STRATEGIES TO DEAL WITH EPIDEMICS USING A SYSTEM DYNAMICS MODEL: A COVID-19 STUDY CASE[1]

Alvimar de Lucena Costa Junior[a]*, Mischel Carmen Neyra Belderrain[b]

[a]Programa de Pós-Graduação em Ciências e Tecnologias Espaciais, Gestão Tecnológica – CTE-G
Instituto Tecnológico de Aeronáutica – ITA, São José dos Campos-SP, Brasil

[b]Departamento de Ciências Fundamentais, Gestão e Apoio à Decisão
Instituto Tecnológico de Aeronáutica – ITA, São José dos Campos-SP, Brasil

RESUMO

Este artigo apresenta um modelo em Dinâmica de Sistemas que permite verificar algumas estratégias de como lidar com a epidemia de COVID-19, usando como base o modelo clássico epidemiológico SIR. Três estratégias foram testadas, baseadas no principal objetivo de políticas públicas, que deve ser salvar vidas. Também foi testado o efeito do atraso na ação por parte de autoridades. Das estratégias testadas, entre a extensão de quarentena, a quarentena vertical e a identificação de infectados, a considerada mais promissora foi a de identificação de infectados e a menos aconselhável é a de quarentena vertical. Além disso, a simulação indicou que o enrijecimento da quarentena a qualquer tempo tende a poupar vidas, mas a tomada de ação tardia de autoridades pode trazer prejuízos certos ao sistema de saúde de um país, o que pode impactar diretamente também na letalidade da epidemia.

Palavras-chave: Dinâmica de sistemas, COVID-19, Suporte à decisão.

ABSTRACT

This paper presents a System Dynamics Model to verify well-known strategies to deal with the COVID-19 outbreak, based on the classical epidemiological SIR model. Three main strategies were tested, considering the idealized main goal of public policies, to save lives. In addition, the authorities' reaction time on implementing actions to control the pandemic is analyzed. From the tested strategies, between quarantine extension, vertical quarantine, and identification of infected persons, the most promising is to identify infected persons and the least suitable is vertical quarantine. Also, the simulations indicated that tightening quarantine at any time tends to save lives, but late action by authorities can bring overpressure on a country's health care system, which has also direct impact on the lethality of the epidemic.

Keywords: System dynamics, COVID-19, Decision support.

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*Autor para correspondência. E-mail: alvimar.lucena@gmail.com / lucenaalcj@ita.br

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[1]*Todos os autores assumem a responsabilidade pelo conteúdo do artigo.*

1. Introduction

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is the virus that causes the new Corona Virus Disease, 2019 (COVID-19). The WHO (World Health Organization, 2020a) COVID-19 timeline indicates that the first information about the novel disease was on Dec 31, 2019. After five months, information on the COVID-19 is still uncertain, and new characteristics of the infection are identified every day. At the present date (May 15, 2020), WHO statistics point to 4,248,389 cases (77,965 new cases on May 14, 2020) and 292,046 deaths (4,647 new deaths reported on May 14, 2020). Brazil is reported as the current epicenter of Latin America, with 202,918 confirmed cases (13,944 new cases on May 14, 2020) and 13,993 deaths (844 new deaths reported on May 14, 2020) (Ministry of Health of Brazil, 2020).

So far, it is known that COVID-19 is significantly more harmful when it affects the elderly, requiring different strategies for each group.

Recently published articles indicate that the infectivity of COVID-19 (R0) is greater than previous coronavirus outbreaks. The calculated R0 for SARS-CoV-2 ranges from 6.47 (Tang et al., 2020) to 5.7 (Sanche et al., 2020). For comparison, the 1918 global swine flu outbreak had an estimated R0 value between 1.4 and 2.8 (Coburn et al., 2009), for the 2009 H1N1 pandemic it was assessed between 1.4-1.6 (Coburn et al., 2009) and for measles, R0 is often cited as being between 12-18 (Guerra et al., 2017).

The global spread of the disease requires action by governments around the world. Most initiatives have focused on establishing quarantines of different levels and closing agglomeration sites (Zhu et al., 2020). Social distancing, as defined by the American Centers for Disease Control and Prevention (CDC, 2020), is the main strategy, i.e., to stay within two meters of each other, not to meet in groups, to stay out of crowded places, and to suspend most economic activities except those classified as essential. Some countries have adopted the "Lockdown", where people are forced to stay inside their homes, leaving it only in special cases, such as to buy food or go to the doctor. Quarantine strategies have as a common result the drastic reduction or complete suspension of economic activities, relying on the practices of home-office when possible. A report by the World Bank Group (Maliszewska et al., 2020) sees the world's gross domestic product declining by 2%, with 2.5% for developing countries and 1.8% for industrialized countries, due to restrictions associated with Social Distancing and Lockdown.

Currently, many countries are dealing with COVID-19 along with its economic effects. A likely effect of declining GDP worldwide could be to further accentuate the health system problems of less developed countries, which could eventually lead to an increase in the overall mortality rate, as some studies suggest (Hone et al., 2019). Countries with little or no monetary reserves will be more affected by the consequences of Social Distancing. Thus, strategies should cover both economic and health aspects and be able to measure how to balance them.

In the current scenario, many countries seem to be divided into only two alternatives to deal with the economic effects and health problems: making quarantine more restricted, to avoid further contamination, and/or loosening it, allowing people to return to their jobs and schools.

This article presents a simulation model in System Dynamics to help find a balance in different strategies on the COVID-19 epidemic, seeking to understand the results of changing control variables available to State Authorities, and trying to find viable alternatives based on the real objective pursued, i.e., saving lives. The balance between health and economic aspects is not covered, since, under current conditions, such aspects are still unclear in academic simulation studies.

