Mathematical modelling and *in silico* experimentation to estimate the quantity of COVID-19 infected individuals in Tijuana, México

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1. Introduction

On December 31, 2019, a case of pneumonia with unknown cause was reported for the first time in Wuhan, China, to the World Health Organization (WHO). The outbreak was declared an international public health emergency on January 30, 2020, and on February 11 the viral respiratory disease caused by the new coronavirus was officially named COVID-19, or SARS-Cov-2. **Figure 1** presents the data from the Secretary of Health of México on the dynamics and outcomes of the disease caused by SARS-Cov-2, showing that a mitigation strategy in the spread curve is necessary [1]. Mathematical models are useful to predict the temporal evolution of infectious diseases such as COVID-19 [2], one of the most used is the called susceptible-infected-recovered also known as SIR. With the purpose to estimate the real number of active infected, accumulated infected and recovered in the city of Tijuana, the proposed model and the information corresponding to the number of deaths registered on the Government's 'Monitoring of COVID-19 cases' page of Baja California that is updated daily with new statistics will be used [3].
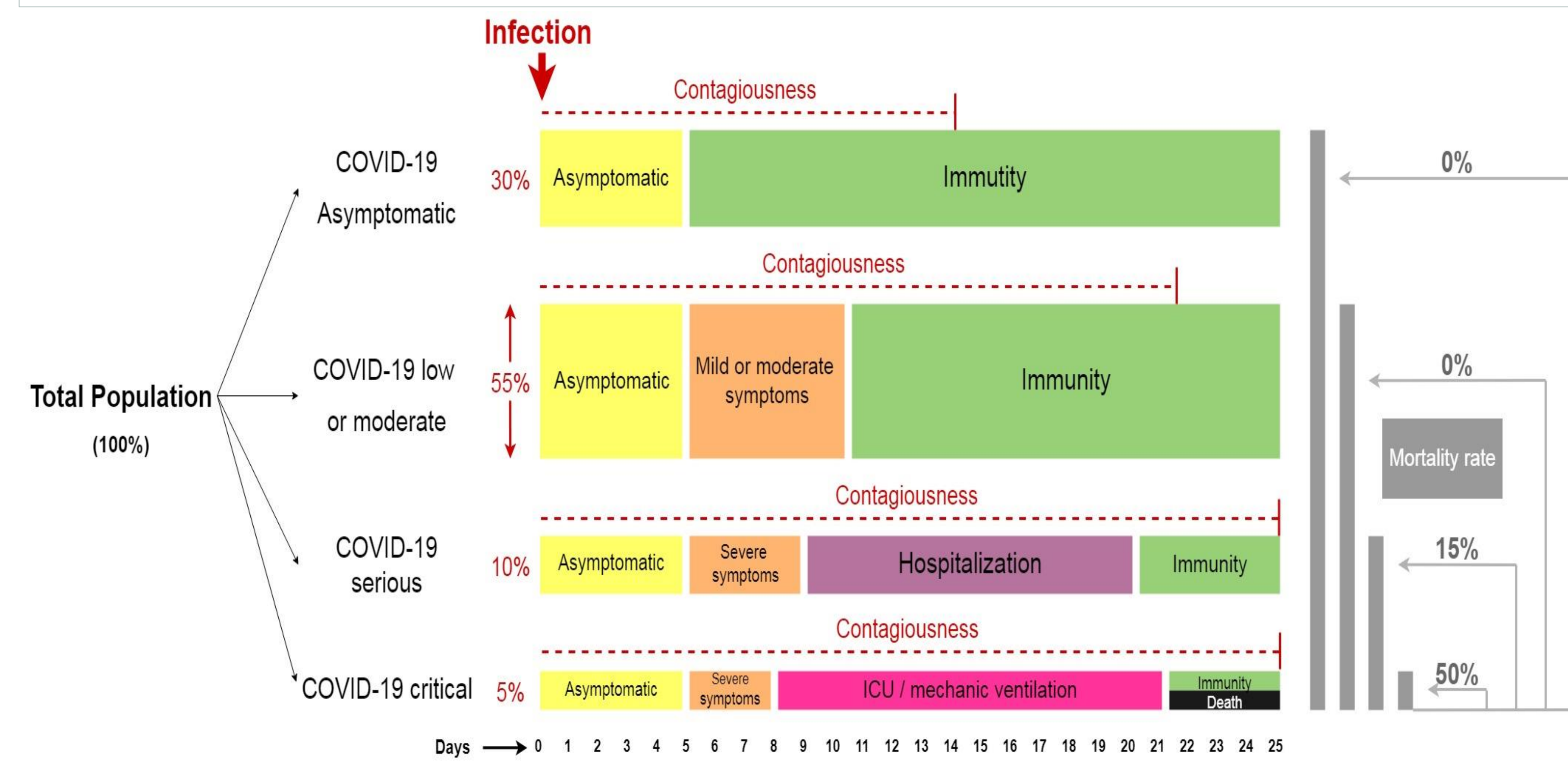
Figure 1. Dynamics and outcomes of SARS-Cov-2 disease [1].

