COVID-19 Spread Model in Hubei Province

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Abstract. This article provides prognosis of COVID-19 spread in Chinese province Hubei from January 22 2020 using SIR model. To compare the results with real data, we use statistics obtained by Johns Hopkins University.

1. Introduction

Pandemics are large-scale outbreaks of infectious disease that can greatly increase morbidity and mortality over a wide geographic area and cause significant economic, social, and political disruption. Evidence suggests that the likelihood of pandemics has increased over the past century because of increased global travel and integration, urbanization, changes in land use, and greater exploitation of the natural environment [1]. First detected in Wuhan, China, in December 2019, the Coronavirus Disease (COVID-19) had rapidly spread by late January 2020 to all Chinese provinces and many other countries. On January 30, 2020, the World Health Organization (WHO) issued a Public Health Emergency of International Concern (PHEIC) and on March 11th, the WHO declared a pandemic for the COVID-19. By April 6, 2020, the virus had affected more than 1,200,000 people and caused the deaths of 70,000 in more than 180 countries [2].

It is critically important to predict count of infected people and death cases through the pandemic. There are plenty models to use them for different tasks [3-26]. In our work we apply standard susceptible-infected-recovered (SIR) model that has more advantages and provides better results than susceptible-infected (SI) model [27]. A feature of diseases such as influenza and those caused by coronaviruses such as SARS, MERS and COVID-19, is that individuals practice social distancing to reduce the contact rate [28], so quarantine factor is implemented in our model, providing more flexibility and letting to control peak of disease. In the SIR model individuals are classified as Susceptibles (S), Infected (I) or Recovered (R), and that the only possible transitions are S → I (new infection) and I → R (recovery with permanent immunity). Also that model does not consider new births or deaths (other than because of the disease), so it is appropriate for an epidemic that develops on a time-scale much faster than demographic turn-around [29].

Recent researches show that Covid-19 activity hardly disappears completely [30]. Even with very strong restrictions in Wuhan, it stayed on an intermediate level for several days, and then went down to almost zero. To describe the global Covid-19 spread, Johns Hopkins University established database of cumulated numbers of confirmed cases, deaths and recoveries, for each day and each
Main goal of this page is to provide results of modeling spread of COVID-19 in China, Hubei and match them with already collected data.

2. COVID-19

Coronavirus was first detected in humans in 1965 with acute respiratory viral infections and did not cause further interest. Currently, 40 species of this RNA-containing virus are known, 7 of them are pathogenic for humans. The most difficult are three varieties:

- SARS-CoV - the causative agent of SARS caused an epidemic in 2002-2003. at the same time 8000 people fell ill 800 deaths amounted to 10%.
- MERS-CoV has been registered since 2012. During the outbreak of 2015, 183 died.
- SARS-CoV 2 virus pathogen COVID-09 is registered since 2019.

HKU1, NL63,2 29E and OS 43 circulate, constantly without causing severe tenia, occupy about 12% in the etiological structure of acute respiratory viral infections.

Coronavirus infection COVID-19 (abbreviation for the COronaVIrus Disease 2019), previously coronavirus infection 2019-nCoV is a potentially severe acute respiratory infection caused by the SARS-CoV-2 coronavirus (2019-nCoV). It is a dangerous disease that can occur both in the form of an acute respiratory viral infection of a mild course and in a severe form, specific complications of which may include viral pneumonia, which entails acute respiratory distress syndrome or respiratory failure with a risk of death. The most common symptoms of the disease include fever, fatigue, and dry cough [32].

No specific antiviral treatment or prophylaxis drugs are yet available against the disease. In most cases (approximately 80%), no specific treatment is required, and recovery takes place on its own. Severe forms of the disease are more likely to develop in older people and in people with certain concomitant illnesses, including asthma, diabetes and heart disease. In severe cases, funds are used to maintain the functions of vital organs.

The disease is caused by a new virus, people do not have acquired immunity to it, therefore people of all age categories are susceptible to infection. The virus spreads by airborne droplets through inhalation of droplets of the virus sprayed in the air during coughing or sneezing, as well as through the spread of the virus on the surface and then into the eyes, nose or mouth. Effective preventive measures include frequent hand washing and compliance with the rules of respiratory hygiene [33].