This article is divided into five Sections. This introductory Section describes the problem to be focused on in the document, and its basic context. Section two reviews the literature on reference to epidemic models, focusing on System Dynamics, and what is known about the numbers of OVID-19, as well as the gap that this work intends to fill. Section three describes and justifies the use of System Dynamics on the theme and limitations of the model. Section four brings the results and findings of the simulations. Section five lists the conclusions and implications of the results.

2. Review of Literature

2.1. Bibliographical Search

Mathematical epidemic behavior has long been cited in academic literature. Kermack and McKendrick, in 1927, described most variables that define epidemic simulations currently used, including population phases, exponential curves and rates that mathematically describe the classical SIR model (Susceptible, Infected, and Recovered population).

This mathematical SIR model inspired a classical System Dynamics Tutorial by Sterman (2000) and subsequent works that presented models using this basis, such as the simulation of SARS spread in 2002 (Wang et al., 2009) and that of MERS-Cov in 2015 (Shin et al., 2017).

The development of the SIR model, also available in Kermack and McKendrick (1927), is the SIRD model, where the stock "Dead population" (D) is included and computed, making the recovered population smaller within each interaction.

Looking for references that worked in the same path, none showed a model with the considerations proposed in this work. From the Scopus database (Elsevier), the terms "System Dynamics" together with "COVID-19" returned an article (from May 18, 2020), still to be published in Aug 2020 (Ibarra-Vega, 2020), which deals with the classic 2000 Sterman SIR model, and some results related to the duration of quarantine. In another research, also using Scopus base, the term "System Dynamics" was combined with the keywords "Coronavirus", "SARS-CoV-2", "Disease Outbreak" and a total of twelve articles were found, including the 2020 Vega article already cited. The combination of keywords limited to "System Dynamics" and "Epidemic", did not return any work related to the new COVID-19, although 60 papers were found, none of them proposing a deviation from the classic System Dynamics SIR Model to study a specific behavior of a given disease. This broader list of articles shows a total of 934 keywords of which 57 articles cited the keyword "system dynamics" and 41 articles cited "epidemics".

2.2. Framework

International headlines and political speeches are divided between two discourses: one of the "Save the Economy" type, against quarantine and its economic consequences, and the other of the "life is what matters" type, seeking an extension of quarantine and isolation policies until the spread of infection is considered impossible. Keeney (1992) referred to this way of thinking as "alternative-focused thinking", where decision-makers tend to choose between some alternatives that are clearly established rather than determine their true objective, seeking the real value that the decision must seek and the possible ways to achieve this value. As opposed to this way of thinking, Keeney suggested Value Focused Thinking (VFT), a detailed Problem-Structuring Method (PSM). Applying this idea in an abbreviated form, the conclusion is that the Goal should be "Save Lives" in a broader sense.

As a complex system, the impact of the isolation and confinement of most of the workforce in the world economy can only be measured in small steps of interaction, using specific economic variables such as GDP or the unemployment rate. Trying to escape any prejudice resulting from the current heated discussions on the subject, papers have been recently published before any news about the outbreak of COVID-19 was mentioned. According to Hone (Hone et al., 2019), an increase in the unemployment rate of one percentage point was associated with an increase of half a percentage point in the mortality rate (95% CI 0.09-0.91) by all causes, especially, in this case, due to cancer and cardiovascular diseases, where most of the increase was computed in the black and mixed race population, without significant association with the white population. Although the proportion of changes in deaths in this study is related to the mortality rate of the country, not its total population, it shows that a balance must be sought between the measures taken. Taking this result into consideration, the best likely way to achieve the goal of "Saving Lives" would be a mixed strategy, between the

complete Lockdown, with an increasing impact on the economy and mortality rates of minorities and the poorest population, and the policy of "open doors", which would certainly compromise the risk group of this new disease.

Determining what this mixed strategy might look like is the goal of this document, using simulations of System Dynamics to understand how specific strategies will work over time, and how certain measures may affect the system in the future (Kunc and Morecroft, 2007).

3. Methodology

Based on the Kermack and McKendrick (1927) SIRD System Dynamics Model (SDM), information gathered from updated sources guided the development of a Stock-and-Flow model, comprehending many specific characteristics for the present disease outbreak.
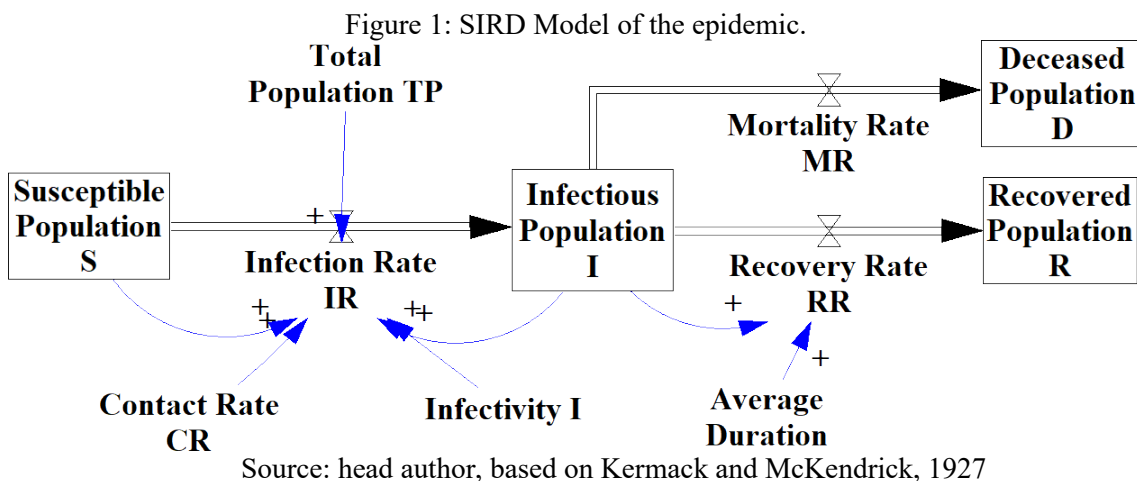
3.1. Classical SIRD System Dynamics Model

Based on the mathematical description (Kermack and McKendrick 1927), the main variables involved in an epidemic model are groups of the population, divided into susceptible, infected, recovered, and deceased (SIRD).

