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RESEARCH ARTICLE

Summaries, Analysis and Simulations of Recent COVID-19 Epidemic in Shanghai

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Abstract

After successfully preventing the spread of five wave COVID-19 epidemics in Shanghai, Omicron and Delta variants have been causing a surge COVID-19 infection in this city recently. Summaries, analysis and simulations for this wave epidemic are important issues. Using differential equations and real word data, this study modeling and simulates the recent COVID- 19 epidemic in Shanghai (March 1 ~ June 14, 2022), estimates transmission rates, recovery rates, and blocking rates to symptomatic and asymptomatic infections, and symptomatic (infected) individuals' death rates. Visual simulations predict the outcomes of this wave Shanghai epidemic. It compares with the recent mainland China COVID-19 epidemics (RMCE). The simulation results were in good agreement with the real word data at the end points of 13 investigated time-intervals (day 0 to day 75). The visual simulations imply that in the last month (day 76to day 105), the blocking rates to the symptomatic and asymptomatic infections almost reach 100%, the recovery rate of symptomatic and asymptomatic infections increase significantly, and the death rate of the infected individuals decrease significantly. The transmission rate of the symptomatic infections caused by the symptomatic individuals was much lower than the corresponding average transmission rate of the RMCE. The transmission rate of the asymptomatic infections caused by the symptomatic individuals was much higher than the first 75 day's average trans-mission rate of RMCE. The transmission rate of the symptomatic infections caused by the asymptomatic individuals was much lower than the first 75 day's average transmission rate and the last 30 days' average transmission rate of RMCE. The transmission rate to the asymptomatic infections caused by the asymptomatic individuals was much higher than the corresponding average transmission rate of RMCE. The average recovery rate of the symptomatic individuals was much lower than the corresponding average recovery rate of the symptomatic individuals of RMCE. The first 30 days' average recovery rate of the asymptomatic individuals was much lower than the first 30 days' average recovery rate of RMCE. The last 30 days' average recovery rate of the symptomatic individuals was higher than the last 30 days' average recovery rate of RMCE. The average low blocking rates to the symptomatic infections, the first 30 day's low blocking rates to the symptomatic infections, the low recovery rates of the symptomatic individuals, and the high transmission rate of the asymptomatic infections may be the reasons to cause the rapid spread of the recent Shanghai epidemic. The last month's strict prevention and control strategies, the high recovery rates of symptomatic and asymptomatic infections, and the low death rates have prevented the rapid spread of the sixth wave COVID-19 epidemic in Shanghai.

Keywords: *Shanghai COVID-19, infection transmission rates, infection blocking rates, recovery rates, death rates, modeling, simulations.*

Introduction

Omicron and Delta variants have been causing surge COVID-19infections in word wide. Many countries have experienced multiple outbreaks of the COVID-19 epidemics caused by the variants. As of 15 May 2022, over 518 million confirmed cases of COVID-19and over six million deaths have been reported globally [1].

After successfully preventing the spread of five wave COVID-19epidemics in Shanghai, Omicron variants have broken through the COVID-19 prevention of this city recently. Analysis and simulations for this wave epidemic are important issues.

Since the outbreak of COVID-19 in Wuhan China, a large number of articles on modeling and predictions of COVID-19 epidemics have been published (for examples see [2–10]). Recently, the author has used several simple differential equation models to describe successfully the dynamics of spreads of the COVID-19 epidemics in mainland China [11–14].

Using the differential equation model and real word data, this study modeling and simulates the recent sixth wave COVID-19 epidemic (March 1 to April 30, 2022) in Shanghai, estimates transmission rates, recovery rates, and blocking rates to symptomatic and asymptomatic infections, and symptomatic individuals' death rate. Visual simulations predict the outcomes of this wave Shanghai epidemic. It compares parallelly with the recent mainland China COVID-19 epidemics (RMCE).

