Assessing the Reproducibility of the Covid-19 Pandemic with COMOKIT: A Case Study in Ibirama, Brazil

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Abstract. *Agent-based models have proven to be effective alternatives for simulating the spread of infectious diseases, as they account for the heterogeneity and interactions among individuals. The Covid-19 Modeling Kit (COMOKIT) is one such model, designed to study Covid-19 containment policies. Implemented in the GAMA platform, COMOKIT was originally calibrated to simulate Covid-19 in a community in Vietnam. This paper investigates whether COMOKIT can reproduce the Covid-19 dynamics observed in the municipality of Ibirama, Santa Catarina, Brazil. Reliable sources were used to obtain demographic, geographic, and epidemiological data, and simulations were conducted under different configurations, including scenarios with and without lockdowns, testing, and hospitalizations. The results show that, despite careful parameterization, COMOKIT was unable to reproduce the number of cases and deaths observed in Ibirama during the first three months of the pandemic. These findings highlight limitations in applying the model to Brazilian municipalities without additional calibration, suggesting the need for further studies using more accurate data.*

1. Introduction

Agent-based models (ABMs) have been used to understand behavioral patterns of systems, either existing or emerging. In an ABM, the central elements are agents, which behave autonomously and can interact with each other and with the environment. ABMs differ from other models by explicitly incorporating the unique behavior of individuals and their interactions [Macal e North 2014].

The spread of diseases is a phenomenon that can be studied through ABMs, particularly in cases where propagation is influenced by population heterogeneity and interactions among individuals. Using ABMs in these cases yields more realistic results, since interactions among individuals consider geospatial aspects, such as their location. With ABMs, [Eisinger e Thulke 2008] demonstrated that it is possible to control the spread of a disease by vaccinating 10% fewer individuals compared to other modeling and simulation paradigms that ignore geospatial aspects.

At the end of 2019, a new type of coronavirus emerged and quickly spread across five continents, causing a global pandemic. Since then, many ABMs have been developed to study the spread of Covid-19. The most emblematic was the one that supported the adoption of containment measures in the United Kingdom [Adam 2020]. [Alsharhan 2021] conducted a survey of ABMs focused on the Covid-19 pandemic. Both

[Alsharhan 2021] and [Wooldridge 2020] emphasize that validation and calibration of ABMs are essential to increase trust in agent-based modeling.

The Covid-19 Modeling Kit (COMOKIT) is among the available ABMs for studying disease spread [Gaudou et al. 2020]. It is a model designed to study and evaluate different intervention and containment policies for Covid-19. COMOKIT has already been validated and calibrated with data from a community in Vietnam. However, there are no reports of its use to study the spread of Covid-19 in Brazil. If it proves possible to reproduce the dynamics of Covid-19 using COMOKIT, this ABM could be considered a trusted alternative for evaluating future pandemic scenarios.

This paper presents a case study to verify whether COMOKIT is capable of reproducing the Covid-19 dynamics that occurred in the municipality of Ibirama (in Santa Catarina, Brazil) during the three months following the first reported case on May 21, 2020. The municipality was chosen for being the location of the university campus of the authors. The spread of Covid-19 in this municipality was already considered in a previous work [Teixeira e Santos 2020], but using an ad hoc ABM developed in the NetLogo tool. The present study considered geographic, demographic, and epidemiological parameters obtained from reliable sources such as scientific articles, the municipal government, the Brazilian Institute of Geography and Statistics (IBGE), and the Health Emergency Operations Center (COES) of Santa Catarina. Scenarios with and without lockdown, testing, and hospitalization of individuals were simulated. The results demonstrate the feasibility of parameterizing COMOKIT to run simulations for the chosen municipality. However, with the adopted parameter values, COMOKIT was not able to reproduce the Covid-19 dynamics observed in Ibirama.

2. Background

2.1. Agent-Based Simulations

A model is a simplified and abstract representation of something that already exists or is idealized. Models are typically defined to study and explain observed phenomena or to predict future ones. Agent-based models (ABMs) are characterized by the presence of one or more agents performing some type of behavior in a shared environment [Bandini et al. 2009]. An ABM consists of the following elements: (i) a set of agents with their attributes and behaviors; (ii) a set of relationships between these agents and their interactions; and (iii) the environment in which the agents are situated [Macal e North 2014].

