

Pandemic responses in vulnerable communities: a simulation-oriented approach

Vinicius Picanço Rodrigues ¹

Igor Czermainski de Oliveira ²

Gisele de Lorena Diniz Chaves ³

Ellen Larissa de Carvalho Aquino ⁴

Cláudia Viviane Viegas ⁵

¹ Insper Instituto de Ensino e Pesquisa, São Paulo / SP – Brazil

² University of Bergen / Faculty of Social Sciences, Bergen – Norway

³ Universidade Federal do Espírito Santo / Department of Engineering and Technology, Vitória / ES – Brazil

⁴ Universidade Federal de São Carlos / Science, Technology and Society Program, São Carlos / SP – Brazil

⁵ Universidade Federal de Santa Catarina, Florianópolis / SC – Brazil

Populations living in favelas are facing even more vulnerabilities with the sudden escalation of the COVID-19 pandemic, as social distancing is challenging in such settings. Furthermore, these populations typically lack proper sanitation and hygiene conditions, which are requirements to adequately control the outbreak. This paper proposes the use of System Dynamics modeling to support the public policy-making process in order to avert negative effects of the pandemic in the Brazilian favelas based on measures elicited from the social movement named “Favelas Contra o Corona.” The simulation model assessed the effectiveness of strategies and policy bundles encompassing temporary transfer of the favela population, supply of hygiene products, emergency sanitation structures, and expansion of Intensive Care Units. Results indicate that a suitable combination of strategies can bring significant effects to the number of avoidable deaths and the availability of Intensive Care Units for the population.

Keywords: COVID-19; system dynamics; slum; public policy; sanitation; health.

Respostas à pandemia em comunidades vulneráveis: uma abordagem de simulação

Populações vivendo em favelas no Brasil enfrentam ainda mais vulnerabilidade com o advento da COVID-19, já que para elas o isolamento social é uma tarefa difícil. Além disso, esses locais carecem de saneamento e condições de higiene, que são requisitos importantes para controlar a pandemia. Este artigo propõe o uso de Dinâmica de Sistemas para apoiar decisões de políticas públicas relativas a medidas para aliviar os efeitos negativos da disseminação do vírus baseado em medidas definidas a partir do trabalho do movimento social “Favelas Contra o Corona”. O modelo proposto avalia a efetividade de estratégias e conjuntos de políticas que envolvem: transferência temporária da população da favela, suprimento de produtos de higiene, estruturas emergenciais de saneamento e expansão de Unidades de Terapia Intensiva. Os resultados apresentam o impacto de cada uma das estratégias. Entretanto, somente a combinação adequada de medida traz resultados significativos sobre o número de mortes evitadas e à disponibilidade de leitos de Unidades de Terapia Intensiva para a população.

Palavras-chave: COVID-19; dinâmica de sistemas; favela; política pública; saneamento; saúde.

Respuestas a la pandemia en comunidades vulnerables: un abordaje de simulación


Las poblaciones que viven en barrios de bajos recursos enfrentan aún más vulnerabilidades con el surgimiento de la pandemia de COVID-19, ya que para ellos el aislamiento social es una tarea difícil. Además, carecen de condiciones adecuadas de saneamiento e higiene, que son requisitos para controlar la pandemia. Este estudio propone el uso de la Dinámica de Sistemas para apoyar las decisiones de políticas públicas que leen las medidas que se tomarán para aliviar los efectos negativos de la propagación del virus basado en medidas obtenidas del trabajo del movimiento social “Favelas Contra o Corona”. Se desarrolla un modelo considerando estrategias y conjunto de políticas basado en: transferencia temporal de la población de barrios de bajos recurso, suministro de productos de higiene, estructuras de saneamiento de emergencia y expansión de la Unidad de Cuidados Intensivos. Se concluye que la solamente por la combinación de políticas efectos significativos serán alcanzados en el número de muertes evitadas y en el logro de la disponibilidad de Unidade de Cuidados Intensivos en el sistema de salud.

Palabras clave: COVID-19; dinámica de sistemas; favela; política pública; saneamiento; salud.

DOI: <http://dx.doi.org/10.1590/0034-761220200250x>

Article received on April 29, 2020 and accepted on June 22, 2020.

