Analysis of measures for stopping post-pandemic rebound or future epidemic infections in Colombia. A system dynamics approach, based in COVID 19

Análisis de medidas para frenar el repunte pospandémico o futuras infecciones epidémicas en Colombia. Un enfoque de dinámica de sistemas, basado en COVID 19

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ABSTRACT

In Colombian different measures have been formulated to stop the outbreak of COVID 19, all focused on reducing social contact, depending on the phase of the dynamics of the epidemic. In this article, thresholds for implementing measures have been defined based on the percentage of the total infected population. Similarly, a mathematical model has been created with systems dynamics. The process starts from the SIR standard model, with the inclusion of hospitalized and dead variables as stock variables. As a result, a model with five stock variables is presented. Using piecewise functions was possible to model for containment and mitigation measures focused on preventing the massive contagion. It was possible to see the reduction in contacts, and it was possible to see the reduction of infected people. The results of the model for the city of Cali, Colombia, which has a population of 2,200,000 inhabitants, are presented. The model presents an easy-to-understand structure to evaluate the measures implemented by the authorities to mitigate the COVID outbreak. The results allow seeing the trends of the outbreak and the effectiveness of the measures in stopping the infection. This work is a tool to understand outbreaks and rebounds in times of post-pandemic and future infections.

Keywords: COVID 19; Measures; Pandemic dynamics; Simulation; System Dynamics (SD).

RESUMEN

En Colombia se han formulado diferentes medidas para detener el brote de COVID 19, todas enfocadas a reducir el contacto social, dependiendo de la fase de la dinámica de la epidemia. En este artículo se han definido los umbrales para implementar las medidas con el porcentaje de la población total infectada. Asimismo, se ha creado un modelo matemático con dinámica de sistemas. Partimos del modelo estándar

SIR, con la inclusión de variables de hospitalizados y muertos como variables de nivel. Como resultado, se presenta un modelo con cinco variables de nivel. El uso de funciones por partes fue posible para modelar cuatro medidas de contención y mitigación enfocadas en prevenir el contagio masivo. Se pudo ver la reducción de contactos y se pudo ver la reducción de personas infectadas. Se presentan los resultados del modelo para la ciudad de Cali, Colombia, que tiene una población de 2.200.000 habitantes. El modelo presenta una estructura de fácil comprensión para evaluar las medidas implementadas por las autoridades para mitigar el brote de COVID. Los resultados permiten ver las tendencias del brote y la efectividad de las medidas para detener la infección. Este trabajo es una herramienta para comprender los brotes y los rebrotes en tiempos de infecciones posteriores a una pandemia y futuras.

Palabras clave: COVID 19; Medidas; Dinámica pandémica; Simulación; Dinámica de sistemas (SD).

1. INTRODUCTION

The occurrence of epidemics and pandemics has marked the history of Humanity, given the catastrophic impacts that have affected life in various dimensions of the daily living of human beings. Impacts that have generated crises, for which several years have been required for the recovery of living conditions, and that in post-crisis, have created new mental models and new operating styles in these dimensions. For example, the influenza pandemic, or the Spanish flu of 1918, wreaked considerable havoc on the world population. Currently, COVID 19 [1], an infectious disease caused by the SARS-CoV-2 virus [2], was first detected in the Chinese city of Wuhan (Hubei province) in December of 2019 [3] and spread to more than 180 countries, specifically, the entire planet. When it reached more than 100 territories, on March 11, 2020, the World Health Organization, declared pandemic [4]. To date, there is no known vaccine or effective treatment for the disease [5], although several countries already say they have made significant progress in its development. Many of the patients who have died have previous pathologies such as high blood pressure, diabetes, or cardiovascular disease that weaken their immune systems [6].

Some countries have formulated mitigation measures in the early stages resulting in less spread of COVID-19 at the time these measures had an impact [7]. In the case of China, it was shown that through quarantine, social distancing and isolation of infected populations, the authorities were able to contain the epidemic [8].

In Colombia, following the guidelines of the WHO and other international organizations, the authorities, especially governments, health, education, security, and mobility, have sought to reduce the transmission of the virus, and if possible, advance and decrease the peak epidemic, known as flattening of the epidemic curve. For this, they also took measures to reduce the risk that:

-the health system becomes overloaded and saves time until a vaccine or treatment is developed,
-the educational system results in massive contagions from their community,
-the economic system collapse in the face of the inevitable economic recession, and
-the general public suffers the negative impact of a catastrophe.

The preparation phase in Colombia consisted of improving the preventive development of hygiene activities for citizens. Controlling entrances at airports, to prevent their arrival or detect the first imported case effectively Then, once the first imported case was verified on Friday, March 6, it entered the containment phase, in order to control its spread rate. In this phase, measures are already being formulated, such as the promotion of basic social distancing, cancellation of massive events, and closure of schools and universities. However, a large part of the population ignored social distancing, imported cases also continued to arrive without significant control, and in a short time, the country entered the mitigation or community contact phase as it was not certain of the origin of each case. In this phase, airports were closed, social distancing modalities, hygiene practices, bio-protection care, and security protocols were strengthened. Likewise, more drastic additional measures will be formulated, such as total quarantine decrees (including restrictions on mobility and penalties for citizens who carry out activities that threaten public health, including infected people). There has been much emphasis on isolation for people over 60 years and children.

On the other hand, the government recommends a) use the applications for migration and to consult on the disease, b) attend specific planes for populations with a higher level of risk, such as health workers and hotel workers *, and c) increase self-care, increasing hygiene measures and promoting them. However, in principle, bio-protection inputs and security protocols have not been necessary. In this phase, the first person died on March 16 in Colombia and the first health worker, a doctor, who died on April 11, was presented. As of April 30, 6507 infected people were lost in Colombia, 293 died, and 1,439 recovered **. As of this date, 945 infected persons were registered in Valle del Cauca, and in the city of Cali, 740 confirmed cases, 42 deceased and 138 recovered [9]. In this phase of the epidemic, it is carried out this study in the city of Cali, taken as a pilot. Cali. It is the third most populated city in the country with 2.200. 000 inhabitants.

