TAMING COVID-19 EPIDEMIC IN SÃO PAULO WITH A LOGISTIC MODEL AND NON-PHARMACEUTICAL MEASURES

MARCELO MARCHESIN-FEDERAL UNIVERSITY OF MINAS GERAIS, BRAZIL

ABSTRACT. In this paper we use the simple logistic mathematical model to represent the development of COVID-19 epidemic in São Paulo city under quarantine regime and we estimate the total amount of time it is necessary to decrease the number of seriously ill in order to reduce the demand for ICU hospital beds to tolerable levels. Clearly the same reasoning used here can be used for any other city in similar conditions.

Key Words: Coronavirus, Quarantine, Epidemics, Logistic models

AMS : 92D30, 93C15, 34H05

1. INTRODUCTION

On December 2019 in Wuhan City (China), several cases of pneumonia of unknown etiology were detected. The Chinese Country Office of the World Health Organization was informed and a novel coronavirus (officially named COVID-19) was identified on January 7th, as the cause of such infection. An international alert was issued because an eminent potential for worldwide spread had been recognized.

According to the website Worldometers [10] which features the first figures on China (Wuhan), on January 22nd there were already 571 confirmed cases and 2 days later there were already 1,287 with 41 deaths. COVID-19 has been shown to be easily spreading and very lethal. China’s effort to mitigate the harm were quickly taken yet as many as more than 75,000 infected cases were reached in Wuhan before the end of January (see [3]). Due to the highly interconnected world we presently live in, the disease quickly spread outside China reaching practically all countries around the world with several different degrees of seriousness. On March 11th due to the worrying situation the World Health Organization (WHO) declared it a Pandemic.

The scientific world community understood it was time for an international effort to provide scientific reliable information to help the world’s leaders in the choice of public policies to face the pandemic. On March 16th a group of about 30 researchers from the London Imperial College published a blunt paper [2] considering the various options of several different public policies measures that should be taken. They have analyzed several possibilities varying from total no intervention to complete lockdown of the whole population and they have estimated the number of lives loss in each case. Lately, because of the seriousness of the situation, there has been many other papers researching the same topic: Li Q. et. al. [3], Wu P. et. al.[12], Wu J. et. al.[13], just to mention a few. Among the conclusions drawn from these papers it was clear that no easy choice was available for the governments,
and that the main question to be answered was “What is the optimum equilibrium between saving lives and minimizing the loss to the economy?”

Although the motivation for this study is the present situation of the epidemic in Brazil and a try to shed some light on this very crucial dilemma, we understand that the results presented here are general enough to work as a guideline to any other country and city facing the same uncertainties. Given the continental size of Brazil and the ongoing local policy of quarantine it seems reasonable to face the problem locally. At the present moment most of the Brazilian cities, specially the large ones, are fairly well isolated from the others so that a local approach is justified. We particularly study the case of São Paulo city because it was the Brazilian city where the first case of COVID-19 was diagnosed, it has been under quarantine practically since the beginning of the onset, it presents relatively reliable data on the epidemic and it is the largest and most important city in Brazil.

This paper consists of using the logistic mathematical model to the epidemic situation in São Paulo city. We study the situation of the total number of ICU beds in São Paulo and then use the results the quarantine in Wuhan has produced in the decreasing number of cases of infected individuals, to infer similar results to São Paulo considering several levels of strictness of its quarantine model. We conclude estimating the time period necessary to decrease the number of infected individuals in order to avoid overwhelming the ICU system of the hospitals network in the city of São Paulo.

This paper is organized as follows: In Section 2 we present the mathematical model we shall use: the logistic model. In order to justify the choice of such a model, in Section 3, we fit the data from Wuhan to it to show that is has an awesome level of accuracy. In Section 4 we use the data of Wuhan to estimate quantitatively how the strictness of the quarantine regime influences on the decreasing of the parameter $r$. In Section 5 we fit the logistic model to the data of São Paulo and finally in Section 6 we estimate when the total demand for ICU beds reaches 80% of the total number of such beds available and how long it can take to reduce these numbers based on the level of accession of the quarantine regime in the city. In Section 7 we summarize the results and present suggestions of public policies to increase the rate of reduction of the number of new infected cases. The data and theorem used in this study are presented in Section 8.

