Analyzing Countermeasures by Mathematical Models

Xiaokai Wang*

Tianjin TEDA Maple Leaf International School, China

Keywords: Epidemiological Models, SEIR Model, Counter Measurements, Peak of outbreak.

Abstract: The outbreak of COVID-19 was rapid. Most regions had taken measures to avoid the infection and decreased the mortality by producing necessary medical resources. Epidemiological model was a new sort of mathematic model that was invented to predict the disease spreading situation in last century. There were only two categories of population and a few considerations. As the time goes, more details were added to make these models more real. It could be used to predict COVID-19 virtually. SI (susceptible-infected) models, SIR (susceptible-infected-recovered) models and SEIR (susceptible-exposed-infectious-recovered) models are the main types of these models. This paper will analyze how these measures contribute to blocking the pandemic by mathematical models. Based on the analysis of these counter measurements, different models could be made due to the parameters in the model formula varies. This paper would focus on the time and the population of the peak of outbreak (the point with the most infected in the whole model) to reflect the change to the pandemic of a counter measurement. Any model that is included in a comparison all follows the single variable rule. Therefore, the effectiveness of counter measurements could be shown clearly.

1. Introduction

COVID-19 was initially found in December 2019, when the illness started to outbreak in Wuhan, capital of Hubei province China. The first large-scale outbreak happened in January 2020. At that time, the virus spread into many nations. Global cases of COVID-19 soared. The pathogen of COVID-19 is SARS-CoV-2, which has a single positive sense RNA genome. (Chen et al., 2020) To get rid of this pandemic, scientists from different areas investigated the pathogen from many aspects which includes pathology, societal Governments and have taken measures. Locking down, wearing masks and vaccination are effective.

In the history of human, there are many outbreak and infections of illness, such as Ebola, Zika, malaria, and cholera. Building a permanent public health system is difficult mission. Some scientists, for instance, Keeling and Eames (2005) consider disease spread like a “mixing network” As for COVID-19, Tang et al. (2020) build a SEIR model which includes quarantine, isolation and treatment to simulate the process of COVID-19 in Chinese mainland. Chinese government published policies that required citizens kept certain distance and wearing masks. A research done by Chu et al. (2020) demonstrate that keeping at least 1 metre will result a large reduction of infections. Wearing masks could reduce the risk of infection. Another research done by Leng et al. (2021) shows that having a vaccination contributes to herd immunity.

2. Mathematic Model

2.1 SI Model

In an epidemic model, Susceptible represents the people who haven’t had the disease before. Contagious disease spread by contact of an infected person with a susceptible person. The total population is usually assumed by variable N. The number of S and I are often assumed by S and I respectively. Therefore, $S+I=N$. SI Model is the simplest model that is proposed. The individual is either susceptible or infected. This model is suitable for the disease with no treatments and incubation period. An appropriate example is HIV (human immunodeficiency virus). The model has many

limitations, Sattenspiel (1990) mentioned that the assumption made by this model is unrealistic, for example, individuals are not randomly mixed. This simple model is the basis of epidemic model.

2.2 SIR Model

SIR model is proposed by Bailey in 1975, on the fundamental of SI Model, SIR model contains a new category: Recovered. This means the patients are once recovered, they are not able to be infected again. The infected have the possibility, often assumed as γ, which could be the reciprocal of the length of recovery period. Since the categories change is not reversible, all susceptible would be infected then recovered. So the disease would die out.

2.3 SEIR Model

Sattenspiel (1990) mentioned that the role of E (Exposed) is the consideration of incubation period. Because of COVID-19 is infective during the latent period. SEIR Model is suitable to analyze the reality situations. A new parameter σwhich means the infectivity during incubation period is added. σis the reciprocal of length of incubation period in mathematical sense. After a susceptible person is infected. She/he would transmit to an Expose then become an infected person. SEIR Model is more universal than previous models because it consider the incubation period, which is more realistic.