The rate at what people are infected is a function of the Contact Rate of this population and the Infectivity of the disease, where the Contact Rate is how many people one person has contact (physical contact, get nearby to someone) during one time-step of the simulation, and Infectivity is the proportion of the contacts between Susceptible and Infected people that became a new infection during one time-step of the simulation.

The rate at what people recover (or die) from the infection is a variable that is also included in the system, depending on the average duration of the disease. The Recovery Rate is the Infectious Population

Figure 1 illustrates the SDM that includes all these points.

Figure 1: SIRD Model of the epidemic.

Source: head author, based on Kermack and McKendrick, 1927

Dynamic Hypotheses on the behavior for COVID-19 were used to adapt and customize the SIRD System Dynamics Model for the present study.

3.2. Case Study in São José dos Campos, Brazil

Brazil is the largest country in Latin America and has the fifth largest population in the world. At the time of this study, it is the country most affected by COVID-19 in the subcontinent.

The Brazilian Health System is centralized and is of interest for comparison with non-centralized health systems and large populations.

São José dos Campos is a medium-sized city, geographically located between the two largest cities in Brazil, with an estimated population of 721,944 according to the Brazilian

Institute of Geography and Statistics (IBGE, 2019a). Its health system can be reported as of average quality in Brazil, being in the central third in all health indicators available (IBGE, 2019a). This city was chosen to represent and validate model strategies based on these characteristics.

The data used to validate the model are from the epidemiological reports of the city of São José dos Campos (São José dos Campos City Hall, 2020).

3.3. Customization of Classic SIRD SDM: Dynamic Hypothesis

Age

The first Dynamic Hypothesis considered for the behavior of COVID-19 is that it attacks older people more severely. Significantly higher lethality rates were observed in the group.

US reports on patients with COVID-19 indicate that the Confirmed Death Rate (CFR) was 1% for persons under 65 years old and 6% for persons over that age (Sanche et al., 2020). In Spain, the CFR for people under 70 years old was, until May 16, 2020, 1.72%, and the CFR for people over 70 years old was 18.8% (CCAES, 2020). In Italy, according to the Italian Health Secretariat, at Mar 31, 2020, the CFR for people under 70 years old was 3.21% and for people over 70 years old it was 24.68%. In the city of São José dos Campos, the CFR for people under 70 years old was calculated at 3%, and for people over 70, 23%.

The reasons why the older fraction of the population is more susceptible to complications due to COVID-19 are not yet fully understood.

This difference in behavior of the group inspired the customization of the SIRD stocks for each fraction of the population on this SDM proposal. In the 2019 IBGE population estimate, São José dos Campos had 4% of the population over 70 years of age.

Infectivity (I) and Contact Rate (CR)

Scientists have tried to measure the speed of the spread of COVID-19, but a major barrier to this measurement is effectively determining the presence of the disease. Underreporting (Mellan et al., 2020) makes it very difficult to have correct numbers and therefore accurate calculation of the infectivity of COVID-19 and its CFR. In addition, the effectiveness of the available tests is an important error to be accounted for, since the rate of false negative results in the test kits for COVID-19 was reported at 29% when compared to the sensitivity of Computed Tomography of the Chest (Fang et al., 2020).

With respect to the SDM Infectivity variable, an epidemiological equivalent medical metric to support it is R0 (R-nough, also known as the reproduction number), a mathematical term that indicates how contagious an infectious disease is (Delamater et al., 2019). As the infection is transmitted to new people, it multiplies in the population (Ramirez and Biggers, 2020). Although there are such problems in measuring the R0 of COVID-19, the infectivity of the new disease is considered high by publications already available.

For the current SDM, the value represented for the R0 is a composition of the Infectivity (I) and Contact Rate (CR) variable, both proportional to R0. The values described in Sterman (2000) for an outbreak of a respiratory disease were considered as the baseline for the Contact Rate (CR) (10 people per person per day). The value of infectivity was adjusted by validation in the values of São José dos Campos at the beginning of the outbreak and will be discussed later in this article.

Recovered Population

On its Scientific Brief on 24APR2020, WHO declares that "there is currently no evidence that people who have recovered from COVID-19 and have antibodies are protected from a second infection" (WHO, 2020b). However, recently published research (Ni et al., 2020) indicates that recovered people keep showing antibodies after discharged from hospitalization, which implies both that these people retain its immunity during a certain amount of time and that an effective vaccine is possible.

Another relevant hypothesis in this paper is that data on recovered cases are less precise than infected cases, because of the hospitalization rate and the asymptomatic fraction of the population.

This way, as on Classic SIRD SDM, the recovered population can dilute the contagious effect of the infected population, decreasing the probability of Infected-Susceptible Contacts (ISC).

Average Duration of Infection

The duration of infection related to COVID-19 is still under discussion (Sanche et al., 2020). The average duration of the disease seems to be influenced by how the infection occurred and by the symptomatic response of the infected subject. To cover the large sigma distribution reported (from 33% to 43%), an Average Duration of 14 days was arbitrarily chosen.