[Original version]

ISSN: 1982-3134 

1. INTRODUCTION

Over the past century disease outbreaks have been changing the policies societies use to respond to humanitarian and health crises (Biggerstaff, Cauchemez, Reed, Gambhir, & Finelli, 2014). In particular, the recent COVID-19 pandemic has challenged governments and civil society with respect to their agility and flexibility to respond to the rapid spread of the virus. The ensued health and socioeconomic crisis have resulted in the infection of millions of people and caused the death of hundreds of thousands worldwide, in official accounts from the United Nations' World Health Organization (WHO, 2020). Economically, it is expected that the pandemic will cost the world around US\$ 3 trillion (Orlik, Rush, Cousin, & Hong, 2020).

Physical distancing and good hygiene practices greatly diminishes the probability of infection. However, these basic resources are not equally available to communities with impoverished living and working conditions (Khalidi, 2020). Slums and other low-income agglomerates are typically entailed by overcrowded households, lacking adequate sanitation, water and housing infrastructure (Perosa, Leite, Fonseca, & Lebraron, 2016). These conditions gravely increase the risk of people contracting and spreading infectious diseases across large areas (Unger & Riley, 2007), which characterizes them as communities with high *social vulnerability* (Ito & Pongeluppe, 2020).

Overcrowded households in Brazil, defined as the situation where a household has more than three people per room, peaked in 2018 with 5.6% of the general population living in such conditions. Considering only the population living daily with under US\$ 5.50 per capita per household (purchase power parity), the share increases to 14.5% living in overcrowded households across the country (Brazilian Institute of Geography and Statistics [IBGE], 2019).

Given the high complexity imposed by the combination of poverty, inequality and overcrowding conditions, understanding the potential effect of public policies in order to effectively implement them in Brazilian favelas becomes a daunting challenge (Alirol, Getaz, Stoll, Chappuis, & Loutan, 2011; Weiss & McMichael, 2004). This research seeks to answer: *how policymakers can rapidly and effectively analyze the potential effects of containment measures in the face of the COVID-19 pandemic in Brazilian favelas?*

Within such context, this paper *aims at presenting the development of a simulation-oriented approach - based upon System Dynamics - to analyze the potential effects of policies designed to alleviate the consequences of the pandemic in communities living in Brazilian favelas*. Data from Rio de Janeiro favelas demonstrated the model applicability based on the measures proposed by the social movement "Favelas Contra o Corona" in March 2020. The results show that only a balanced combination of different measures targeted at vulnerable communities can avert deaths and limit the overutilization of the healthcare system. The study also demonstrates that simulation allows policymakers to derive scenarios safely and cost-effectively in such an emergency context, without wasting public resources or risking lives.

2. RESEARCH APPROACH

System Dynamics (SD) has an established tradition of applicability to public policy problems (Forrester, 2007; Ghaffarzadegan, Lyneis, & Richardson, 2010; Lane, 2016). SD is mainly employed whenever there are reasons to believe that the systems created to solve problems (e.g. the health system in each location) are contributing to such problems, a point of view known as the

“endogenous approach”. The SD approach encompasses computational modelling and simulation methods geared towards designing and analyzing policies in highly complex and dynamic systems, i.e. nonlinear systems that display high levels of interconnectedness, information feedback and delays over time (Sterman, 2000). Furthermore, the systems thinking space - within which SD is contained - is an overarching tool to create critical discourses in the public sphere, advancing reflective and emancipatory practices (Ulrich, 2003). We employed this approach in the context of urgent politicized policy processes at the dawn of the COVID-19 pandemic. Under extreme pressure, governments and civil society organizations lack adequate tools to deal with the dynamic aspects of urgent decision-making that affect millions of lives. In such context, models make a pivotal contribution as they become rationalization tools amidst information and policy warfare (King & Kraemer, 1993).

We followed the standard SD modelling process prescribed by Sterman (2000), which encompasses five steps: (1) *problem articulation*, with theme selection, listing of key variables and dynamic problem definition; (2) *formulation of dynamic hypothesis*, or mapping of the structure of variables; (3) *formulation of a simulation model*, the model’s computational specification, along with parameter and behavior estimation; (4) *testing*, including sensitivity analysis; and (5) *policy design and evaluation*, based on scenario specification, strategy development, and emphasis on key policy interactions. **Figure 1** summarizes the instantiation of each mentioned step.

