omicron epidemic in Jilin City. In particular, the confirmed cases and asymptomatic cases from March 3 to April 7 showed an obvious exponential growth trend, while after April 8, the output value of the parametric model showed a gentle trend, which was well matched with the actual data (see black dotted line and green dot), further verifying the reliability of the parameter

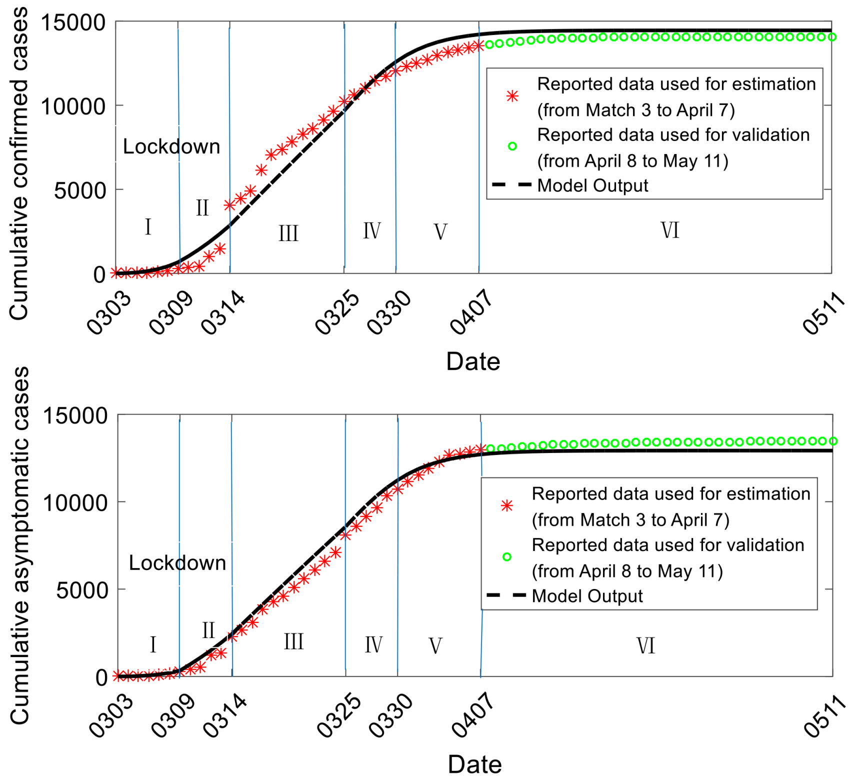

Figure 3. Comparison between model output and actual daily data. The best fit curve (black dotted curve from March 3 to April 7) shows that our prediction is very consistent with the reported cumulative case data (red star). The validation of estimates from April 8 to May 11 (see black dotted lines and green dots) also shows that the parameterized model makes perfect predictions. Here, the data of Red Star and Green Dot are the cumulative cases reported by Jilin Municipal Health Commission. The initial and parameter values are listed in Table 1 and Table 2.

estimation.

4.2. Analysis of the Influence of Latency Infectivity

The average incubation period of Omicron mutants is further shorter than that of the previous mutants, about 2 - 4 days, and COVID-19 is infectious in the incubation period, which makes the generation spacing of Omicron virus shorter and easier to spread in the population. This section analyzes the impact of the length of the incubation period on the spread of the epidemic. As shown in the simulation results in Figure 4, the duration of infectivity in the incubation period significantly affects the development speed of the epidemic, the scale of infection, etc. Compared with the baseline condition (duration of latency infectivity $1/\sigma_2 = 2$ days), if the incubation period lasts for $1/\sigma_2 = 1$ day, the cumulative number of confirmed cases (blue curve in Figure 4(a)) is basically the same as the baseline, and the cumulative number of asymptomatic cases (orange curve in Figure 4(b)) is slightly lower than the baseline; If the incubation period is not infectious (*i.e.* $1/\sigma_2 = 0$), the cumulative number of confirmed cases is about 6222 (light blue curve in Figure 4(a)), and the cumulative number of asymptomatic