The dynamic model presented in this article is created to evaluate public health and safety measures, formulated by the Colombian authorities to stop the transmission of COVID 19, in the absence of a vaccine or treatment. The determination to build this model is to analyze qualitative results, rather than precisely quantitative results of the performance of the measurements, and not to evaluate other aspects of the capacity or dynamics of the pandemic that had been studied by internationally recognized organizations. The model estimates different moments of implementation of the measures to mitigate and, in the best case, stop the spread of the virus. For this, have been formulated different scenarios based on threshold values to implement each measure, using a system dynamics model.

This paper consists of six sections organized as follows: section 2 presents the review of the main contributions of interest to this research, section 3 presents the methodology used to develop the model, section 4 presents the model components of the pandemic dynamics based on the standard SIR model. Likewise, section 5 presents the results of the simulation, this section is dedicated to formulating and evaluating scenarios based on thresholds defined for each measure, thus, several results of the model are presented based on the behavior resulting from the outcome variables, infected, deceased and recovered. The discussions and conclusions are presented in Section 6.

2. REVIEW OF THE MAIN CONTRIBUTIONS

Wu et al. [10] published the first dynamic transmission study of COVID-19, estimating the basic reproduction number R0, as invariant over time. Other authors have also carried out studies estimating the reproduction rate, the trend of the epidemic using mathematical models, and the need to make significant efforts to control the outbreak and prevent its spread. Liu et al., [11] perform an analysis of some of these models, including their model, and review the basic reproduction number (R0) of the COVID-19 virus. Tite et al. [12] evaluated the effectiveness of non-pharmaceutical interventions to control the 2019 coronavirus disease pandemic (COVID-19) and reduce the burden on the healthcare system in Canada. Their results showed that without substantial physical distancing or a combination of moderate physical distancing with better case finding, they projected that ICU resources would be overwhelmed. Dynamic physical distancing could maintain the capacity of the health system and also allow periodic psychological and economic respite for populations.

Bordehore et al. [13] developed an open model (using STELLA® from Iseesystems) that could be customized to any area/region and by any user, allowing them to evaluate the different behavior of the COVID-19 dynamic under different scenarios.

Anderson et al. [7], presents an analysis of how country-based mitigation measures influence the course of the COVID-19 epidemic; also, the authors perform an analysis of the usefulness of model-based predictions, confirming that these can help policymakers make the right decisions on time, even with uncertainties about COVID-19. According to them, this reinforces the need to study scenarios that start from monitoring and knowing the proportion of infected people in a total population as an indicator of pressure to take measures in the early stages of growth in the number of infected people. They also emphasize the importance of knowing the mechanisms of infection so that the formulators of the measures select them and evaluate them in scenarios to simulate. However, they consider that some necessary measures that contribute to social distancing and quarantine are more difficult to implement, due to cultural factors and economic impacts that they may cause. The truth is that, as Anderson and colleagues say, how people respond to advice about the best way to prevent transmission will be as important as the actions of the government and other authorities, if not more. The truth is that measures are also required to mitigate the negative impact of isolation measures on the economy, especially on employment. All this supported by a good system of communication of the measures.

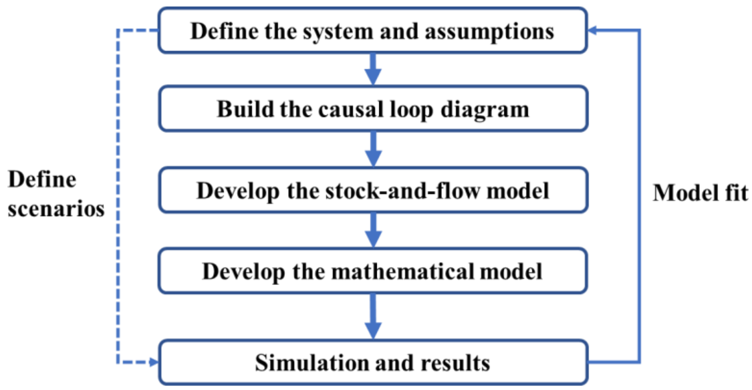
Ferguson et al. [14] present the results of microsimulation epidemiological modeling for policy formulation in Britain and the United States in February. In the absence of a COVID-19 vaccine, the authors assess the potential role of a series of public health measures, called non-pharmaceutical interventions (NPIs), aimed at reducing contact rates in the population, and therefore reducing the virus transmission. They concluded that the effectiveness of any isolated intervention might be limited, showing the need for multiple responses to be combined with having a substantial impact on transmission. The authors demonstrated that in the context of the United Kingdom and United States, suppressing the growth of the epidemic will minimally require a combination of social distancing from the entire population, isolation of cases at home, and household quarantine of their relatives, this may need to be complemented by the closure of schools and universities. However, they acknowledge that such closings can have negative impacts on health systems due to increased absenteeism.

Another mathematical modeling study on the early transmission dynamics of COVID 19, was developed by Kucharski et al. [15]. The authors combined a stochastic transmission model with data on cases of the disease.

3. METODOLOGY

The procedure of the SD modeling approach applied in this research is shown in Figure 1. This procedure allowed working with the relevant information on the real situation of the pandemic and the measures to be simulated, in a practical search for the objective of this research.

