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 principais estratégias foram testadas, baseadas no principal objetivo de políticas públicas, que deve ser salvar vidas, além da verificação do resultado do atraso na ação por parte das 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 enrijeçamento da quarentena a qualquer tempo tende a poupar vidas inicialmente, 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 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 delay in action 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.
In addition, the simulation indicated that tightening quarantine at any time tends to save lives initially, 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

During last days of 2019 and the first semester of 2020, explain what the 2019-Novel Coronavirus (2019-nCoV) outbreak of Corona Virus Disease 2019 (COVID-19) is not an easy task. Everyday new information on the disease is published, many times disproving predecessors. The World Health Organization (WHO) COVID-19 timeline [https://www.who.int/news-room/detail/27-04-2020-who-timeline---covid-19] indicates that first information about the novel coronavirus was on 31 DEC 2019. After five months, information on the COVID-19 is still uncertain, and everyday new characteristics of the infection are identified. 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, where there are 202.918 confirmed cases (13.944 new cases as of 14MAY2020) and 13.993 deaths (844 new reported deaths as of 14MAY2020), according to the Health Ministry website [http://covid.saude.gov.br, as of 15MAY2020].

So far it is known that COVID-19 tends to be significantly more deleterious when it strikes elders, making two (or more) very different groups to be protected and taken care of.

Besides, recently published papers indicates that the infectivity of COVID-19 is higher than previous coronavirus outbreaks, even than the measured infectivity for Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), with a R0 of 5.7 (95% CI 3.8–8.9) (Sanche et al, 2020). According to a review article published in BMC Medicine, the swine flu of 1918 worldwide outbreak had a R0 value estimated to be between 1.4 and 2.8 [Coburn, Wagner, Blower, 2009].

The spread of the disease globally demanded actions from governments around the world. Most of initiatives were concentrated on implant quarantines, of many levels, but also travel restrictions, confinements, event cancellations, and the closure of establishments (Zhu et al, 2020). The favorite chosen flavor of quarantine was Social Distancing, also called physical distancing [CDC, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html, 16MAI2020], what means keeping space between people. Generally, it means 2 meters of distance from each other, no gather in groups, and to stay out of crowded places, avoiding mass gatherings, and most of economic activities suspended, listing some classified as essentials. Some countries, adopted a more incisive quarantine, that has been called “Lockdown”, were people is strictly and enforced to remain inside their homes, allowing leaving only in special cases, like to buy food and to go to see a doctor. All quarantine strategies have in common that economical activities are drastically reduced, relying on home-office practices when possible. Industrial activities were considered “essentials” in many places, but most of stores and deposits remains closed, so, yet industries would produce, no one would buy. This fact led to some curious results, like US oil prices got to a negative value, where producers would pay to someone take the oil away.

A report from the World Bank Group (World Bank Group, 2020) describes a simulation that “models the shock as underutilization of labor and capital, an increase in international trade costs, a drop in travel services, and a redirection of demand away from activities that require proximity between people (Social Distancing). A baseline global pandemic scenario 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.”

At present date, many countries are dealing with the COVID-19 together with the economic effects trying to avoid its spread brings. One probable effect of GDP decreases worldwide could be stressing even more health systems on less developed countries, what could
lead, eventually, to an increase on mortality rate. Countries with small or no savings 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.

On the present scenario, many countries seems to be divided on only two alternatives to cope with the economics effects and the sanitary problems: worsens quarantine to avoid larger contamination and or make it loosen, and allow people 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, with Sensibility Analysis that could help understand the flow of the outbreak and the outcomes of altering managing variables available for State Authorities, in this way, looking to find viable alternatives based on the real objective pursued, that is to save lives.

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

2. Review of Literature

2.1. Bibliographical Search

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

This SIR mathematical model inspired a classical System Dynamics Tutorial from Sterman (Sterman, 2004) and other papers models using this basis, simulating the spread of SARS in 2002 (Wang, Li and Zhang, 2009), the case of MERS-Cov in 2015 (Shan et al., 2017).

Looking for references that worked on same route, no reference showed a modelling with the depth 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, Ibarra-Vega, 2020, that deals with the classical SIR model from Sterman, 2000, and some results related to length of quarantine. Also, from Scopus, the term “System Dynamics” was combined to keywords “Coronavirus”, “SARS-CoV-2”, “Disease Outbreak” and a sum of twelve papers were found including the 2020 Ibarra-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, listing a total of 934 keywords from which 57 cited keyword “system dynamics” and 41 cited “epidemics”.

2.2. Framework

Brazilian national scenario on the government actions are not much different from other countries. International headlines divide between a “Save the Economy” fight against quarantine and a “Life is what matters” looking for extension of quarantine options until the spread of the infection is impossible. Keeney (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.