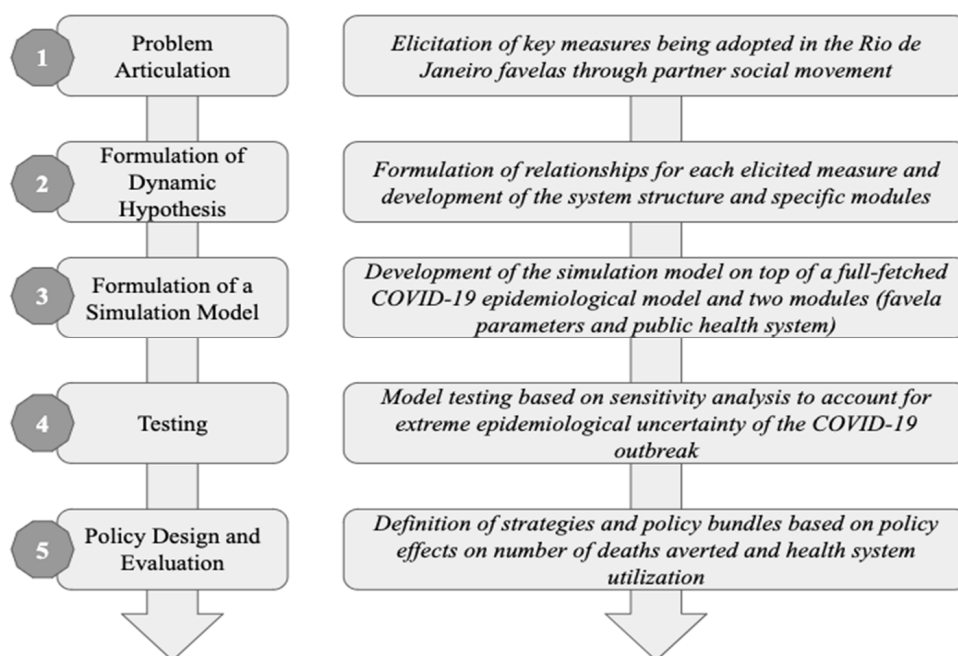
Our approach was designed on a project-oriented, organic initiative that comprised 19 volunteers (researchers and consultants from different fields) with a clear goal to contribute to the policy-making process in order to address the challenging situation that favela population is dealing with during the pandemic. A core team of six people was formed, and the project was open to any volunteers regardless of their background. They could find the ongoing tasks and files (including links to models) in a public document and easily join the efforts. During the 1-month work sprint starting in March 21st, 2020, all files have been stored online and shared in real time. This approach is closer to open-source modelling projects, diversely from the usual project management style.

We directly identified and elicited measures proposed by community leaders in the favelas of Rio de Janeiro under a social movement named “Favelas Contra o Corona”. The movement aims to adequately inform favela residents about the most effective measures to keep the virus at bay, while simultaneously tackling the emergence of fake news and the harsh socioeconomic aspects of the outbreak in impoverished areas.

We elicited seven measures via online communication with the social movement leaders to be tested as policies in our SD model: 1) temporary transfer of favela residents to public facilities (e.g. public schools, vacant buildings etc.); 2) temporary transfer of favela residents to hotel rooms (based on other ongoing social projects aimed at utilizing the available capacity of hotels); 3) subsidies for hygiene products; 4) basic income aimed at hygiene products; 5) establishment of emergency sanitation structures; 6) Intensive Care Units (ICU) expansion; and 7) use of face masks by the general population. An extra measure (ambulance routes in favelas) was elicited but later ruled out as the simulator showed no effectiveness in tackling the outbreak.

The simulation model was built on top of a full-fetched COVID-19 epidemiological model, with two modules encompassing variables of favela-specific context and the local healthcare system. Once the simulation model was ready, a front-end interface was built on a standalone website in which people could play with the simulator (Retrieved from <http://www.favelascontracorona.com.br>). This was achieved with HTML5 integration enabled by Isee Exchange (Isee Systems, 2020). In order to facilitate the public understanding of the model, the website was geared towards communicating the policy bundles we recommend as results of the simulations.

FIGURE 1 INSTANTIATION SCHEME OF THE RESEARCH APPROACH



Source: Adapted from Sterman (2000).