2. The Logistic Model

The logistic model (see [4] for more details) has been classically used modeling population growth in a scenario in which the rate of growth is exponentially quick in the beginning, being proportional to the number of the whole population, but it losses strength as it starts getting close to an upper threshold, for instance the natural storage capacity of the environment. Here this idea seems to be very reasonable, for the spread of the total number of infected individuals of COVID-19 is exponentially quick as we see it in the early days, but it is reasonable to believe it will slow down as the number of exposed susceptible individual, not yet infected, decrease. It is indeed a very simple model which can be mathematically written by an unique ordinary differential equation with an initial condition:

$$I'(t) = rI(T - I)$$  \hspace{1cm} I(t_0) = I_0.$$
in which \( t_0 \) is the time chosen to represent the beginning of the outbreak, \( I_0 \) in the number of infected individuals at such an initial time, \( I = I(t) \) is the total number of infected individuals up to time \( t \), \( r \) is a positive constant of proportion and \( T \) is the total number of susceptible exposed individuals. We say that the rate of change in the number of infected individuals is proportion to the number of infected individuals as well as to the number of remaining non-infected individuals. The solution of such equation is broadly known to be:

\[
I(t) = \frac{I_0 T}{I_0 + (T - I_0)e^{-rt}}.
\]

Clearly such a solution is a function of \( I_0 \) as well as of \( T \) and \( r \). We do not have any control on the number of cases at time \( t = 0 \) but we believe we do have relatively great amount of control on \( r \) and \( T \) as we shall point out in section 7. Clearly we have that

\[
\lim_{t \to \infty} I(t) = T,
\]

so that \( T \) will be the total final number of infected individuals forecasted by the model. Typical graphics of such solution functions are given in figure (1).

Many other papers have been written on this topic using some more sophisticated mathematical tools such as the several SIERs epidemiological models (see Castilho et. al. [1], for instance) but we have preferred to use the logistic model exactly because of its simplicity. Furthermore we shall be studying the development of the epidemic in a relatively short period of time and very locally so that such approach is easily seen to be efficient.

3. Fitting the Wuhan case to the Model

The most valuable argument in favor of the use of the logistic model is the extremely nice way it shows to fit the iconic “closed case” of the COVID-19 epidemic in Wuhan as we see now.

Throughout this study we shall consider the data for the Chinese city of Wuhan, updated until April 21\(^{st}\). It is taken from the website Worldometer [10] and it is
presented in Section 8. We consider the Chinese quarantine policy used in there and we suppose the strict Chinese laws were so literally followed that the total amount of infected individual was the part of the population susceptible due to working conditions or that deliberately refused to quarantine. By April 13th, Continental China had 83,607 confirmed cases meanwhile the Hubei province had 67,803 confirmed cases (see [8]), mostly in its capital, meaning that Wuhan represents approximately 80% of all the Chinese cases.

Wuhan has a population $T_0 = 11,08$ million people living in a region of 8.494 $Km^2$ which features a demographic density of 1,304.45 inhabitants per $Km^2$ (see [11]). Therefore 67,803 individuals represent less than 0.5% of its total population. Thus we can consider that the quarantine regime in Wuhan has isolated 99.50% of its whole population. Furthermore, the demographic density of the susceptible exposed individuals during the epidemic was approximately 8 individuals per $Km^2$. That may have been the reason for the rapid success of the Chinese’s public policies.

We consider the date of January 22nd as the date of the beginning of the outbreak in Wuhan, with initial value of 571 infected individuals. Furthermore, on April 8th Wuhan lifted the quarantine restrictions which had been imposed to its population since January 23rd, so Wuhan can be considered as the first city in the world “free of COVID-19”.