Figure 1. The procedure of SD model development

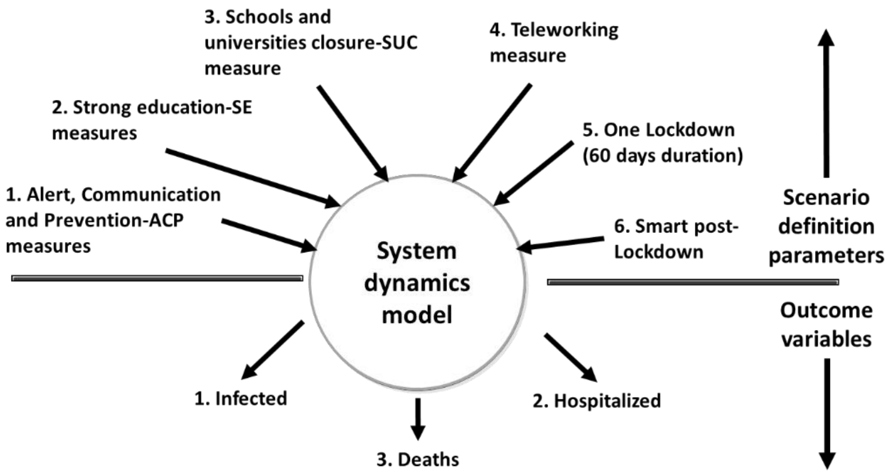


4. THE MODEL

4.1 Problem map

The identification of the parameters for defining the scenarios and the output variables of the system, allows building the map of the problem (Figure 2). To fulfill the purpose of this work, the parameters selected for the definition of scenarios are decision variables or measures to contain the spread of the virus, these are: 1) Alert, Communication and Prevention-ACP measures, 2) Strong education-SE measures, 3) Schools and universities closure-SUC measure, 4) Teleworking measure, 5) One Lockdown (60 days duration) and 6) Smart post-Lockdown. The output variables are 1) Infected, 2) Hospitalized, and 3) Deaths.

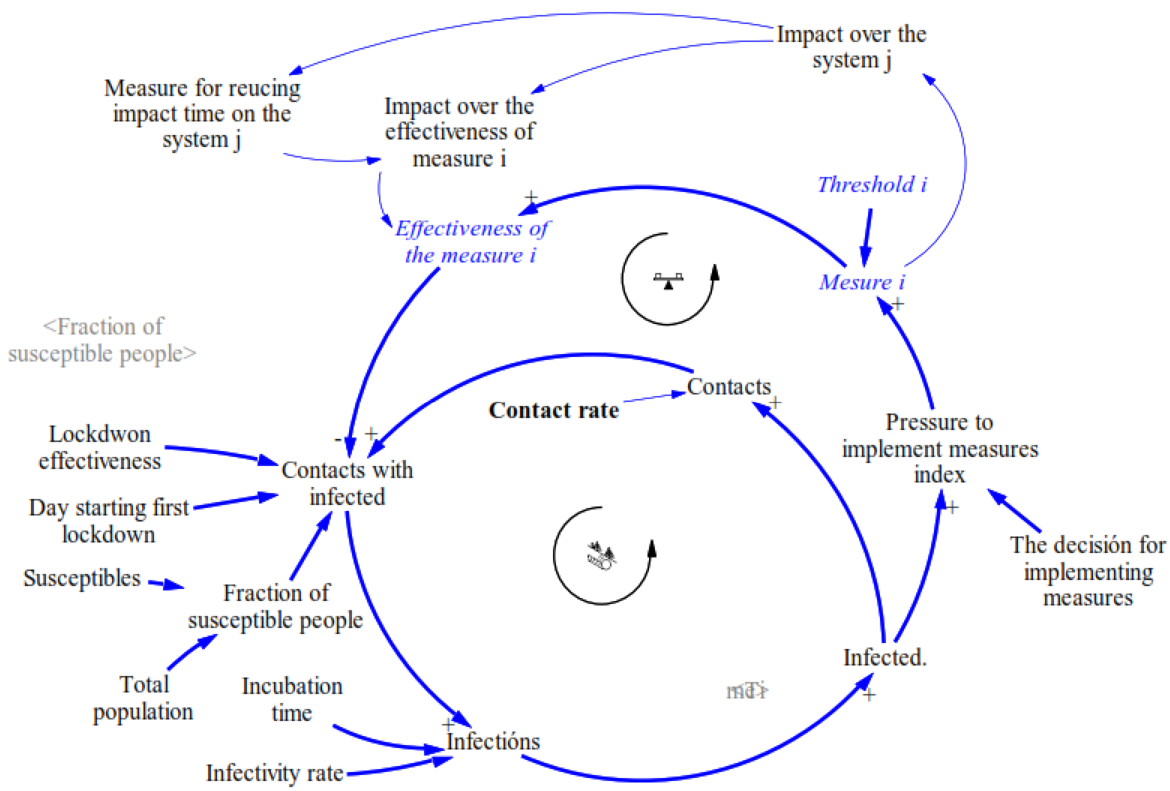
Figure 2. Map of the problem



4.2 Causal loop diagram.

The relationships between the main variables are expressed in the causal loop diagram (Figure 3), where it is posible detect the two main feedback loops acting.

Figure 3. Causal Loop of the problema and general measures



4.3 Stock and Flows model

The modeling carried out in this study starts with the developed model by [16], following the methodology proposed by Sterman [17]. Our model has been complemented by linking, physical movements, hospitalized patients due to their severity, and on the side of information flows, the need for governments to take measures to reduce the rate of contact between infected people and susceptible people. The supplemented mathematical model is formulated in detail. For the activation of each measure, the corresponding stakeholders use a threshold value ("trigger") of the proportions of infected people in the total population. This proportion is defined in the model using the variable "Pressure for measurements." The model is expected to allow the government to make decisions and opportunities to manage the spread of the virus in time and avoid the collapse of the health system, or even, given the peak load, have time to increase the capacity of the system.

In this model, a pressure indicator is used to take measurements, expressed in terms of the proportion of infected concerning the total population. Based on this indicator, select thresholds to formulate the different measures, and choose parameters to assess your level of opportunity.