3. SIMULATION MODEL

3.1. Data sources and dynamic hypothesis

The SD model was built based upon the COVID-19 epidemiological model developed by Isee Systems (2020). It encompasses a classic SIR (susceptible-infected-recovered) epidemiological model tailored to the COVID-19 outbreak, considering the asymptomatic phases of the disease. Isee Systems has a long tradition of making generic SD models available for the community of modelers to adapt and enhance. Two modules were added to the underlying SD model: 1) contextual parameters typical of Brazilian urban areas with favelas, and 2) public healthcare system capacity regarding number of beds, ICUs and ventilators. The fraction of patients who require ICU and

ventilator was assumed to be 0.1 and 0.05, respectively. The demand of ICUs and ventilators from other diseases was assumed to remain stable at 0.9 and 0.5 of the total capacity respectively, based on a generalization made by Jucá (2020).

The number of ICUs per state was supplied by the Federal Medicine Council [FMC] (2018). Data on ventilators per state was collected from the Health Ministry (2020). The fraction of the population living in favelas per state was taken from Data Favela (2020). Favela characteristics in terms of sanitation, density and people per domicile were based on Pasternak & D'Ottaviano (2016).

3.2. Development of the simulation model

We first calibrated the Isee Systems (2020) model to a total population of 17 million (approximate Rio de Janeiro State population), then added simple rules to connect it to the local reality of favelas and healthcare system capacity. We also expanded the run time of the model from one year to two years, to be able to see longer term effects.

One of the simple rules we adopted to connect the epidemiological model to the favelas contexts was to consider a double effect of density in infection: both population density at large and people per domicile should have an impact on the number of contacts per day. Additionally, we adopted access to sewage as a proxy for hygiene, which affects the frequency of risky contacts for the favela population. We also assumed that absence of ICU or ventilator, when needed, doubles the death rate for those who need it.

Epidemiological scenarios as observed in March 2020 were inspired by Fiddaman (2020), who highlighted that, at that time, there was an ongoing confusion on the interpretation of the basic reproduction numbers of different models. Models with supposedly lower R_0 (basic reproduction number), such as Ferguson et al. (2020), implied a higher growth rate during the growth phase of the epidemic. That is explained by the excessive generalization on the calculation of reproduction numbers, overlooking the very distinct phases of the epidemics.

Given Fiddaman's observations and the fact that our goal was not to predict the epidemic, we decided to assume an enormous epidemiological uncertainty in the model described as two extreme scenarios (extremely optimistic and extremely pessimistic). So, the impact of different strategies could be verified on the healthcare system across different epidemiological possibilities. As shown in **Table 1**, quarantine effectiveness was considered as one of the uncertainty parameters. This methodological choice was made because social isolation was already a heavily politicized topic when this project started, subject to several information warfare maneuvers by elected officials and other actors. We had no hope of influencing the effectiveness of such measures and decided to treat them as contextual along with other variables in the epidemiologic scenarios, as opposed to testing it as a policy.

TABLE 1 PARAMETERS ADOPTED IN THE TWO SCENARIOS

Variable	Optimistic scenario	Pessimistic scenario
Days contagious but not symptomatic	4	5.4
Severity distribution of cases	20% asymptomatic 35% mild 40% moderate 5% severe	10% asymptomatic 30% mild 40% moderate 20% severe
Days symptomatic and contagious (depends on severity levels' spread above)	0.64x the original from Isee Systems (2020)	1.5x the original from Isee Systems (2020)
Infectivity parameter	0.32	0.48
Baseline contact rate per day	0.8	1.18
Contacts with at risk (people/day)	0.95 * contact rate * fraction susceptibles	contact rate * fraction susceptibles
Quarantine effectiveness	0.6	0.1

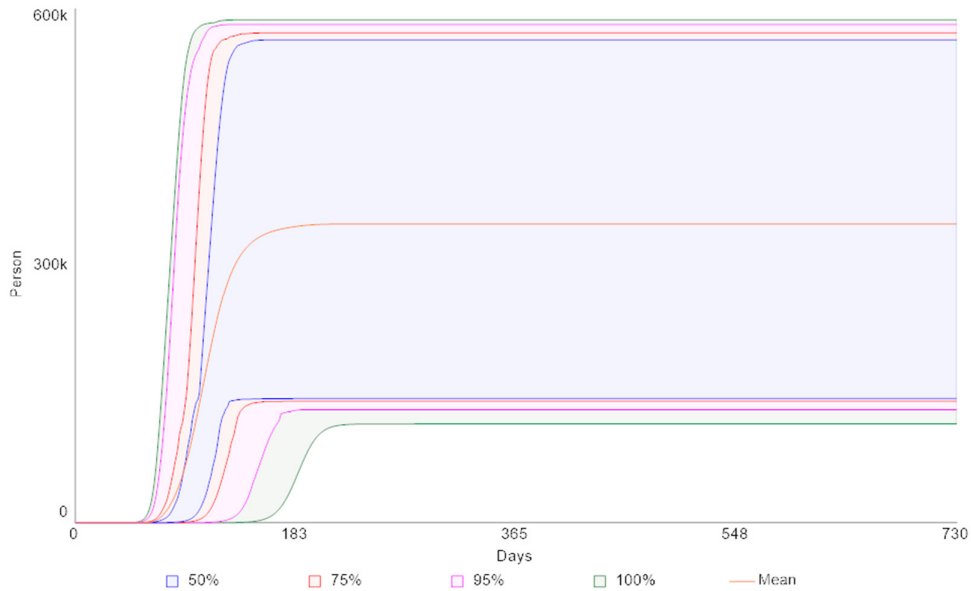
Source: Research data.