We use software Mathematica to estimate the best values for the parameters $I_0$, $T$ and $r$ of the logistic model to fit Wuhan’s data. The “FindFit” tool of Mathematica, which does the fitting, is based on the least-square mathematical method to fitting date to a curve. For China it features:

\begin{align}
&I_0 \rightarrow 1315.32, \quad T \rightarrow 80875.7, \quad r \rightarrow 0.224114, \\
&I_c = \frac{1.09042 \times 10^8}{1344.19 + 79777e^{-0.222593t}}, \\
&I_w = \frac{8.72336 \times 10^7}{1344.19 + 79777e^{-0.2226t}}.
\end{align}

Based on our previous comment we consider that the function of the total number of infected individuals for Wuhan is 80% of the one for the whole China, so we get:

\begin{align}
&I_w = 0.8 \times I_c, \\
&I_w = \frac{1.09042 \times 10^8 \times 0.8}{1344.19 + 79777e^{-0.222593t}}, \\
&I_w = \frac{8.72336 \times 10^7 \times 0.8}{1344.19 + 79777e^{-0.2226t}}.
\end{align}

Also $r = 0.2226$ indicates the rate of infection in Wuhan. Several peculiarities for Wuhan and São Paulo (climate conditions, demographic density, advance preparation for the outbreak) would justify this rate of infection to be different in both cities. Also there is clearly a time delay between both onsets (January 22nd for Wuhan and February 25th for São Paulo), besides the difference for the initial data: 571 in Wuhan and 1 in São Paulo.

We now plot the function obtained with Mathematica together with the official data (figure 2) to see how incredibly good is the fitting for Wuhan:
Remark: We notice that the total number of infected individuals increased drastically on February 12th, in China, after a change in the official methodology for diagnosing and counting cases, thousands of new cases were added to the total figures (see figure 3). We believe this will cause no problem in our reasoning.

4. THE EFFECTS OF NON-PHARMACEUTICAL MEASURES IN WUHAN FROM AN ONGOING PERSPECTIVE

The quarantine in Wuhan was declared on January 23rd. The Chinese government closed down schools, churches and prohibited social clusters of any kind. Within about 15 days, around February 5th, the results started to be felt in the number of new cases of infected individuals (see figure 3).
measured from the day zero, i.e. from January 22\textsuperscript{nd}, until some days after February 5\textsuperscript{th}. We present such values of \( r \) and \( T \) in the table 1:

|                | Jan 22\textsuperscript{nd} | Jan 23\textsuperscript{rd} | Jan 24\textsuperscript{st} | Jan 25\textsuperscript{rd} | Jan 26\textsuperscript{th} | Jan 27\textsuperscript{th} | Jan 28\textsuperscript{th} |
|----------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| \( r \)        | 0.4574                      | 0.415475                      | 0.380517                      | 0.349581                      | 0.319166                      | 0.303118                      | 0.299476                      |
| \( T \)        | 17622                       | 21548                         | 26081                         | 31631                         | 39573                         | 45218                         | 46542                         |
|                | Jan 29\textsuperscript{rd}  | Jan 30\textsuperscript{th}   | Jan 31\textsuperscript{st}   | Fev 1\textsuperscript{st}    | Fev 2\textsuperscript{nd}    | Fev 3\textsuperscript{rd}    | Fev 4\textsuperscript{th}    |
| \( r \)        | 0.29459                     | 0.29355                       | 0.28922                       | 0.28530                       | 0.2825                        | 0.2256                        | 0.19371                       |
| \( T \)        | 48156                       | 48463                         | 49596                         | 50540                         | 51161                         | 69766                         | 94572                         |
|                | Fev 5\textsuperscript{rd}   | Fev 6\textsuperscript{th}    | Fev 7\textsuperscript{rd}    | Fev 8\textsuperscript{th}    | Fev 9\textsuperscript{rd}    | Fev 10\textsuperscript{th}   | Fev 11\textsuperscript{th}   |
| \( r \)        | 0.18725                     | 0.19019                       | .19480                        | 0.19919                       | 0.20281                       | 0.2072                        | 0.21095                       |
| \( T \)        | 102632                      | 99103                         | 94647                         | 91275                         | 88993                         | 86654                         | 85011                         |

Table 1. Values of \( r \) and \( T \) obtained from the fitting process in several dates around the beginning of the onset.