3. Discussion

In order to understand the evolution of the COVID-19 pandemic in Tijuana, numerical simulations of the system (1) - (5) were performed to estimate cases from March 19, 2020, to August 1, 2021, 500 days after the first confirmed case in the city. Based on the numerical simulations, it is observed that for July 2, 2021, 471 days after the first confirmed case, there are no longer individuals infected by the SARS-Cov-2 coronavirus. Finally, based on the information shown in **Figure 1**, we formulate **Figure 4**. From the beginning of the confinement in Tijuana on March 19, 2020, until August 1, 2020, the evolution of the pandemic is observed with respect to time, where the blue curve of the graph shows the evolution of those infected in the city. According to the numerical simulations, the day on which the maximum peak of infected is reached in Tijuana is July 4, 2020, therefore, from this date, there is a decrease in the number of active infected in the city.

References

[1] Desenlaces SARS-Cov-2 (2020). Secretará de Salud: Conferencia de prensa 29 de abril. https://www.youtube.com/watch?v=Y_sDVLsWWPE. Last accessed: 01/06/2020.
[2] Modeling in Biology (2020). Modeling Life. Modeling in biology. https://modelinginbiology.github.io/Epidemic-modeling-interactive-simulations?loc=0. Last access: 01/06/2020
[3] COVID B.C. (2020). Seguimiento de casos COVID-19. http://www.bajacalifornia.gob.mx/coronavirus. Last accessed : 01/06/2020.
[4] Nutonian. (2020). Eureqa: The A.I.-Powered Modeling Engine.
[5] INEGI (2020). INEGI: Censos y conteos. https://www.inegi.org.mx/programas/ccpv/cpvsh/. Last accessed: 01/06/2020.

2. Description of the mathematical model of COVID-19 in Tijuana

The mathematical model to estimate the number of cases in the city of Tijuana at different stages of the disease COVID-19 (see the kinetic model illustrated in **Figure 2**) is presented below by the following set of 5 first-order Ordinary Differential Equations (ODEs):

$$\dot{S} = -\beta SI/(S + I + R) \tag{1}$$

$$\dot{A} = \beta SI/(S + I + R) \tag{2}$$

$$\dot{I} = \beta SI/(S + I + R) - \gamma I \tag{3}$$

$$\dot{R} = (a + m)\gamma I + g(1 - \mu_g)\gamma I + c(1 - \mu_c)\gamma I \tag{4}$$

$$\dot{F} = (g\mu_g + c\mu_c)\gamma I \tag{5}$$

The β parameter describes the virus transmission rate in each encounter between a susceptible and an infected individual and is formulated as follows:

$$\beta = 2^{1/\sigma} - 1 + \gamma \tag{6}$$

The susceptible population represents the estimated population in Tijuana city for the year 2020. We estimated this value from the statistics recovered from the INEGI [5] and determined the following function:

$$p(t) = 370,877t + ((1,328,536,670,302)/t) - 1,404,867,171 \tag{7}$$

We formulated the latter by applying Eureqa [4].

Equation (7) has a correlation coefficient of 0.992 and a coefficient of determination (R^2) of 0.980. Therefore, the estimated population for the city of Tijuana for the year 2020 is

$$p(2020) = p_0 \approx 1,995,790$$

On the information provided by the Baja California State Secretary of Health [4], the first confirmed case of an individual infected by the SARS-Cov-2 virus in the city of Tijuana is registered on March 19, 2020. Hence, the following initial conditions are proposed for the COVID-19 system.