Materials and Methods

The dataset of the Shanghai COVID-19 epidemic from March 1, 2022 to May 15, 2022 was collected and edited from the Health Commission of Shanghai official web- site [15]. Using the differential equation model stimulates the outcomes of the numbers of the current symptomatic individuals, the current asymptomatic individuals charged in medical observations, the cumulative recovered symptomatic individuals, and the cumulative asymptomatic individuals discharged from medical observations, and the number of the cumulative died symptomatic (infected) individuals. The equation parameters were determined by so-called minimization error square criterion described in references [11, 14]. Using virtual simulations estimates the outcomes of the spreads of the recent COVID-19 epidemic in Shanghai. Simulations and figure drawings were implemented via MATLAB programs.

Summaries, Analysis and Simulations of Recent Shanghai Epidemic

Summaries

On March 1 (denoted by day 0), one new symptomatic individual was reported, there were ten cumulative asymptomatic individuals charged in medical observations, and there was one asymptomatic individual discharged from the medical observations.

On March 9 (day 8), one new asymptomatic individual discharged from medical observations, there were 306 asymptomatic individuals charged in medical observations, and 23 current symptomatic individuals.

The first symptomatic individual's recovery day was on March 19 (day 18), 10 symptomatic individuals and 72 asymptomatic individuals re- covered on that day. There were 175 current symptomatic (hospitalized) individuals and 2099 asymptomatic individuals charged in the medical observations.

The asymptomatic infection turning point appeared on day 44 (April 14), there were 245812 asymptomatic individuals charged in medical observations, there were 12684 symptomatic individuals in hospitals. There were 2215 cumulative re-covered symptomatic individuals, and cumulative 43768 asymptomatic individuals discharged from the medical observations.

The symptomatic infection turning point appeared on day 52 (April 22), there were 25010 symptomatic individuals in hospitals and 223682 asymptomatic individuals charged in medical observations. There were 11965 cumulative recovered symptomatic individuals. There were 207012 cumulative asymptomatic individuals discharged from the medical observations. There were cumulative 48 died symptomatic individuals. The first 3died symptomatic individuals appeared on day 47.

On the investigated end day 75 (May 15) there were 4086 symptomatic individuals in hospitals and 39043 asymptomatic individuals charged in medical observations. There were 52137 cumulative recovered symptomatic individuals and 523859 cumulative asymptomatic individuals dis- charged from medical observations. There were 69 daily increased symptomatic individuals and 869 daily increased asymptomatic individuals. There were 575 cumulative died symptomatic individuals.

Simulations

In order to describe and understand the spread of an infectious disease, we need to set up a differential equation model to estimate the transmission rates and the blocking rates to symptomatic and asymptomatic infections. Assume that the process of the spread of an infectious disease are divided into m time intervals, representing different prevention control measures and treatment efficacy, respectively. Over the lth time interval, the model has the form (also see [11, 13, 14])

$$
\begin{cases}
\dfrac{dI}{dt} = \theta_1(l)(\beta_{11} I + \beta_{21} I_a)S - (\kappa(l) + \alpha(l))I & \text{(1a)} \\
\dfrac{dI_a}{dt} = \theta_2(l)(\beta_{12} I + \beta_{22} I_a)S - \kappa_a(l) I_a & \text{(1b)} \\
\dfrac{dI_r}{dt} = \kappa(l) I & \text{(1}c\text{)} \\
\dfrac{dI_{ra}}{dt} = \kappa_a(l) I_a & \text{(1}d\text{)} \\
\dfrac{dD}{dt} = \alpha(l) I & \text{(1}e\text{)}
\end{cases}
$$

where 1(l)=(1-1(l)) and2(l)=(1-2(l)) (l= 1, 2, m) represent the blocking rates to symptomatic and asymptomatic infections, respectively. I and Ia represent the numbers of current symptomatic individuals and current asymptomatic individuals charged in medical observations, respectively. Ir and Ira represent the numbers of current cumulative recovered symptomatic individuals and current cumulative asymptomatic individuals discharged from medical observations, respectively. D represents the number of current cumulative died symptomatic individuals. β12 and β22 represent the transmission rates of the symptomatic infections caused by symptomatic individuals and asymptomatic individuals, respectively. β12 and β22 represent the transmission rates of the asymptomatic infections caused by symptomatic individuals and the asymptomatic individuals, respectively. S represents susceptible population (can assume S = 1, see [11]). κ(l) and κa(l) represent the recovery rates of the symptomatic individuals and the asymptomatic individuals, respectively. α(l) represents the death rate of the symptomatic individuals.