From an ABM, it is possible to perform an agent-based simulation (ABS) to study and understand a phenomenon of interest. An ABS consists of the execution, over a period of time, of the agents' processes and their interactions as specified in the ABM. ABSs have been used in several areas of study, such as epidemiology, traffic, and economics [Macal e North 2014].

2.2. The COMOKIT Agent-Based Model

COMOKIT [Gaudou et al. 2020] is an ABM developed in the GAMA agent-based simulation tool. This model aims to study the spread of Covid-19 in the community of Son Loi, Vietnam. [Gaudou et al. 2020] used COMOKIT to analyze the impact of virus containment policies such as the wearing of masks, lockdowns, and testing. The authors also claim that COMOKIT can be adapted to study the spread of Covid-19 in other communities by updating the required geographic, demographic, and epidemiological data.

To represent the infection of individuals and disease progression, COMOKIT is based on the SEIR compartmental epidemiological model [Huppert e Katriel 2013], with adaptations to better reproduce Covid-19 spreading. In the SEIR model, the population is organized into compartments that indicate the individual's state as follows: (S) susceptible to the virus, (E) exposed, (I) infected, and (R) recovered. In COMOKIT, when a susceptible individual is infected, they move to a latent state (L) depending on the transmission probability. The latent state overrides the exposed state of the SEIR model. instead of becoming exposed. After the latent period, the individual can become infected but presymptomatic (IP), asymptomatic (IA), or symptomatic (IS). If presymptomatic, they remain in that state for a period before becoming symptomatic (serial interval). The duration of the symptomatic and asymptomatic states define the infectious period. After this period, agents are no longer infected and are considered either recovered or dead [Gaudou et al. 2020]. Table 1 summarizes the epidemiological states of COMOKIT.

State	Description
S	susceptible to the virus
L	latent state (transition to IA or IP/IS after the incubation period of asymptomatic/symptomatic)
IA	infected, but asymptomatic (transition to R after the infectious period of asymptomatic)
IP	infected, but presymptomatic (transition to IS after the serial interval)
IS	infected and symptomatic (transition to R after the infectious period of symptomatic)
R	recovered from the infection

Table 1. Epidemiological states of COMOKIT

COMOKIT also allows studying the impact of Covid-19 on the healthcare system. The epidemiological model includes compartments related to hospitals. During the infection period, symptomatic individuals may follow different clinical paths: not requiring hospitalization, being hospitalized, or requiring Intensive Care Unit (ICU) admission. Asymptomatic individuals and those who do not require hospital care are considered recovered after the infectious period. Those needing intensive care are considered dead if either ICU beds are unavailable or the disease severity given the individual age is defined as fatal.

Finally, in COMOKIT, individuals have unique characteristics such as age, sex, and occupation, as well as epidemic-related parameters like infection duration. Each individual also has an activity schedule, and each activity may involve interaction with other individuals or with the environment and its buildings (residences, schools, and workplaces) [Gaudou et al. 2020].

3. Materials and Methods

This study investigates whether it is possible to reproduce in COMOKIT the Covid-19 dynamics registered in the municipality of Ibirama/SC. The parameters of COMOKIT ABM were identified from its documentation and source code. It was also necessary to gather demographic and geographic parameters of the municipality, as well as collect epidemiological data regarding the Covid-19 cases and dynamics observed during the pandemic. These materials and methods are detailed below.

3.1. Geographic and Demographic Parameters

The territorial extent of the municipality of Ibirama was obtained from the Open Street Map repository[1]. As a small municipality, Open Street Map does not contain data about its buildings. Therefore, a geographic information file with buildings from the year 2017 was provided by the municipal government. However, this file did not include the type of each building. Thus, buildings such as schools, workplaces, and parks had their types defined based on the locations reported by [Teixeira e Santos 2020]. All other buildings were considered residential. Adjustments were made to ensure the number of residences matched census data [IBGE 2010], which reported 5,515 residences.

The population data used were obtained from the census available at the time of the study [IBGE 2010]. From this census, it was possible to determine the proportion of male population, the probability of active family per residence, retirees, and grandparents in households. The probability of having retirees was determined based on the minimum retirement age for men and women in Brazil [GOV.BR 2022].

