

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

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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 that allows us to verify some strategies on how to deal with the COVID-19 outbreak, using the classical epidemiological SIR model as a basis. Three main strategies were tested, based on what should be the main objective of public policies, to save lives, in addition to verifying the outcome of the authorities' action delay by the authorities. From the strategies tested, between quarantine extension, vertical quarantine, and identification of infected persons, the most promising was considered to identify infected persons, and the least advisable is vertical quarantine.

Also, the simulation indicated that tightening quarantine at any time tends to save lives, but late action by authorities can bring overpressure to a country's health care system, which can also directly impact the lethality of the epidemic.

KEYWORDS. System Dynamics, COVID-19, Decision Support.

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 31 DEC 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 (15MAY2020), WHO statistics appoints to 4.248.389 cases (77.965 new cases as of 14MAY2020) and 292.046 deaths (4.647 new reported deaths as of 14MAY2020). Brazil is reported as the present epicenter for Latin America, having 202.918 confirmed cases (13.944 new cases as of 14MAY2020) and 13.993 deaths (844 new reported deaths as of 14MAY2020) [Brazil Health Ministry 2020].

So far, it is known that COVID-19 is significantly more deleterious when it strikes elders, making it necessary to draw different strategies to each group.

Recently published papers indicate that COVID-19 infectivity (R_0) is higher than previous coronavirus outbreaks. The R_0 calculated for the SARS-CoV-2 varies from 6.47 [Tang et al. 2020] to 5.7 [Sanche et al. 2020]. To compare, the swine flu of 1918 worldwide outbreak had a R_0 value estimated to be between 1.4 and 2.8 [Coburn et al. 2009], for H1N1 2009 pandemic was evaluated between 1.4-1.6 [Coburn et al. 2009] and for measles, R_0 is often cited to be between 12–18 [Guerra et al. 2017].

The global spread of the disease demands actions from governments. Most of the initiatives were concentrated on implant quarantines, of many levels, and the closure of establishments [Zhu et al. 2020]. Social Distancing, as defined by American CDC [Centers for Disease Control and Prevention 2020], is the main strategy, meaning two meters from each other, no gather in groups, to stay out of crowded places and most of the economic activities suspended, except for some classified as essentials. Some countries adopted “Lockdown”, where people is enforced to remain inside their homes, leaving only in special cases, like to buy food or go to see a doctor. Quarantine strategies have in common that economical activities are drastically reduced or completely stopped, relying on home-office practices when possible. A report from the World Bank Group [Maliszewska et al. 2020] sees gross domestic product fall by 2 percent below the benchmark for the world, 2.5 percent for developing countries, and 1.8 percent for industrial countries” because of restriction associated to Social Distancing and Lockdown.

At present date, many countries are dealing with the COVID-19 together with its economic effects. One probable effect of GDP decreases worldwide could be stressing even more health systems on less developed countries, which could lead, eventually, to an increase in general mortality rate, as estates some studies [Hone et al. 2019]. Countries with small or no monetary reserves will be more affected by the Social Distance consequences. This way, strategies should compromise both aspects, economical and sanitary, and be able to measure how to balance them.

In the present scenario, many countries seem to be divided on only two alternatives to cope with the economic effects and the sanitary problems: worsens quarantine to avoid larger contamination and or make it loosen, and allow people to go back to their jobs and schools.

This paper presents a System Dynamics simulation model to help find balance on different strategies on COVID-19 outbreak, helping understand the outcomes of altering managing variables available for State Authorities and looking to find viable alternatives based on the real objective pursued, that is to save lives. The balance between sanitary and economic aspects is not covered, because these aspects under present conditions are yet unclear on academic simulation studies.

This paper is divided into five sections. This introduction section describes the problem to be focused on the paper, and the basic context of it. Section two reviews the literature on referring to epidemics models, focusing on System Dynamics, and what is known over COVID-19 numbers, as well as the gap this paper intends to fill. Section three describes and justifies the use of System Dynamics on the topic and the limitations for the model. Section four brings the results and findings from simulations. Section five lists the conclusions and implications of results.

