# Modeling the Impact of COVID-19 Lockdown in Regional Cities

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## Abstract

The present work aims to study, through a mathematical model, the evolution of the dynamics of COVID-19 cases in a regional center in the interior of the state of São Paulo, more specifically in the region of Presidente Prudente. With numerical modeling we simulate the effects of a lockdown in the main town in the region and its effects on other smaller towns in that same region so as to compare how much this lockdown would have helped to reduce the impacts caused by the pandemic in the other municipalities.

**Keywords:** COVID-19, SIR model, Lockdown.

## Introduction

COVID-19 is a Severe Acute Respiratory Syndrome (SARS): a new respiratory disease caused by SARS-CoV-2 virus that emerged in China in December 2019, which has resulted in more than 6 million deaths globally according to the World Health Organization (WHO). In this work, we formulate a new mathematical model that determines the dynamics of COVID-19 transmission in a conglomerate of contiguous cities from São Paulo State – Brazil, more specifically in the region of Presidente Prudente's city.

## Objectives

Our goal is to assess the impact that a potential lockdown in a principal city could have on its adjacent towns.

## Methods

The so-called SCIRD model, formulated from the well-established epidemiological model SIR (Susceptible–Infected –Recovered) [1], splits the population into five compartments: Susceptible (S), Confined (C), Infected (I), Recovered (R) and Dead (D). Such a compartmental-type model is formulated in terms of the following coupled Ordinary Differential Equations:

$$\begin{cases} \frac{dS_{Ci}}{dt} = -\alpha_i S_{Ci} I_{Ci} - \theta_i S_{Ci} + \delta R_{Ci} + \eta C_{Ci} - \sum_{i,j=1}^{6} f_{ij} S_{Ci} \alpha_i I_{Cj} \\ \frac{dC_{Ci}}{dt} = \theta_i S_{Ci} - \alpha_c C_{Ci} I_{Ci} - \eta C_{Ci} \\ \frac{dI_{Ci}}{dt} = \alpha S_{Ci} I_{Ci} + \alpha_c C_{Ci} I_{Ci} - \beta I_{Ci} - \gamma I_{Ci} + \sum_{i,j=1}^{6} f_{ij} S_{Ci} \alpha_i I_{Cj} \ , \\ \frac{dR_{Ci}}{dt} = \beta I_{Ci} - \delta R_{Ci} \\ \frac{dD_{Ci}}{dt} = \gamma I_{Ci} \end{cases} \quad (1)$$

where $f_{ij}(i \neq j)$,represents the flow of people between small cities and the principal center [2], $\alpha$ and $\alpha_c$ account for the infection rates of the susceptible and confined populations, respectively, $\theta_1$ and $\theta_2$ are the confinement rates for cities 1 and 2, respectively; $\delta$ is the immunity loss rate; $\eta$ defines the insulation loss rate; $\beta$ establishes the proportion of the population that left the infected and went to the recovered; and $\gamma$ determines the death rate due to the disease.

## Results

When we solve the above set of equations, applying lockdown in the municipality of Presidente Prudente, we obtain the evolution curves for each city, which can be seen in Figures 3, 1 and 2.

Figure 3 presents a graph with the curves of infected people from all municipalities in the period from 05/20/2020 to 10/28/2020, the curve for the infected presents an approximate numerical solution compared to the real data. Then, Figures 1 and 2 present the same simulations, however in this case we apply a confinement in the regional center, generating a decrease in its cases. In one of the graphs we applied it from the twentieth to the fortieth day, and the curve of infected people can be seen to rise again as the population leaves confinement, and in the other graph, from the twentieth day with several interruptions of confinement, we can observe the decay of cases towards the extinction of the disease after these periods of confinement in the main municipality.

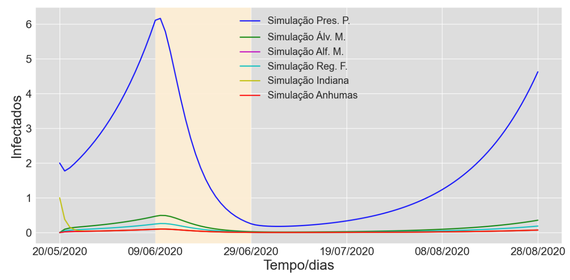


**Figure 1:** Simulation of infected by covid-19 with application of a lookdown between the 20th day and the 40th. Source: Prepared by the author.

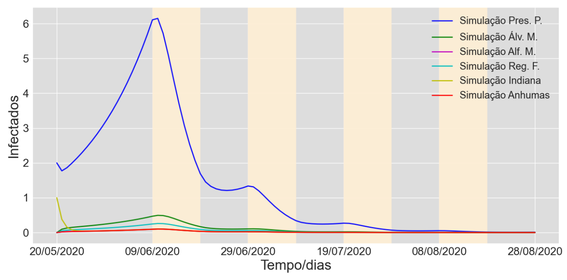


**Figure 2:** Simulation of infected by covid-19 with lockdown application from the 06/09/2020 with reopening several times. Source: Prepared by the author.

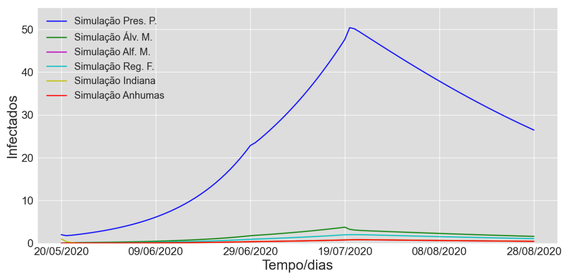


**Figure 3:** Simulation of those infected by covid-19 in a regional center and cities around it from 05/20/2020 to 08/28/2020. Source: Prepared by the author.

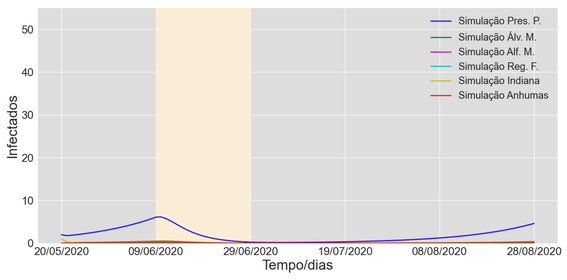


**Figure 4:** Simulation of infected by covid-19 with application of a lookdown between the 20th day and the 40th. Source: Prepared by the author.

## Conclusions

The work aimed to estimate, using a mathematical model, the evolution of the dynamics of COVID-19 cases in a regional center in the interior of the state of São Paulo, more specifically in the region of Presidente Prudente. The predictions made by the simulations showed that the implementation of how the implementation of a lockdown after the appearance of thge first cases of the disease largest town in the regional can significantly help to reduce the impacts caused. As future works we can improve the model, including new compartments and more accurate values for the used parameters, as well as inserting more cities, since there are many others around Presidente Prudente that depend on its services.

## References

[1] W. O. Kermack and À. G. Mckendrick, *A contribution to the mathematical theory of epidemics.* Proc. R. Soc. Lond. A, v. 115, n. 772, p. 700-721, 1927.

[2] IBGE - Brazilian Institute of Geography and Statistics. *Population arrangements and urban concentrations in Brazil*, IBGE, Rio de Janeiro, 2016.

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