In approximately 15% of cases, the disease proceeds in severe form with the need for oxygen therapy, in another 5% the condition of patients is critical. As a whole, on April 8, the mortality rate of the disease is estimated at about 5.85%, however, a rough estimate of mortality, taking into account asymptomatic and mild unaccounted cases of infection, may be at the level of 0.125%. According to the analysis of data on 1099 patients as of February 28, 2020, 91.1% of patients with COVID-19 were diagnosed with pneumonia. Performance may change over time [34].

The CoVID09 pandemic began with the discovery in December 2019 in Wuhan, Hubei, China of the first cases of pneumonia of unknown origin in local residents associated with the local animal and seafood market. On December 31, 2019, Chinese authorities informed the World Health Organization (WHO) of an outbreak of pneumonia of unknown etiology. Since January 22, Wuhan has been quarantined. The virus was subsequently recorded in all administrative entities of China.

In connection with the epidemic, the World Health Organization (WHO) declared an emergency of international importance in the field of health. Risks at the global level are rated as very high. The situation is developing rapidly, the number of sick and dead is increasing daily. Various scientific and clinical studies are underway. Many scientific and medical publishers and organizations have signed up for a free access and exchange of information related to the new disease.

On March 11, the spread of the virus was recognized as a pandemic. This epidemic is the first pandemic in human history that can be brought under control. It makes sense for governments to prepare lists of trained personnel who are able to take control of the situation, as well as lists of medicines, personal protective equipment, supplies and equipment needed for treatment. WHO calls
on countries to prepare hospitals, protect medical workers, and decide on the need for social exclusion measures.

As of April 16, 2,084,049 cases of infection were confirmed in 210 countries and territories, 134,669 deaths, 515,147 recovered, mortality from all registered completed cases of infection is 21%. The regions most affected by the pandemic in terms of the number of cases are the USA, Europe (Italy, Spain, Germany, France, Great Britain), China, Iran. The number of cases of infection can be greatly underestimated - first of all, due to those who have a mild illness. Some countries (for example, Italy and Switzerland) have a policy of not testing people who have only minor symptoms of the disease [35].

There is no specific antiviral therapy against SARS-CoV-2 virus and there is no evidence of effective immunomodulating. Antibiotics against viruses are useless and are not used in treatment. However, they can be prescribed if a bacterial secondary infection is detected. Basically, patients receive symptomatic and supportive therapy. In severe cases, treatment is aimed at maintaining the vital functions of the organs.

COVID-19 and influenza are similar in clinical manifestations of the disease: infections can be asymptomatic, mild or severe, including with a risk of death. Both diseases can cause pneumonia. The viruses that cause both diseases are also transmitted in a similar way: by contact, by airborne droplets, in particular through an aerosol, and through objects or surfaces.

However, the flu has a shorter incubation period (about 3 days), due to which it spreads faster. Moreover, unlike COVID-19, the transmission of influenza viruses occurs to a greater extent until the onset of symptoms. In the case of influenza, the spread is mainly due to children, while COVID-19 affects mainly adults, from whom children are already infected, based on an analysis of cases of diseases among families in China.

With influenza, the percentage of severe and critical cases of the disease is also less. Mortality due to COVID-19 is probably higher than in the case of seasonal flu, in which it is 0.1%. In the case of influenza, children and older people are most at risk, while in the case of COVID-19, current data show that the risk is greater among older people and people with chronic diseases [36].

According to virologists from the UK and Germany, a pandemic can last from one to two years. American epidemiologist professor Justin Lelsler believes that COVID-19, on the one hand, will not disappear, and on the other, it will not become an obstacle to the normalization of life, which will come about thanks to vaccines or due to the population gaining immunity in a natural way.

Employees at Johns Hopkins University conducted a computer simulation of the development of the pandemic, based on which a forecast was compiled for different countries, provided that the anti-epidemic measures are maintained or introduced. According to this forecast, quarantine measures in most countries can be canceled no earlier than August – September 2020.

Morgan Stanley analysts analyzed the situation and released a report for the United States, in which the first wave of patients will go to work in early June 2020, the second in August, and schools will open by October 2020. They predict the emergence of an experimental vaccine and its use for vaccinating medical personnel in November 2020, and mass vaccination in the spring of 2021.