For Shanghai sixth COVID-19 epidemic, it can be assumed that the transmissions are divided into 13-time intervals (see solid points in Figs. 1 and 2). We need to determine the parameters of equation (1) for = 1, 2, .. ., 13.Denote

t1 = 6, t2 = 10, t3 = 15, t4 = 20, t5 = 27,

t6 = 30, t7 = 37, t8 = 40, t9 = 47, t10 = 52,

t11 = 60, t12 = 67, t13 = 75.

[tl−1, tl] is the lth time interval. Denote Ic (tl) to be the number of the reported current symptomatic individuals, and Ica (tl)be the number of the reported current asymptomatic individuals charged in medical observations. Denote Icr (tl) to be the number of the reported current cumulative recovered symptomatic individuals, and Icra (tl) be the number of the reported current cumulative asymptomatic individuals discharged from medical observations. Dc(tl) be the number of the reported current cumulative died individuals. Using the minimization error square criterion:

$$
\begin{aligned}
\delta = \quad \min_{\beta_{ij}(l),\theta_1(l),\theta_2(l),\kappa(l),\kappa_a(l),\alpha(l)\in[0,1]} & ((I(t_l) - I_c(t_l))^2 \\
& + (I_a(t_l) - I_{ca}(t_l))^2 + (I_r(t_l) - I_{cr}(t_l))^2 \\
& + (I_{ra}(t_l) - I_{cra}(t_l))^2 + (D(t_l) - D_c(t_l))^2)^{1/2}
\end{aligned}
$$

determines the β ij(l)'s, κ (l)'s, κ a(l)'s, θ1(l)'s, θ2(l)'s, and α(l)'s. The calculated parameters are shown in Table 1. The corresponding simulation results of equation (1) are shown in Fig. 1 and Fig. 2

Observe that the simulation results of equation (1) were in good agreement with the data of the COVID-19 epidemics. At the end points (see solid dots in Figs. 1 and 2) of the 13 investigated time-interval [tl−1, tl] 's, the simulated numbers and the actual reported numbers were approximate the same (errors were less than one, respectively. See the solid blue lines, the red lines, and the black line in Fig. 1 and Fig. 2).

Results and Discussions

The equation parameters of the recent mainland COVID-19 epidemics (RMCE) are shown in Table 2 (see reference [16] amended version of reference [13]). From Table 1, Table 2, Fig. 1, and Fig. 2, it follows

The transmission rate β11 of the symptomatic infections caused by the symptomatic individuals was much lower than the first 75 day's (December 31, 2021 ~ March 16, 2022) average transmission rate β11 of RMCE (0.0350:0.1072), and was much lower than the last 75 day's (March 1 ~ May 15, 2022) average transmission rate β11 of RMCE (0.0350: 0.2602).

The transmission rate β12 of the asymptomatic infections caused by the symptomatic individuals was much higher than the first 75 days average transmission rate of RMCE (0.4890:0.0417), and was similar to the last 30 day's (April 16~ May 15) average transmission rate of RMCE (0.4890:0.5000).

The transmission rate β21 of the symptomatic infections caused by the asymptomatic individuals was much lower than the first 75 day's average transmission rate of the RMCE (0.0413:0.0637), and was still much lower than the last 30 day's average transmission rate of RMCE (0.0413:0.1).

The transmission rate β22 of the asymptomatic infections caused by the asymptomatic individuals was much higher than the first 75 day's corresponding average transmission rate of RMCE (0.4269:0.0128), and was much higher than the last 30 day's corresponding average transmission rate of RMCE (0.4269: 0.1000).

The last 30 days' average blocking rate of Θ1(l)′s to the symptomatic infections was lower than the last 30 days' average blocking rate of RMCE (82.77%:93.83%).