As it can be seen the value of \( r \) has been decreasing since the beginning of the quarantine period, on January 23\textsuperscript{rd}, but not enough to be able to cause a decrease in the total amount of infected individuals predicted by the model, \( T \). It is only after February 5\textsuperscript{th} (exactly, as expected, when the number of new cases start to decrease) that the decreasing in \( r \) suffices to cause an effective decrease in \( T \). We see that only when the fall of the value of the parameter \( r \) is about 58.41\% the decrease in the value of \( T \) can be noticed. Such a consistent decrease in the values of \( r \) was only possible due to strict quarantine rules.

5. Fitting the model to the data of São Paulo city

São Paulo city is Brazilian financial capital and it was the city where the first case of COVID-19 was confirmed in Brazil. The population of São Paulo city is around 12 million people which puts it into a very nice position to be compared to Wuhan (11.08 million inhabitants). Besides, it is big enough in several senses to be compared to several countries in Europe. The demographic density of São Paulo though is 7,398.26 \textit{inhabitants/km}^2 (according to IBGE’s census [9]) about 5.6 times that of Wuhan.

We have found some very trustable data of the epidemic for the city of São Paulo at the website of the state government (see [6]). Yet we question the values of the number of infected individuals in some specific dates in which they are very discrepant from the ones of the previous and following days. We attribute such distortions to several factors such as under notification, delay on the publication of the screening results as well as weekend and holiday periods. We believe such punctual discrepancies will not cause any problem in our analysis.

We now fit the data for the city of São Paulo, updated to April 21\textsuperscript{st}, (see Section 8) using again software Mathematica. We get the following function for São Paulo’s total number of infected individuals:
which means $r = 0.147662$ and $T \approx 12625$. We plot the graphic of the above function together with the official data obtained for São Paulo (see figure 4) to see that the matching is reasonably good:

![Figure 4. Total number of infected individuals fitting the data for São Paulo (updated to April 21st).](fig4)

6. Avoiding Total Collapse of the Health System of São Paulo

6.1. Estimating the reduction needed in $r$ to relieve the Intensive Care Units. According to local city authorities by the end of May of 2020, São Paulo shall have 1,440 Intensive Care Unit (ICU) beds in both public and private hospital network (promised 1,107 by the end of April, according to [5]). The mean need for these kind of hospital beds for COVID-19 patients in São Paulo city is about 30% of the number of infected individuals. Yesterday, April 21st, São Paulo city had 10,343 confirmed cases and the average time of intern hospitalization is of about 15 days. With the help of function $I_{sp}(t)$ given by (7) and software Mathematica we have computed when the total number of infected individuals of a period of 15 consecutive days reaches 3,840, for then, 30% of it: 1,152 would represent 80% of all the available ICU beds putting under alert the health ICU system. In figure (5) it is shown the period of time such a number of infected (minus the total number of casualties: 1114 ) is above 3,840 individuals. According to the model it has been happening since around day 47th (April 12th). If non public more strict intervention is taken the total amount of simultaneously infected individual shall grow up to 6,000 leading the number of total demand for ICU treatment to reach 1,800 before it starts to decrease, causing total chaos in the system.

We now present a study of how the public policies can help speed up the reduction of such figures. We do our analysis considering the actions as if they were taken yesterday, April 21st, the 56th day from the beginning of the outbreak of the epidemic in São Paulo, because it is necessary to have updated data in order to
Figure 5. The number of simultaneously infected individuals in a period of 15 days (disregarded the casualties).