2.4 Loss of Immunity

The previous models are all irreversible as all susceptible are recovered. This means the immunity is permanent. However, immunity often last for a period of time. So the recovered loss immunity and become susceptible again as a cycle.

3. Counter Measurements

3.1 Quarantine

Quarantine is the simplest counter measurement. Conti (2008) did a research of quarantine history. The concept of quarantine was mentioned in The Holy Bible and be written in law by Justinian, the emperor of Byzantium in 549. This shows that quarantine is effective in any situation. No matter masks, drugs and vaccines are invented. R0 (Basic Reproduction Number) decreases sharply because patients cannot contact with other people.

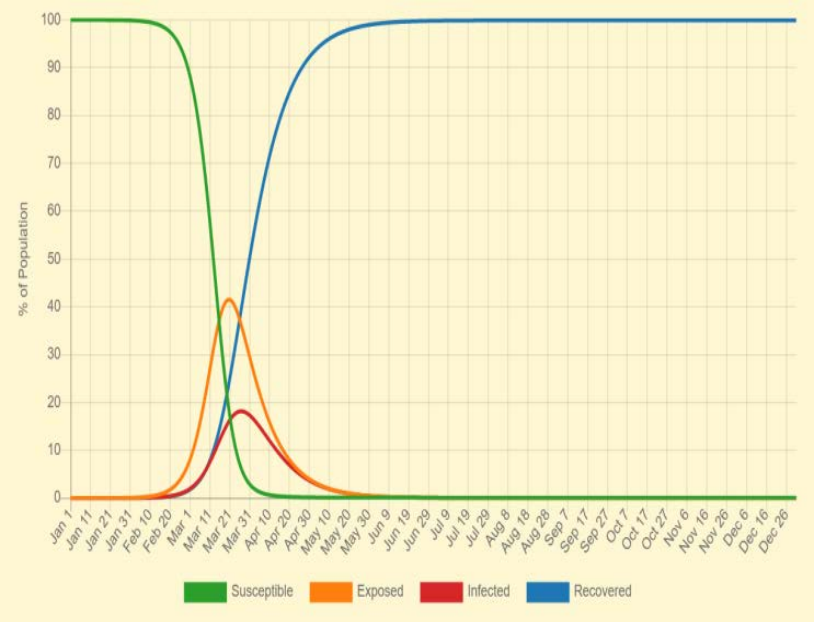

Figure 1. Disease with a high R0 (R0=7)

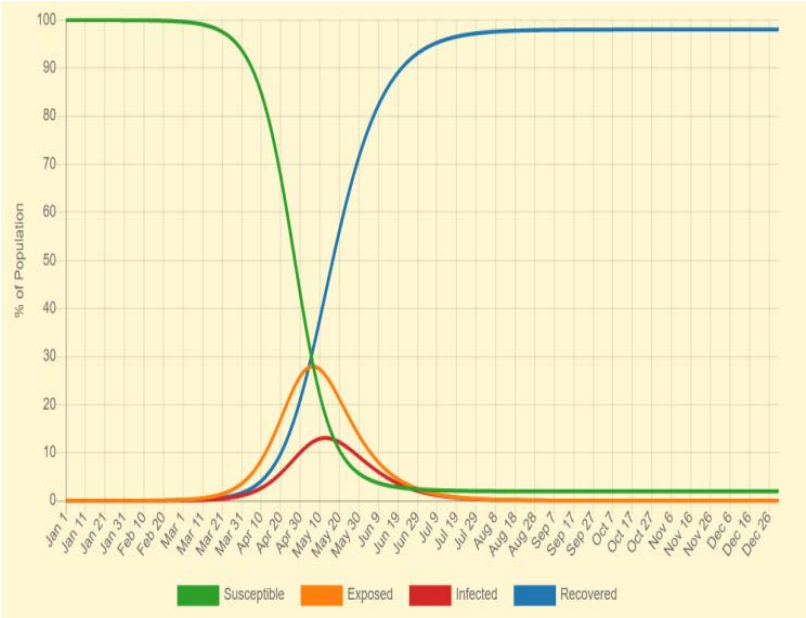

Figure 2. Disease with a lower R0 (R0=4)

The rest parameters in these two figures are constant

From: https://goodcalculators.com/seir-model-calculator/

From the model, the peak of outbreak is obvious delayed and the amount of Exposed and Infected is lower when R0 is relatively lower.