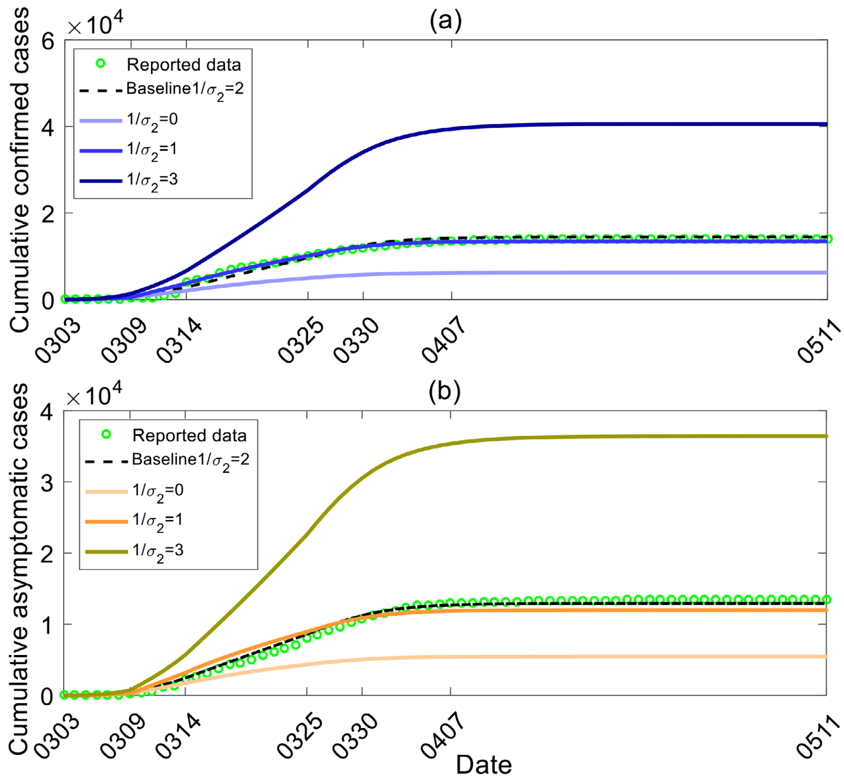

Figure 4. Influence of infectious duration in incubation period. (a) Changes in the number of cumulative confirmed cases; (b) Changes in the number of cumulative asymptomatic cases. As shown in the results, under the existing measures, if the whole incubation period is infectious, the total number of infected cases will more than double. If the incubation period is not infectious, the total number of cases can be controlled at a lower level. Except σ_1 and σ_2, other parameters are the same as in **Figure 3**.

diseases.

The number of cases was about 5400 (**Figure 4(b)** light orange curve), and the final number of infected people was less than 1/2 of the baseline, so the epidemic situation was effectively controlled one week ahead of schedule. Relatively speaking, if the whole incubation period is infectious (*i.e.* $1/\sigma_2 = 3$), the number of infected cases increased rapidly, the duration of the epidemic situation prolonged significantly, the cumulative number of confirmed cases increased to 40,580 (dark blue curve in **Figure 4(a)**), the cumulative number of asymptomatic cases increased to 36,420 (brown curve in **Figure 4(b)**), the increased number of cases were more than twice, and the total epidemic scale would be 2.8 times of the baseline.

4.3. Analysis of the Influence of Infection Rate on Patients with Latent Infection and Asymptomatic Infection

Relevant research shows that Omicron mutant is the most infectious COVID-19 mutant at presents. This section conducts numerical simulation experiments on the relevant attenuation factor η of the infectious rate of symptomatic patients, analyzes the impact of the infectious rate of infected people in the incubation period and asymptomatic infected people on the spread of the epidemic, and compares the impact of different infectious rates on the number of infected people and the epidemic cycle when considering the different infectious duration in the incubation period.

The simulation results in **Figure 5** show that if the relevant attenuation factor $\eta = 0.05$, that is, the infection rate of infected persons and asymptomatic infected persons in the incubation period is 0.05 times higher than that of symptomatic infected persons. Eventually, the number of infected persons shrinks slightly. The number of confirmed cases only decreases by about 4000 (the light blue curve in **Figure 5(a)**), and the number of asymptomatic cases decreases by about 3000 (the light orange curve in **Figure 5(b)**); However, if the infection rate of the infected person in the incubation period and the asymptomatic infected person is half that of the symptomatic infected person (*i.e.*, $\eta = 0.5$), the total

