

Full Dynamic Transmission Model and Threat Analysis of COVID-19

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Abstract. No doubt, the COVID-19 outbreak exemplifies ongoing biothreats to humanity as a whole. This necessitates an emergency response towards its remedy because it is heightened in importance and compressed in the time frame. Consequently, significant research efforts have been noticed to tackle this pressing crisis. In this paper, we endeavor to formulate a mathematical model of the transmission of COVID-19. The dynamics of the disease are illustrated by a compartmental model that involves differential equations. The paper also exhibits a mathematical estimation of the future threats induced by COVID-19 universally, which is computed based on the immediate statistical data. We compute the current transmission rate of COVID-19 to be 0.0462, considering the current fertility and mortality of the world population. From the threat estimation, it is expected that the COVID-19 may eliminate around 30% of the current population by the next three years, and it may obliterate nearly 43% of the current population by the next five years.

Keywords: COVID-19, Dynamic Transmission Model, SIS, Ordinary, Differential Equations, Threat Analysis



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1 Introduction

In 2012, the Middle East suffered from a new coronavirus that caused illness similar to SARS, which is entitled Middle East Respiratory Syndrome Coronavirus (MERS-CoV). Researchers across the globe conducted investigations to understand MERS-CoV and the prevention of it. While the MERS-CoV is still converging on the world, another extremely pathogenic coronavirus emerged in Wuhan, China, currently defined 2019-novel coronavirus (COVID-19). The transmission process of COVID-19 is similar to SARS-CoV and MERS-CoV and has also been reported to be transmitted among wild animals in wet markets. However, the animal sources of COVID-19 has not been confirmed. Early in the COVID-19 outbreak, it has been confirmed that COVID-19 can transmit from human to human. The cause of COVID-19 is the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), known as a novel coronavirus and previously titled 2019-nCoV. SARS-CoV-2 is a positive-sense single-stranded RNA virus. The reported incubation phase is typically between 2-14 days. Bats are likely to be the originator of SARS-CoV-2, due to the strong genetic similarity of bat coronavirus. Although, a Pangolin is thought to be involved as an intermediate reservoir. Mathematical transmission modeling of diseases has been widely studied to estimate and understand the spread of disease amongst humans [1, 2, 3]. These models are helpful to prevent future devastation caused by diseases and demonstrate the level of threat that a disease may cause in the near future. SIS model (S for susceptible and I for infectious) is an epidemiological model that demonstrates the spread of the human transmissible diseases. The transmission of COVID-19 can be mathematically presented with the SIS model. Along with the dynamic transmission model and a quick introduction of COVID-19, the contributions of the paper includes: We illustrate the present COVID-19 outrage based on the recently available reports. We derive a two-dimensional system of the nonlinear differential equation for the COVID-19 transmission, and approximate a transmission value of COVID-19 that satisfies the present scenario of COVID-19 outrage. We conduct future threat analysis using the transmission model using present real-world population data. The rest of the paper is organized as follows. Section 2 presents a short demonstration and properties of the current findings of COVID-19. Section 3 demonstrates the mathematical transmission model based on the cyclic characteristic of COVID-19. Section 4 presents the analysis based on the current COVID-19 statistics. Finally, Section 5 concludes the paper.

2 The Properties of COVID-19

2.1 Structural Biology

Experiments performed on the spike protein of COVID-19 suggests that it has sufficient affinity to the angiotensin-converting-enzyme-2 (ACE2) receptors of the human cell, which is used to perform cell entry. Studies reveal that SARS-CoV-2 has a higher affinity to a human cell than the original SARS virus strain. An atomic-level image of the spike protein (illustrated in Figure 1) has been created using cryogenic electron microscopy [4]

2.2 Epidemiology

In December 2019, the first known human infection occurred by the coronavirus strain. In mid-December 2019, the occurrence of SARS-CoV-2 was first discovered in Wuhan, China. The virus consequently spread to all regions of China and the countries in Africa, Asia, Europe, North America, and Oceania. Except for Africa, the transmission among humans has been confirmed by the other regions. Amongst the cases outside China, nearly all of them had direct or indirect contact with Wuhan.