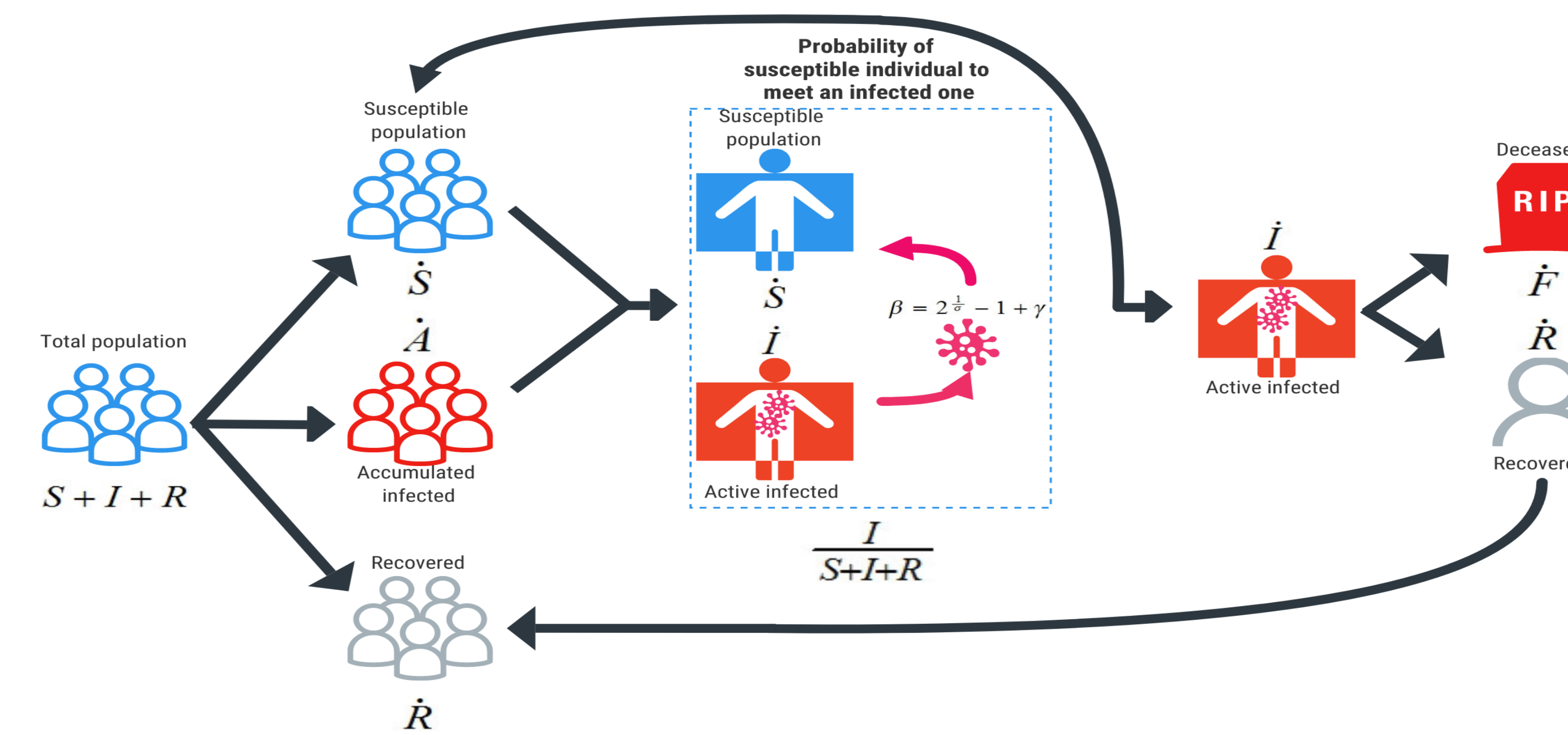$$S(0) = (1 - \phi)(p_0 - 1)$$
$$A(0) = 1$$
$$I(0) = 1$$
$$R(0) = 0$$
$$F(0) = 0$$

It should be noted that the dynamics of the system (1)-(5) is positively invariant for non-negative initial conditions. Then, the domain of the system is defined by

$$R_{0,+}^5 = \{S(t), A(t), I(t), R(t), F(t) \geq 0\}$$

Finally, the description and values of the COVID-19 system parameters (1)-(5) are shown in **Table 1**.


Figure 2. Kinetic model to estimate the number of cases in the city of Tijuana at different stages of the disease COVID-19

Table 1. Description, values and units of the COVID-19 system parameters (1)-(5).