get accuracy with the real situation. Using function $I_s(t)$ for day $56^{th}$ we get the following relation between $r$ and $T$:

$$10343 = I_s(56) = \frac{12.9213T}{(T - 12.9213)e^{-56r} + 12.9213}.$$  

We consider the following function

$$F(r, T) = 10343 - \frac{12.9213T}{(T - 12.9213)e^{-56r} + 12.9213}.$$  

Clearly $F(r_0 = 0.14766, T_0 = 12625) = 0$ and using the Implicit Function Theorem (see Section 8) we can estimate how much a small change (decrease in the case under study), $dr$, in the value of the parameter $r$, can cause in the value of $T$, the maximum number of infected individuals. If $dr$ is small, such corresponding change $dT$ is well approximated by the following relation:

$$dT = - \left( \frac{\partial F}{\partial r}(r_0, T_0) \right) dr = -176,960 dr,$$

Therefore in order to decrease $T$ from 6,000 to, say, 5,800 we need a reduction in $r$ of approximately 0.0011302, (were this action taken around April 21st). But the current value of $r$ is $r = r_0 = 0.14766$. Thus such a decrease represents a reduction of 0.76% in the value of the parameter $r$.

6.2. Estimating the necessary period of time for an specific reduction in the size of $r$.

Our last task is to be able to estimate how a decrease of 0.76% in the parameter $r$ can be realistic achieved and how long such a process shall take in São Paulo under its current quarantine regime restrictions.

The results of the public policies adopted in Wuhan shall give us a hint. An attentive look at table 1 shows us that the period of time taken for achieving an specific reduction on $r$ depends on “where in the curve we are”. So, what we must do first is to fit together the Wuhan and the São Paulo curves so that both curves can represent similar events at similar dates and after that quantify how long it took for the Chineses to get the reduction we want (0.76% in the value of $r$) at that
specific position in the curve. Then, we use it as a baseline for the same reasoning in the São Paulo case.

We consider that the first case in Brazil actually was diagnosed in São Paulo on February 25th in accordance with the website worldometer [10] (for the Brazilian government it were on the 26th). So the epidemic in São Paulo is in approximately 35 days of delay in relation to Wuhan (which first information of infected individuals is of 571 cases and it was done on January 22nd (see [10]). On the other hand the number of infected in São Paulo at time $t_0$ was just 1 individual. These differences of initial date and data does cause a big difference in the real dates and in the order of magnitude of the figures concerning Wuhan and São Paulo so that we shall include 2 “adjusting parameters”, $\mu_0$ and $K$ in order to better compare both data. Since we are considering the data in Wuhan being 80% of that of the whole China, we shall fit the curve of São Paulo, translated 35 days, to the curve of $I(t) = \mu_0 I_c(t) + K$, which we shall call “the adjusted curve of Wuhan”, so that the parameter $\mu_0$ takes care of the 80% factor in itself.

We search for a “shrinking + translation” of the curve for China in such a way to the adjusted curve to be “a best approximation” for the curve for São Paulo. This approximation should be such that, near day 21st their values as well as the values of their first derivatives are in “a best approximation”. This demands us to use the norm of the $C_1$-space, i.e. the space of functions with continuous first derivatives. Such a norm is given by:

\[ ||f|| = \text{Max}|f(x)| + \text{Max}|f'(x)|. \tag{11} \]

In figure (Figure (6)) we have plotted the values of the norms of the difference, $I_{sp} - I_c$ for values of $\mu \in (0.08, 0.085)$ and $K \in (5, 100, 6, 500)$. After refining such analysis we have found the optimum values to be $\mu_0 = 0.08$ and $K = 5,925$. In figure (7) we have plotted both graphics to see how well they match for such values of $\mu_0$ and $K$.

![Figure 6. The values of the norms of the difference $I_{sp} - I_w$ for several values of $\mu \in (0.08, 0.085)$ and of $K \in (5, 100, 6, 500)$.](fig7)