3.3. Testing and calibration

Model testing was conducted as suggested by Barlas (1996). As part of the testing procedures, sensitivity analysis (200 runs, Latin Hypercube) based on Fiddaman (2020) parameters reflected the degree of epidemiological uncertainty of the moment when the model was created. In **Figure 2**, we observe that the number of deaths could vary between 115,000 and 587,000 people in the Rio de Janeiro State, with a mean of 349,000 given uniform distribution for every uncertainty range of each uncertain variable in the model. The mean falls into a wide 50% confidence interval, revealing a high potential for the manifestation of extreme values given the uncertainty parameters treated in the two scenarios.

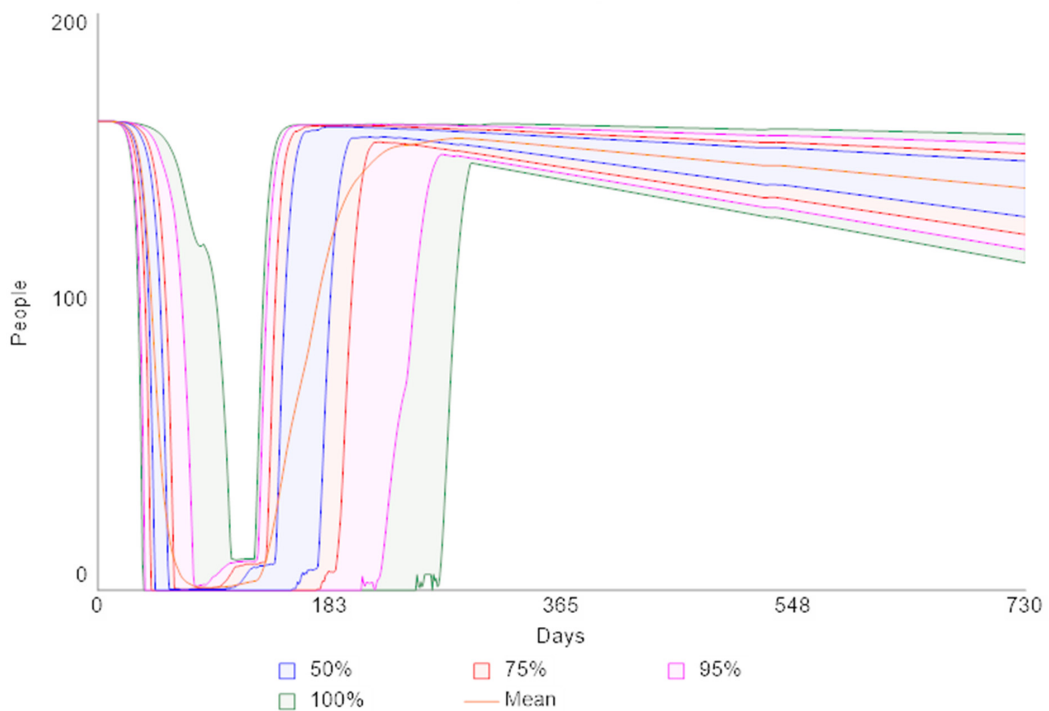
Despite the considerable variation in the parameters of the epidemic itself, ICU availability curve in **Figure 3** remains U-shaped, meaning that, no matter the strength and velocity of the epidemic, there would be a moment when state-wide ICU availability reaches zero if no measures were taken. However, the number of days with zero ICUs available may vary between 34 and 95, with a mean of 53 given uniform distributions within the analyzed uncertainty ranges.