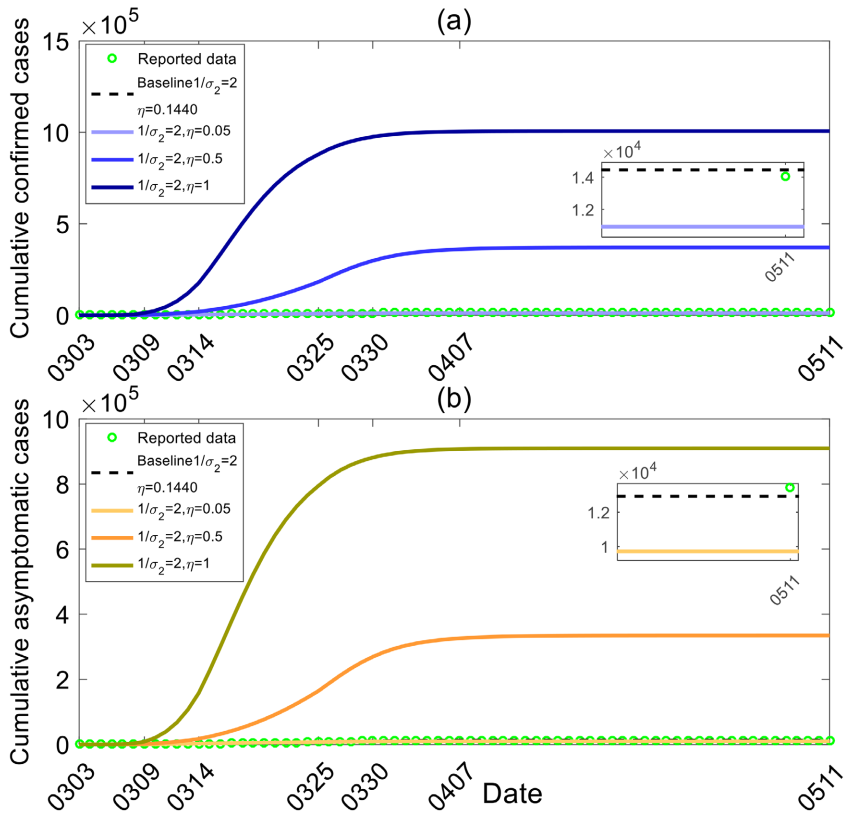

Figure 5. Influence of infection rate of patients with latent infection and asymptomatic infection. (a) Changes in the number of cumulative confirmed cases; (b) Changes in the number of cumulative asymptomatic cases. As shown in the results, under the existing measures, if the infection rate of the latent period infected persons and asymptomatic infected persons is 0.05 times that of the symptomatic infected persons, the total infection cases will be less than the baseline situation; If the infection rate of the latent period infected persons and asymptomatic infected persons expands to 0.5 times that of the symptomatic infected persons, the total number of cases will be greater than the baseline, and the duration will be significantly prolonged; if the infection level of symptomatic infected people is reached, the epidemic situation will be difficult to control. Except η, other parameters are the same as shown in **Figure 3**.

number of infected cases increased significantly, and Jilin City could effectively control the epidemic situation around April 15. What's more, if the infection rate of the infected and asymptomatic infected people in the incubation period is the same as that of the symptomatic infected people (*i.e.*, $\eta = 1$). The total number of infected cases in Jilin City will approach 2 million, the cumulative number of confirmed cases will reach 1 million (dark blue curve in **Figure 5(a)**), and the cumulative number of asymptomatic cases will approach 1 million (brown curve in **Figure 5(b)**), and there will be a sharp increase after the closure of the city on March 9. A large number of cases will appear in a short time, seriously impacting the medical system.

If the whole incubation period of Omicron mutant is infectious, as shown in **Figure 6**. Under the existing measures, only when the relevant attenuation factor $\eta = 0.05$, that is, the infection rate of infected persons and asymptomatic infected persons in the incubation period is 0.05 times higher than that of infected persons with symptoms, so the evolution and final scale of the epidemic situation can be close to the actual situation (the light blue curve in **Figure 6(a)** and the light orange curve in **Figure 6(b)**).

And when the relevant attenuation factor $\eta = 0.5$, the total number of infected