The last 30 days' average blocking rate of Θ2(l)′s to the asymptomatic infections was much higher than the last 30 days' average blocking rate of RMCE (87.61%:65.83%).

However, the first 30 days' average blocking rate to the asymptomatic infections was much lower than the first 30 days' average blocking rate of RMCE (41.86%:53.88%).

The average recovery rate(κ(l)′s) of the symptomatic individuals was much lower than the corresponding average recovery rate of the symptomatic individuals of RMCE (0.0512:0.0636).

The last two weeks' (May 1 May 15) average recovery rate (κ(l)′s) of the symptomatic individuals was similar to the one of the corresponding RMCE (0.1412:0.1323).

The first 30 days' average recovery rate (κa (l)′s) of the asymptomatic individuals was much lower than the first 30 days' average recovery rate (κa (l)′s) of RMCE (0.01026:0.01996). The last 30 days' average recovery rate (κa(l)′s) of the asymptomatic individuals was higher than the last 30 days' average recovery rate of RMCE (0.10066:0.09149).

Virtual simulations

Assume that after day 75 (May 15, 2022), it still keeps the blocking rates Θ1(13) and Θ2(13), the recovery rates κ (13), κa (13), and the death rate α (13) until day 105 (June 14, 2022). The simulation results of equation

(1) are shown in Fig. 1 and Fig. 2 by cyan lines, magenta lines, dot blue line, respectively. Calculated results show that on day 105, the numbers of the current symptomatic and asymptomatic individuals reach about 409 individuals (see cyan solid dot in Fig. 1) and 2460 individuals (see magenta dot in Fig. 1), respectively. The numbers of the cumulative recovered symptomatic individuals and cumulative asymptomatic individuals discharged in medical observations reach about 57152 individuals (see cyan solid dot in Fig. 2), and 572084 individuals (see magenta dot in Fig. 2), respectively. The number of deaths symptomatic individuals reach about 619 individuals (see blue dot in Fig. 2).

Furthermore, assume that after day 75, it still keeps the recovery rates κ (11), κa (11), and the death rate α (11) but increases the blocking rates (Θ1(l), Θ2(l))

≡ (100%, 100%) until day 105. The simulation results of equation (1) are shown in Fig. 1 and Fig. 2 by green lines yellow lines, and dot red line, respectively. Calculated results show that on day 105, the numbers of the current symptomatic and the asymptomatic individuals reduce about 187 (see green solid dot in Fig. 1) and 1005 (see yellow solid dot in Fig. 1), respectively. The numbers of the cumulative recovered symptomatic individuals and cumulative asymptomatic individuals discharged from medical observations reach about 56002 (see green solid dot in Fig. 2) and 561897 (see yellow solid dot in Fig. 2), respectively. The number of death symptomatic individuals reduce to about 609.

Practically on day 105, the numbers of the current symptomatic and asymptomatic individuals, the cumulative recovered symptomatic individuals and asymptomatic individuals, and the death symptomatic individuals reach 137, 57009, 57729 and 588, respectively. It implies that during days 76 ~ 105, the average blocking rates to the symptomatic and the asymptomatic infections reached 100%, and the average recovery rates of the current symptomatic individuals and the current asymptomatic individuals (even data are not available) increased significantly, the average death rate of the death individuals decreased significantly.