The model also considers that deaths take at least one day longer than recovery and are distributed according to the average period of hospitalization. Reference articles show that these discharge times may have been longer in China, from 11.5 days for discharge to 16 days for death in hospital. The period of difference for death outcomes was not considered, since hospitalized persons are already separated from the population during treatment and take a small part in the spread, except for health personnel, a population in which infection has a particular dynamic.

Proportion of Worst Cases

COVID-19 is a disease that presents similar behavior to other types of flu. Some people are strongly affected, others go through it in an almost asymptomatic way. The Center for Evidence-Based Medicine at Oxford University (Heneghan et al., 2020) has studied 21 reports on asymptomatic controlled outbreaks and has reached an asymptomatic cases proportion between 5% and 80%. The case of Diamond Princess, a cruise ship that confined 3,711 people on board, was closely studied and reported an estimated asymptomatic proportion of 17.9%.

The fraction of interest for SDM is the proportion of infected people who should be hospitalized. For Spain (CCAES, 2020), cases confirmed up to May 16, 2020 had a rate of 3.5% of hospitalization in the Intensive Care Unit (ICU), with little difference in age distribution (3.4%). For the USA, on the other hand, the differences between age groups vary between 0.5 and 17 for every 100,000 (Garg et al., 2020).

The problem related to calculating the specific hospitalization rate lies in the aforementioned asymptomatic and mild cases, as many people refuse or simply do not care to take the COVID-19 test. The best available estimate for hospitalization, based on extensive testing resources, was the proportion presented by Spain.

The mortality rate in ICU cases is reported in the same documents, and the model uses 3% for people under 70 and 25% for people over 70.

3.4. Customization of Classic SIRD SDM: Control Variables and Strategies

The procedures to achieve the value-focused goal must deal with the number of dying people. There are two possible options to prevent people from dying from any contagious disease: isolating people until there is a vaccine or learning how to treat all infected people. For the first option, the shortest estimated time until a certified vaccine exists is between twelve and eighteen months (Spinney, 2020).

For the second option, treatment protocols are being tested every day but still need to be confirmed as effective. One hypothesis considered is that the people who have the best medical care will have the best chance to survive. As a result, most available strategies are related to keeping as few people infected as possible, so that the number of people requiring hospitalization is kept below the capacity of the Health Systems, until such time as the vaccine is available and globally produced on a scale of eight billion.

This item discusses the strategies to be implemented and simulated on the model to achieve the value of saving lives.

Days to start the strategy

Governments tend to be slow to decide on drastic strategies, and even slower when it comes to unpopular drastic measures, which may not be supported by their voters.

Newspapers reported the first blockade in Wuhan, China, which began in Jan 23, 2020, but the Chinese government's first official communication to the World Health Organization of a new coronavirus was on Dec 31, 2019 (WHO, 2020a), meaning that the Chinese government knew the seriousness of the problem at least 23 days before taking action.

On Dec 23, 2019, the U.S. Centers for Disease Control and Prevention (CDC) learned of cases in China and began developing reports for the Department of Health and Human Services (HHS) on January 1. Ohio (US State) reported a case of COVID-19 on Jan 06, 2020. Although there were some quarantines requested by the CDC in the U.S., state and local governments began to declare quarantines only in Mar, 2020 (Wikipedia, 2020), about 70 days after the first reported infection in the country.

In Brazil, the first reported case was on Feb 08, 2020, in São Paulo, and the first quarantine order was issued on Mar 13, 2020, to begin on Mar 16, 2020, 37 days after the first case.

Even in Brazil and the USA, countries that already had knowledge of a new outbreak of coronavirus disease, the time to start the new strategy was an important issue, and this SDM studied its sensitivity results.

In the current SDM, the baseline is a 20-day delay for the municipal government's reaction, from an initial stock of an infected population of 20 people, based on data from São José dos Campos.

Days to finish strategy

The same rationale applies to the end of some strategy. The day when a quarantine should end is also a matter of study, as well as a change of strategy is capturable.

Decrease Infected People Contacts

The SDM infection rate variable depends on the total number of infected people among the total susceptible population. Thus, one way to control this infection rate would be to minimize contacts between infected and susceptible people, corresponding to minimize infected-susceptible contacts (SIDS).

On this SIRD SDM, the strategy is translated on the Contact Frequency (CF) variable, a component of the Contact Rate. CF varies according to how the population is free to circulate and meet other persons. On a "lockdown" (the worst type of quarantine), each person would meet no more than one person per day (p/p/day) on average. On a normal day, it is considered that the CF is ten p/p/day. On a party season, like the carnival, these numbers could rise fifteen p/p/day.

The CF variation and sensibility analysis are correspondents to the study of the types of quarantine that a State may impose.

Another way to decrease ISC would be identifying the infected people and isolating them from the rest of the population. Testing is a way to identify infected people but is not the only one.

On the WHO protocols for epidemic outbreaks (WHO, 2014), one of the procedures is to investigate all people who had contact with identified infected persons, and, therefore, isolate them. The efficiency of this investigation may be very high during the early periods of an outbreak.

The control variable WideTesting translates this search for infected persons, as a degree of identification efficiency.

The WideTesting variable means what fraction of the infected population was identified. This way, zero means that no infected is identified. 10% (0.10) means that the government knows who is 10% of infected people. From the proportion of infected people identified, State should calculate the number of tests needed, based on an initial supposition of the infected population.

Decrease Contacts among Riskier Groups

The last control variable discussed is based on the mentioned distinct lethality rates in age groups. A control variable would be to impose a quarantine on the older group of people, which concentrates the individuals most at risk of, if infected, developing the most lethal form of COVID-19. This strategy was called Vertical Quarantine.