In this case, the focused value should be saving lives, of course, but, not only from the new disease. Being a complex system, the world economy impact from the isolation and confinement of most workforce can only be measured in small steps of interaction, like this and next year GDP or the unemployment rate for next 12 months. Anyway, an increase in unemployment rate of 1 percentage-point was associated with a 0.50 increase per 100,000 population per rter (95% CI 0.09–0.91) in all-cause mortality, mainly due to cancer and cardiovascular disease (Hone et al., 2019). This way, the best route to take would be something between the full ‘lockdown’ and the ‘open doors’ policy defended by the extremes.

That is one of the purposes of investing on system dynamics modelling, both using it as a graphic model to the complex system to be aborded, as using its numeric simulations to understand how specific strategies will work over time, and how certain measures may affect the system in the future (Kunc & Morecroft, 2007).

3. Methodology

Based on the previously cited SIR System Dynamics Model (Sterman, 2000), information gathered from updated sources guided the development of a Stock-and-Flow model that comprehends all specific characteristics for the present disease outbreak.

3.1. Classic SIR System Dynamics Model

Based on the mathematical description (Kermack & McKendrick, 1927), the main variables involved on an epidemic model are the population, divided on susceptible, infected and recovered (SIR).

The rate at what people is infected are function of the Contact Rate of this population and the Infectivity of the decease, where the Contact Rate is how many people one person has contact during one time-step of the simulation, and Infectivity is how many people is infected during one time-step of the simulation.

The rate at what people recovers (or dies) from the infection are also discussed, depending on the average duration of the disease. The Recovery Rate is the Infectious Population.

The FIGURE illustrates the system dynamics model (SDM) developed on Sterman (2000) that includes all these points.

Dynamic Hypothesis on the behavior for COVID-19 were used to adapt and customize the SIR System Dynamics Model for the present study.
3.2. Case Study in São José dos Campos, Brazil

Brazil has been the most affected country in Latin America, and is also the largest country at the subcontinent, fifth in largest population in 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, between the two largest cities in Brazil, having an estimate population of 721,944 according (Instituto Brasileiro de Geografia e Estatística (IBGE), 2019). Its health system may be reported as among the medium quality in Brazil, being between the second third on all health indicator from the Brazilian Institute for Geography and Statistics (2019). This city was chosen to represent and validate strategies from on the model based on these characteristics.

The data used to validate model is from the São José dos Campos City Epidemiological reports (São José dos Campos, 2020).

3.3. Customization of Classic SIR SDM: Dynamic Hypothesis

**Age**

The first Dynamic Hypothesis observed in COVID-19 is that it attacks older people more severely, where significantly higher lethality rates have been observed.

A preliminary description of outcomes among patients with COVID-19 in the United States 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 Epidemiology Bulletin 107 of 16th May 2020, from the Health Ministry, indicated that the (CFR) for people under 70 years old was, up to that moment, 1.72%, and CFR for people over 70 years old was 18.8%.

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%.

Looking for the city of São José dos Campos, in Brazil, a middle-size city between the two largest cities in the country, its Epidemiologic Report, up to 08th may 2020, indicates that CFR under 70 years old was 3% and over 70 years old was 23%.

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

This Dynamic Hypothesis have a correspondence to SDM on the customization of Stocks to each fraction of population, according to its Age Pyramid. At the 2019 population estimation from IBGE (2019), São José dos Campos had 4% population over 70 years old.

**Infectivity (I) and Contact Rate (CR)**

Coronavirus disease (COVID-19) is an infectious disease caused by a newly discovered coronavirus. The virus that causes COVID-19 is like the one that caused the 2003 SARS outbreak: both are types of coronaviruses. Much is still unknown, but COVID-19 seems to spread faster than the 2003 SARS and may cause less severe illness.

Scientists have been trying to measure how fast this spread is, but the lack of knowledge of how to effectively measure its presence is a great barrier. Underreporting (Imperial College Report 21, 2020) is a great difficulty on correct measures and calculation for COVID-19 infectivity. Also, testing efficacy is an error to be accounted for, once the false negative for COVID-19 have been reported to 29% when compared to Chest CT (Computer Tomography) sensitivity.
In relation to the variable System Dynamics Infectivity, there’s a medical equivalent epidemiologic metric to support it, called R0 (Rough), a mathematical term that indicates how contagious an infectious disease is (Delamater et al., 2019). It’s also referred to as the reproduction number. As an infection is transmitted to new people, it reproduces itself (Ramirez & Biggers, 2020). R0 is, basically, the number of people to whom one infected person would transmit the disease through the contagious period. By its mathematical definition, R0 relates to the number of contacts, and to many other characteristics.