A first reinforcing feedback loop (Figure 3) shows that there is one cause and effect relationship between the contacts with infected and infections in whose interaction. An increase in contacts with infected leads to increased infection. This effect spreads by making the flow of infections cause an increase in the number of infected, which in turn increases the number of contacts, reinforcing this, the contacts with infected.

This feedback loop is the vicious circle that the population entered from the first case of infection and caused the spread of COVID 19. In the early stages of the epidemic, the health of the people had pressured the government to implement the first necessary measures. Such as, campaigns for prevention, education, and controls at airports, but the dominance of this unwanted feedback loop, caused by the recklessness of people who ignored the first, recent measures, the spread of the virus, generating the exponential growth of those infected.

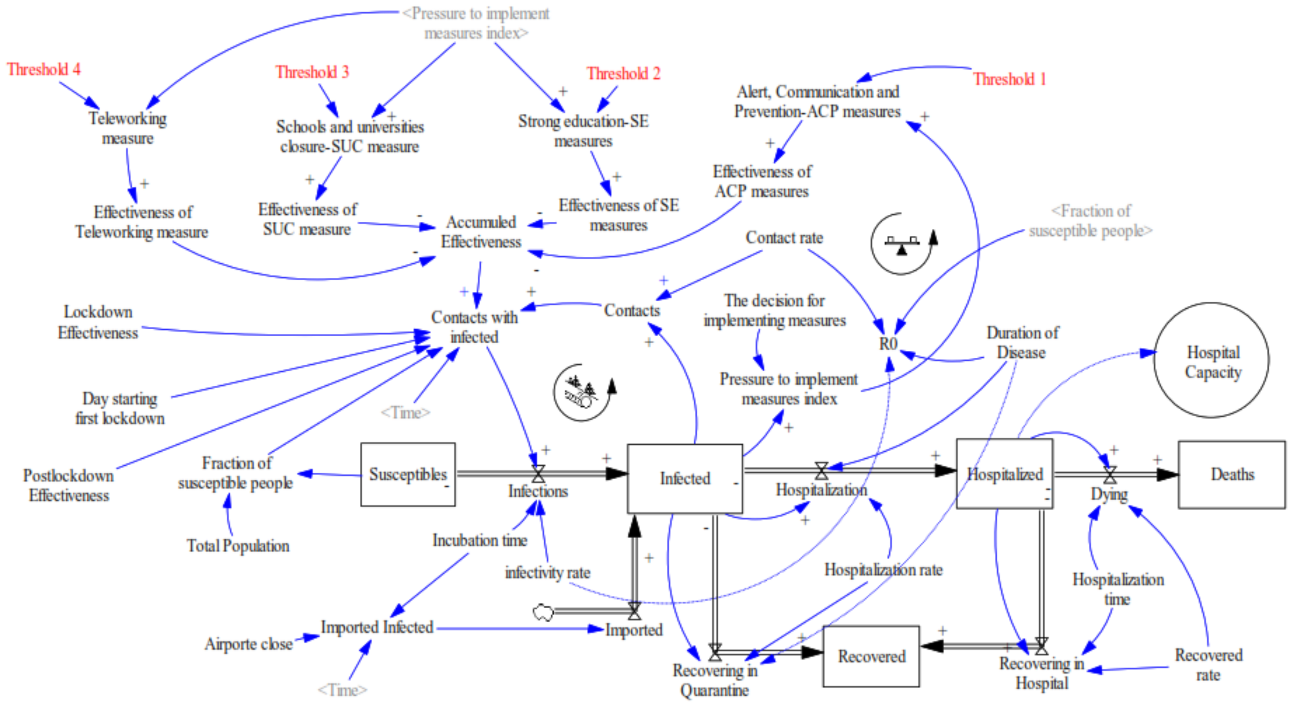
On the other hand, looking for possibilities to weaken the dominance of the reinforcement loop described, in this study, the implementation of countermeasures was modeled, structuring compensation feedback loops. This means that, in the case of the pressure to implement index measures increase and reach a certain threshold value, the implementation of an additional measured measure is shown, generating an additional compensation loop and causing these loops to gain dominance by promoting the mitigation of their problems in the different affected systems, stories such as the educational system, the health system, the economic system and citizens in general.

The first compensation feedback loop (figure 4) inserted in the model arises from needing to implement the first countermeasure. The loop shows that a direct cause-effect relationship is generated between the pressure to implement the measure index and the first measure in whose interaction, Alert, communication and prevention-ACP measures, this effect is transmitted so that, in the measure implemented, It increases the effectiveness of ACP measures, which in turn reduces contacts with infected people, stabilizing this, in turn, the behavior of infections, the infected people and the pressure index to implement measures. The performance of a second and other additional compensation feedback loops in the model increased the implementation of different measures, on the way to a flattening state of the infected curve. See table 3 the notation of variables that are in the stock and flows diagram.we s

Table 3. Notation of variables

Types of variable	Variable/Parameter	Notation
Auxiliary	Contacts rate	μ
Auxiliary	Fatality rate	Fr
Auxiliary	Hospital Capacity	HC
Parameter	Incubation time	it
Parameter	Disease duration	Dd
Parameter	Hospitalization rate	Fh
Parameter	Infectivity rate	β
Parameter	Hospital Capacity	HC
Parameter	Lockdown Efectivity	ƛ
Parameter	Post Lockdown Efectivity	q
Parameter	Serious cases	SC
Parameter	Hospital Capacity	HC
Flow	Contacts with infected	Ci
Stock	Susceptible	S
Stock	Infected	I
Stock	Recovered	R
Stock	Hospitalized	D
Stock	Deaths	D