The idea would be to restrict contacts between the infected population and older people, thus reducing the number of deaths. This would allow the younger workforce to return to active economic life, while the older fraction would be protected in isolation.

The critics of this Vertical Quarantine understand that in some countries, where many parents live with their adult sons, the efficiency of this strategy is highly questionable. For example, in Brazil, according to the newspaper Folha de São Paulo collaborating with specialists from the Minas Gerais Federal University, 25% of the older population lives with three or more younger family members, and 60% lives with one or more persons that would not be isolated in a Vertical Quarantine (Barbon, 2020). This way, we might consider that only 15% of the older population would be adequately isolated on this type of quarantine, but all range of this practice will be analyzed using the Customized SIRD SDM

3.5. Customized SIRD SDM: Environmental Variables

The city of São José dos Campos is the baseline for the study and its numbers on COVID-19 up to May 08, 2020.

All environmental variables, like Population, fraction over 70 years old, death rates, ICU needs, are already defined in previous sections.

The period for simulations was established as one year (365 days). Time-step was one day.

3.6. Customized SIRD SDM: Results to Be Measured

The main result to be measured and compared on the Sensitivity Analysis for the Customized SIRD SDM is the "number of deaths", directly related to the Value Focused objective of the listed control strategies.

The "number of Intensive Care Unit (ICU) beds needed" would be a direct function of the "number of infected people". This way, the peak of the number of Infected People and the time to get to this peak is also an important number to be followed.

3.7. Limitations of Customized SIRD SDM

Given all estimates that are used on the model, and all the fast changes each variable takes, the numbers that result from the simulation are not to be taken as directly valid. The exponential nature of SDM tends to make small deviations of variables result in large errors after some iterations. This way, all analysis should be focused on the tendencies of the stocks, rates, and variables of interest.

Validation tests of SIRD SDM were conducted according to Forrester and Senge (1980) confirming its usefulness on the Structure-Verification Test to the Sterman SIR SDM and the Extreme-Conditions Test for the behavior on the sensibility analysis results, as well as behavior sensitivity.
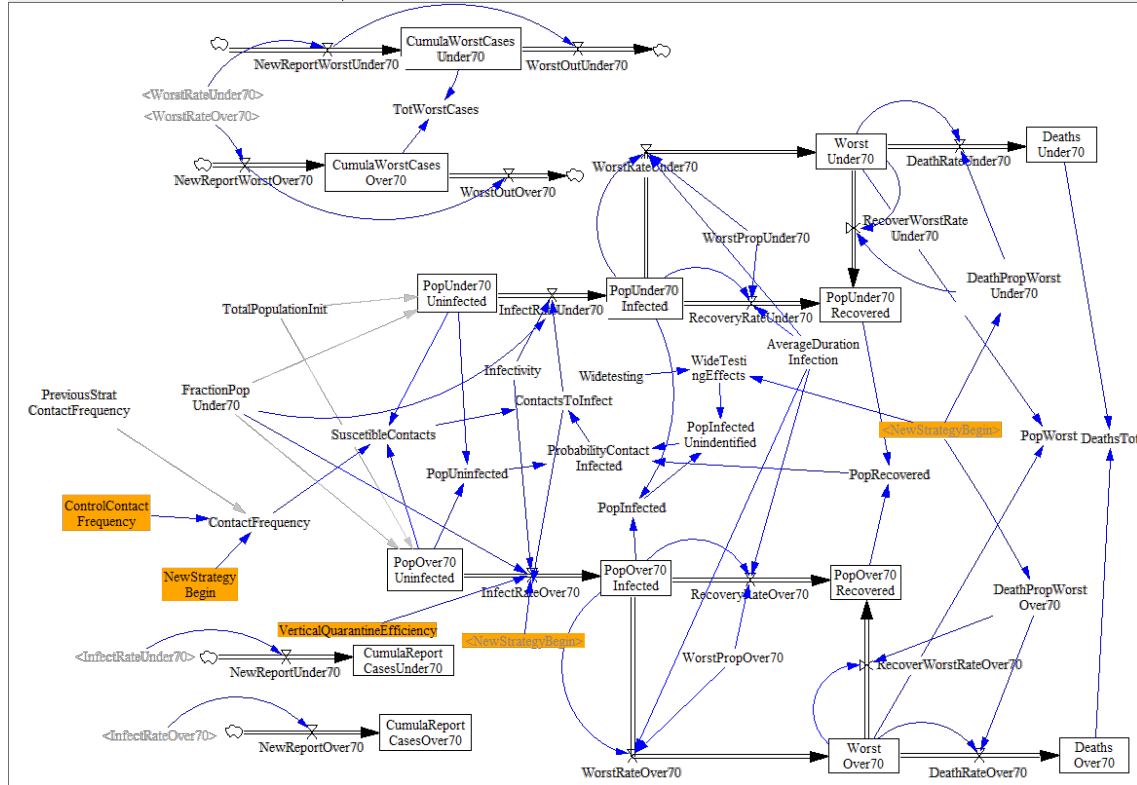
4. Findings and Results

This Section will first describe the Customized SIR SDM, on item 4.1. Then, on 4.2, it will establish the Baseline results.

After that, on items from 4.3 to 4.6, a sensibility analysis for four different Strategies are described.

4.1. Customized SIR System Dynamic Model

Figure 2 illustrates the proposed model, designed on VENSIM PLE Plus, version 7.0.