2. Review of Literature

2.1. Bibliographical Search

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

This SIR mathematical model inspired a classical System Dynamics Tutorial from Sterman [2000] and subsequent papers that presented models using this basis, for example, simulating the spread of SARS in 2002 [Wang et al. 2009] and the case of MERS-Cov in 2015 [Shin et al. 2017].

Development of the SIR model also available in Kermack and McKendrick (1927) is the SIRD model, where Deceased (D) is included and computed too, making Recovered population smaller. The control of the D stock was included highlight the different mortality rates on each age group considered.

Looking for references that worked on the same route, none showed modeling with the considerations proposed in this paper. From Scopus (Elsevier) database, the terms “System Dynamics” together with “COVID-19” returned one paper (as of 18MAY2020), yet to be published to AUG2020 [Vega 2020], that deals with the classical SIR model from Sterman in 2000, and some results related to the length of quarantine. On another search, also using Scopus, the term “System Dynamics” was combined with keywords “Coronavirus”, “SARS-CoV-2”, “Disease Outbreak” and a sum of twelve papers were found including the 2020 Vega paper already cited. The keyword combination limited to “System Dynamics” and “Epidemic”, returned no papers relating to the new COVID-19, although 60 papers were found, none of them proposing a deviation from the classical System Dynamics SIR Model to study a specific disease behavior. This broader paper list shows a total of 934 keywords from which 57 papers cited keyword “system dynamics” and 41 papers cited “epidemics”.

2.2. Framework

International headlines and politician discourses are divided between a “Save the Economy” fight against quarantine and its economical consequences, and a “Life is what matters” looking for an extension of quarantine and isolation policies until the spread of the infection is considered impossible. Keeney [1992] referred to that way of thinking as “alternative-focused thinking”, because the decision-makers tend to choose some alternatives that are clearly instated, instead of looking for the real value that the decision must seek and the possible ways to achieve this value. In opposition to that way of thinking, Keeney suggested the Value Focused Thinking (VFT), a detailed Problem Structuring Method (PSM). Applying this idea, in a general format, the conclusion is that the Objective should be “Saving Lives”, in a wider sense.

Being a complex system, the world economy's impact from the isolation and confinement of most workforce can only be measured in small steps of interaction, using specific economic variables, like GDP or the unemployment rate. Trying to run away from any bias resulting from the present heated discussions on the matter, recently published works published before any news on the COVID-19 outbreak were used. According to Hone et al. [2019], an increase in the unemployment rate of one-percentage-point has been associated with a half percentage point increase per on mortality rate (95% CI 0,09–0,91) in all-cause mortality, mainly due to cancer and cardiovascular disease, where most of the increase was computed on black and mixed-race population, with no significant association to the white population. Although the proportion of change in deaths in this study is related to the country's mortality rate, not to its full population, it shows it should have a balance on the measures taken. Taking this result into account, the probable best route to achieve the “Saving Lives” objective would be a mixed strategy, between the full ‘lockdown’, with a growing impact to economy and mortality rates for

the minorities and the poorer population, and the ‘open doors’ policy, that would certainly jeopardize the risk group of this new disease.

Determine how could be this mixed strategy is the purpose of this paper, using System Dynamics simulations to understand how specific strategies will work overtime, and how certain measures may affect the system in the future [Kunc and Morecroft 2007].

3. Methodology

Based on the 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 on 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 are variables that are also included in the system, depending on the average duration of the disease. The Recovery Rate is the rate at which the Infectious Population recovers from the disease and is no longer infectious.

Figure 1 illustrates the SDM that includes all these points.