For the SDM, the representation of R0 is a mix from the Infectivity variable (I) and Contact Rate (CR), and these variables are proportional to R0. Values described on Stermen 2000 for the SARS outbreak in 2002 were considered as a base and the baseline for Contact Rate (CR) was considered 10 persons per person per day. The value of the infectivity was left to validation on São José dos Campos values on the beginning of outbreak and will be discussed later in this paper.

Although the problems remaining on the measure of R0, the COVID-19 infectivity is considered high. For comparison, the value calculated to the 1918 pandemic (swine flu) estimated to be between 1.4 and 2.8, H1N1 2009 pandemic was evaluated between 1.4-1.6 (Coburn et al., 2009). For measles, R0 is often cited to be 12–18 (Guerra et al., 2017). Numbers for COVID-19 R0 varies from 6,47 (Tang et al., 2020) and 5,7 (Sanche et al., 2020).

**Recovered Population**

On the document “Immunity passports in the context of COVID-19”, 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, 2020).

Another important fact is that data on recovered cases are less precise than infected cases, because of the hospitalization rate and the asymptomatic fraction of population.

However, newer papers indicate that the assumption that recovered people keeps showing antibodies after discharged from hospitalization, what implies both that these people retains its immunity during a certain amount of time and that an effective vaccine is possible (Ni et al., 2020).

This way, as on Classic SIR SDM, the recovered population is able to dilute the contagious effect of infected population, decreasing probability of Infected Susceptible Contacts (ISC).

**Average Duration of Infection**

Sanche (2020) brings a lot of estimate for the periods related to COVID-19 known up the moment, and, based on these numbers, an Average Duration of 14 days was chosen. The model also considers that deaths take at least one day longer than recovery and is distributed according to mean time of hospitalization. Reference shows that these times of discharge may have been longer in China, from 11,5 days to health discharge up to 16 days to death on hospital. These times were not considered, once hospitalized people is already separated from population during treatment and takes small part on dissemination, with the exception from health personnel, that has a infection dynamic completely different from regular population.

**Proportion of Worst Cases**

COVID-19 is a disease that behaviors similarly to other types of flu. Some people are heavily affected, other passes 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 to the interval from 5% to 80%. The case of the
Dimond Princess, a cruise boat that confined 3,711 people on board, was closely studied and reported an estimated asymptomatic proportion of 17.9%.

Also, there’s a proportion of infected people that must be hospitalized, and this is the fraction of interest for the SDM. For Spain, according to Epidemiology Bulletin 107, the cases confirmed up to 16th MAY 2020 had a 3.5% rate of Intensive Care Unit (ICU) hospitalization, with little difference on age. For USA, on the other hand, differences from age group varies from next to under 0.5/100.000 to 17/100.000 (CDC COVID-19 Response Team, 2020).

The problem related to calculate the specific rate of hospitalization resides on the asymptomatic and mild cases reported, cited before, once many people refuses 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.

Death rate on ICU cases are reported on 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 SIR 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 strategy is related to time to a vaccine. Best estimates points to a 12 to 18 months due (Spinney, 2020).

Treatment protocols are being tested every day, yet to be confirmed as effective. But it’s common sense that people that have better medical care will have more chances to survive. As a result, most of strategies available are related to make as little as possible the infected population, both to wait for a vaccine being developed and globally produced to a eight-billion scale, and to make the amount of people needing hospitalization keep under the capacity of Health Care Systems.

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 23rd JAN 2020, but first official communication from China Government to World Health Organization of a novel coronavirus was on 31st DEC 2019 ((WHO), 2020), what means that China government knew about this problem at least 23 days before it went public.

On 31st DEC 2019, 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 1. Ohio (State of USA) reported a case of COVID-19 on 6th JAN 2020. Although some quarantines declared from the CDC over USA, State and City governments began declare quarantines only on March 2020 (Wikipedia, 2020), after roughly 70 days after first infection reported on country.

In Brazil, first reported case was on 08th FEB 2020, in São Paulo, and first quarantine order was issued on 13rd MAR 2020, to begin on 16th MAR 2020, 37 days after first case (São Paulo, 2020).

Even on the cases of Brazil and USA, that were already aware of the occurrence of a new coronavirus disease outbreak, the time to begin the new strategy is an important issue. This way, this variable was studied on its sensitivity to results.
On the present model, the baseline is 20 days to government reaction, from a initial stock of infected population of 20 persons, based on São José dos Campos data.

**Days to finish strategy**
Same rational applies to the end of some strategy. The day when a quarantine should end is also a matter of study.