Of great importance in understanding the mechanisms of the spread of the disease is the stability of the virus in the environment. So on different surfaces it is different and depends on temperature and humidity at +22 °C and humidity of 65%. on paper, the virus is destroyed in 3 hours, on banknotes in 4 days, on wood and clothes in 2 days, on glass in 4 days, on metal and plastic in 7 days. Testing was carried out by PCR test, that is, it was not the time required to deactivate the virus, but its complete destruction — before the destruction of all copies of its RNA. In the external environment, coronoviruses are usually inactivated from surfaces at +33 °C in 16 hours, at +56 °C in 10 minutes.

For the pathogen COVID-19, special studies have established that it is stable at a temperature of +4 °C. At this temperature, the virus is destroyed very slowly and even after 14 days the PCR test detects the whole genome of the virus. At room temperature around +22 °C, the PCR test detects the virus according to the genome within a week, and after 14 days the virus is completely destroyed to RNA. The sensitivity of coronaviruses to ultraviolet radiation from the Sun and an increase in temperature
makes them seasonal diseases, but a significant factor is the combination of temperature with humidity and the angle of incidence of sunlight, which allows you to specify cities with an unfavorable climate where a surge in the incidence of coronaviruses can be expected. A study by American scientists found that large cities with a climate conducive to the spread of coronaviruses include: London, New York, Warsaw, Kiev, Berlin, Prague. In these cities, infectious disease specialists predict a surge in the COVID-19 pandemic due to favorable climatic conditions for coronaviruses.

All means of processing the hands within 30 seconds destroyed the virus below the detection threshold. Thus, the use of hand sanitizers is effective against coronaviruses. WHO recommends the use of alcohol-containing antiseptics against coronaviruses. Also, WHO notes that thorough washing of hands with soap is effective against coronaviruses, since viruses are effectively washed off the skin mechanically [37].

COVID-19 is anthropozoonosis (only in 1% of cases is transmitted from animals to humans)

The transmission mechanism is aerogenic (through air); transmission methods airborne, airborne dust, contact-household, possibly fecal-oral (6% found in feces, 6% in urine) Infectious rate 2-3

Coronavirus SARS-CoV-2 has the largest non-segmented RNA, that is, it has the most complicated structure of all known viruses. The corona-shaped teeth on its surface carry fake (false) proteins at the end, which are captured by the receptors for angiotensin-converting enzyme 2 on the wall of the target cell and through the transmembrane protein penetrate into the cell, the virus replicates and exocytoses it, accompanied by cell death. The mechanism is the same as that of SARS-CoV.

The incubation period is usually about 5 days, but can last from 2 to 14 days in rare cases, up to 24. The disease becomes contagious before the onset of symptoms. A distinctive feature of the current pandemic, which makes it difficult to combat it, is a long incubation period. Another adverse feature is the large number of asymptomatic patients, that is, individuals who, having become infected with a coronavirus infection, do not show clinical manifestations, although they are able to infect others [13].

The main symptoms are [39]: fever - 89%, cough-68%, diarrhea-4%, vomiting-5%.

Complications:

Among the complications, viral pneumonia is leading. Deterioration in viral pneumonia is proceeding rapidly, and many patients have already developed respiratory failure within 24 hours, requiring immediate respiratory support with mechanical ventilation. Quickly started treatment helps to alleviate the severity of the disease.

Mortality among completed cases is 20%. Death occurs against the background of viral lung damage and the development of acute respiratory distress syndrome. Effective etiotropic treatment to date does not exist. Non-specific prophylaxis. The vaccine is being developed and the probable time of occurrence is autumn 2020.

3. The SIR model

In this work we use standard SIR model with some changes.

\[
\begin{align*}
\frac{dS}{dt} &= -\alpha SI - u, \\
\frac{dK}{dt} &= u, \\
\frac{dI}{dt} &= \alpha SI - bI, \\
\frac{dR}{dt} &= \delta bI, \\
\frac{dP}{dt} &= (1 - \delta) bI,
\end{align*}
\]

S(t) – susceptible population, K(t) - quarantined population, I(t) – infected population, R(t) – recovered population, P(t) – number of death cases, \( \delta \) - proportion of survivors of the acute phase of the disease, \( \alpha \) - empirical incidence rate, \( u \) – number of people quarantined per day, \( b \) - coefficient inverse to the characteristic length of the disease.