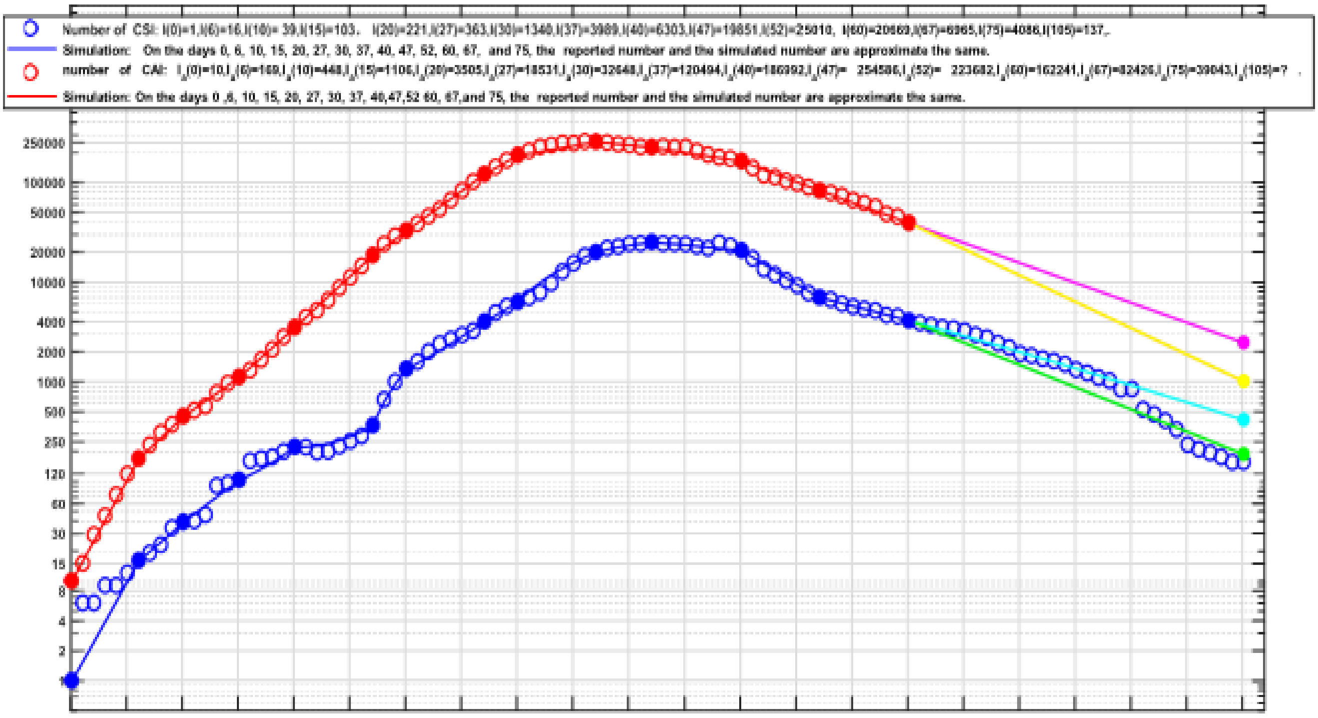

Fig 1: Blue circles: outcome of the number of the current symptomatic individuals (CSI), blue line: out- come of the corresponding simulation of equation (1). Red circles: outcome of the number of the current asymptomatic individuals (CAI) charged in medical observations, red line: outcome of the corresponding simulation of equation (1). The lines colored by cyan, magenta, green and yellow correspond the virtual simulation results of equation (1). See Section visual simulations for details.

Table 1: Equation parameters of the COVID-19 epidemic in Shanghai during 2022.3.1- 2022.5.15. $\beta_{11} = 0.035$, $\beta_{12} = 0.489$, $\beta_{21} = 0.0413$, $\beta_{22} = 0.4269$.

I	Days	Dates	Θ1(*I*)	Θ2(*I*)	κ(*I*)	κa(*I*)	α(*I*)
1	0-6	3.01-3.07	0%	0%	0	0.00288000	0
2	7-10	3.08-3.11	55.25%	48.06%	0	0.00090000	0
3	11-15	3.11-3.15	60.3%	61.18%	0	0.00220000	0
4	16-20	3.16-3.20	70 %	44.953%	0.025470	0.02445000	0
5	21-27	3.21-3.27	90.11%	42.18741%	0.067400	0.01851900	0
6	28-30	3.28-3.30	67.218%	54.78091%	0.025610	0.011209	0
7	31-37	3.31-4.07	85.797%	56.1531%	0.011920	0.0083930	0
8	38-40	4.08-4.10	84.775%	64.6838%	0.040690	0.0100525	0
9	41-47	4.11-4.17	74.642%	78.45215%	0.036238	0.0540004	0.0000330
10	48-52	4.18-4.22	75.807%	85.3491 %	0.06766	0.0952666	0.0003960
11	53-60	4.23-4.30	77.0718%	88.20378%	0.108624	0.09744147	0.0020400
12	61-67	5.01-5.07	93.989%	92.07175%	0.1804539	0.1346101	0.0012995
13	68-75	5.08-5.15	92.344%	93.9226%	0.101955	0.121974	0.0008990