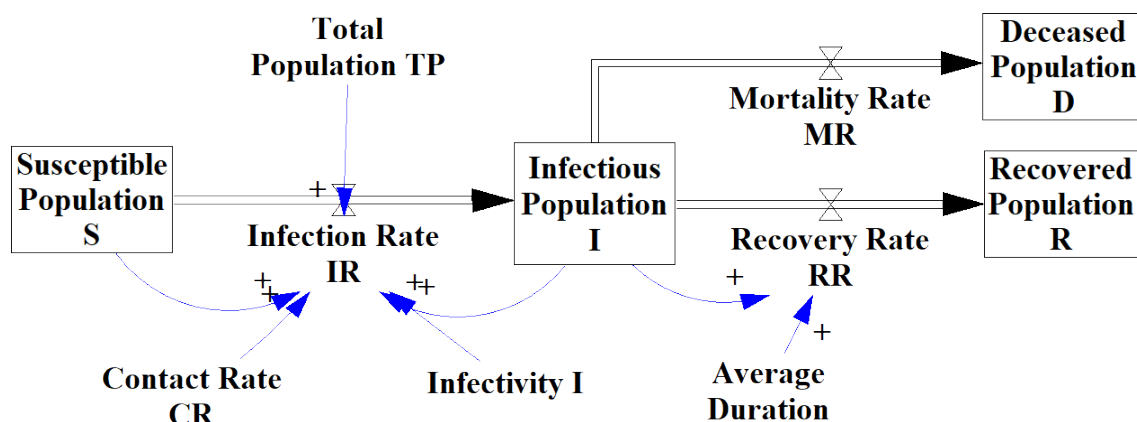


Figure 1 - SIRD Model of an epidemic

Dynamic Hypothesis 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 being the most affected country in Latin America and is also the largest country at the subcontinent, fifth-largest population in the world.

Brazilian Health Care System is centralized and is of interest to the comparison with non-centralized health care systems and large populations.

São José dos Campos is a medium-size city, geographically located between the two largest cities in Brazil, having an estimated population of 721.944 according to Brazilian Institute for Geography and Statistics [IBGE 2019]. Its health system may be reported as among the medium quality in Brazil, being between the second third on all health indicators from the

Brazilian Institute for Geography and Statistics (2019). This city was chosen to represent and validate strategies from the model based on these characteristics.

The data used to validate model is from the São José dos Campos City Epidemiological reports [Prefeitura de São José dos Campos 2020].

3.3. Customization of Classic SIRD SDM: Dynamic Hypothesis

Age

The first Dynamic Hypothesis considered for the COVID-19 behavior is that it attacks older people more severely, and significantly higher lethality rates have been observed in the group.

USA reports over patients with COVID-19 indicates that Confirmed Death Rate (CFR) was 1% for people under 65 years old and 6% for people over 65 years old [Sanche et al. 2020]. In Spain, the CFR for people under 70 years old was, up to 16MAY2020, 1.72%, and CFR for people over 70 years old was 18.8% [Centro de Coordinación de Alertas y Emergencias Sanitarias (CCAES) 2020]. In Italy, according to Health Secretary of Italy Information on 31MAR2020, CFR under 70 years old was 3.21%, and over 70 years old was 24.68%. In the city of São José dos Campos, CFR under 70 years old was reported 3% and over 70 years old, 23%.

Reasons, why the older fraction of the population is more susceptible to complications due to the COVID-19, are yet not completely understood.

This difference group behavior inspired the customization of SIRD Stocks to each fraction of the population on this proposed SDM. At the 2019 population estimation from IBGE [2019], São José dos Campos had a 4% population over 70 years old.

Infectivity (I) and Contact Rate (CR)

Scientists have been trying to measure how fast the spread of COVID-19 is, but how to effectively measure its presence is a great barrier. Underreporting [Mellan et al. 2020] is a difficulty in bringing in the correct numbers and the calculation for COVID-19 infectivity and CFR. Also, testing efficacy is an error to be accounted for, once the false-negative for COVID-19 has been reported to 29% when compared to Chest Computer Tomography sensitivity [Fang et al. 2020].

About the variable Infectivity on the SDM, a medical equivalent epidemiologic metric to supporting it is the R_0 (R-nough), a mathematical term that indicates how contagious an infectious disease is [Delamater et al. 2019]. It is also referred to as the reproduction number. As infection is transmitted to new people, it reproduces itself [Ramirez and Biggers 2020]. Although the problems on the measure of R_0 , the COVID-19 infectivity is considered high by literature already available.