FIGURE 2 CONFIDENCE INTERVALS FOR ‘CUMULATIVE NUMBER OF DEATHS’ (RJ STATE, SIMULATED)
SOURCE: RESEARCH DATA.



Source: Research data.

FIGURE 3 CONFIDENCE INTERVALS FOR ‘AVAILABLE ICU BEDS’, MEASURED IN NUMBER OF PEOPLE (RJ STATE, SIMULATED)SOURCE: RESEARCH DATA.



Source: Research data.

3.4. Policy design and evaluation: strategies and policy bundles

The policies suggested by the partner social movement were initially tested in the model independently to verify each isolate impact. Due to the results of these preliminary tests, we eliminated one policy proposal to which the model showed no support (ambulance routes in favelas). As all the other policies generated desired effects in the model, we proceeded to bundle them and analyze the effects of five strategies composed by different policy bundles, described in **Table 2**.

TABLE 2 TESTED PARAMETERS FOR THE FIVE STRATEGIES

Strategy	Temporary transfer of favela population	Supply of hygiene products	Emergency sanitation structures	ICU expansion
A	50% of the favela population	50% of the favela population	44% (all favelas without sanitation)	20 ICUs/day since the beginning of the epidemic
B	15%	50%	44%	35 ICUs/day
C	35%	50%	30%	7 ICUs/day
D	5%	20%	10%	8 ICUs/day
E	zero	25%	zero	21 ICUs/day

Source: Research data.

The initial intent was to show the possibility of saving 15,000 lives in the optimistic scenario with strategy A, 10,000 by implementing strategies B or C, or else 5,000 lives with strategies D or E. A more careful model analysis in **Table 3** shows some of the outcomes of each strategy.

TABLE 3 SIMULATED OUTCOMES FOR THE FIVE STRATEGIES (OPTIMISTIC;PESSIMISTIC)

Strategy	Lives saved	Days without ICUs available	Max people waiting for ICUs
A	15400;2180	0;34	0;75400
B	10200;1510	43;31	379;75900
C	9800;1350	65;37	106;75900
D	3440;421	60;36	1560;76500
E	4480;588	48;33	2090;76500

Source: Research data.

A model output that may be considered counterintuitive is the higher number of days without ICUs in the optimistic scenario in combination with strategies B, C, D and E. This is explained by the fact that the optimistic scenario is less abrupt, therefore more spread over time. The maximum number of people waiting for ICUs is always much smaller in this epidemiologic scenario. Later, we added the use of masks as a possible measure as suggested by Leung et al. (2020). If Leung et al. (2020) is accurate, this measure could have an important effect in all scenarios.

4. DISCUSSION AND CONCLUSIONS

The goal of this paper was to present the articulation and development of a System Dynamics approach to design sets of policies and analyze their potential effects on alleviating the consequences of the COVID-19 pandemic in extremely vulnerable communities living in Brazilian favelas. In the current debate of the COVID-19 pandemic, a multitude of narrative-shaping tools with much more resources (e.g. combining social media analysis, psychometrics and targeted digital marketing) are at play in the public sphere.

In the case of Brazil, the widespread government use of such tools makes it harder to insert a fact-based and model-driven narrative in the public debate regarding the potential strategies to fight the extreme negative health and socioeconomic consequences of the pandemic. This paper reports an effort to inform decision-makers in critical issues of public interest using simulation models, as suggested by King and Kraemer (1993) and extensively discussed and implemented by Ghaffarzadegan et al. (2010) and Lane (2016). Newer versions of the model, available online, can be parametrized by the user with their own local context data (city or region).

From a policy implication standpoint, one of the key insights generated by the model is that only through the combination of policies that significant effects in the number of deaths averted and the utilization of the healthcare system are attained. With respect to fighting the COVID-19 pandemic in environments of vulnerable communities, there is no “silver bullet”.

Furthermore, from a methodological point of view, the approach and the results might support a broader use of modelling and simulation tools to formulate and analyze public policies and to engage in communication with key stakeholders. The use of simulation allows decision-makers to derive “what-if” scenarios in a cost-effective and safe fashion, without wasting public resources or risking people’s lives in challenging contexts. This is particularly important when public policymakers have no benchmarks or proven policies, therefore requiring plural and intensive collaboration inside public bureaucracy (Ito & Pongeluppe, 2020).