So we consider that the graphic of $\bar{I}(t) = 0.08I_c + 5,925 = 0.1(0.8I_c) + 5,925 = 0.1I_w + 5,925$ represents very well the curve of $I_{sp}$ translated 35 days backwards. We now use it to estimate how long the quarantine period in Wuhan took to produce a reduction of 0.76% in the value of the parameter $r$. 
We have computed the values of the parameter $r$ relative to the data of Wuhan on days 21st and 22nd and they were found to be $r_{21} = 0.2825$ and $r_{22} = 0.22563$ respectively which means a decrease of 20.13% in the value of the parameter $r$ at this position on the curve. We suppose linearity of these relations in here and therefore, under this hypothesis, a decrease of 0.76% could be achieved after 54 minutes. As we have already pointed out the demographic density of the exposed (non quarantined) susceptible individuals of Wuhan was 8 individuals per km$^2$ on the other hand the mean level of quarantined portion of the population in São Paulo is accounted to be around 50% of its total population (according to website [7]) which means about 6 million individual wandering over a total area of 1,622 km$^2$ meaning a demographical density of approximately 3,700 individuals per km$^2$ which means approximately 462.5 times the demographical density of exposed individuals in Wuhan. We use a simple rule of direct proportion to estimate the time spent in the city of São Paulo (under a quarantine of 50% of the total population) to decrease the number of total infected individuals from 6000 to 5800, (i.e. around 3.3%): $54 \times 462.5 = 1387.5$ minutes, i.e. 17.45 days.

The final conclusion is that a decrease of 0.76% in the value of $r$ in the city of São Paulo, would take 17.45 days and that would cause a reduction of about 3.3% in the number of total simultaneously infected individual, supposing a quarantine accession of 50% of the whole population.

We repeat the above analysis for several other cases of quarantine accession and corresponding reductions in $r$ of 2%, 3%, 5% and 7%. We point out that the level of imprecision of our forecasting increases when the percentages of reduction of $r$ increases. The results are presented in table (2).

| $\eta$ | 50%  | 55%  | 60%  | 65%  | 70%  | 75%  | 80%  |
|--------|------|------|------|------|------|------|------|
| 2%     | 10.55| 9.5  | 8.43 | 7.38 | 6.32 | 5.27 | 4.21 |
| 3%     | 15.82| 14.24| 12.65| 11.07| 9.49 | 7.9  | 6.33 |
| 5%     | 26.37| 23.73| 21.1 | 18.46| 15.82| 13.18| 10.55|
| 7%     | 37   | 33.22| 29.5 | 25.84| 22.15| 18.46| 14.77|

Table 2. Total amount of days to a decrease of $\eta\%$ in the value of the parameter $r$ under quarantine regime of $\Delta\%$ of accession.
7. Conclusion

We have used the logistic model to represent the COVID-19 epidemic in the city of Wuhan in China with astonishing good fitting. We analyze the effect some non-pharmaceutical measures has had in the epidemic spreading in Wuhan. Specifically we estimate how many days of a 99.40% effective quarantine are necessary to decrease the spreading parameter $r$ by 0.76%.

We use the same model to the ongoing epidemic in São Paulo to forecast its final endings. We conclude that if nothing else be done the number of infected people in São Paulo will reach 20,000 around May 1st.

Based on the official number of ICU beds in the public and private health system we mathematically estimate the amount of reduction in the parameter $r$ which is necessary to cause a decrease in the value of the total number of simultaneously infected individual in need of special intensive care in order to guarantee this number remains below 80% of the total capacity of ICU beds. Then, based on the experience in Wuhan, we have estimated how restrict a quarantine must be in order to produce this desired reduction in the parameter $r$.

Based on this study we strongly advice the local government of the city of São Paulo to urgently adopt the implementation of the public measures listed below:

1. The most important measure to be taken undoubtedly is to increase the level of social adherence to the quarantine by any means as possible such as advertising campaigns, heavy fines to the infractors, etc. This makes the results of quarantine for São Paulo closer to those of Wuhan making more effective the decrease in $r$.

2. Decrease the number of infected (or possibly infected) individuals in public areas by adopting the use of infrared cameras to detect fevers, massive screening of the population and consequent massive hospitalization of infected individuals. This promotes a decrease in the number of $I(t)$ in contact with $T - I(t)$.

3. Reinforce the importance of sanitation measures such as frequent hand washing and to make mandatory the use of face masks, gloves and goggles in public areas. This causes a direct decrease in the rate of contagious determined by $r$.