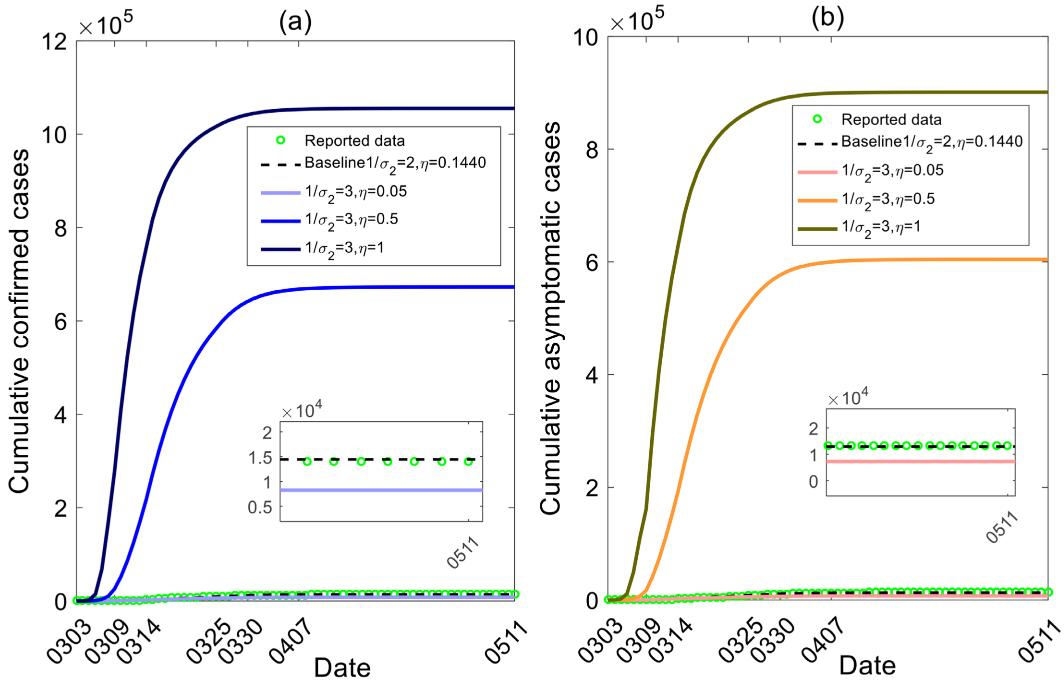

Figure 6. The influence of the duration of incubation period and the infection rate of infected persons and asymptomatic infected persons in incubation period. (a) Changes in the number of cumulative confirmed cases; (b) Changes in the number of cumulative asymptomatic cases. The virus is infectious throughout the incubation period. If the infection rate of the infected and asymptomatic infected persons in the incubation period is 0.05 times that of the symptomatic infected persons, the epidemic scale is equivalent to the actual situation; If the infection rate of the latent infected persons and asymptomatic infected persons is greater than or equal to 0.5 times of the infection rate of the symptomatic infected persons, the total number of cases will be greater than the baseline and the epidemic situation will break out in a large scale before the closure of the city. Except η, σ_1 and σ_2, other parameters are the same as shown in **Figure 3**.

cases in Jilin City will exceed 1 million, and the cumulative number of confirmed pathology is more than 5 times of the baseline (blue curve in **Figure 6(a)**). Once the infection rate of the latent period and asymptomatic infected persons reaches the level of the symptomatic infected persons, the epidemic situation begins to spread in a large scale, and the actual prevention and control measures are difficult to control the outbreak of the epidemic.

Figure 7 shows the development trend of the epidemic situation along with the infection rate of asymptomatic infected people when the latency is not considered. If asymptomatic and symptomatic infections have the same infection rate, the cumulative number of confirmed cases is close to 90,000 (dark blue curve in **Figure 7(a)**), and the cumulative number of asymptomatic cases is less than 80,000 (brown curve in **Figure 7(b)**), which is far less than the infectious situation in the incubation period (**Figure 5** and **Figure 6**). When the infection rate of asymptomatic infected persons is reduced by 1/4 compared with symptomatic infected persons ($\eta = 0.75$), the total number of infections in Jilin City