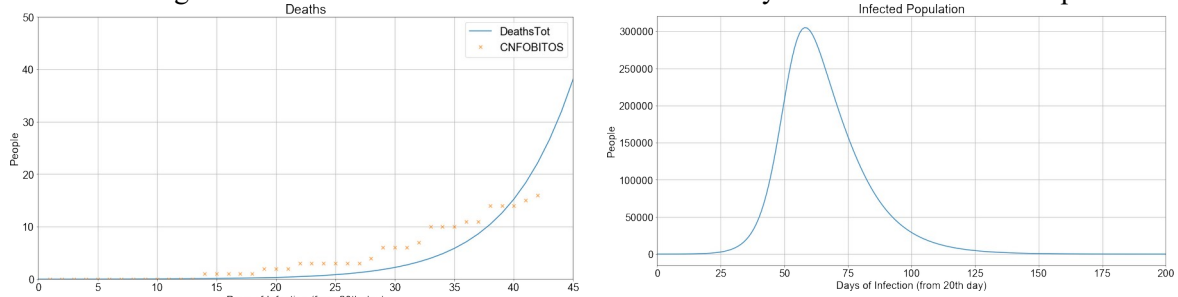Figure 2: SIRD System Dynamics Model for COVID-19.

Source: the head author

4.2. Baseline Results

The model was validated using baseline results based on Death Counts for São José dos Campos only. ICU beds and infected population registered were not considered reliable for validation purposes because testing levels are low in Brazil and São José dos Campos, and ICU beds proportion depends on information that was not being provided by private hospitals at the beginning of the study period. The Death Count is considered the most reliable number closer to the reality of COVID-19 contamination.

Figure 3: Validation of model based on Death history from São José dos Campos.
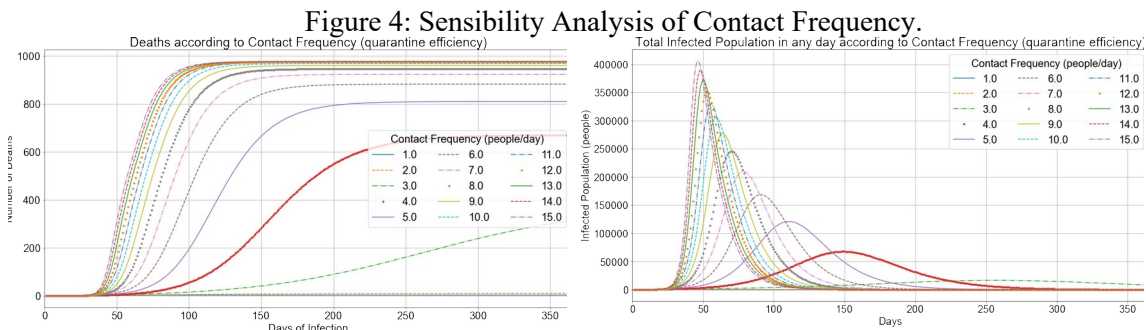

Source: the head author

Figure 3 brings that the tendency of the graph corresponds to the one observed up to May 08, 2020, in São José dos Campos.

The shape of the infected population, shown in Figure 3, corresponds to the generic classic epidemic behavior observed on Kermack and McKendrick (1927), and the model predicts a total number of deaths of 968 people, around the 165th day.
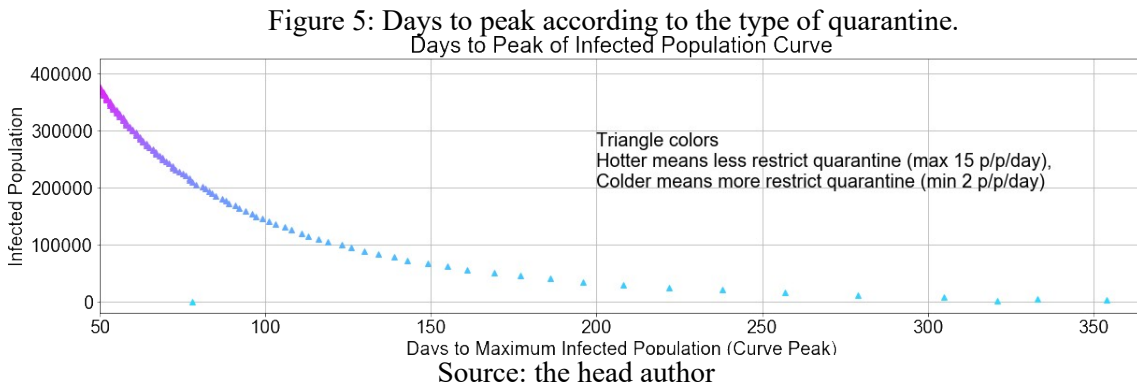
4.3. Sensibility Analysis: Contact Frequency

The Contact Frequency (CF) Strategy may be translated as levels of quarantine. It was studied using values from 1 p/p/day (extreme lockdown) to 15 p/p/day (party events contacts), using 0.1 contact p/p/day steps.

Analysis of graphs shows that the higher the CF variable (meaning less restrict lockdown), the higher the total of deaths in São José dos Campos. The difference from the predicted deaths on a CF=4 lockdown goes from 670 deaths to 968 deaths on the normal situation (CF=10), a 45% increase. A lockdown of CF=3 would predict a death toll of 315, less than half of the result from CF=4, and about 1 third of the CF=10 normal situation.

Figure 4: Sensibility Analysis of Contact Frequency.

Source: the head author

Figure 5: Days to peak according to the type of quarantine.

Source: the head author

A more restrict lockdown flattens the curve, as may be seen in Figure 5. A lockdown with CF=3 would have a maximum of 16.646 people infected at the same time, and this peak would take 257 days to occur.