Figure 4. Stock and Flows diagram of the COVID- 19Epidemic and measures



4.4 The Mathematical Model

From the Stock and Flows diagram was possible to build the following differential equations that represent the problem. The model also presents auxiliary variables and parameters that were constructed from bibliographic references or some estimated, as shown in the Table 2.

$$\frac{dS}{dt} = -\frac{\beta Ci}{it} \tag{1}$$

$$\frac{dI}{dt} = \frac{\beta C + IM}{it} - \frac{I}{Dd}(Hr) - \frac{RQ}{Dd}\,(1 - Hr) \tag{2}$$

$$\frac{dR}{dt} = \frac{RQ}{Dd}\,(1 - Hr) + \frac{RH}{Ht}(Rr) \tag{3}$$

$$\frac{dH}{dt} = \frac{I}{Dd}(Hr) - \frac{RH}{Ht}(Rr) - \frac{H}{Ht}(Rr) \tag{4}$$

$$\frac{dD}{dt} = \frac{H}{Ht}(1 - Rr) \tag{5}$$

5. SIMULATION AND RESULTS

For the simulation of the model, a time limit of 500 days was taken into account, and the integration method was the RK-4 established in the Vensim Ple software.

Table 2. Initial conditions

Name	**Intial Value**	**Units**	Reference
Susceptible	2'200.000	People	DANE [18]
Incubation time	5	Days	Wu et al. [10]; Ibarra [16]
Disease duration	14	Days	Sanche and Lin [19]
ººHospitalization rate	13	%	WHO report 73 [20], Li et al. [21]
Infectivity	0.025	Dimensionless	Estimated with RO (5-8), Sanche and Lin [19]
Contacts rate	45	Contacts/Person	Assumed
Hospital Capacity	3000	Beds	INS [9]
Fatality rate	5	%	Sanche and Lin [19]; INS [9]
Lockdown effectiveness	0.6	%	INS [9]
Postlockdown Effectiveness	0.8	%	Assumed

The simulation without any type of measures (Scenario A) is presented in Figure 5, where the typical behavior of an epidemic is presented.

In Table 3, is presented the parameters of scenarios evaluated with measures. Theses measures are: Alert, Communication and Prevention measures; Strong education measures; Schools and universities closure, Teleworking; Lockdown.

Figure 5. Scenario without measures

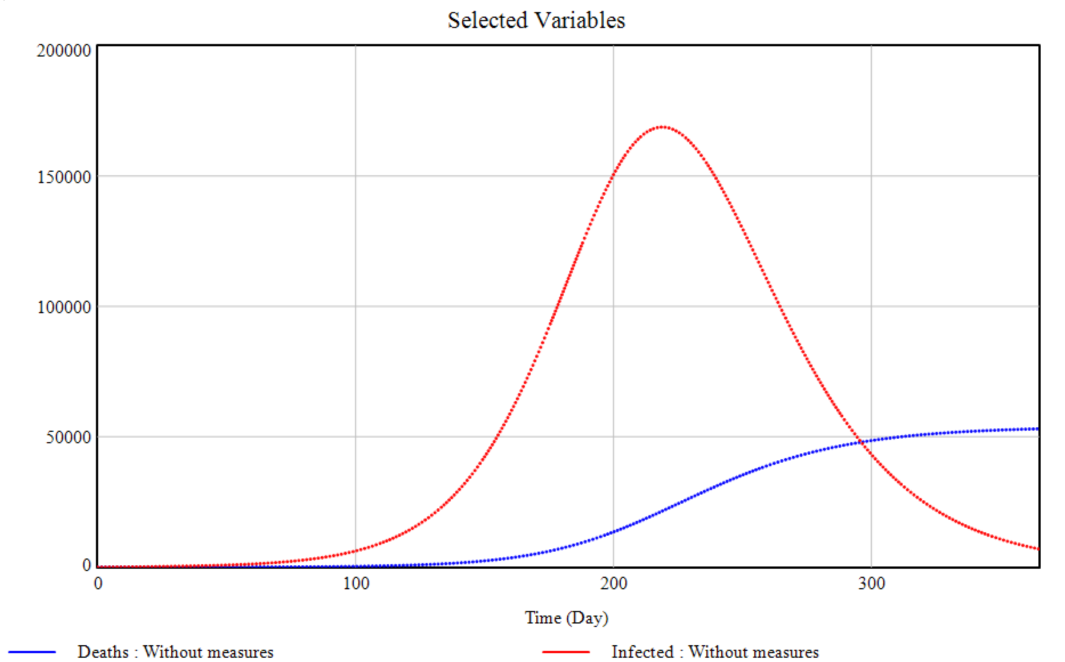


Table 3. Parameters of scenarios evaluated with measures

Scenario	Initial Day	Final Day	Initial Day of Smart Lockdown	Final Measure
A. Without meausres				
1. Alert, Communication and Prevention-ACP measures	1	360		
2. Strong education-SE measures	3	120		
3. Schools and universities closure-SUC measure	10	120		
4. Teleworking measure	15	120		
B. With the previous four measures + One Lockdown (60 days duration)	25	85		
C. Scenario B + Smart post-Lockdown	25	85	86	360

Figures 6 and 7 show the number of infected people that can exist in the scenarios in which the measures are implemented without lockdown and with one lockdown. Figure 8 shows the infectedwith four measures, one lockdown and a smart prevention postlockdown. This beheaviur is presented currently in several cities in Colombia.