Despite its contributions, the research displays limitations. First, the epidemiological model by Isee Systems (2020) was used as the basis for the development of the favela-specific model. Second, the full range of potential testing strategies for SD models was not applied. Third, the model is limited to the aggregation levels of currently available demographic data. These limitations will be tackled by future research streams aimed at: (i) testing different underlying epidemiological models to check for robustness; (ii) systematically performing further testing strategies for SD models (i.e. extreme condition tests, structure assessment, behavior anomaly etc.) and (iii) further investigating data disaggregation to capture particular behaviors of micro-areas or particular

favelas. By the time of the review of this paper, the number of deaths in Rio de Janeiro was still falling into the uncertainty ranges in Figure 2, but only in about two years we will know how suitable the epidemiological model was to test policies. It will also be possible to assess the realism of key aspects of our additions to the model, such as the waiting line lengths in Table 3.

REFERENCES

- Alirol, E., Getaz, L., Stoll, B., Chappuis, F., & Loutan, L. (2011). Urbanisation and infectious diseases in a globalised world. In *The Lancet Infectious Diseases*, 11(2), 131-141. Retrieved from [https://doi.org/10.1016/s1473-3099\(10\)70223-1](https://doi.org/10.1016/s1473-3099(10)70223-1)
- Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review: The Journal of the System Dynamics Society*, 12(3), 183-210. Retrieved from [https://doi.org/10.1002/\(SICI\)1099-1727\(199623\)12:3%3C183::AID-SDR103%3E3.0.CO;2-4](https://doi.org/10.1002/(SICI)1099-1727(199623)12:3%3C183::AID-SDR103%3E3.0.CO;2-4)
- Biggerstaff, M., Cauchemez, S., Reed, C., Gambhir, M., & Finelli, L. (2014). Estimates of the reproduction number for seasonal, pandemic, and zoonotic influenza: a systematic review of the literature. *BMC Infectious Diseases*, 14(1), 480. Retrieved from <https://doi.org/10.1186/1471-2334-14-480>
- Brazilian Institute of Geography and Statistics (2019). *Síntese de Indicadores Sociais: Uma análise das condições de vida da população brasileira 2019*. (Estudos e Pesquisas, 53). Rio de Janeiro, RJ: Author. Retrieved from <https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=2101678>
- Data Favela. (2020, March). *Coronavírus nas favelas*. Retrieved from https://drive.google.com/open?id=1TqxxZk6a5SGObY19C_VvK_qjatWgMVQa
- Federal Council of Medicine. (2018). *Medicina Intensiva no Brasil*. Retrieved from <http://portal.cfm.org.br/images/PDF/leitosedestados2018.pdf>
- Ferguson, N., Laydon, D., Nedjati Gilani, G., Imai, N., Ainslie, K., Baguelin, M. ... Dighe, A. (2020). *Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand*. London, UK: Imperial College London. Retrieved from <https://www.imperial.ac.uk/media/imperial-college/medicine/sph/ide/gida-fellowships/Imperial-College-COVID19-NPI-modelling-16-03-2020.pdf>
- Fiddaman, T. (2020). *Steady State Growth in SIR & SEIR Models*. Retrieved from <https://metasd.com/2020/03/steady-state-growth-sir-seir-models/>
- Forrester, J. W. (2007). System dynamics — the next fifty years. *System Dynamics Review*, 23(2-3) 359-370. Retrieved from <https://doi.org/10.1002/sdr.381>
- Ghaffarzadegan, N., Lyneis, J., & Richardson, G. P. (2010). How small system dynamics models can help the public policy process. *System Dynamics Review*, 27(1), 22-44. Retrieved from <https://doi.org/10.1002/sdr.442>
- Health Ministry. (2020). *Cadastro Nacional dos Estabelecimentos de Saúde do Brasil*. Retrieved from <http://cnes.datasus.gov.br>
- Isee Systems. (2020). *COVID-19*. Retrieved from <https://exchange.iseesystems.com/models/player/isee/covid-19-model>
- Ito, N. C., & Pongeluppe, L. S. (2020). The COVID-19 outbreak and the municipal administration responses: resource munificence, social vulnerability, and the effectiveness of public actions. *Revista de Administracao Publica, Early View*.
- Jucá, B. (2020, March 16). Crise do coronavírus põe à prova gargalo de UTIs no SUS. *El País*. Retrieved from <https://brasil.elpais.com/brasil/2020-03-17/crise-do-coronavirus-poe-a-prova-gargalo-de-utis-no-sus.html>
- Khalidi, J. R. (2020, March 30). *Inequality Affects the Covid-19 Pandemic*. (KR News, 22/20). Kuala Lumpur, Malaysia. Khazanah Research Institute. Retrieved from http://www.krinstitute.org/assets/contentMS/img/template/editor/20200330_Articles_Covid_Inequality_v9.pdf
- King, J. L., & Kraemer, K. L. (1993). *Models, facts, and the policy process: the political ecology of estimated truth*. (Working Paper #URB-006). Oakland, CA: University of California. Retrieved from <https://escholarship.org/uc/item/1c31s58g>
- Lane, D. C. (2016). “Till the Muddle in my Mind Have Cleared Awa”: Can We Help Shape Policy Using Systems Modelling? *Systems Research: The Official Journal of the International Federation for Systems Research*, 33(5), 633-650. Retrieved from <http://dx.doi.org/10.1002/sres.2422>
- Leung, N. H., Chu, D. K., Shiu, E. Y., Chan, K. H., McDevitt, J. J., Hau, B. J. ... & Seto, W. H. (2020). Respiratory virus shedding in exhaled breath and efficacy of face masks. *Nature Medicine*, 26, 676-680. Retrieved from <https://doi.org/10.1038/s41591-020-0843-2>
- Orlik, T., Rush, J. Cousin, M., & Hong, J. (2020). *Coronavirus Could Cost the Global Economy \$2.7*