3.2 Lockdown

Since COVID-19 is infective during the latent period, governments had lockdown many regions to make sure that the Exposed are not contacting with others until they are diagnosed. Atalan (2020) demonstrated that lockdown is effective in psychology, environment, economy and prevention of COVID-19. The most obvious change of the epidemic is R0, which is shown by **fig 1&2**. Lockdown result in the sharp decline of contact between people. This is thought to be an effective method.

3.3 Masking

N95 mask could block 95% of particles within 3μm. It is widely used in the pandemic. After the beginning of the pandemic, there was a rush production of N95 masks. The electrostatic layer would produce electrostatic force applied on the virus. So the virus couldn't enter the mask. Juang and Tsai (2020) research on the methods of reusing N95 masks. N95 mask could endure high temperature and humidity. Wearing N 95 mask contributes to reducing R0 as well.

3.4 Vaccination

COVID 19 vaccine was developed and popularized in many nations around the world. Vaccination increases the immunity of people whether the vaccine is classified into mRNA, vector, deactivated. Vaccines help our body to produce antibodies of SARS-CoV-2, which make us immune COVID-19. The susceptible are directly become recovered without being infected and recovery in hospital. Variable γsoared if more people are vaccinated in a region.

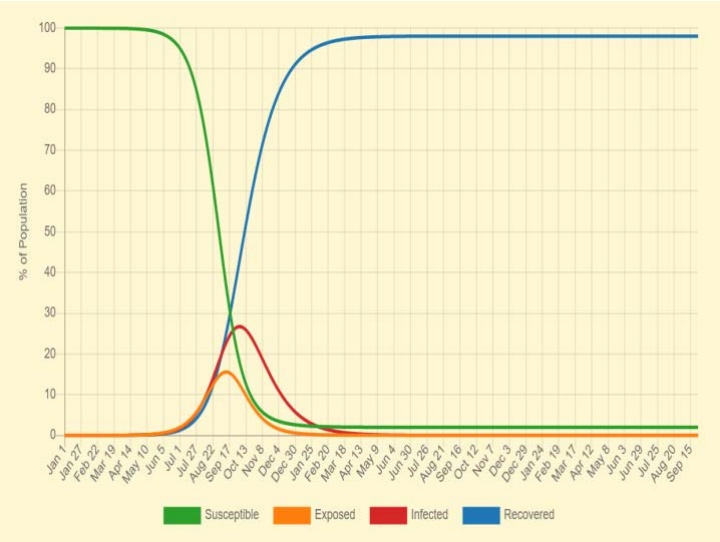

Figure 3: Disease with a low immunity (5%)

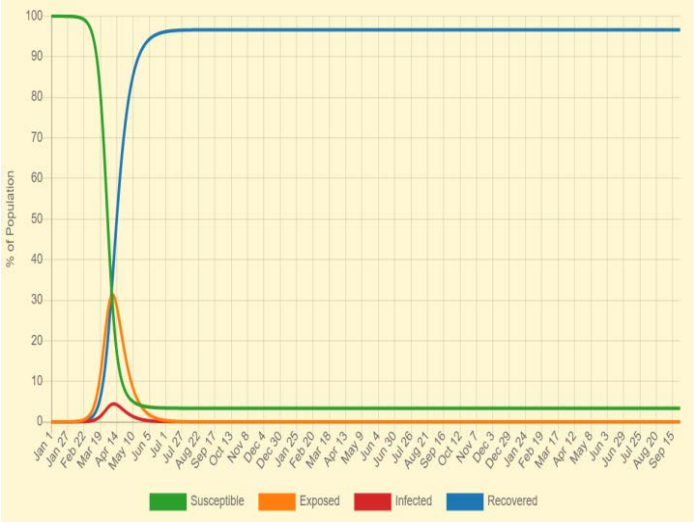

Figure 4: Disease with a high immunity (50%)