Figure 6. Infected with four measures

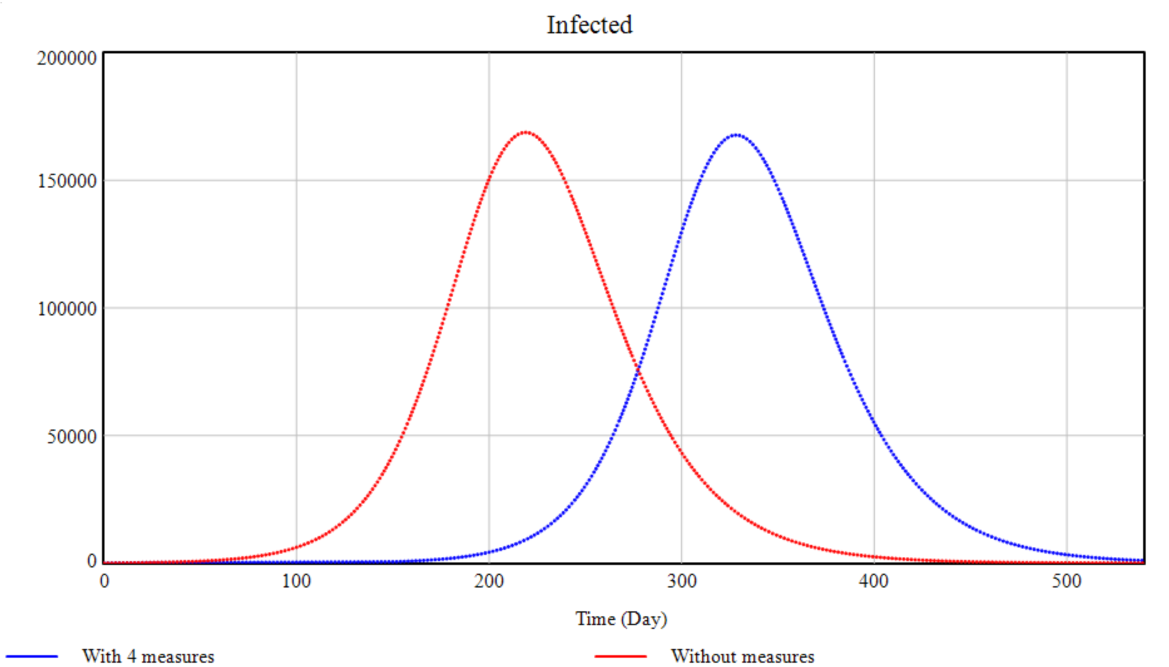


Figure 7. Infected with four measures, and one lockdown

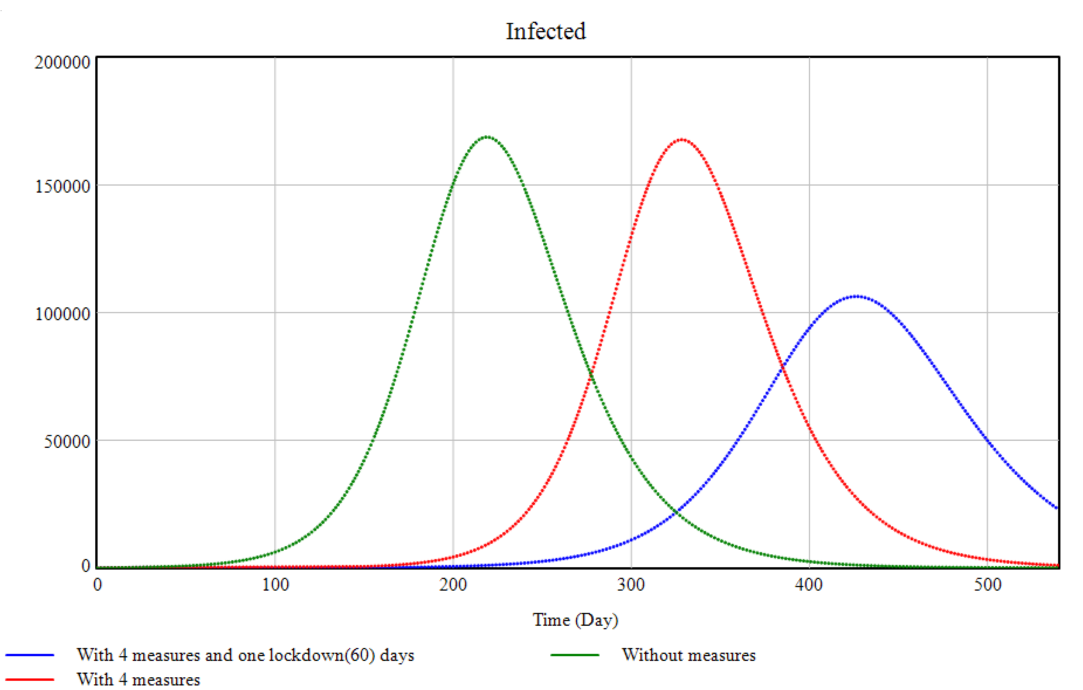


Fig 8. Infected with four measures, one lockdown and a smart prevention postlockdown