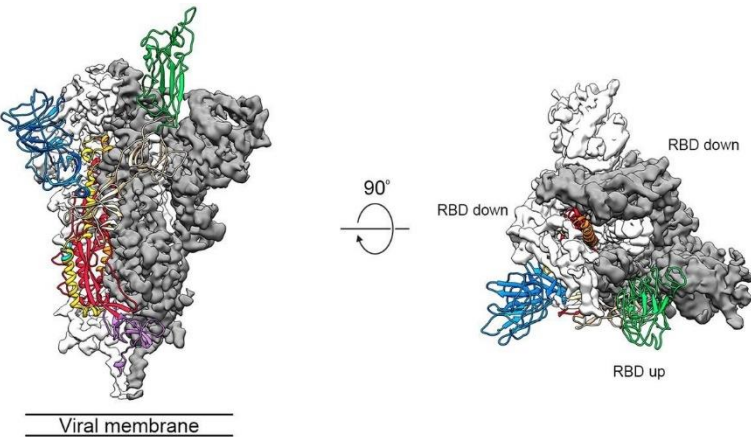


Fig. 1 The introduced structure of 2019-nCoV S in the prefusion conformation [4].

2.3 Transmission

COVID-19 is a human to human transmittable disease. It can spread from an infected individual through small droplets from nose or mouth. People can be infected by COVID-19 if they are in contact with these droplets directly or indirectly. It is also advised to keep distant more than 1 meter from a person who is sick. World Health Organization (WHO) is researching the period of COVID-19 transmission.

2.4 Symptoms

The most common symptoms of COVID-19 are reported to be tiredness, fever, dry cough, sore throat, runny nose, nasal congestion, aches, pains, and even diarrhea. The symptoms are at first mild and, rise gradually although some reports suggest that some infected individuals may not develop any symptoms at all. About 80% of the infected population overcome the disease without requiring any special medical treatment. On the contrary, every 1 out of 6 infected individuals becomes seriously ill with difficulty in breathing. Aged people are more likely to develop serious illness caused by the virus.

2.5 Diagnosis

Real-time reverse transcription-polymerase chain reaction (RRT-PCR) is one of the suggested testing protocols by the WHO, which can be performed on the respiratory or on blood samples. Generally, results of RRT-PCR can be extracted within several hours to days. However, the RRT-PCR has a higher false-positive rate of 50-70% [5]. The strain of the coronavirus has already been isolated, and the genetic sequence has been published [6].

2.6 The Mushrooming of COVID-19

As of February 11, 2020, according to a Chinese article [7], the mortality rate caused by COVID-19 is considered to be 2.3%. Also, aged masses have a higher mortality rate caused by COVID-19, as illustrated in Figure 2.

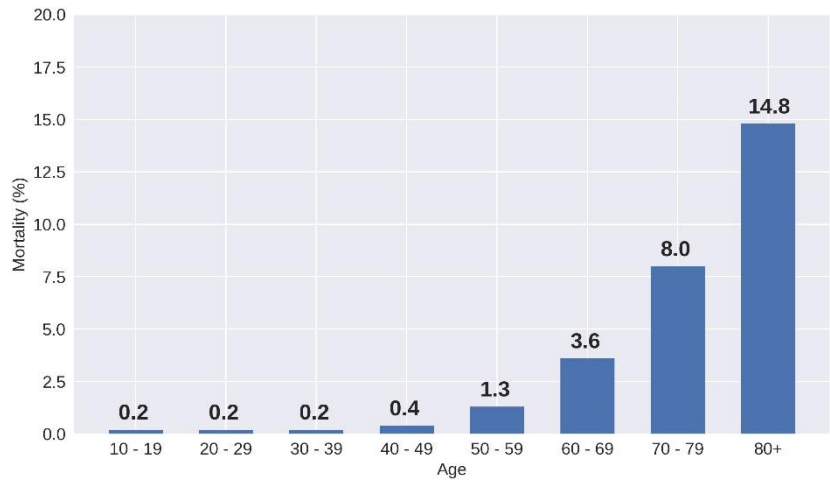


Fig. 2 Reported COVID-19 mortality rage by age (as of February 11, 2020) [7].