Parameter	Description	Values
β	Virus transmission rate	0.1867
σ	Period in which confirmed cases double	5.0608
γ	Recovery period from illness	1/25
a	Proportion of asymptomatic infected	0.30
m	Proportion of infected with moderate symptoms	0.55
g	Proportion of infected with severe symptoms	0.10
μ_g	Probability of death of an infected person with severe symptoms	0.15
c	Proportion of infected in critical condition	0.05
μ_c	Probability of death of an infected in critical condition	0.50
p_0	Estimated population for the city of Tijuana in 2020	1,995,790
φ	Social distancing coefficient	$\varphi \in [0,1)$
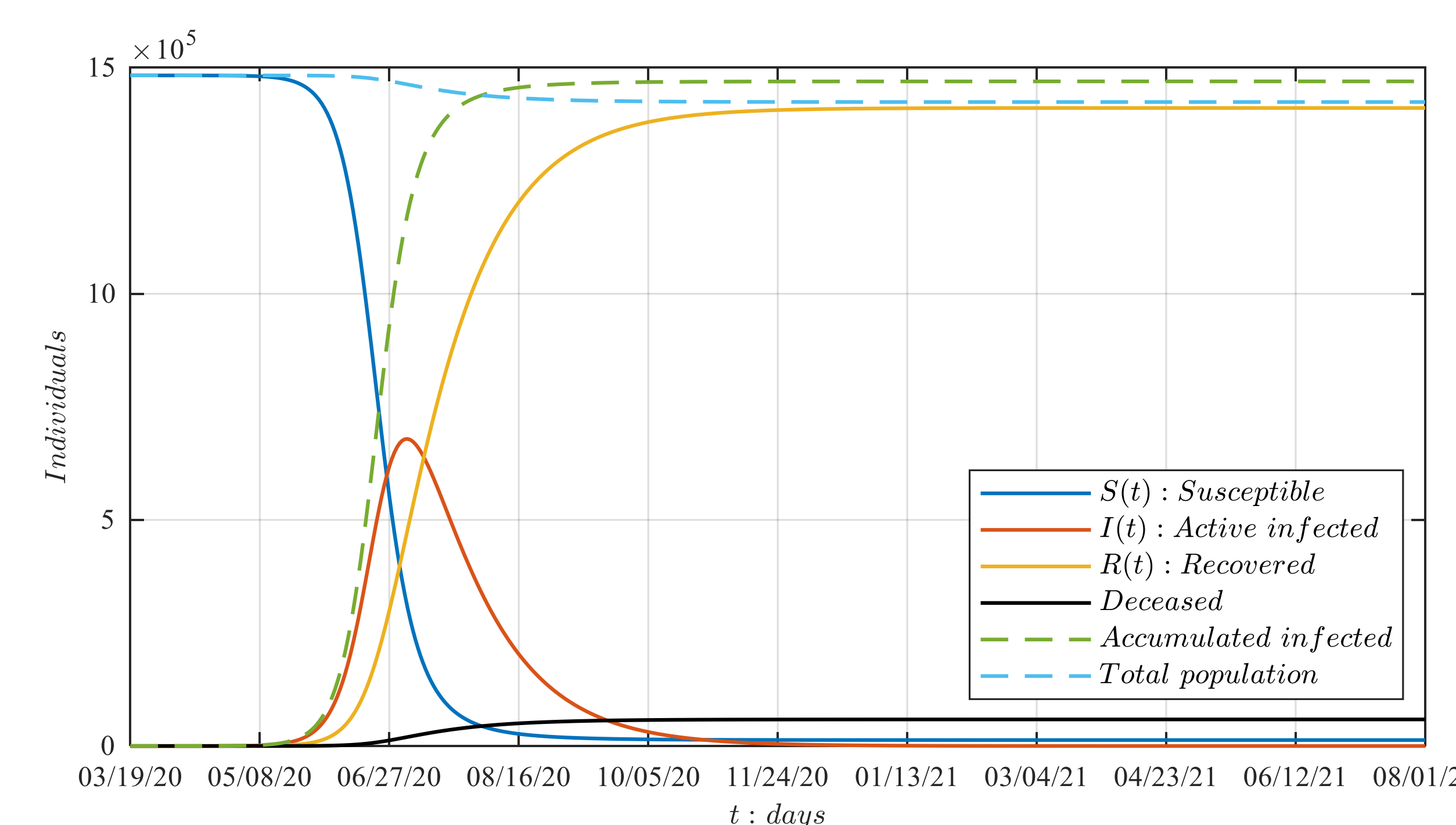
Figure 3. Evolution of COVID-19 cases in the city of Tijuana from the day of the first active infected on March 19, 2020, until the day on which the last active infected in the city is estimated, on July 2, 2021.
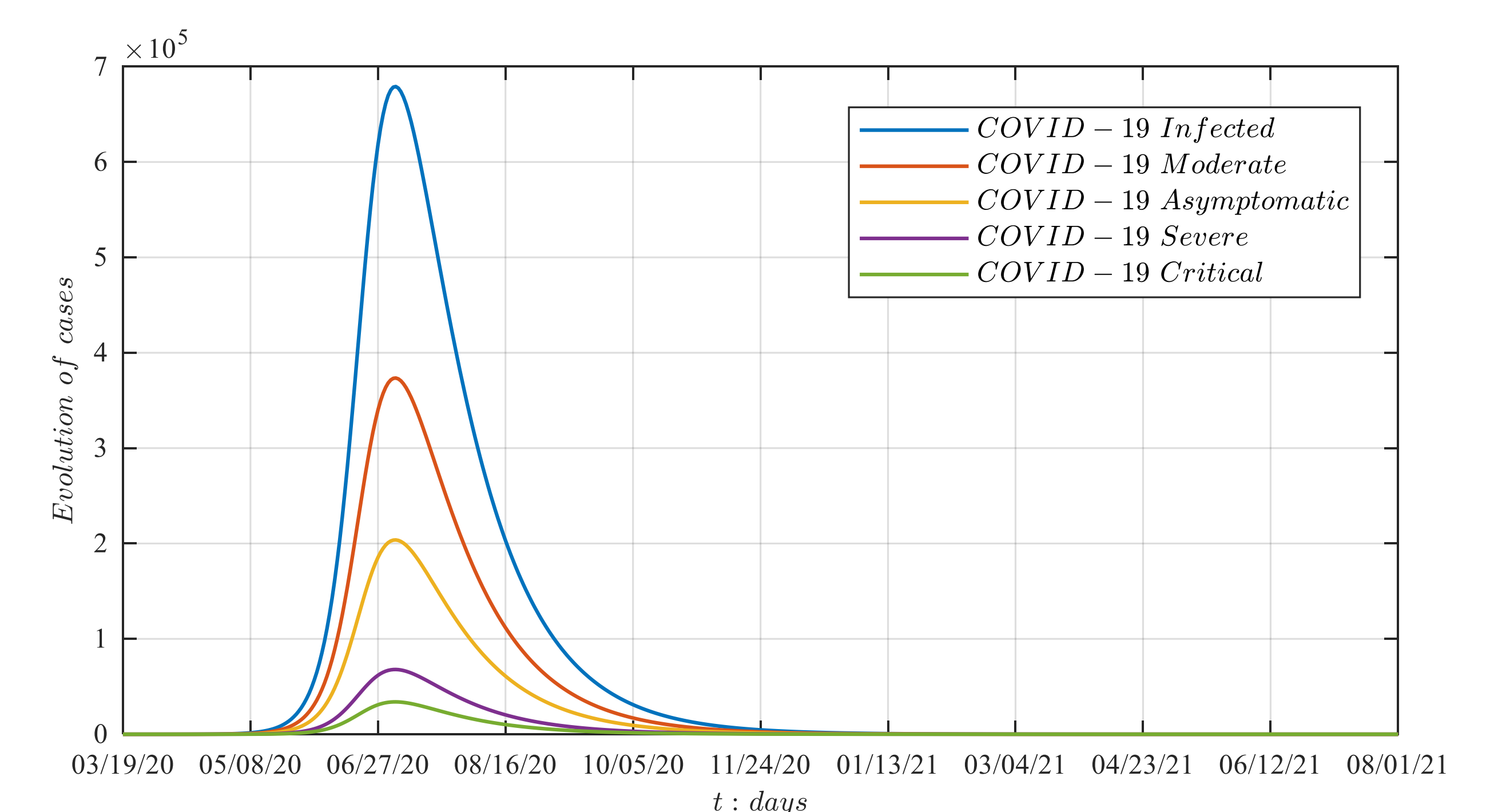
Figure 4. Dynamics and outcomes estimated using the system (1) - (5) for the evolution of COVID-19 in the city of Tijuana based on the information of Figure 1.