A CF=5 would tend to get more than 120.000 infected people on the peak, arriving at this value on 111 days. On a considered "normal" situation of CF=10, the concomitant infected population would arrive at 305.000 people, in less than two months (59 days).
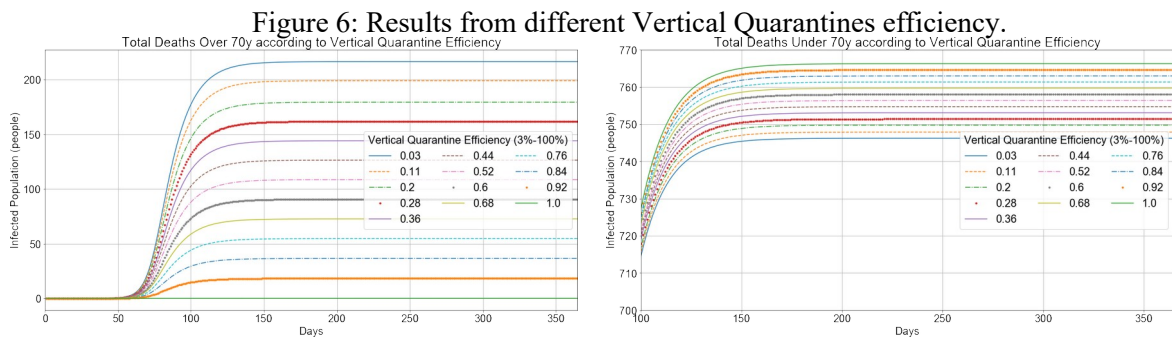
ICU bed occupation would follow close the same tendencies observed on Infected Population.

It is important to highlight that these numeric values serve only as a reference, once all information on COVID-19 is very volatile. As explained sooner in this paper, what these numbers show is that the smaller the CF, the more probable effects on decreasing the concomitant infected population, which relieves the pressure on Health Care System.
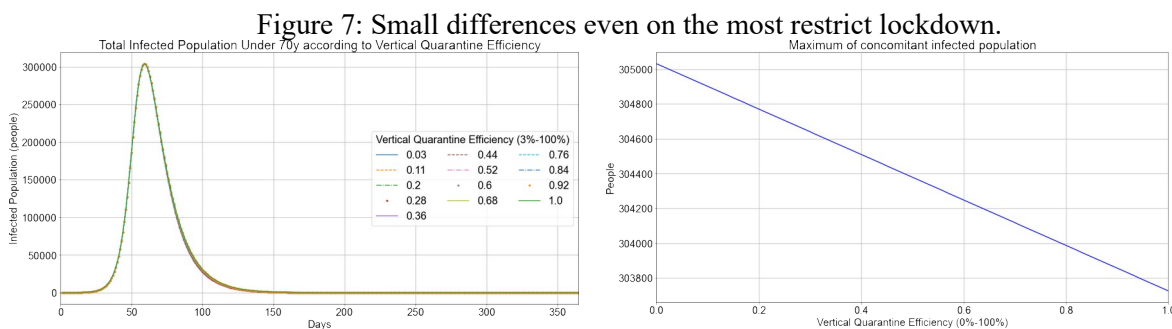
4.4. Sensibility Analysis: Vertical Quarantine

Although not realistic for values higher than 15%, because of the practical difficulty to separate most of the older population in Brazil from younger people, the Vertical Quarantine values represent the efficacy of isolating the older population. It ranges from 0% of efficacy (no elder is isolated) to 100% (all elders are locked up). The government had no other action in this simulation.

The difference in Death Toll from a complete older people lockdown ("elder lockdown") to no-lockdown would be around 20%, as may be seen in Figure 6. A closer look at the different age groups reveals that most of the saved lives come from the older group. On a 100% unrealistic "elder lockdown", 222 older people would be saved, but this would mean that 21 more younger persons would die. No lockdown would correspond to the death of 745 younger persons, but 100% lockdown would mean the death of 766 younger persons. This way, the Vertical Quarantine not only would not save younger people's lives but even worsens this situation on around 3%.

Figure 6: Results from different Vertical Quarantines efficiency.

Source: the head author

Figure 7: Small differences even on the most restrict lockdown.

Source: the head author

All other results are not different and bring all the social costs of the Vertical Quarantine from no quarantine at all. The small fraction of the older population (4% of the total population on study for the chosen scenario) reflects little on the total infected population, almost unnoticeable in Figure 7.

ICU beds' occupation follows the same proportion and didn't change significantly.

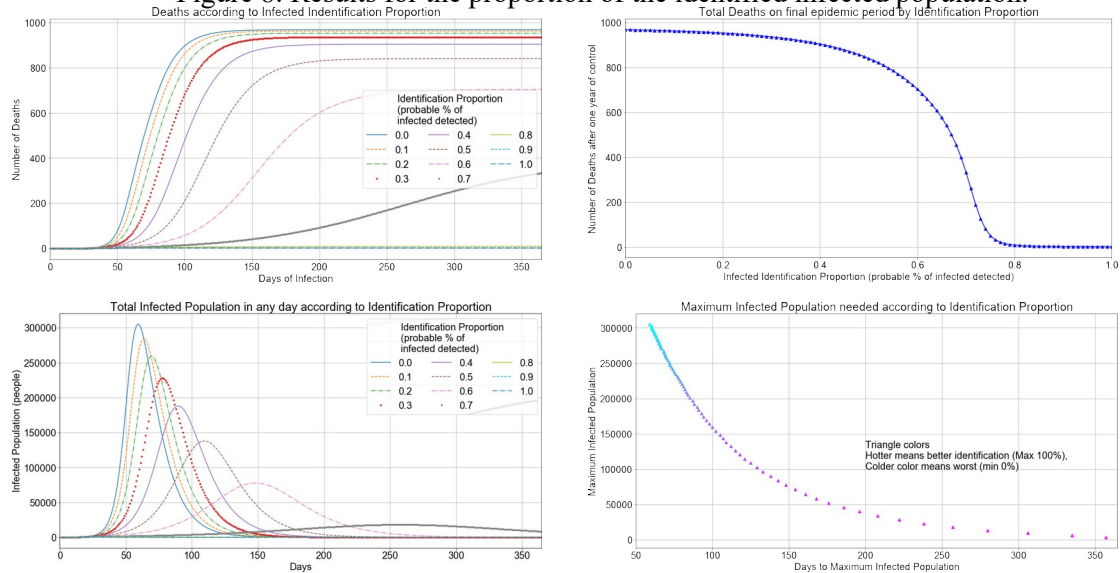## 4.5. Sensibility Analysis: Infected Identification