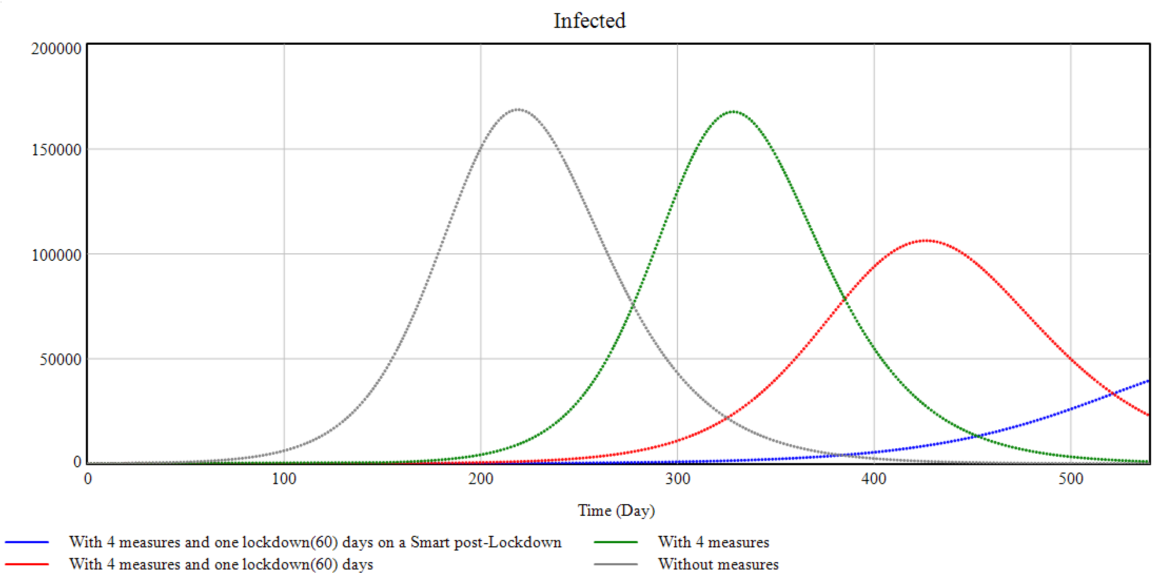


Figure 9 shows the comparison of the number of deaths that could have in the three proposed scenarios.

Figure 9. Deaths comparison in all scenarios

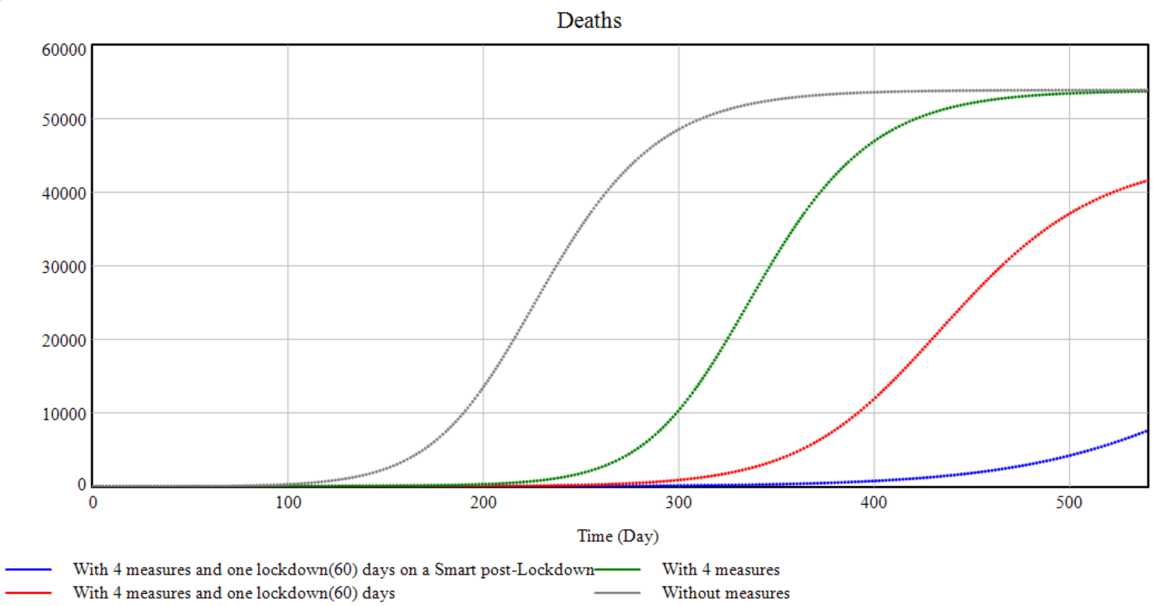
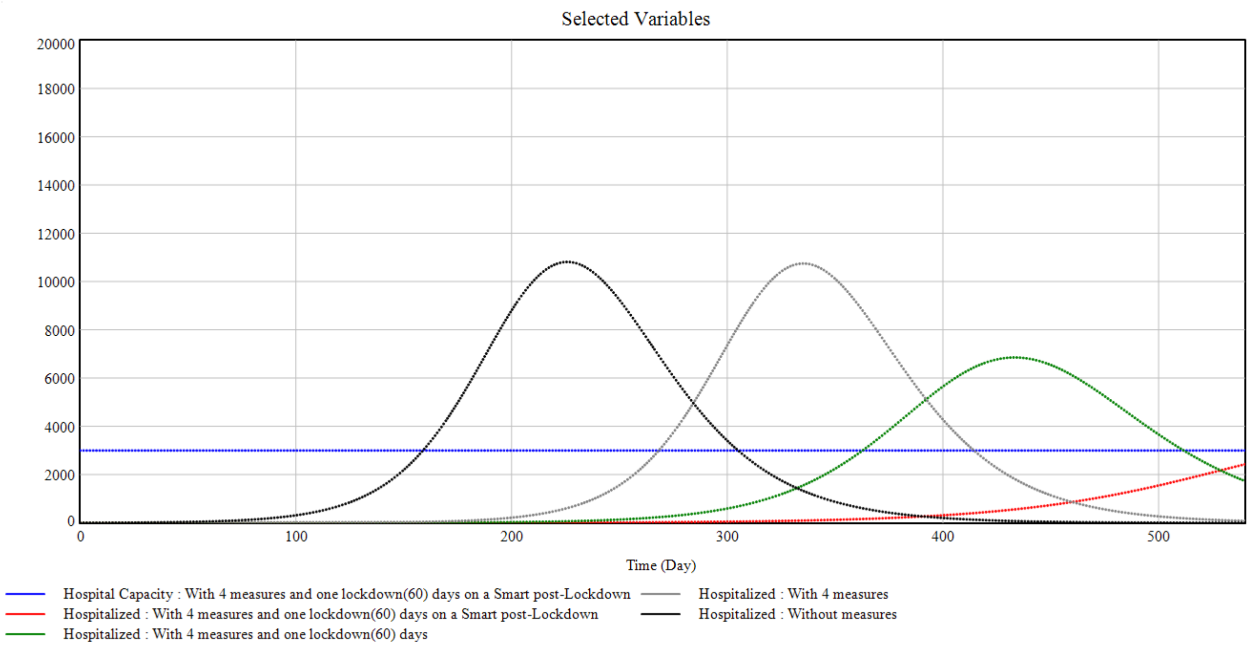


Figure 10 shows the number of hospitalized in the three scenarios and shows the capacity of beds for hospitalization. This capacity must be increased with the different stages of the epidemic; otherwise it could increase the mortality rate due to incapacity to care for the sick.