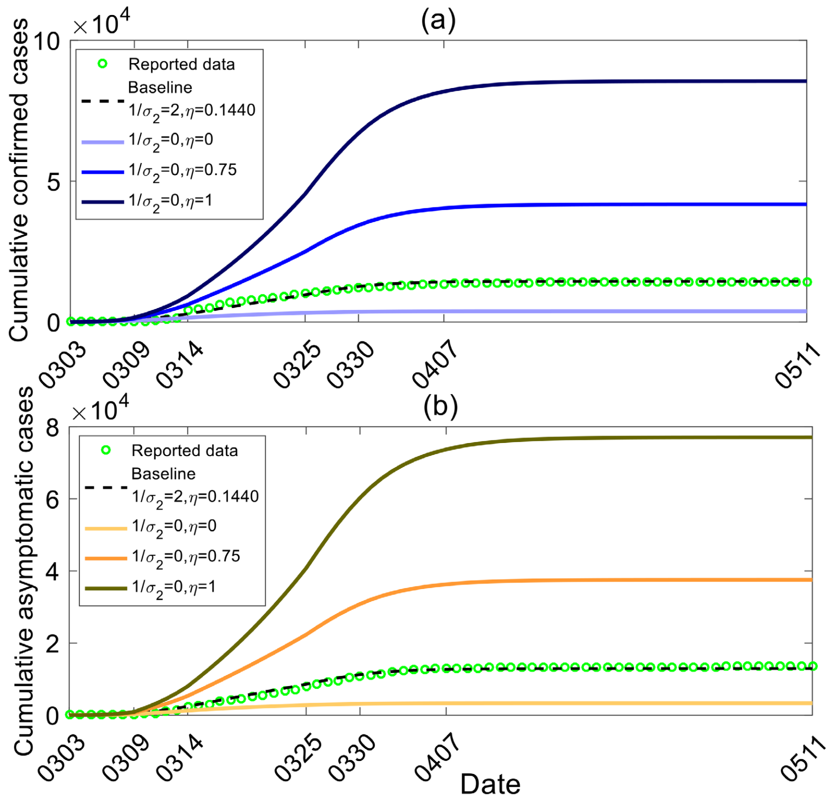

Figure 7. When the incubation period is not infectious, the infection rate of asymptomatic infected persons is affected. (a) Changes in the number of cumulative confirmed cases; (b) Changes in the number of cumulative asymptomatic cases. As shown in the figure, if the infection rate of asymptomatic infected persons is the same as that of symptomatic infected persons, the epidemic scale will exceed 100,000 cases; If the infection rate of asymptomatic infected persons is 0.75 times that of symptomatic infected persons, the total number of cases is about 3 times of the actual situation. If the incubation period and asymptomatic infected persons are not infectious, the epidemic will end about a month earlier. Except η, σ_1 and σ_2, other parameters are the same as shown in **Figure 3**.

does not exceed 80,000, and the cumulative number of confirmed cases is about 3 times the baseline situation (blue curve in **Figure 7(a)**). Assuming that the incubation period is not infectious, and asymptomatic infected people are not infectious, the total number of infected people will be less than 7000. The epidemic situation was effectively controlled on March 25 and ended about a month earlier.

4.4. Analysis of the Influence of the Proportion of Asymptomatic Infections

COVID-19 is constantly mutating, the toxicity of Omicron mutants is relatively weakened, and the coverage of COVID-19 vaccine is gradually increasing, as well as the implementation of epidemic prevention measures such as "dynamic zero COVID-19", many Omicron patients do not show clinical symptoms after infection. However, asymptomatic infected persons are infectious, which is also one of the characteristics of hidden transmission of Omicron epidemic. This section analyzes the impact of the proportion of asymptomatic infected people infected with Omicron virus on the overall epidemic scale.

As shown in **Figure 8**, if the infectious duration of incubation period is 2 days, the proportion of asymptomatic infected persons is less than the baseline ($1-\varepsilon=0.475$). The scale of the epidemic has increased significantly, and the number of new cases per day has been running at a high level for a long time. For example, when the proportion of asymptomatic infected people is 0.3 (0.175 less than the baseline, the dark blue curve in the figure), the cumulative number of cases in Jilin City will exceed 60,000; If the proportion of asymptomatic infected persons is 0, that is, all of them are symptomatic infected persons (black curve in the figure), the total number of cases is close to 80,000, the duration of the epidemic is significantly prolonged, and the epidemic can be effectively controlled in the first ten days of May. In comparison, if the proportion of asymptomatic infected persons expands, the number of infected persons will decrease significantly under the existing "dynamic zero COVID-19" measures. When the proportion of asymptomatic infections is 0.5 (blue curve in the figure), it is only 0.025 higher than the baseline situation, and the cumulative number of cases is significantly reduced compared with the actual situation; If the proportion of asymptomatic infected people is further increased to 0.7 (light blue curve in the figure), the final number of infected people is about 30% of the actual situation, effectively reducing the scale of infection. If it is assumed that all the infected people are asymptomatic (light blue dotted line in the figure), and the implementation of the "dynamic zero COVID-19" measures remains the same as the baseline situation, the Omicron epidemic situation can be controlled quickly, and the cumulative number of cases will not exceed 3000.