The infected identification strategy looks for how much the State should invest in tests and on the identification of infected persons.

The control variable varies from an unrealistic 100%, which would mean that State would be able to know every person who has the disease, to 0%, where there's no information on who is infected.

Figure 8 shows that the identification and isolation of infected people's returns are relatively fast. For a 40% identification proportion, the peak delay for the infected population curve comes from a peak of 305.000 infected people on 59 days to 188.000 infected people on 90 days, 40% less infected people on 50% more time to peak.

The result points to the need to develop strategies related to the identification of infected people, even if it could mean isolating some "false positives". The final objective would be to isolate from contacts most of the infected population, efficiently delaying the spread of the disease, and saving people with no history of contacts or exposure to COVID-19.

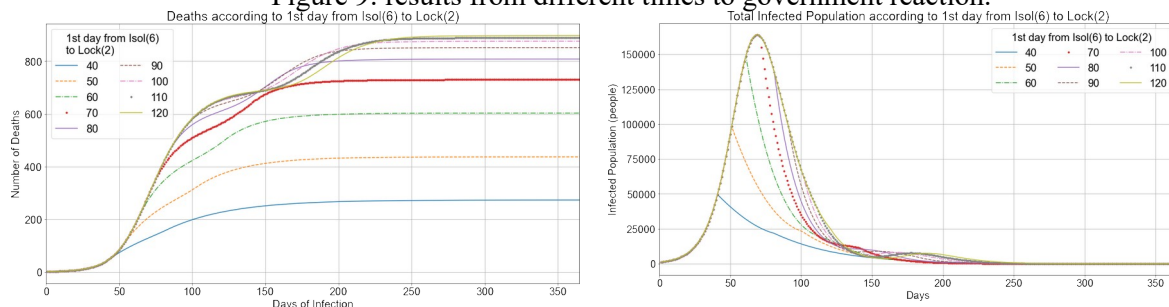Figure 8: Results for the proportion of the identified infected population.

Source: the head author

4.6. Sensibility Analysis: Days to Strategy

The simulation shows what would be the difference in results depending on how long authorities would last to impose a more restrict quarantine, passing from a Social Isolation with CF=6 to a stronger lockdown where CF=2, for example.

Figure 9: results from different times to government reaction.

Source: the head author

Figure 9 shows that the sooner authorities act in the direction of a more restricted quarantine, more lives could be saved. The difference could be from less than 300 deaths (40 days to act) to more than 700 deaths with a month more of delay (70 days to act).

Also, after some delay (around 70 days after the 20th infected person), the simulation shows almost no difference in the maximum of infected people. That means that after 70 days of delay, the Health Care System would be solicited on the maximum pressure during the peak of the epidemy.

5. Conclusion

The customization of the Classical SIRD SDM demonstrated how it could be used to simulate diverse strategies to deal with a disease outbreak with different effects on specific groups on the affected population.

The model permits a graphical analysis of the Stock-and-Flow system, allowing the identification of new possible strategies based on the control variables that could be connected to existing variables, rates, and stocks. This scheme allowed inferring that one of the central strategies to achieve the value-focused target of decrease deaths should be to decrease the number of Infected-Susceptible Contacts, which gave way to three control variables and proposed strategies.

Between the three direct strategies discussed, the strength of quarantine, the vertical quarantine, and the identification of infected people, the one that showed a faster return was the identification strategy, where a mean identification of infected people could lead to decreases of 50% on-time t peak and 40% less infected people maximum, what corresponds to proportional less need for ICU beds and less pressure over the country's Health Care System.

The worst proposed strategy was the Vertical Quarantine, that, when applied, enlarges the death toll on the younger fraction of the population and have a large social cost, besides the fact that is unrealistic suppose that vertical quarantines could happen on higher efficiency numbers in countries where the majority of the older population tend to live together with younger persons, that would not be isolated and living under the same roof.

The last verification, belonging to the delay of the authorities' action, revealed that a rapid response to an outbreak of these characteristics would result in saving lives. In addition, the simulation indicated that, after a certain delay, deaths could still be avoided, but the pressure on the Health System would already be inevitable, and people would probably have less access to medical care, which could worsen the mortality rates initially considered.

The model is limited by the unknown and changing variables related to the COVID-19, but, although the absolute numbers resulting from simulation cannot be used by its face-value, the tendencies observed on the curves may be used, because of its validated behavior.

Other strategies that could be tested on the model for future exercises include the use of a restricted number of ventilators and the health care workforce, and how treatments that abbreviate time to recover could impact on the epidemic flow.

This model is available to other simulations and tests that may be of interest to COVID-19 policies.

A development of this paper could include other Infected-Susceptible Contact reduction strategies, regarding, for example, a decrease of infectivity rate based on strategies using masks. Another important development would be a more detailed application of Value Focused Thinking method.

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