The rest parameters in these two figures are constant

From: https://goodcalculators.com/seir-model-calculator/

From **Fig 3&4,** an obvious difference is that the maximum of Infected of high immunity is much lower than that of low immunity. Once people are vaccinated, they are recovered so the disease is faster to die out.

4. Conclusion

This report paper gives analysis of the pandemic by SEIR mathematic models. The models represent the effectiveness of each counter measurement made by governments. Rate of increase of Infected and Exposed and the time of the peak of outbreak is mainly factor of the consideration.

Quarantine, lockdown, masking and vaccination are all thought as effective measurements that were taken. There are still limitations about SEIR model. It cannot predict the anti-mask, anti-lockdown and anti-vaccine groups, mortality due to the pandemic, SARS-CoV-2 variants infection and new birth. Despite of that, SEIR Model is still considered as a suitable model for COVID-19 pandemic due to the role of Exposed.

Overall, governments are weighing public health and economy during the pandemic by using the strategy of “the lesser of two evil”. Although these measurements violate citizens’ right of freedom.

According to Conti (2008), the measurements are effective procedure and are proven by mankind's history.

COVID-19 is still a challenge because it is not die out and the concept of "Disease X" that means more unknown disease would change our life completely in the future. Counter measurement that are published by government and authorities are the best way with the minimum of loss.

References

[1] Anli Leng, Elizabeth Maitland, Siyuan Wang, Stephen Nicholas, Rugang Liu, Jian Wang, Individual preferences for COVID-19 vaccination in China, Vaccine, Volume 39, Issue 2, 2021, Pages 247-254, ISSN 0264-410X, https://doi.org/10.1016/j.vaccine.2020.12.009.

[2] Atalan, Abdulkadir. "Is the lockdown important to prevent the COVID-9 pandemic? Effects on psychology, environment and economy-perspective." Annals of medicine and surgery (2012) vol. 56 (2020): 38-42. doi:10.1016/j.amsu.2020.06.010

[3] Bailey NTJ (1975) The Mathematical Theory of Infectious Diseases and its Applications. New York: Hafner Press

[4] Chen, Y., Liu, Q., Guo, D.: Emerging coronaviruses: genome structure, replication, and pathogenesis. J. Med. Virol. 92, 418–423 (2020)

[5] Chu DK, Akl EA, Duda S, et al. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. Lancet.395: 1973-1987 (2020)

[6] Conti, A.A.. "Quarantine Through History." International Encyclopedia of Public Health (2008): 454–462. doi:10.1016/B978-012373960-5.00380-4

[7] Juang, Pascal S C, and Peter Tsai. "N95 Respirator Cleaning and Reuse Methods Proposed by the Inventor of the N95 Mask Material." The Journal of emergency medicine vol. 58,5 (2020): 817-820. doi:10.1016/j.jemermed.2020.04.036

[8] Keeling, M.J., Eames, K.T.D.: Networks and epidemic models. J. R. Soc. Interface 2, 295–307 (2005)

[9] Lisa Sattenspiel. Modeling the Spread of Infectious Disease in Human Populations, YEARBOOK OF PHYSICAL ANTHROPOLOGY 33:245-276 (1990)

[10] Tang, B., Wang, X., Li, Q., et al.: Estimation of the transmission risk of the 2019-ncov and its implication for public health interventions. J. Clin. Med. 9, 462 (2020)

[11] Ross Beckley , Cametria Weatherspoon , Michael Alexander , Marissa Chandler , Anthony Johnson , and Ghan S Bhatt. Modeling epidemics with differential equations, Tennessee State University, Philander Smith College. 2013