5. Conclusions

In this paper, an infectious disease dynamics model for the Omicron epidemic of COVID-19 pneumonia is established, and the real epidemic data is used to explore the factors affecting the recessive transmission of Omicron virus. In this study, a dynamic model was established for the Omicron epidemic situation in Jilin City from March to May 2022, and the values of key parameters at each stage were appropriately adjusted according to the implementation of vaccination, "dynamic zero COVID-19 policy" and other interventions in Jilin City. Based on the cumulative confirmed case data and cumulative asymptomatic case data from March 3 to April 7, the contact infection rate of Omicron was estimated by the least square method β, attenuation factor η, detection rate of symptomatic cases before closure α_{I1}, and asymptomatic cases α_{A1} and the initial value $E_1(0)$ of the exposed person. Then, based on the report data from April 8 to May 11, the model was validated. Finally, a numerical simulation experiment was carried out to evaluate the impact of infectious and asymptomatic infected people in the incubation period on the occult transmission of Omicron in Jilin City.

The study found that the latency infectivity and the infectivity of asymptomatic infected persons are important factors causing Omicron's covert transmission. According to the analysis in **Figure 4**, the longer the incubation period is infectious, the larger the final epidemic scale is, and the longer it takes to successfully control the epidemic. On this basis, it is assumed that the infectious persons in the incubation period and asymptomatic infected persons have the same infection rate, and their infection rates are numerically tested. If the incubation period lasts for 2 days (**Figure 5**), when the infection rate of infected persons and asymptomatic infected persons in the incubation period is lower than that of symptomatic infected persons, the number of infected cases can be controlled below the baseline; however, once the infection rate of both of them reaches half of those with symptoms, the final number of infected people will exceed one million; furthermore, it is assumed that the whole incubation period is infectious and the infection rate of both is equal to that of symptomatic infected persons (**Figure 6**), more than half of the city's population will be infected with COVID-19, seriously impacting the city's medical system. The existing epidemic prevention measures are not enough to prevent the rapid spread of the epidemic. Even if the virus is not infectious in the incubation period, if the infection rate of asymptomatic infected persons is 0.75 times that of symptomatic infected persons (**Figure 7**), the final infection scale of Omicron epidemic in Jilin City will also increase significantly, and more intensive "dynamic zero COVID-19" and other epidemic prevention measures are needed to effectively control the epidemic.

According to the study of the proportion of asymptomatic infected persons (**Figure 8**), if the proportion of asymptomatic infected persons is small, the high transmissibility of Omicron infected persons is dominant in the hidden transmission, and the number of new cases in a single day is at a high growth stage for a long time, and the epidemic lasts more than two months. If the proportion of asymptomatic infections is larger than that of symptomatic infections, and the

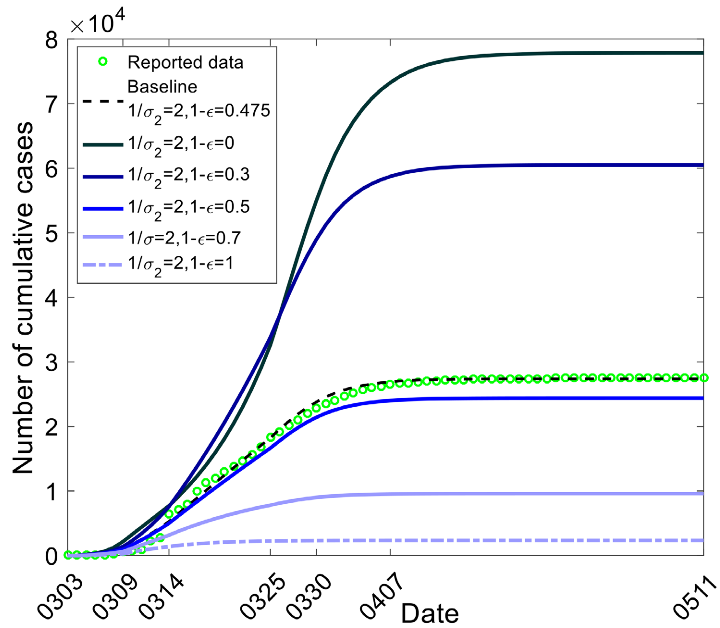

Figure 8. The influence of the proportion of asymptomatic infections on the cumulative number of cases. As shown in the figure, under the current implementation intensity of the "dynamic zero COVID-19 policy", the epidemic scale gradually decreases with the increase of the proportion of asymptomatic infected people; If the proportion of symptomatic infections and asymptomatic infections is the same, the total number of cases is about 3000 less than the actual situation. Except ε, other parameters are the same as shown in **Figure 3**.

"dynamic zero COVID-19" measures such as limiting social distance and multiple rounds of large-scale nucleic acid testing are strictly implemented, the cumulative number of cases will be significantly reduced, and the epidemic situation will be effectively controlled soon.