As of February 27, 2020, globally a total of 82,294 cases are confirmed with 2804 death cases [8] which is illustrated in Table 1.

3 **Dynamic Transmission Model of COVID-19**

The model describes the dynamics of COVID-19 transmission on a particular population. In this transmission model, we consider one area that holds a total

Table 1. The confirmed cases and deaths by COVID-19 (as of February 27, 2020) [8].

	Confirmed	Deaths	Mortality Rate
China	78,630	2,747	3.49%
Outside China (47 Countries)	3,664	57	1.55%
Globally	82,294	2,804	3.41%

population of N , including two disease status, S , and I (where $N = S + I$). The subset of the population who are susceptible to the virus declared as S whereas, the subset of the population who are infected by the virus is declared as I . Someone who is cured of the virus (was on population subset I) is moved to the susceptible state. The infected individuals of the population subset I have a recovery rate of γ . The population of infectious individuals is increased by infection of susceptible with a transmission rate of β . We also consider the birth rate of the total population, which is denoted as μ . The natural death rate of the susceptible individuals is denoted as ν whereas the COVID-19 provoked death rate of the infectious is denoted as η . Figure 3 illustrates the models along with the parameters. Table 2 contains a short description of the parameters.

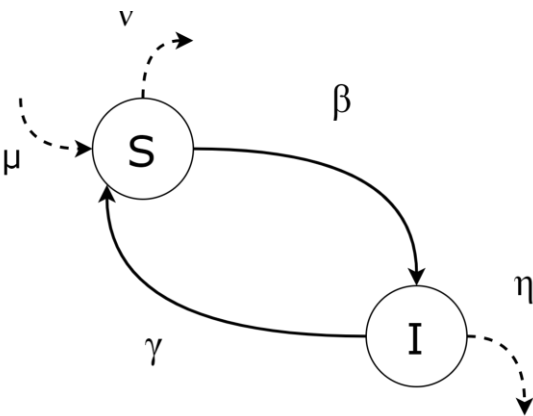


Fig. 3 The SIS transmission diagram of COVID-19 model.

Table 2. The parameters used in the SIS model.

Description	Parameter
Birth rate of the overall population	μ
Natural death rate of susceptible population subset	ν
COVID-19 death rate of infectious population subset	η
Transmission rate of COVID-19	β
Recovery rate from COVID-19	γ

With the stated assumptions and the illustrated model in Figure 3, we derive an two-dimensional system of nonlinear differential equation for the COVID-19 trans-
mission,

$$\frac{dS}{dt} = \mu N - \frac{\beta SI}{N} + \gamma I - \nu S$$

(1)

$$\frac{dI}{dt} = \frac{\beta SI}{N} - \gamma I - \eta I$$

(2)

All the parameters used in the model are positive and variable domain of the model, denoted as Ω is estimated as

$$\Omega = \{(I,S) \in \mathbb{R}^2 : I, S \geq 0\}$$

(3)

4 Threat Analysis

4.1 Assumptions

To calculate the parameters of the model as presented in Section 3, we assume the following scenarios:

- The world population is 7.511 billion (as of 2017) [9].
- The infected population (from the world population) is 82,294 [8].
- The natural mortality rate (per 1000 population) of the world population is 7.542 per year [10].
- The birth rate (per 1000 population) of the world population is 18.657 per year [11].
- We assume each individual of the population requires 31 days to completely overcome COVID-19.

Table 3 contains the parameter values that is calculated considering the above estimations. In the rest of the estimations, we assume all the parameters except β are constant. Figure 4 shows the infectious population over one year, based on the overall value of transmission rate (β).

Table 3. The estimated parameter values of the SIS model.