For the present SDM, the representation of R_0 is a mix from the Infectivity variable (I) and Contact Rate (CR), variables proportional to R_0 . Values described in Sterman (2000) for the SARS outbreak in 2002 were considered as the baseline for Contact Rate (CR) (10 persons per person per day). The value of the infectivity was adjusted by validation on São José dos Campos values at the beginning of the outbreak and will be discussed later in this paper.

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” [World Health Organization 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

There are some discussions around the duration of the infection-related to COVID-19 up to the moment [Sanche et al. 2020]. The measure of average duration for disease looks to be influenced by the contagious date and the symptomatic response by infected subject. To cover the large sigma distribution reported (from 33% to 43%), an Average Duration of fourteen days was arbitrarily chosen.

The model also considers that deaths take at least one day longer than recovery and are distributed according to the mean of hospitalization duration. Reference shows that these times to discharge may have been longer in China, from 11.5 days to health discharge up to 16 days to death in hospital. The difference period for death outcomes was not considered, once hospitalized people are already separated from the population during treatment and takes a small part on dissemination, except for health personnel, that has an infection dynamic completely different from the regular population.

Proportion of Worst Cases

COVID-19 is a disease that behaviors similar to other types of flu. Some people are heavily affected, others pass through it almost asymptotically. The Centre for Evidence-Based Medicine, from the University of Oxford [Heneghan et al. 2020] studied 21 reports on asymptomatic controlled outbreaks and arrived at the interval that varied from 5% to 80%. The case of the Diamond Princess, a cruise boat that confined 3.711 people on board, was closely studied and reported an estimated asymptomatic proportion of 17.9%.

The fraction of interest for the SDM is the proportion of infected people that must be hospitalized. For Spain [Centro de Coordinación de Alertas y Emergencias Sanitarias (CCAES) 2020], the cases confirmed up to 16MAY2020 had a 3.5% rate of Intensive Care Unit (ICU) hospitalization, with little difference on age distribution (3.4%). For the USA, on the other hand, differences from age group vary from next to under 0.5/100000 to 17/100000 [Centers for Disease Control and Prevention COVID-19 Response Team 2020].

The problem related to calculating the specific rate of hospitalization resides on the asymptomatic and mild cases reported, cited before, once many people refuse to go under a COVID-19 test, or just don't care to take it. The best estimate available to hospitalization, based on wide testing resources, was the Spain proportion.

The death rate on ICU cases is reported on the same papers, and the model uses 3% for persons under 70 years old and 25% for over 70 years old.

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

Strategies to achieve the value-focused objective should deal with the number of people dying. There are two possible strategies to prevent people from dying on any disease: isolate until there's a vaccine or learn how to treat all infected persons. First, the time to a vaccine best estimates points to twelve to eighteen months due [Spinney 2020].

Treatment protocols are being tested every day, yet to be confirmed as effective. A considered hypothesis is that people that have better medical care will have more chances to survive. As a result, most of the strategies available are related to keeping as small as possible the infected population, to make the number of people needing hospitalization kept under the capacity of Health Care Systems, up to the moment when a vaccine is available and globally produced to an eight-billion scale.

Days to begin strategy

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

Newspapers reported the first lockdown on Wuhan, China, begun on 23JAN2020, but first official communication from China Government to World Health Organization of a novel coronavirus was on 31DEC2019 [World Health Organization 2020a], what means that China government knew about the gravity of the problem at least 23 days before they gone to measures.

On 31DEC2019, the U.S. Centers for Disease Control and Prevention (CDC) became aware of cases in China and began developing reports for the Department of Health and Human

Services (HHS) on January 1st. Ohio (State of USA) reported a case of COVID-19 on 06JAN2020. Although some quarantines declared from the CDC over the USA, State and City governments begun to declare quarantines only on MAR2020 [Wikipedia 2020], after roughly 70 days after the first infection reported on the country.

In Brazil, the first reported case was on 08FEB2020, in São Paulo, and the first quarantine order was issued on 13MAR2020, to begin on 16MAR2020, 37 days after first case (São Paulo, 2020).