One day was taken as the unit of time and one thousand people as unit of measurement of quantities. As initial conditions we use data for January 22: \( S_0 = 58000, I_0 = 0.444, P_0 = 0.017, K_0 = 0, R_0 = 0.028 \)

4. Results

The following are the simulation results with the selected parameters.
$a = 0.0000035$
$b = 1/20$
$\delta = 0.982$
$u = 660$

$\alpha = 0.0000035$
$\beta = 1/20$
$\delta = 0.982$
$\mu = 660$

$\alpha = 0.000004$
$\beta = 1/20$
$\delta = 0.982$
$\mu = 800$
\[ a = 0.000004 \]
\[ b = \frac{1}{20} \]
\[ \delta = 0.982 \]
\[ u = 800 \]

\[ a = 0.000005 \]
\[ b = \frac{1}{20} \]
\[ \delta = 0.976 \]
\[ u = 1100 \]
\[ a = 0.0000052 \]
\[ b = 1/20 \]
\[ \delta = 0.97 \]
\[ u = 1200 \]

5. Conclusion
In this work we constructed model that predicts spread of COVID-19 from January 22 in Hubei. As it may be seen from the graphs peak of disease is already over. However, it will totally disappear not earlier than start of June. It shows that even province where quarantine was implemented first is still in danger. Also it is worth mentioning that the number of deaths almost stopped growing. It shows how quarantine factor may be important in large pandemics such as COVID-19.

6. References
[1] Madhav N 2017 Disease Control Priorities: Improving Health and Reducing Poverty. 3rd edition.
[2] Liu D, Clemente L, Poirier C, Ding X, Chinazzi M, Davis J, Vespignani A, Santillana M A machine learning methodology for real-time forecasting of the 2019-2020 COVID-19 outbreak using Internet searches, news alerts, and estimates from mechanistic models
[3] Malafeyev O, Redinskikh N, Zaitseva I, Smirnova T, Kolesov D 2019 Model of information multi-stage process in structured system
[4] Pichugin Y, Malafeyev O, Zaitseva I 2019 Mathematical model for identifying the leading
geopolitical actor by the principal component analysis

[5] Zaitseva I, Malafeyev O, Shevchenko E 2019 Modeling the optimal decision-making strategy of an organization using mathematical methods

[6] Zaitseva I, Malafeyev O, Kostyukov K 2020 Dynamic programming method in the tasks of optimal labor capital distribution programs

[7] Malafeyev O and Saifullina D and Ivaniukovich G and Marakhov V and Zaytseva I 2017 The model of multi-agent interaction in a transportation problem with a corruption component (AIP Conference Proceedings) http://dx.doi.org/10.1063/1.4992360

[8] Zaitseva I and Bogdanova S and Malafeyev O and Kolesov D and Marencukh Y 2019 Competitive Mechanism for the Distribution of Labor Resources in the Transport Objective Journal of Physics: Conference Series https://doi.org/10.1088/1742-6596/1172/1/012089

[9] Malafeyev O and Lakhina J and Redinskikh N and Smirnova T and Smirnov N and Zaitseva I 2019 A mathematical model of production facilities locatio Journal of Physics: Conference Series, https://doi.org/10.1088/1742-6596/1172/1/012090

[10] Malafeyev O and Onishenko V and Zubov A and Bondarenko L and Orlov V and Petrova V and Kirjanen A and Zaitseva I 2019 Optimal location problem in the transportation network as an investment project: A numerical method AIP Conference Proceedings https://doi.org/10.1063/1.5114525

[11] Zaitseva I and Malafeyov O and Kolesin I and Ermakova A and Shlaev D 2018 Modeling of the labour force redistribution in investment projects with account of their delay (Proc. ICPCSI) p 68-70

[12] Malafeyev O and Awasthi A and Zaitseva I and Rezenkov D and Bogdanova S 2018 A dynamic model of functioning of a bank (AIP Conference Proceedings) http://doi.org/10.1063/1.5032004

[13] Solving a dynamic assignment problem in the socio-economic system

[14] Malafeev O A 1974 Equilibrium situations in dynamic games (Cybernetics and System Analysys) 10(3) 504-513

[15] Malafeyev O A and Nemnyugin S A and Ivaniukovich G A 2015 Stochastic models of social-economic dynamics SCP Proceedings 483 – 485