Figure 10. Hospitalized and Hospital Capacity



5.1 Validation

The models built with system dynamics have structure and behavior validation. The validation of the model structure is based on the coherence of the units, definition of the set of parameters and systemic representation with the identification of the feedback structures of the problem. For the behavior of the result variables, the extreme conditions were validated, it was evaluated that the model showed a behavior consistent with that shown by the recognized epidemiological models.

The quantitative results of the scenario simulations were not validated due to the difficulty to verify with a high approximation the infections in the city and in the world. To date, a true contagion rate is still unknown, and the real number of infected is unknown, in fact, the model carried out by the National Institute of Health, estimated a much worse scenario than the one the country is going through.

Similarly, there is a lack of data on: i) people who depend on the informal economy and other formal sectors but with similar needs, who, in a high proportion, have not heeded the call for isolation from the health authorities, and ii) infections caused by social indiscipline in other sectors of the population.

6. DISCUSSIONS AND CONCLUSIONS

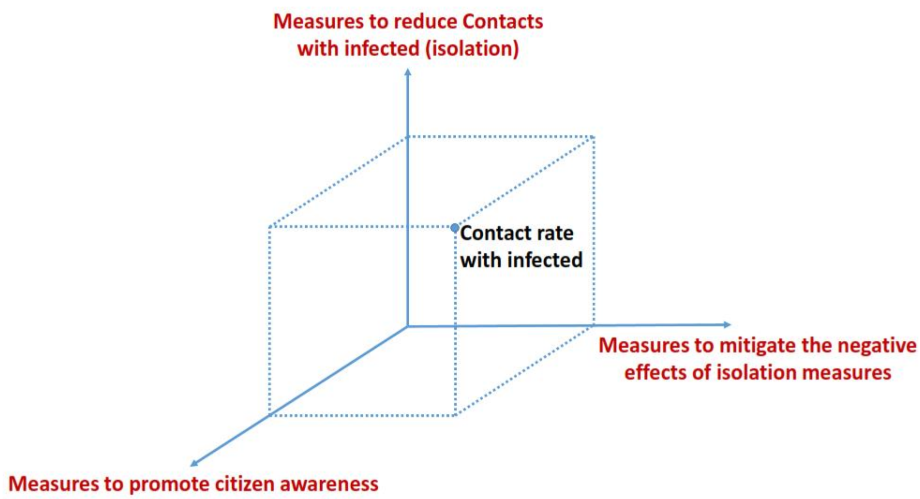
6.1 Discussions

The main objective is to regain normalcy in its ways of operating sustainable. Unfortunately, this normality will not be easy to achieve in the same proportion in each of the affected systems, for example, the economic system now requires great government efforts for the sustainable recovery of sufficient levels of performance, at all kinds of expenses.

A comprehensive view of the problem allows us to analyze three interdependent dimensions that explain any context (See Figure 11) This interdependence also guides the implementation of efforts both to mitigate the pandemic and to mitigate the collateral effects of the measures implemented to minimize contacts with infected.

The amount of contact rate with infected will depend on the intensity and effectivity fo these three kinds of measures. The measures to mitigate the adverse effects of isolation measures they focus, for example, on the collateral impact on the educational, health, and economic systems. The Measures to promote citizen awareness seeks to educate and sensitize the population about the pandemic, and the need to adhere to isolation measures. It is important to say that Systems Dynamics models seek to guide the understanding of trends behavior.

Figure 11. Meausres integration for futures pandemic or postpandemic



6.2 Conclusions

Through modeling with Systems Dynamics, successful representation of the coronavirus outbreak was created for a population of 2,200,000 inhabitants, similar to Cali, Colombia. The mathematical model has a general structure like the model presented by (Ibarra, 2020). However, due to the flexibility of the methodology, the effects of implemented measures in differen times have been modeled.
With the measures to reduce contact, the following is a) Formulate procedures and operational routines to manage the dynamics of the virus and supply management inputs and bio-protection at the management points. For this, what follows is to develop the technological, physical, human, cognitive, security and infrastructure capacities necessary for the measures to be effectively implemented, and the health, education, mobility and citizenship systems in general are protected while develop and implement a vaccine; b) a proper awareness, education and communication program that are also key to accompanying these measures; c) Regarding preventive measures, on the one hand, biomedical security protocols in all types of establishments should not be absent, and on the other hand, any person who, due to some circumstance of the sea suspected of having contracted the virus, must continue entering quarantine, for which adequate legislation must be maintained; d) the biosecurity protocols of health workers must design the agreement to the levels of exposure in relation to the contact with patients, the same for workers who move around the city and have contact with the rest of citizens; It is important to emphasize that the morale of these health workers cannot be violated, discriminating as in some cases in Colombia; e) solidarity networks, and care and assistance programs for vulnerable populations are also necessary in order for them to stay home during quarantine; f) it will be essential to verify the level of awareness and adequate behavior of citizens and

organizations is maintained; g) the implementation of the much-needed smart quarantine will require, first, gradual sea, and second, rigorous and controlled policies of social distancing, and continue educating citizens, if you do not want to lose all the effort invested in managing the pandemic and stopping the spread of the virus at least partially and saving many lives.

Conflict of interests

The authors declare that they have no competing interests.

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