Such measures shall decrease the value of the parameter $r$ pushing the curve of total number of infected individuals forward as well as decreasing the final number of total infected individuals. Both consequences shall relieve the demand pressure on the need of hospitalization as well as on the demand for ICU beds as a whole.

8. Appendix

We present the Implicit Function Theorem used in Section 6:

**Theorem 1.** Suppose $F : \mathbb{R}^2 \to \mathbb{R}$ is a continuously differentiable function defining a curve $F(x, y) = 0$. Let $(x_0, y_0)$ be a point on the curve such that $F(x_0, y_0) = 0$ and $\frac{\partial F}{\partial y}(x_0, y_0) \neq 0$ then for the curve around $(x_0, y_0)$ we can write $y = f(x)$, where $f$ is a real differentiable function. Furthermore:

$$f'(x) = -\left(\frac{\partial F}{\partial x}(x_0, y_0) \frac{\partial F}{\partial y}(x_0, y_0)\right).$$
We now present in table (3) below the total number of infected individuals up to the corresponding dates both for Wuhan and São Paulo city obtained from the website worldometer ([10]) and the website of the local government of the city of São Paulo ([6]) accessed along the months of March and April of 2020.

REFERENCES

[1] Castilho, C., Gondim, J., Marchesin, M., Sabeti, M.: “Assessing the efficiency of different control strategies for the coronavirus (covid-19) epidemics”. Preprint submitted to the Electronic Journal of Differential Equations. Also on ArXiv: http://arxiv.org/abs/2004.03539

[2] Ferguson, N.M. et.al. “Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand”. Imperial College COVID-19 Response Team. March 16th (2020) Preprint at https://mcacsc.org/multimedia/files/COVID19.pdf

[3] Li Q, Guan X, Wu P, et al. “Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia”. N Engl J Med (2020); published online Jan 29. DOI:10.1056/NEJMoa2001316. 35.

[4] Maia Martcheva, “Introduction to epidemic modeling, An Introduction to Mathematical Epidemiology”, Springer, 2015, pp. 931.

[5] Website of the newspaper “Folha de São Paulo”: https://agora.folha.uol.com.br/sao-paulo/2020/04/gestao-covas-abre-mais-29-leitos-de-uti-para-tratar-coronavirus.shtml. Accessed on April 27th (2020).

[6] Website of the city government of São Paulo: https://www.prefeitura.sp.gov.br. Accessed throughout March and April (2020).

[7] Website of Globo television network: g1: https://g1.globo.com/. Accessed on April 20th (2020).

[8] Website of Statistics Institute in China https://www.statista.com/statistics/1090007/china-confirmed-and-suspected-wuhan-coronavirus-cases-region

[9] Website of the Brazilian Institute of Estatistics and Geography (IBGE) https://www.biblioteca.ibge.gov.br

[10] Website Worldmeter http://www.worldometers.info/coronavirus/country/brazil. Accessed throughout March and April (2020).

[11] Website of Wikipedia: https://pt.wikipedia.org. Accessed on April 18th (2020).

[12] Wu P, Hao X, Lau EHY, et al. “Realtime tentative assessment of the epidemiological characteristics of novel coronavirus infections in Wuhan”, China, as at January (2020). Eurosurveillance 2020; 25(3): pii=2000044.

[13] Wu, J.; Leung, K.; Leung, G.: “Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan”, China: a modelling study, The Lancet, 395(10225)(2020), 689 – 697.

(M. Marchesin) DEPARTMENT OF MATHEMATICS, FEDERAL UNIVERSITY OF MINAS GERAIS (UFMG), BELO HORIZONTE, BRAZIL.