Trillion. Retrieved from <https://www.bloomberg.com/graphics/2020-coronavirus-pandemic-global-economic-risk/>

Pasternak, S., & D'Ottaviano, C. (2016). Favelas no Brasil e em São Paulo: avanços nas análises a partir da Leitura Territorial do Censo de 2010. *Cadernos Metrópole*, 18(35), 75-100. Retrieved from <https://doi.org/10.1590/2236-9996.2016-3504>

Perosa, G.S., Leite, C.K.S., da Fonseca, F.C.P., Lebraron, F. (2016). *Patologias sociais* na metrópole de São Paulo: análise socioespacial de indicadores nas subprefeituras. *Revista de Administração Pública*, 50(4), 635-657. Retrieved from <http://dx.doi.org/10.1590/0034-7612151585>

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. London, UK: McGraw-Hill.

Ulrich, W. (2003). Beyond methodology choice: critical systems thinking as critically systemic discourse. *Journal of the Operational Research Society*, 54(4), 325-342. Retrieved from <https://doi.org/10.1057/palgrave.jors.2601518>

Unger, A., & Riley, L. W. (2007). Slum health: from understanding to action. *PLoS Medicine*, 4(10), 1561-1566. Retrieved from <https://doi.org/10.1371/journal.pmed.0040295>

Weiss, R. A., & McMichael, A. J. (2004). Social and environmental risk factors in the emergence of infectious diseases. *Nature Medicine*, 10(S12), S70-S76. Retrieved from <https://doi.org/10.1038/nm1150>

World Health Organization (2020). *Dashboard of the Coronavirus disease (COVID-19) outbreak situation*. Retrieved from <https://covid19.who.int/>

Vinícius Picanço Rodrigues



<https://orcid.org/0000-0002-6647-9291>

Ph.D. in Mechanical Engineering (Technical University of Denmark); Assistant Professor of Operations and Sustainability at Insper. E-mail: vinicius.picanco@insper.edu.br

Igor Czermainski de Oliveira



<https://orcid.org/0000-0001-9492-1561>

M.Sc. in System Dynamics (European Master in System Dynamics). E-mail: mrigoroliveira@gmail.com

Gisele de Lorena Diniz Chaves



<https://orcid.org/0000-0001-6359-9063>

Ph.D. in Industrial Engineering (Federal University of São Carlos); Associate Professor in the Department of Engineering and Technology at Federal University of Espírito Santo (UFES). E-mail: gisele.chaves@ufes.br

Ellen Larissa de Carvalho Aquino



<https://orcid.org/0000-0002-9729-5970>

M.Sc. in Science, Technology and Society (Federal University of São Carlos). E-mail: ellen.lcaquino@gmail.com

Cláudia Viviane Viegas



<https://orcid.org/0000-0002-7602-9366>

Ph.D. in Engineering and Knowledge Management (Federal University of Santa Catarina). E-mail: cldviegas@gmail.com