Description	Parameter	Value
Birth rate of the overall population	μ	5.25×10^{-5}
Natural death rate of susceptible population subset	ν	2.12×10^{-5}
COVID-19 death rate of infectious population subset	η	1.11×10^{-1}
Recovery rate from COVID-19	γ	3.22×10^{-2}

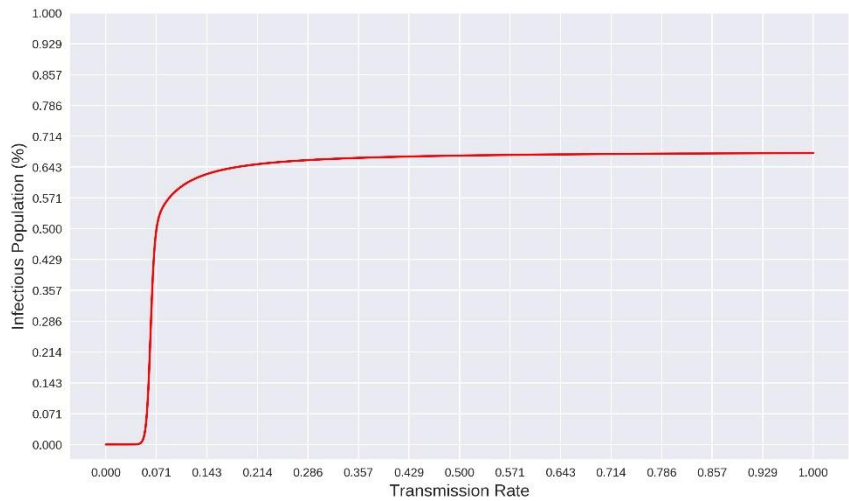


Fig. 4 Increase of infectious population w.r.t COVID-19 transmission rate over one year.

4.2 Transmission Rate Calculation

To estimate the future threat of COVID-19, we investigate to detect the most approximate value of the transmission rate of the virus. According to the ten days of WHO COVID-19 situation report 29 to 38, the COVID-19 has infected, on average 1,067.3 people, daily [12]. We use this average infection increase to calculate the transmission rate of COVID-19 based on our model. By applying the bisection method, the transmission rate (β) is computed to be 0.0462.

4.3 Analysis

By using $\beta = 0.0462$, we calculated the overall population distribution over the susceptible and infectious population subset. Figure 5 illustrates the population distribution result of the next five years, which is alarming. The model estimates that half of the population may be obliterated if the spread of the virus remains the same and more than 25% of the overall population will be infected by the disease.

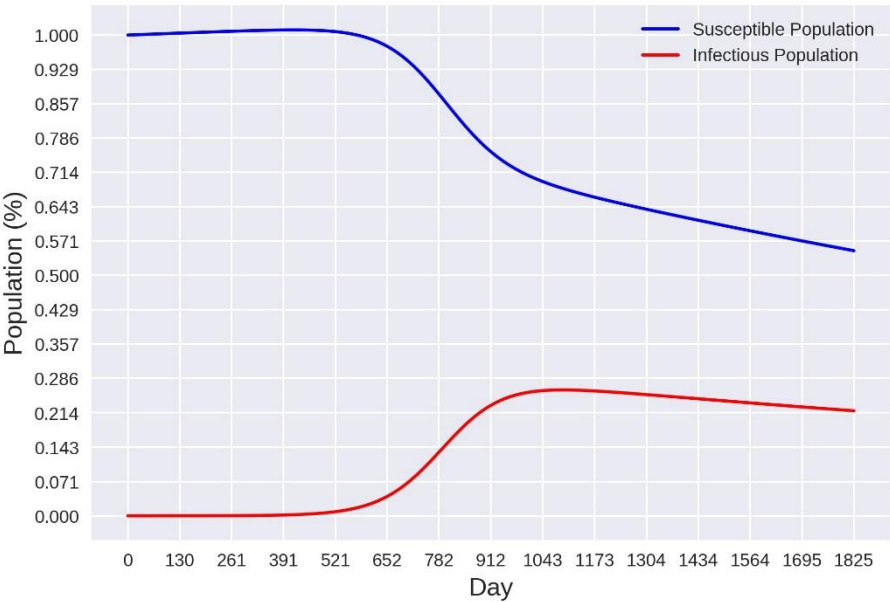


Fig. 5 The five years distribution of susceptible and infectious population based on the estimated values.