In this study, combined with **Figure 5** and **Figure 7**, we also found that with the extension of the incubation period, the time of large-scale outbreak of the epidemic was earlier, the peak value of the epidemic increased, and the end time was delayed. Similarly, the analysis in **Figure 8** also shows that when the incubation period infectious duration, infectious rate, and infectious rate of asymptomatic infected persons remain the same as the baseline situation, if the proportion of asymptomatic infected persons can be increased, the final scale of the epidemic can be effectively reduced. The emergence of these results, on the one hand, may be that the coverage of COVID-19 vaccine has expanded, and the enhanced vaccination rate has increased, which makes the body immune to Omicron mutant virus; On the other hand, due to multiple rounds of large-scale nucleic acid testing, the use of shelter hospitals, and the implementation of the "dynamic zero COVID-19" measures, infected cases were found and transferred in a timely manner, cutting off the spread of the epidemic in a timely manner. In the future, it may also be a way to prevent and control COVID-19 by developing COVID-19 specific drugs to reduce the infectivity in the incubation period and the infection rate of asymptomatic infected people, while increasing the proportion of asymptomatic infected people.

In conclusion, COVID-19 is still a global pandemic. With the constant variation of COVID-19, the occult transmission of COVID-19 has increased. Everyone should be the first responsible person for health, vaccinate and strengthen the needle as soon as possible, improve the autoimmune ability, establish an immune barrier, actively maintain social distance, consciously avoid gathering with multiple people, and strengthen personal health protection, which will play a key role in the prevention and control of the epidemic.

Funding

This work was partially supported by the Jilin Provincial Science and Technology Program (No. YDZJ202201ZYTS585, No. YDZJ202201ZYTS519), National Natural Science Foundation of P. R. China (No. 11401092), Jilin Industrial Technology Research and Development Project (No. 2022C047-2).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Hoffmann, M., Krüger, N., Schulz, S., *et al.* (2021) The Omicron Variant Is Highly Resistant against Antibody-Mediated Neutralization: Implications for Control of the COVID-19 Pandemic. *Cell*, **185**, 447-456.e11. https://doi.org/10.1101/2021.12.12.472286

[2] Elliott, P., Eales, O., Bodinier, B., *et al.* (2022) Dynamics of a National Omicron SARS-CoV-2 Epidemic during January 2022 in England. *Nature Communications*, **13**, 4500-4521. https://doi.org/10.1038/s41467-022-32121-6

[3] Liao, C.X., Wang, B., Lv, J., *et al.* (2022) Progress in Research of Etiology and Epidemiology of 2019-nCoV Omicron Variant. *Chinese Journal of Epidemiology*, **43**, 1691-1698.

[4] Gao, W.J. and Li, L.M. (2020) Advances on Presymptomatic or Asymptomatic Carrier Transmission of COVID-19. *Chinese Journal of Epidemiology*, **41**, 485-488.

[5] Zhu, W.W., Li, H., *et al.* (2020) The Differential Equation Model for the Novel Coronavirus Pneumonia by Time and Region. *Advances in Applied Mathematics*, **9**, 630-639. https://doi.org/10.12677/AAM.2020.95075

[6] Rothe, C., Schunk, M., Sothmann, P., *et al.* (2020) Transmission of 2019-nCoV Infection from an Asymptomatic Contact in Germany. *The New England Journal of Medicine*, **382**, 970-976. https://doi.org/10.1056/NEJMc2001468

[7] Su, W.T., Lei, S.Q., *et al.* (2020) Infectivity of 14 Patients with Latent COVID-19 Infection in Operating Room and Their Postoperative Outcomes. *Medical Journal of Wuhan University*, **41**, 702-705.

[8] Jansen, L., Tegomoh, B., Lange, K., *et al.* (2021) Investigation of a Sars-Cov-2 B.1.1.529 (Omicron) Variant Cluster-Nebraska, November-December 2021. *Morbidity and Mortality Weekly Report*, **70**, 1782. https://doi.org/10.15585/mmwr.mm705152e3

[9] Wu, Y., Liu, J., Liu, M., *et al.* (2022) Research of Epidemiologic Feature and Control of SARS-CoV-2 Omicron Subvariants BA.4 and BA.5. *Chinese General Practice*, **25**,

3721-3725.