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

On present SDM, the baseline is 20 days to municipal government reaction, from an initial stock of an infected population of 20 persons, based on São José dos Campos data.

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

SDM infection rate depends on the total of infected people amongst the total susceptible population. This way, one way to control this infection rate would be to minimize contacts between infected and susceptible people, corresponding to minimize the Infection-Susceptible Contacts (ISC).

On this proposed 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 carnival, these numbers could rise up to 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 [World Health Organization 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 are 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 discussed control variable is based on the cited distinguished rates of lethality on age groups. A control variable would be to impose quarantine over the elder group of people, that concentrates the riskier individuals. This strategy has been named Vertical Quarantine.

The idea would be to restrict contacts between infected population and older people, therefore, making smaller the death numbers. That would allow the younger workforce could go back to active economic lives, while the older fraction would be protected isolated.

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 08MAY2020.

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 question.

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 on 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

4.1. Customized SIR System Dynamic Model

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

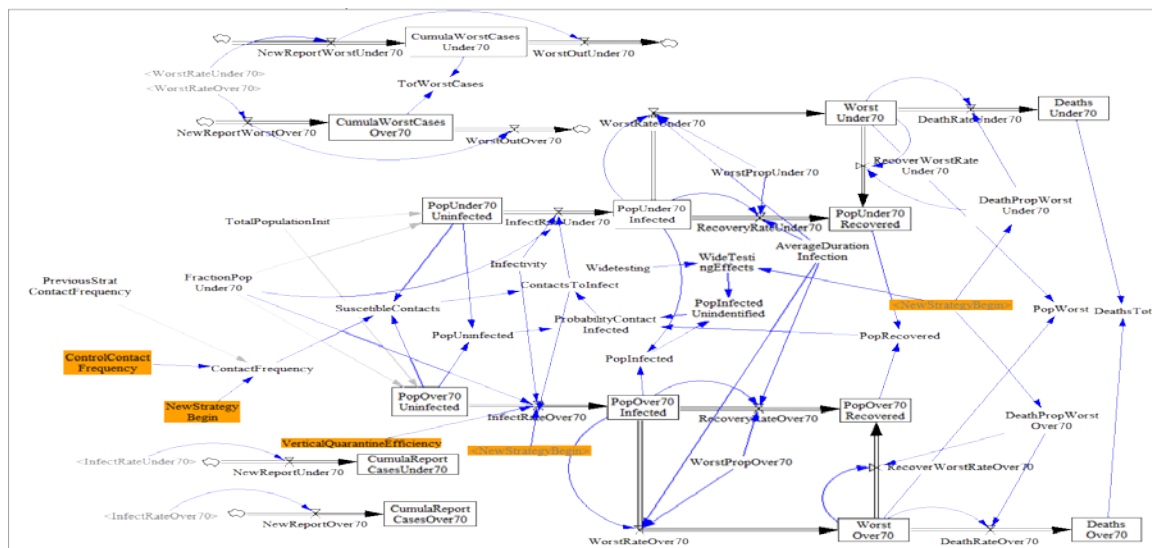


Figure 2 – SIRD System Dynamics Model for COVID-19

4.2. Baseline results

Using baseline results, validation of the model was made 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 in the beginning of study period. The Death Count is considered the most probable and available number closer to the reality of COVID-19 contamination.