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

On the classic SIR SDM, this strategy is translated on the Contact Frequency (CF) variable, a component of the Contact Rate. CF varies according to how 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 (1 p/p/day). On a normal day, it is considered that the CF is ten p/p/day. On a party season, like carnival, these numbers could raise up fifteen p/p/day.

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

Other way to decrease ISC would be identifying the infected people and isolating them from the rest of 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 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 infected population was identified. This way, zero means that none is identified as infected. 10% (0,10) means that government knows 10% of infected people.

**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 and, therefore, the infection rate between infected population and its older fraction. That would allow that the workforce could go back to active duty, 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, but it will be also analyzed using the Customized SIR SDM.

### 3.5. Customized SIR SDM: Environmental Variables

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

All environmental variables, like Population, fraction over 70 years old, death rates, ICU needs, are already defined on previous sections.
Period for simulations was established as one year (365 days).

3.6. Customized SIR SDM: Results to be measured

The results to be measured and compared on the Sensitivity Analysis for the Customized SIR SDM are related to the Value Focused objective of the listed control strategies. There should be measured against time: Amount of Deaths and Amount of Infected People. The Amount of Intensive Care Unit (ICU) Beds needed would be a direct function of Amount of Infected People. This way, the peak of the Amount of Infected People and the time to get to this peak is also an important question.

3.7. Limitations of Customized SIR SDM

Given all estimates that are used on the model, and all the fast changes each variable takes, the numbers that results from the simulation are not to be taken as directly valid. Exponential nature of System Dynamics Models 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.

4. Findings and Results

4.1. Customized SIR System Dynamic Model

FIGURE illustrates the proposed model. It was designed on VENSIM PLE Plus, version 7.0.
4.2. Baseline results

Using baseline results, validation of model was made based on Death Counts for São José dos Campos only. ICU beds and infected population registered were considered not trustable for validation purposes, once testing levels are low in Brazil and in São José dos Campos and ICU beds proportion depends on information that were not being provided by private hospitals on the beginning of study period.

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

FIGURE brings that the tendency of the graph corresponds to the one observed up to 08th MAY 2020, in São José dos Campos.
The shape of the infected population, shown in FIGURE, corresponds to the generic classic epidemic behavior observed on (Kermack & 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 was studied using values from 1 (extreme lockdown) to 15 (party events contacts), using 0,1 contacts person/person/day as step.

![FIGURE – Sensibility Analysis on Contact Frequency](image)

Analysis of graphs show that the higher the CF variable, meaning less restrict lockdown, higher the total of deaths in São José dos Campos. The difference from the predicted deaths on a mild lockdown (CF=4) goes from 670 deaths to 968 deaths on normal situation (CF=10). A strong lockdown of CF=3 would predict a death toll of 315 only.

![FIGURE – Days to Peak of Infected Population Curve](image)

Same way, a more restrict lockdown flattens the curve, as expected. As may be seen on FIGURE, besides the maximum of infected population, a lockdown with CF=3 would have a maximum of 16,646 people infected at same time, and this peak would take 257 days to occur.
A CF=5 would tend get more than 120,000 infected people on peak, arriving at this value on 111 days. On a considered “normal” situation of CF=10, infected population would arrive to 305,000 people, on less than two months (59 days).

ICU bed occupation would follow close the same tendencies observed on Infected Population.

Important to highlight that these numeric values serve only as reference, once all information on COVID-19 are very volatile.

4.4. Sensibility Analysis: Vertical Quarantine

Although not realistic for values higher than 50%, the Vertical Quarantine values represents 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 system.

![FIGURE – Results from different Vertical Quarantines efficiency](image)

The difference on Death Toll from a complete lockdown to older people to no lockdown would be around 20%. The specific study on the different age groups reveals that that most of the saved lives comes 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. 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%.
All other results are little different with all the social cost 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 on graph. ICU beds occupation follows same proportion, and wouldn’t change much.

4.5. Sensibility Analysis: Infected Identification

Infected identification control variable varies from the unrealistic 100%, where one would be able to know every person who has the disease, to 0%, where there’s no information on who is infected.

Graphs show that 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 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.
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 strong lockdown where CF=2.

Graphs show that the sooner authorities act on 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 on 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 SIR 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 on existing variables, rates and stocks. This scheme made possible to infer that one of the central strategies to achieve the value focused target of decrease deaths should be decrease the number of Infected Susceptible Contacts, what 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 older tend to live together with their sons.

The last verification, belonging to the delay of action from authorities revealed that a fast response to an outbreak of these characteristics would result on 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, what 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 under the validation of the classical SIR model behavior.

Other strategies that could be tested on the model for future exercises include the use of a restricted number of ventilators and 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 for COVID-19 policies.

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