[16] Malafeyev O and Farvazov K and Zenovich O and Zaitseva I and Kostyukov K and Svechinskaya T 2018 Geopolitical model of investment power station construction project implementation AIP Conference Proceedings https://doi.org/10.1063/1.5032028

[17] Neverova E G and Malafyef O A 2015 A model of interaction between anticorruption authority and corruption groups AIP Conference Proceedings http://dx.doi.org/10.1063/1.4912671

[18] Malafeyev O and Rylow D and Zaitseva I and Zelenkovskii P and Popova M and Novozhilova L 2017 Game-theoretic model of dispersed material drying process AIP Conference Proceedings http://dx.doi.org/10.1063/1.4990216

[19] Malafeyev O A and Rylow D and Zaitseva I and Ermakova A and Shlaev D 2018 Multistage voting model with alternative elimination AIP Conference Proceedings http://doi.org/10.1063/1.5043756

[20] Vlasov M A and Glebov V V and Malafeyev O A and Novichkov D N 1986 Experimental study of a electron beam in drift space Soviet journal of communications technology &amp electronics 31(3) 145-149

[21] Malafeyev O A and Redinskikh N D 2016 Stochastic analysis of the dynamics of corrupt hybrid networks, Proceedings of International Conference &quot;Stability and Oscillations of Nonlinear Control Systems (Pyatnitskiy’s Conference) http://dx.doi.org/10.1109/STAB.2016.7541208

[22] Kolokoltsov V N and Malafayev O A 2018 Corruption and botnet defense: a mean field game approach International Journal of Game Theory 47(3) 977-999

[23] Malafeyev O A and Redinskikh N D 2018 Compromise solution in the problem of change state control for the material body exposed to the external medium AIP Conference Proceedings
https://doi.org/10.1063/1.5034734
[24] Malafeyev O A and Nemnyugin S A and Rylow D and Kolpak E P and Awasthi A 2017 Corruption dynamics model AIP Conference Proceedings http://dx.doi.org/10.1063/1.4992358
[25] Kolesin I and Malafeyev O and Andreeva M and Ivanukovich G 2017 Corruption: Taking into account the psychological mimicry of officials, AIP Conference Proceedings http://dx.doi.org/10.1063/1.4992359
[26] Kirjanen A I and Malafeyev O A and Redinskikh N D 2017 Developing industries in cooperative interaction: Equilibrium and stability in processes with lag Statistics Optimization and Information Computing 5(4) 341-347
[27] Chong Qi1, Daniel Karlsson, Karl Sallmen, Ramon Wyss 2020 Model studies on the COVID-19 pandemic in Sweden
[28] Rose Baker 2020 Reactive Social distancing in a SIR model of epidemics such as COVID-19
[29] Andrea Pugliese, Mattia Sensi 2020 A geometric analysis of the SIR, SIRS and SIRWS epidemiological models
[30] Christoph Bandt 2020 Transparent Covid-19 prediction
[31] 2020 Johns Hopkins University Coronavirus covid-19 global cases by the center for systems science and engineering https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html
[32] World Health Organization 2020 Statement on the meeting of the international health regulations (2005) emergency committee regarding the outbreak of novel coronavirus (2019-ncov)
[33] World Health Organization, 2020 “Coronavirus disease (covid-2019) situation reports - 62”
[34] Gazzetta Ufficiale della Repubblica Italiana, 2020 “Further implementing provisions of the d.l. 6/2020, containing urgent measures regarding the containment and management of the epidemiological emergency of covid-19, applicable on the whole italian national territory”
[35] World Health Organization, “Report of the who-china joint mission on coronavirus disease 2019 (covid-19)”
[36] Coronavirus Disease 2019 vs. the Flu John Hopkins Medicine 2020
[37] David L. Heymann, Nahoko Shindo. 2020 COVID-19: what is next for public health?
[38] Symptoms 2019 Novel Coronavirus, Wuhan, China. Centers For Disease Control and Prevention (CDC)
[39] Wei-jie Guan, Zheng-yi Ni, Yu Hu, Wen-hua Liang, Chun-quan Ou. 2020 Clinical Characteristics of Coronavirus Disease 2019 in China New England Journal of Medicine

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