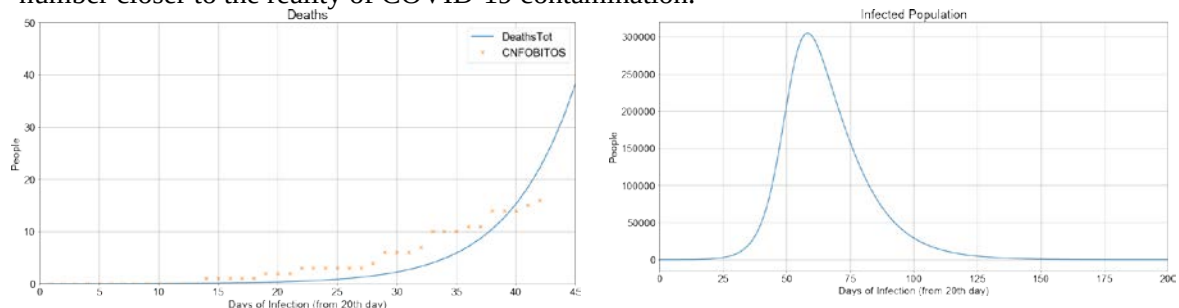


Figure 3 – validation of model based on Death history from São José dos Campos

Figure 3 brings that the tendency of the graph corresponds to the one observed up to 08MAY2020, 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

Contact Frequency (CF) 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 as step.

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.

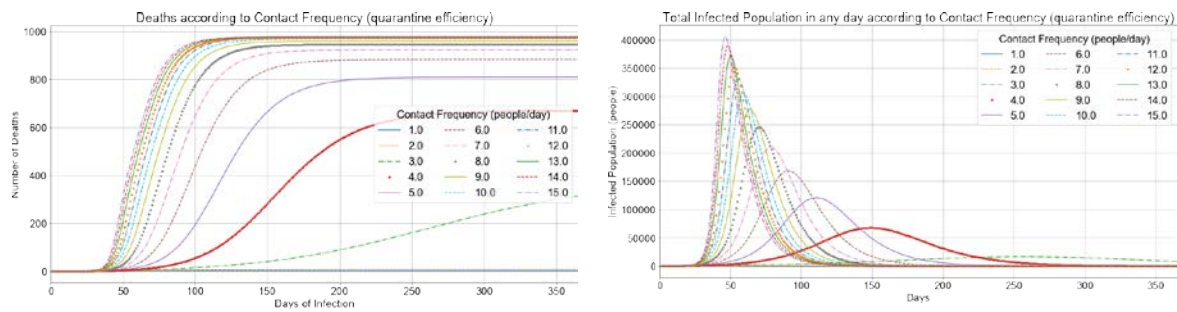


Figure 4 – Sensibility Analysis on Contact Frequency

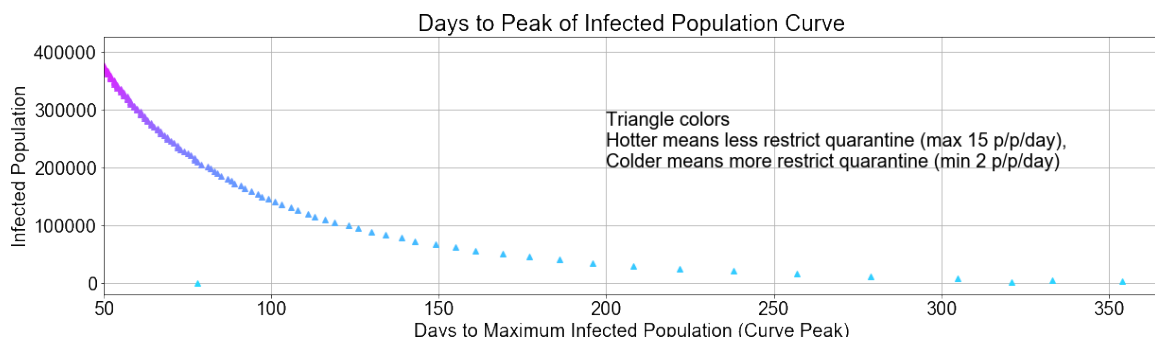


Figure 5 – Days to peak according to the type of quarantine

Same way, a more restrict lockdown flattens the curve, as expected. As may be seen in Figure 5, besides the maximum of infected population, a lockdown with $CF=3$ would have a maximum of 16646 people infected at the same time, and this peak would take 257 days to occur.

A $CF=5$ would tend to get more than 120000 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 305000 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, as already discussed, the Vertical Quarantine values represent the efficacy of the Older population isolation and ranges from 0% of efficacy (no elder is isolated) to 100% (all elders are locked up). No other government measure is applied in this simulation.