[10] Lu, H., Stratton, C.W., Tang, Y.W., *et al.* (2020) Outbreak of Pneumonia of Unknown Etiology in Wuhan China: The Mystery and the Miracle. *Journal of Medical Virology*, **92**, 401-402. https://doi.org/10.1002/jmv.25678

[11] Eminetra (2021) WHO: Most Omicron Cases Are "Mild" or Asymptomatic, and Existing Vaccines Need to Provide Protection.

[12] Jiang, J.J., Gao, C., *et al.* (2022) Research Progress on Detection Methods of the Asymptomatic COVID-19 Infected Persons. *Journal of Hainan Medical University*, **28**, 161-165.

[13] Sun, T.Z. and Cui, J. (2021) Modeling the Asymptomatic Infections for COVID-19 Epidemic. *Acta Sciencetiarum Naturalium Universitatis Sunyatseni*, **60**, 103-110.

[14] Sun, T. and Weng, D. (2020) Estimating the Effects of Asymptomatic and Imported Patients on COVID-19 Epidemic Using Mathematical Modeling. *Journal of Medical Virology*, **92**, 1995-2003. https://doi.org/10.1002/jmv.25939

[15] Subramanian, R., He, Q.X. and Pascual, M. (2021) Quantifying Asymptomatic Infection and Transmission of COVID-19 in New York City Using Observed Cases, Serology, and Testing Capacity. *PNAS*, **118**, e2019716118. https://doi.org/10.1073/pnas.2019716118

[16] The Asymptomatic Infected Person Turns into a Confirmed Case. https://www.hunan.gov.cn/hnszf/xxgk/hygq/202110/t20211022_20843639.html

[17] Wu, Y. and Liu, M. (2022) The Incubation Period of COVID-19 Caused by Different SARS-CoV-2 Variants. *Chinese General Practice*, **25**, 1309-1313. https://doi.org/10.1001/jamanetworkopen.2022.28008

[18] van den Driessche, P. and Watmough, J. (2002) Reproduction Numbers and Sub-Threshold Endemic Equilibria for Compartmental Models of Disease Transmission. *Mathematical Biosciences*, **180**, 29-48. https://doi.org/10.1016/S0025-5564(02)00108-6

[19] Jilin Municipal Health Commission. http://wjw.jlcity.gov.cn

[20] Total Population of Jilin City. http://jl.gov.cn/sj/sjcx/ndbg/pcgb/202105/t20210524_8079109.html

[21] As of February 26, 2022, the Proportion of Whole Process Vaccination of COVID-19 Vaccine in China. http://www.nhc.gov.cn/xcs/fkdt/202202/8f49f6627a6540ce87511ac708ea7ad9.shtml

[22] Jilin Epidemic Prevention and Control Notice on March 3, 2022. http://wjw.jlcity.gov.cn/gsgg/202203/t20220303_1022831.html

[23] Kuhlmann, C., Mayer, C.K., Claassen, M., *et al.* (2022) Breakthrough Infections with SARS-CoV-2 Omicron despite mRNA Vaccine Booster Dose. *The Lancet*, **625**, 625-626. https://doi.org/10.1016/S0140-6736(22)00090-3

[24] Kiesha, P., Cook, A.R., Mark, J., *et al.* (2017) Projecting Social Contact Matrices in 152 Countries Using Contact Surveys and Demographic Data. *PLOS Computational Biology*, **13**, 1-21. https://doi.org/10.1371/journal.pcbi.1005697

[25] Zhao, S. and Chen, H. (2020) Modeling the Epidemic Dynamics and Control of COVID-19 Outbreak in China. *Quantitative Biology*, **8**, 11-19. https://doi.org/10.1007/s40484-020-0199-0

[26] Time of Isolation. http://www.nhc.gov.cn/xcs/xxgzbd/gzbd_index.shtml

[27] Cjlm, A. (2022) COVID-19 Will Continue but the End of the Pandemic Is Near. *The Lancet*, **399**, 261-270. https://doi.org/10.1016/S0140-6736(22)00100-3

[28] Aleta, A., Martín-Corral, D., Pastore y Piontti, A., *et al*. (2020) Modelling the Impact of Testing, Contact Tracing and Household Quarantine on Second Waves of COVID-19. *Nature Human Behaviour*, **4**, 964-971.
https://doi.org/10.1038/s41562-020-0931-9

[29] Li, Y., Hou, S., Zhang, Y., *et al*. (2021) The Effect of Travel Restrictions of Wuhan City against the COVID-19: A Modified SEIR Model Analysis. *Disaster Medicine and Public Health Preparedness*, **16**, 1431-1437. https://doi.org/10.1017/dmp.2021.5