E-mail address: mmd@mat.ufmg.br
| DATE   | CHINA | SAO PAULO | DATE   | CHINA | SAO PAULO |
|--------|-------|-----------|--------|-------|-----------|
| Jan 22nd | 571   | 0         | Mar 12th | 80813 | 42        |
| Jan 23rd | 830   | 0         | Mar 13th | 80824 | 54        |
| Jan 24th | 1287  | 0         | Mar 14th | 80844 | 62        |
| Jan 25th | 1975  | 0         | Mar 15th | 80860 | 136       |
| Jan 26th | 2744  | 0         | Mar 16th | 80881 | 147       |
| Jan 27th | 4515  | 0         | Mar 17th | 80894 | 154       |
| Jan 28th | 5974  | 0         | Mar 18th | 80928 | 337       |
| Jan 29th | 7711  | 0         | Mar 19th | 80967 | 347       |
| Jan 30th | 9692  | 0         | Mar 20th | 81008 | 358       |
| Jan 31st | 11791 | 0         | Mar 21st | 81054 | 450       |
| Feb 1st  | 14380 | 0         | Mar 22nd | 81093 | 453       |
| Feb 2nd  | 17205 | 0         | Mar 23rd | 81171 | 477       |
| Feb 3rd  | 20440 | 0         | Mar 24th | 81218 | 484       |
| Feb 4th  | 24324 | 0         | Mar 25th | 81285 | 722       |
| Feb 5th  | 28018 | 0         | Mar 26th | 81340 | 899       |
| Feb 6th  | 31161 | 0         | Mar 27th | 81394 | 1044      |
| Feb 7th  | 34546 | 0         | Mar 28th | 81439 | 1108      |
| Feb 8th  | 37198 | 0         | Mar 29th | 81439 | 1197      |
| Feb 9th  | 40171 | 0         | Mar 30th | 81518 | 1233      |
| Feb 10th | 42638 | 0         | Mar 31st | 81554 | 1885      |
| Feb 11th | 44653 | 0         | April 1st | 81589 | 2418      |
| Feb 12th | 58761 | 0         | April 2nd | 81620 | 2815      |
| Feb 13th | 63851 | 0         | April 3rd | 81639 | 3202      |
| Feb 14th | 66492 | 0         | April 4th | 81669 | 3496      |
| Feb 15th | 68500 | 0         | April 5th | 81708 | 3612      |
| Feb 16th | 70548 | 0         | April 6th | 81740 | 3754      |
| Feb 17th | 72436 | 0         | April 7th | 81802 | 4258      |
| Feb 18th | 74185 | 0         | April 8th | 81865 | 4947      |
| Feb 19th | 75576 | 0         | April 9th | 81907 | 5471      |
| Feb 20th | 79465 | 0         | April 10th | 81953 | 5982      |
| Feb 21st | 76288 | 0         | April 11th | 82052 | 6131      |
| Feb 22nd | 76936 | 0         | April 12th | 82160 | 6352      |
| Feb 23rd | 77150 | 0         | April 13th | 82249 | 6395      |
| Feb 24th | 77658 | 0         | April 14th | 82295 | 6418      |
| Feb 25th | 78064 | 1         | April 15th | 82341 | 7764      |
| Feb 26th | 78497 | 1         | April 16th | 82367 | 7908      |
| Feb 27th | 78824 | 1         | April 17th | 82692 | 8744      |
| Feb 28th | 79251 | 1         | April 18th | 82719 | 9428      |
| Feb 29th | 79824 | 2         | April 19th | 82735 | 9668      |
| Mar 1st  | 80026 | 2         | April 20th | 82747 | 9815      |
| Mar 2nd  | 80151 | 2         | April 21st | 82758 | 10342     |
| Mar 3rd  | 80270 | 3         | April 22nd | 82788 | 10691     |
| Mar 4th  | 8040  | 3         | April 23rd | 82798 | 11225     |
| Mar 5th  | 80552 | 6         | April 24th | 82804 | 11800     |
| Mar 6th  | 80651 | 10        | April 25th | 82816 | 13098     |
| Mar 7th  | 80695 | 13        | April 26th | 82827 | 13513     |
| Mar 8th  | 80735 | 14        | April 27th | 82830 | 13989     |
| Mar 9th  | 80754 | 15        | April 28th | 82836 | 15397     |
| Mar 10th | 80772 | 19        | April 29th |       |           |
| Mar 11th | 80793 | 30        | April 30th |       |           |

**Table 3.** Total number of infected individuals in Wuhan and in São Paulo up to the mentioned dates.