The difference in Death Toll from a complete lockdown to older people to no lockdown would be around 20%, as may be seen in Figure 6. The specific study on 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 persons younger than 70 years old 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 lives but even worsens this situation on around 3%.

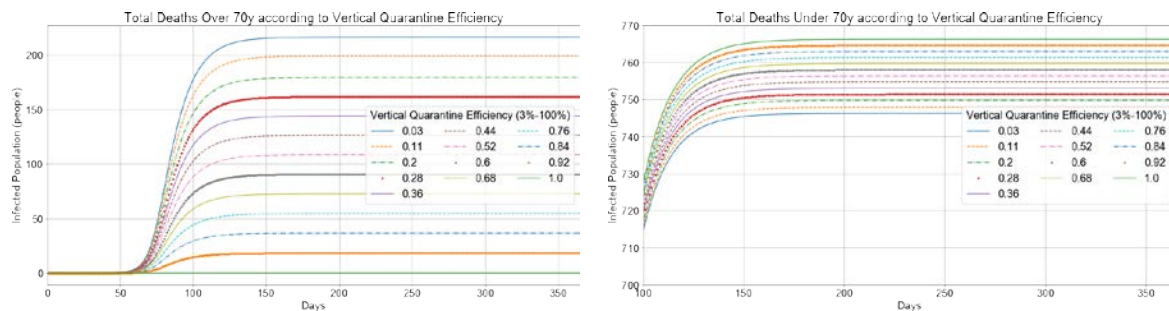


Figure 6 – Results from different Vertical Quarantines efficiency

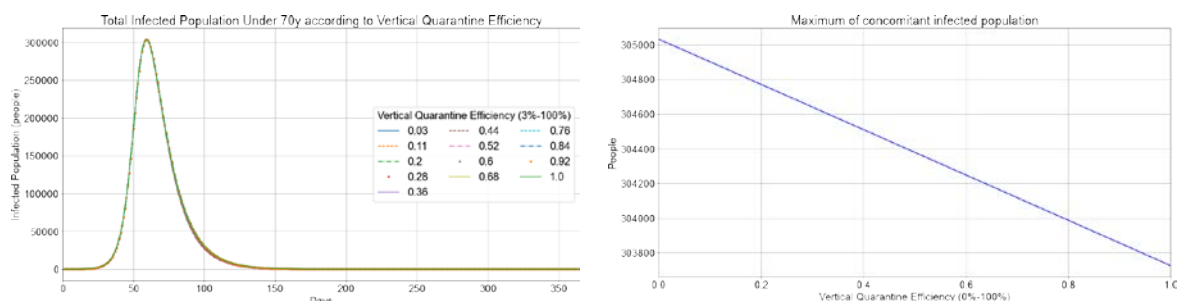


Figure 7 - small differences even on the most restrict lockdown

All other results are a little different from all the social costs of the Vertical Quarantine from no quarantine at all. The small fraction of the “older” population (4% on 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

Infected identification control variable varies from an unrealistic 100%, which means 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 returns are relatively fast. For a 40% identification proportion, the peak delay for the infected population curve comes from a peak of 305000 infected people on 59 days to 188000 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 some “false positives”. The final objective would be to isolate from contacts most of the infected population, efficiently delaying spread of the disease, and saving people with no history of contacts or exposure to COVID-19.