The census data indicated that the municipality's population was 17,330 inhabitants. In COMOKIT, the number of agents in the simulation is derived from demographic parameters. Parameters related to the number of children per household had to be determined experimentally to ensure the number of agents created matches the number of inhabitants. Available census data were used as heuristics to estimate these values. To estimate the number of children per household, we used data on the number of residents and retirees per household. We assumed that the probability of having a retiree in a household is the sum of the probabilities of having a grandfather or grandmother, which is 0.134 + 0.163 = 0.297. Consequently, the probability of a resident being a child was considered to be 1 - 0.297 = 0.703. Additionally, for households with three or more residents, we assumed that two of them form a couple and are therefore neither children nor retirees. The default COMOKIT values were used for the remaining demographic parameters. Table 2 presents the demographic parameters used. The *source* column indicates the source adopted to specify the values.

The default values from COMOKIT were used for parameters that define population activities. These parameters specify, for instance, the weekly day off (sundays), working and school hours, lunchtime, and the probability of attending social activities at night. Regarding hospital and bed capacity, during the pandemic, Ibirama had only one hospital with 95 beds and 30 ICU beds [CAMARA DE VEREADORES DE IBIRAMA 2021].

3.2. Epidemiological Parameters

Epidemiological data on Covid-19 in Ibirama/SC were collected from the open data portal of Santa Catarina, specifically from the dataset of confirmed cases [COES 2021]. This dataset presents structured and anonymized data on confirmed cases in Santa Catarina, allowing filtering by city. The dataset was downloaded on May 11, 2022.

To verify whether COMOKIT reproduces the Covid-19 scenario observed in Ibirama/SC, the accumulated number of infections in the three months following the first registered case was used as baseline. According to the dataset, the first case was recorded on May 21, 2020. Figure 1 shows the accumulated number of cases in the three subsequent months. It can be seen that the virus spread slowly during this period, reaching

[1] `www.openstreetmap.org`

Parameter	Value	Source
Number of residences	5515	[IBGE 2010]
Male ratio	0,50005	[IBGE 2010]
Probability of active family	0,8783	[IBGE 2010]
Number of children per household (mean)	0.99	experimental
Number of children per household (std)	1.3	experimental
Number of children per household (max)	7	experimental
Probability of grandfather per household	0,134	adapted from [IBGE 2010]
Probability of grandmother per household	0,163	adapted from [IBGE 2010]
Retirement age	64	[GOV.BR 2022]
Max age	100	COMOKIT default
Number of friends (mean)	5	COMOKIT default
Number of friends (std)	3	COMOKIT default
Number of classmates (mean)	10	COMOKIT default
Number of classmates (std)	5	COMOKIT default
Number of work colleagues (mean)	5	COMOKIT default
Number of work colleagues (std)	3	COMOKIT default
Probability of unemployed male	0,1	COMOKIT default
Probability of unemployed female	0,1	COMOKIT default
Probability of working at home	0,1	COMOKIT default

Table 2. Demographic Parameters of COMOKIT

approximately 300 cases by the end of the third month. Additionally, nearly two months elapsed between the first case and the moment when the virus began to spread more intensively. This is the baseline scenario adopted in this paper.

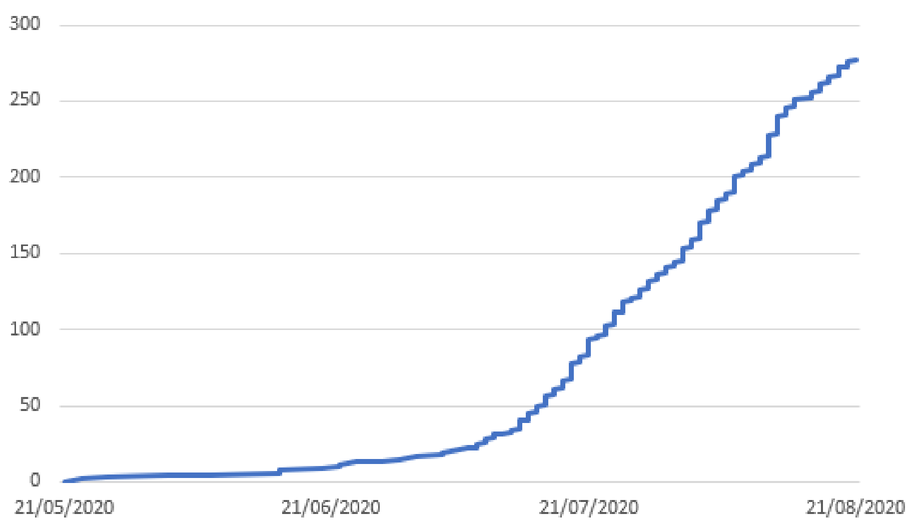

Figure 1. Accumulated cases in 3 months after the first case was registered

In addition to daily infections, the [COES 2021] dataset also includes data on the ages of infected individuals, hospitalizations, ICU bed usage, and deaths. Based on this data, the COMOKIT parameters related to the proportion of hospitalizations, ICU usage, and deaths by age were determined. Probability distributions related to the duration of symptomatic periods, hospitalizations, and ICU beds occupation were also determined. These parameters are presented in Table 3. The *age* column specifies age intervals for cer-