The model estimates that the amount of infectious population will continue to rise over the first year (illustrated in Figure 6), and it would proceed downwards after three years (illustrated in Figure 7).

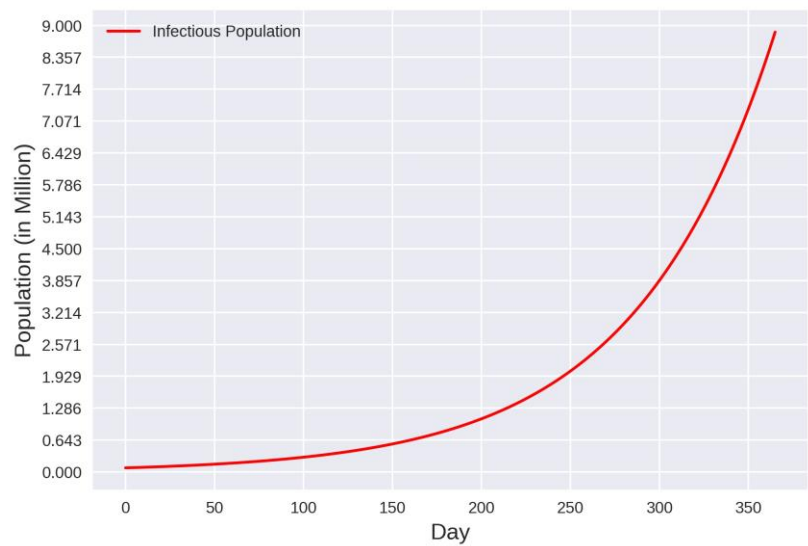


Fig. 6 The one year distribution of infectious population based on the estimated values.

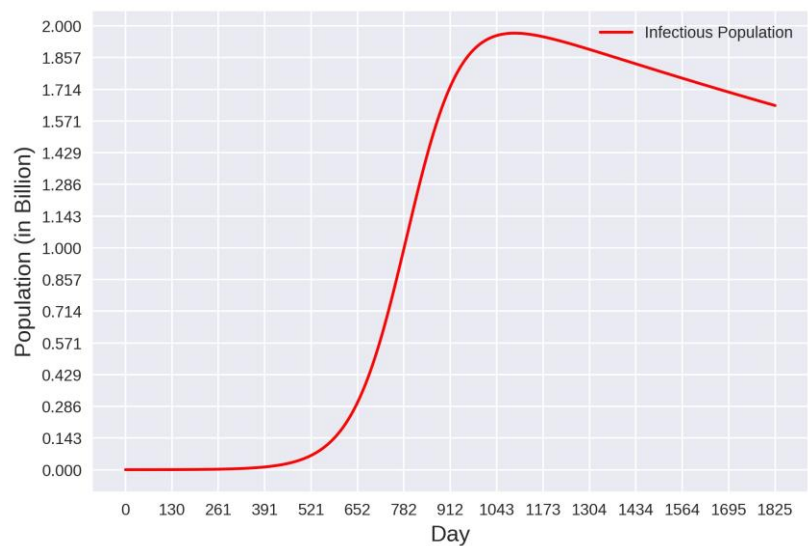


Fig. 7 The five year distribution of infectious population based on the estimated values.

5 Conclusion

This paper discusses the recent findings of COVID-19 and derives a mathematical transmission model of the COVID-19 in one area. The paper also illustrates the future estimated devastation caused by COVID-19. We calculate parameter values based on recent statistical reports and we compute the COVID-19 transmission rate, which satisfies the present statistical estimations. From the approximated calculations, it can be confirmed that if necessary steps are not taken, the devastation of COVID-19 will be at large. The approximate calculations illustrate that almost half of the population may be demolished if the current outburst of the COVID-19 is not restricted. The transmission rate of COVID-19 can be reduced if proper medical guidance is followed. By controlling the transmission rate, the number of infected humans can be decreased significantly. We strongly hope that the contribution of this research work informs the world about the potential danger of COVID-19.

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