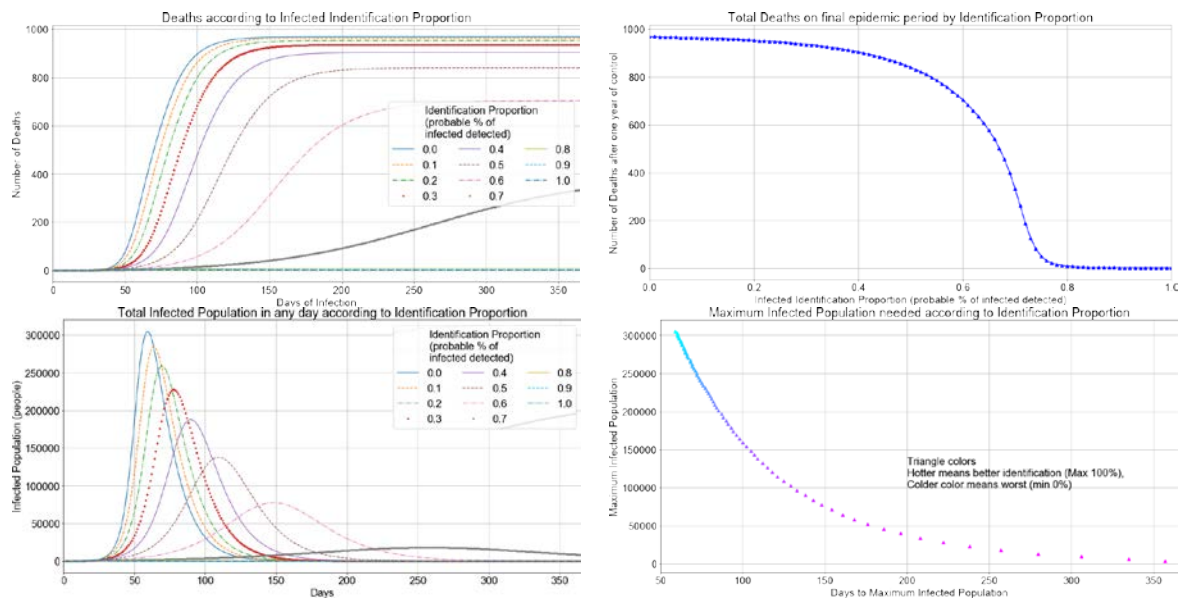


Figure 8 – results for the proportion of the identified infected population

4.6. Sensibility Analysis: Days to Strategy

The simulation shows how long authorities would last to impose a more restrict quarantine, passing from a Social Isolation with $CF=6$ to a stronger lockdown where $CF=2$.

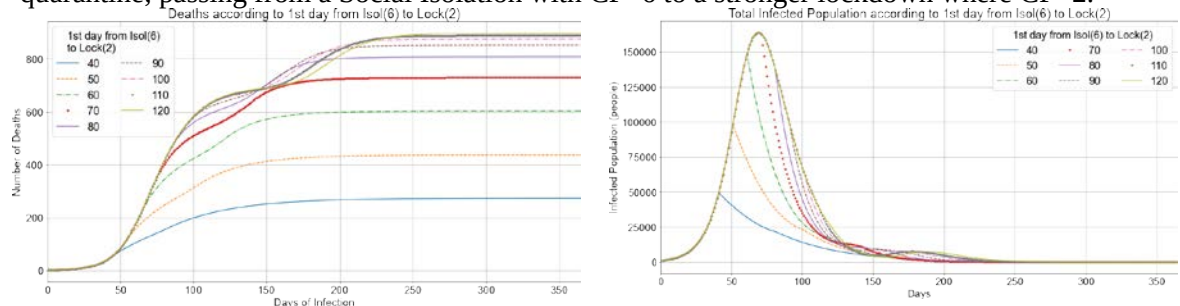


Figure 9 – results from different times to government reaction

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 epidemic.

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 groups on the affected population.

The model itself 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 population and have a large social cost, besides the fact that is unrealistic suppose that vertical quarantines could happen on higher efficiency numbers on 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 action from authorities revealed that a fast response to an outbreak of these characteristics would result in saving lives. Also, the simulation indicated that, after a certain delay, deaths could still be saved, but the pressure over the Health Care System would already be unavoidable, and probably people would be forced out of medical care, which could worsen mortality rates initially considered.

Model is limited from the unknown and changing variables related to the COVID-19, but, although the absolute numbers resulting from simulation cannot be used by this face-value, the tendencies observed on the curves may be used, because 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 of using masks. Another important development would be a more detailed application of Value Focused Thinking method.

Acknowledgement

This study was financed in part by the Coordination for the Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil - CAPES) - Finance Code 001.

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