Parameter	Age	Detail	Value 1	Value 2	Source
Infectious period of symptomatic	-	normal dist	12,53	3,37	[Zhu et al. 2020]
Infectious period of asymptomatic	-	normal dist	12,53	3,37	[Zhu et al. 2020]
Serial interval	-	normal dist	4,7	2,9	[Nishiura et al. 2020]
Incubation period of symptomatic	-	normal dist	5,5	2,1	[Ferretti et al. 2020]
Incubation period of asymptomatic	-	normal dist	5,5	2,1	[Ferretti et al. 2020]
Proportion hospitalization	0	numerical	0,013	-	[COES 2021]
Proportion hospitalization	20	numerical	0,026	-	[COES 2021]
Proportion hospitalization	45	numerical	0,069	-	[COES 2021]
Proportion hospitalization	55	numerical	0,115	-	[COES 2021]
Proportion hospitalization	65	numerical	0,200	-	[COES 2021]
Proportion hospitalization	75	numerical	0,324	-	[COES 2021]
Proportion hospitalization	85	numerical	0,445	-	[COES 2021]
Proportion ICU hospitalization	0	numerical	0,157	-	[COES 2021]
Proportion ICU hospitalization	20	numerical	0,227	-	[COES 2021]
Proportion ICU hospitalization	45	numerical	0,259	-	[COES 2021]
Proportion ICU hospitalization	55	numerical	0,304	-	[COES 2021]
Proportion ICU hospitalization	65	numerical	0,338	-	[COES 2021]
Proportion ICU hospitalization	75	numerical	0,297	-	[COES 2021]
Proportion ICU hospitalization	85	numerical	0,187	-	[COES 2021]
Proportion death of symptomatic	0	numerical	0,0007	-	[COES 2021]
Proportion death of symptomatic	20	numerical	0,002	-	[COES 2021]
Proportion death of symptomatic	45	numerical	0,012	-	[COES 2021]
Proportion death of symptomatic	55	numerical	0,031	-	[COES 2021]
Proportion death of symptomatic	65	numerical	0,080	-	[COES 2021]
Proportion death of symptomatic	75	numerical	0,172	-	[COES 2021]
Proportion death of symptomatic	85	numerical	0,283	-	[COES 2021]
Onset to hospitalization (days)	-	lognormal dist	1,9561	0,6574	[COES 2021]
Hospitalization to ICU (days)	-	lognormal dist	0,9170	0,7642	[COES 2021]
ICU to discharge (recovered or dead)	-	lognormal dist	2,2292	0,8368	[COES 2021]

Table 3. Epidemiological parameters of COMOKIT

tain parameters, the *detail* column indicates whether the parameter is a simple numerical value of a distribution, *value 1* is the parameter value, and *value 2* shows the distribution parameter when applicable.

Some epidemiological parameters could not be determined from the [COES 2021] dataset due to the lack of related data. In such cases, values available in the literature were used. This includes the average incubation period identified by [Ferretti et al. 2020], the average infection period from [Zhu et al. 2020], and the serial interval suggested by [Nishiura et al. 2020].

4. Results and Discussion

To verify whether it is possible to reproduce the Covid-19 dynamics registered in Ibirama using COMOKIT, different parameter values were considered. Each combination of values represents an experimental scenario. Ten simulations were ran for each scenario.

Figure 2 shows a COMOKIT execution. The screenshot highlights the central region of Ibirama. Geometric shapes with white borders represent the buildings, and green points individuals susceptible to Covid-19. COMOKIT 1.0.1 was used in this study[2].