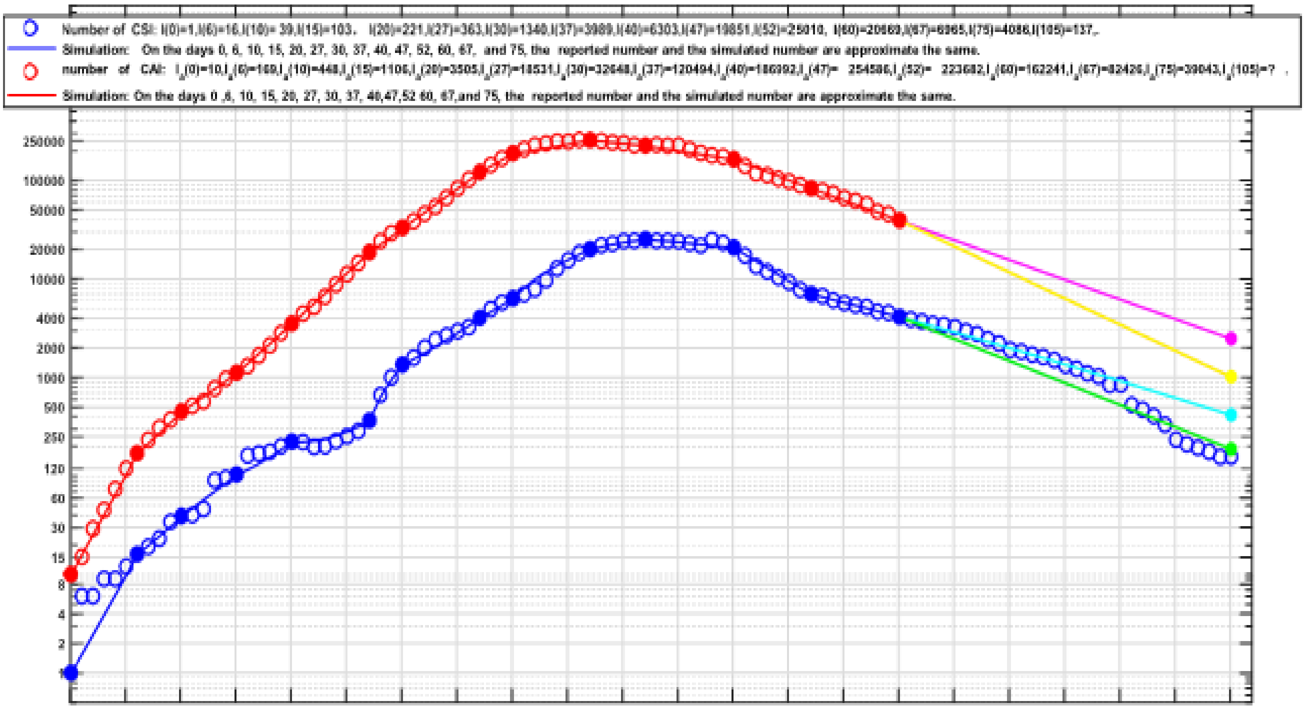

Fig 2: Blue circles: outcome of the number of the current cumulative recovered symptomatic individuals (CCSI), blue line: outcome of the corresponding simulations of equation (1). Red circles: outcome of the number of the current cumulative asymptomatic individuals (CCAI) discharged in medical medical observations, red line: outcome of the corresponding simulations of equation (1). Black circles: outcome of the number of the current cumulative died individuals (CCAI). Black line: outcome of the corresponding simulations of equation (1). The lines colored by cyan, magenta, green and yellow correspond to the virtual simulation results of equation (1). The dotted lines colored by blue and red corresponding to virtual simulation results for the cumulative died individuals. See Section visual simulations for details.