[2] `https://github.com/COMOKIT/COMOKIT-Model/releases/tag/v1.0.1`

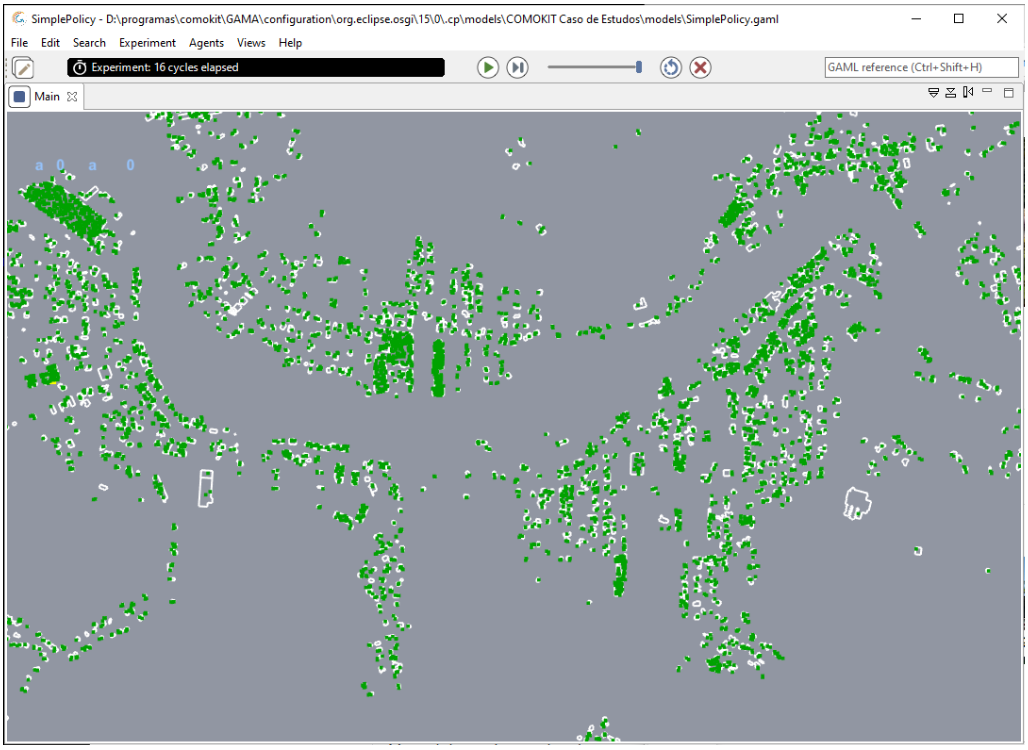

Figure 2. COMOKIT execution

The first scenario considers the default parameter values of COMOKIT, i.e., the values already predefined in the ABM. Figure 3 presents the results obtained in each simulation of this scenario. The vertical axis shows the number of accumulated cases in Ibirama during the simulated period, while the horizontal axis shows the simulation time in hours.

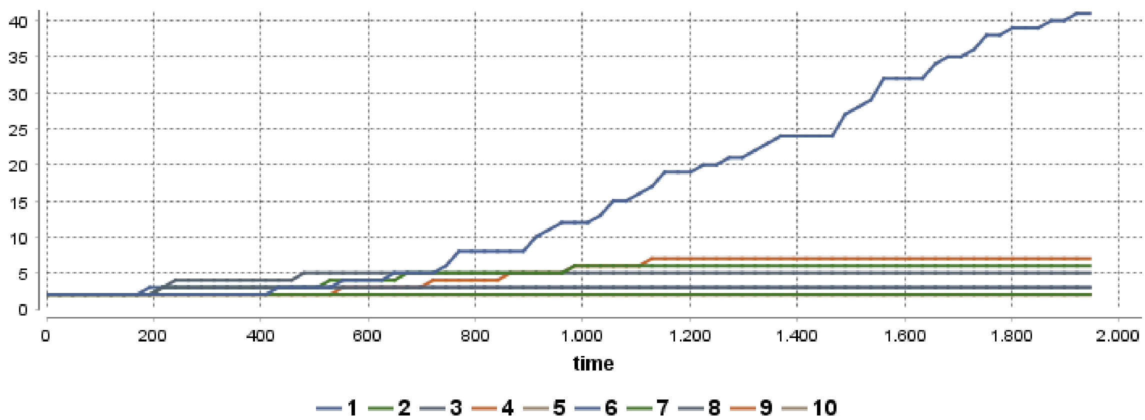

Figure 3. Accumulated cases with COMOKIT's default parameter values

It is observed that the simulations start with two infected agents, who are responsible for initiating the virus spread. However, the accumulated number of infected agents is below what was reported for the city in the first three months of the outbreak, as previously presented in Figure 3. In these simulations, it was noted that when the number of infected agents drops to zero (indicating that the virus is no longer circulating), no new agents are infected, and the number of accumulated cases stabilizes. This does not necessarily indicate an inconsistency in COMOKIT, as the data from [COES 2021] do not allow us to determine whether the reported cases were due to local transmission or imported cases.

Given the results obtained in the first scenario, parameter adjustments were made to allow for more flexible virus propagation and assess whether the Covid-19 dynamics observed in Ibirama could be reproduced. In the first adjustment, the lockdown feature was disabled. Figure 4 shows the results for the scenario without lockdown. The accumulated number of infected individuals remains below what was observed in Ibirama.

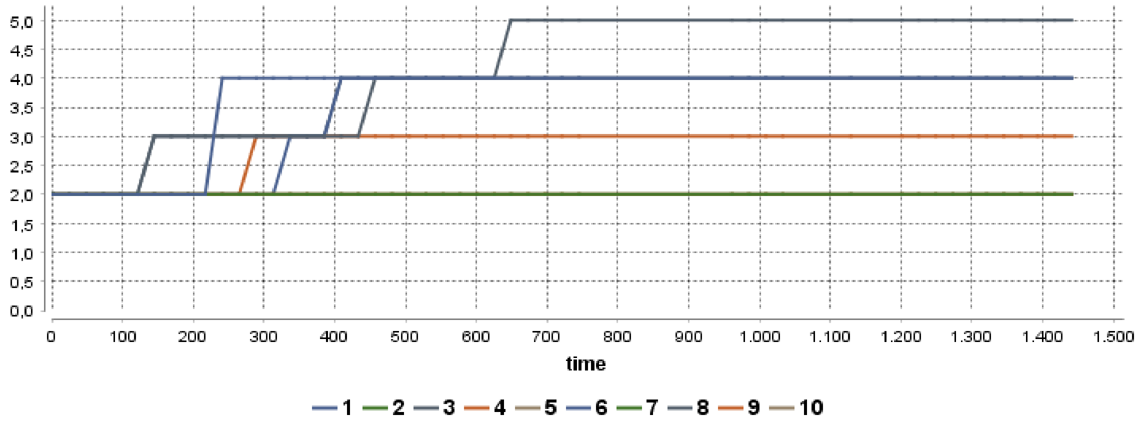

Figure 4. Accumulated cases without individual lockdown

Another scenario evaluated involved the testing policy. In COMOKIT, the testing policy includes parameters that define the percentage of individuals tested per day, the type of individual to be tested (symptomatic or not), the false negative rate, and the proportion of individuals who comply with isolation. Figure 5 presents the results for the scenario without testing, preventing the isolation of positive individuals. In this scenario, an increase in accumulated cases is observed, significantly exceeding the number observed in Ibirama.

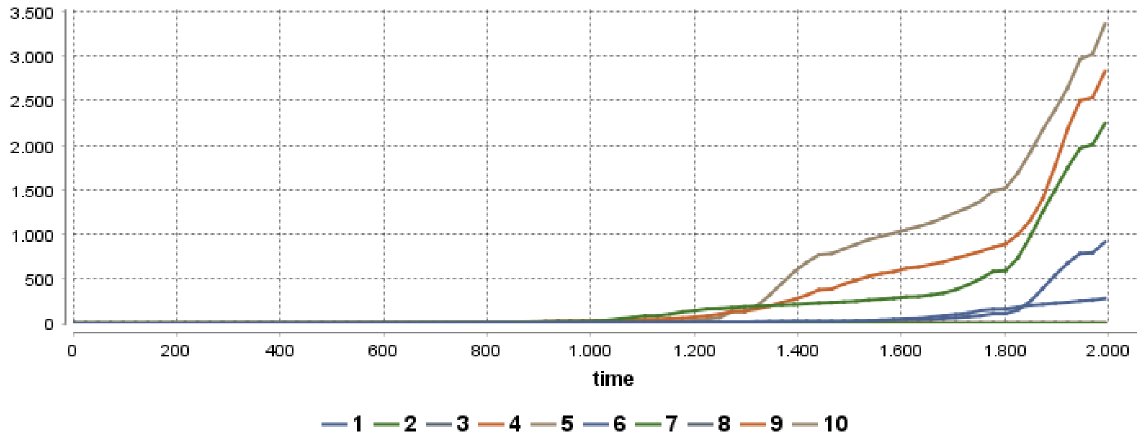

Figure 5. Accumulated cases without testing

Finally, a scenario with changes to the hospitalization policy was considered. The hospitalization policy involves parameters such as hospital and ICU admission and the number of negative tests required for discharge. Figure 6 presents the results for the scenario without hospitalizations, i.e., no medical treatment for infected individuals. In this scenario, the number of accumulated cases in some simulations is closer to what was observed in Ibirama. However, in several runs, the spread was interrupted, and the number of cases stabilizes. These results suggest that in COMOKIT, testing policy has a greater impact on virus propagation than hospitalization.