Table 2: Equation parameters of the COVID-19epidemics in mainland China during 2021.12.31- 2022.5.15 [16]

l	**Days**	***β*11(*l*)**	***β*21(*l*)**	***β*12(*l*)**	***β*22(*l*)**	**Θ1(*l*)**	**Θ2(*l*)**	***κ*(*l*)**	***κ*a(*l*)**	***α*(*l*)**
1	0-4	0.049056	0.072052	0.002102	0.094068	0%	0%	0.017296	0.0310702	0
2	5-11	0.058990	0.072052	0.000100	0.000100	10.6%	99%	0.045215	0.0313170	0
3	12-20	0.056600	0.072052	0.002102	0.000094	25%	99%	0.053450	0.0003170	0
4	21-30	0.044400	0.072052	0.004100	0.003990	49.84%	17.5%	0.073030	0.0171500	0
5	31-43	0.077340	0.071000	0.002500	0.003	51.02%	72.5%	0.065000	0.05645	0
6	44-48	0.124800	0.071000	0.025000	0.003	51.15%	71.6%	0.059440	0.04670	0
7	49-55	0.124800	0.071000	0.020900	0.003	25.04%	72.377%	0.031460	0.03130	0
8	56-64	0.124900	0.017800	0.059000	0.003	31.98%	70.29%	0.031550	0.01290	0
9	65-70	0.125200	0.017800	0.141000	0.009	26.02%	21.07%	0.032950	0.00319	0
10	71-77	0.287270	0.1	0.160680	0.009	43.839%	26.337%	0.024098	0.004689	0.000027
11	78-82	0.287270	0.1	0.160680	0.009	73.264%	37.524%	0.028489	0.018943	0
12	83-90	0.287270	0.1	0.294230	0.009	87.602%	39.037%	0.039845	0.0183963	0
13	91-100	0.287200	0.1	0.500010	0.1	92.89%	28.441%	0.087194	0.0164510	0
14	101-107	0.287200	0.1	0.5	0.1	91.382%	40.774%	0.071904	0.0534810	0.000017
15	108-110	0.287200	0.1	0.500010	0.1	91.692%	60.786%	0.071146	0.0875565	0.000242
16	111-115	0.287270	0.1	0.5	0.1	93.337%	56.636%	0.092125	0.0809330	0.001099
17	116-120	0.287270	0.1	0.5	0.1	92.093%	76.839%	0.1199341	0.1000628	0.001758
18	121-127	0.287270	0.1	0.5	0.1	97.57%	77.476%	0.1650770	0.1232887	0.001060
19	128-135	0.287270	0.1	0.5	0.1	96.878%	82.469%	0.0995065	0	

Conclusion

The main contributions of this paper are summarized as follows:

- It is the first time to summary and analyze the sixth Shanghai COVID-19 epidemic, and compare with the recent mainland China COVID-19 epidemics (RMCE).
- It uses model (1) to simulate the dynamics of the sixth Shanghai COVID-19 epidemic. The simulation results were approximate the same as the reported practical data at the end points of the investigated time intervals.
- The first 30 day's low blocking rates to the symptomatic infections, the low recovery rates of the symptomatic individuals, and the high transmission rate of the asymptomatic infections may be the reasons to cause the rapid spread of the Shanghai epidemic in the first two months.
- It is not wise strategy to withdraw all prevention and control measures before no new COVID-19 infected cases are reported. 100% blocking rate to COVID-19 infection spread is key strategies for early clearance or reduction of epidemic spread [11–14].
- The administration should at least maintain the prevention and control measures implemented 7 days after reaching the infection turning point of the numbers of the current hospitalized symptomatic individuals and the current asymptomatic

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Conflict of Interest

The author declares no potential conflict of interest.

Data availability statement

Data are available on reasonable request. Please email the author (13501029489@163.com).

Ethical Statement

Not applicable/No human participants included

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