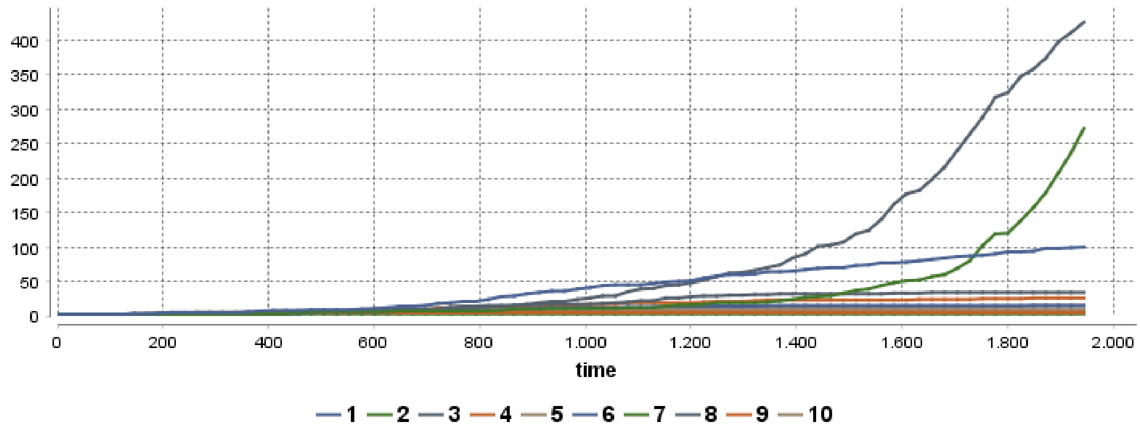

Figure 6. Accumulated cases without hospitalization

Based on the results obtained, it is observed that the simulations using COMOKIT did not reproduce the accumulated number of cases observed in Ibirama. Furthermore, no deaths were recorded in the simulations, which diverges from reality, as 7 deaths were reported in the three months following the first case. These findings indicate that even with parameter adjustments, COMOKIT was not able to reproduce the observed scenario during the initial phase of the Covid-19 pandemic in Ibirama with the adopted parameters.

5. Conclusion

This paper presented a case study that investigated the use of the agent-based model COMOKIT to simulate the Covid-19 dynamics in the municipality of Ibirama, Santa Catarina, Brazil. The study considered parameter values for COMOKIT obtained from reliable sources. The goal was to verify whether COMOKIT would be capable of reproducing Covid-19 dynamics based on the adoption of parameter values grounded on real data. The sources used to establish COMOKIT's parameter values included scientific papers, the municipal government, the Brazilian Institute of Geography and Statistics, and the Health Emergency Operations Center of Santa Catarina.

Simulations were run in COMOKIT using the model's default parameter values. The results were then compared with simulations that considered parameter values determined from the considered sources, in scenarios with and without lockdowns, testing, and hospitalizations. In none of the scenarios considered did the results reproduce the Covid-19 dynamics observed in Ibirama during the first three months of the pandemic, in terms of the number of accumulated cases and deaths.

The results indicate that COMOKIT was unable to reproduce the pandemic dynamics during the considered period using the adopted parameters. However, this does not imply that COMOKIT is entirely unsuitable for studying the spread of Covid-19 in Brazilian municipalities. Despite careful parameter selection, it is possible that some values deviated from reality, particularly in cases where accurate data were unavailable and heuristics were used to estimate parameters (e.g., the number of children per household and the exclusion of churches and commercial buildings from the analysis). To address this limitation, future case studies should be conducted in municipalities where accurate values for the parameters required by COMOKIT are available. Additionally, future work could investigate the causes of the premature interruption of virus spread observed in some simulation runs, which may be related to agent behavior or social connectivity. It is also recommended that future studies explore the factors contributing to the greater impact of testing policies on virus propagation compared to lockdown measures.

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