Modeling the Transmission of SARS-COV-2 (COVID-19) in a NetLogo Environment

1. Background and Relevance

The COVID-19 pandemic [1] has affected the entire world, leading to a significant health crisis, including over 6.8 million lost lives [2], an economic disruption that is only beginning to start, and permanent societal changes. One of the most important factors in controlling the spread of the virus was understanding how it transmits between people. The use of medical masks [3], staying at home [4], and later on the vaccinations [5] have all been put into effect across the globe as ways to slow the spread of the virus, but it is not clear how effective these measures would have been if they have been applied consistently from day 0 on their own or in combination with each other. A NetLogo model can simulate the spread of the virus, the effect of preventative measures and show the importance of response time to help researchers and policymakers understand the impact of different prevention strategies.

2. Introduction and The Goal of This Project

The goal of this project is to use NetLogo to simulate the transmission of COVID-19 between people, and to investigate how different preventative measure strategies such as mask-wearing, staying at home, and vaccination could have slowed down the spread of the virus if applied or available from day 0 on their own or in combination with each other. Therefore, the importance of response time from policymakers, the applicability of such measures and the available resources - access to masks and to an effective vaccine - are meant to be highlighted. The project is also meant to rank the effectiveness of such policies, in means of how sharp the infection curve is, how much of the population gets infected per strategy and the length it takes for each policy combination to reduce the number of infected to zero again. In case of any future outbreak, the potential outcome and effectiveness of such policies being applied solitary or in combination with each other are clearly known, which can influence future decision-making and keep our society prepared.

3. The Research Question

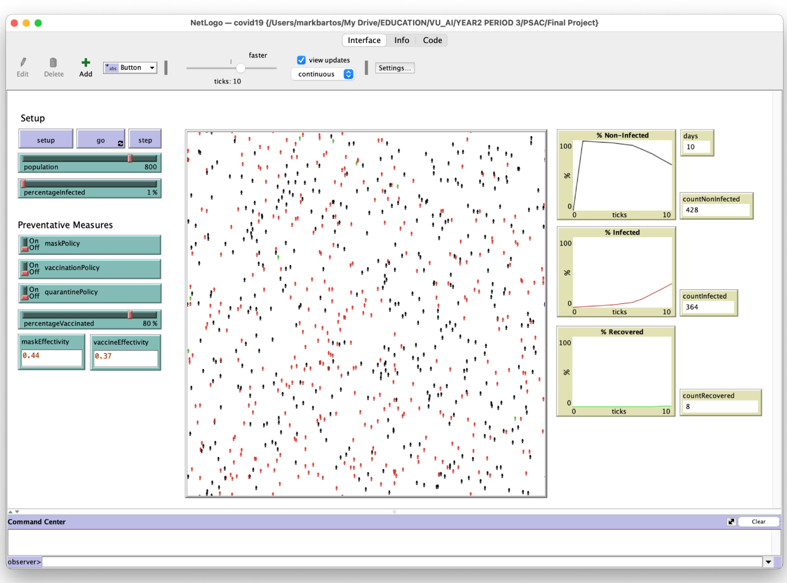
How does the combination of different strategies and their early applicability impact the spread of the SARS-CoV-2 virus in a simulated population?

4. Hypotheses

The combination of mask-wearing, staying at home, and being vaccinated will be the most effective preventative strategy for slowing down the spread of COVID-19, with almost zero infections and death. Likewise, applying none of the preventative measures will result in the highest number of infected people. However, some measures, especially combined measures will lengthen the time frame the virus is present in the population, compared to none or all measures.

5. Approach

A NetLogo model has been created that simulates the transmission of COVID-19 between people. The model includes turtles, representing people moving around and contacting each other, while also spreading the virus. Movement length is slightly randomized and the measure of quarantining slows down the movement of people by 0.1 times. Time is symbolically represented by ticks, as one tick equals one day. An agent can be in three states: being non-infected, being infected and being recovered. The initial state of the population and the percentage of infected people could be predetermined in NetLogo. To regulate the contraceptive measures, the state of mask-wearing, vaccination and stay-at-home regulation could be toggled with a button. The effectiveness of masks and vaccines could be adjusted, but these values are predetermined based on current research detailed below.



Infection takes place if an agent is in contact with another infected agent in a 1.5m radius. Without any preventative measures, the agent is instantly getting infected. However, wearing a mask and being vaccinated reduces the chances of getting infected. If two agents are in-radius of each other, NetLogo checks if (1) wearing a mask is required, if yes, then that reduces the probability of getting infected by 66% [3]. (2) Vaccination status of the agent is also checked based on probability, and on default the model is set to resemble reality, with 80% of the population [7] being pre-immunized with a 63% effective vaccine [5]. This infection function is meant to fulfill the "cooperation" sub-topic, as a kind of "negative cooperation" in-between turtles.

Recovery takes place if an agent has been infected for 14 days, plus or minus 7 days [6]. As this model is focused solely on the first period of an outbreak, and to prevent the exponential growth of infected individuals, reinfections and the slow degradation of vaccine effectiveness is not discussed. Both degradation of immunity is significant after 90 and 180 days [5] respectively, and have minor influence in such models. Deaths are also not considered, as this could be calculated from the number of immune people. Although vaccination reduces the chance of dying after infection, based on the preset percentage of vaccinated people, again, it could be calculated in need.

6. Experiments

The model will be run 40 times, 5 times on each different possible combinations to investigate the solo and combined impact of intervention strategies. The following possibilities arise: (1) No effects are in effect, (2) Masks policy is in effect, (3) Vaccination policy is in effect, (4) Quarantine policy is in effect, (5) Mask and Vaccination policies are in effect, (6) Mask and Quarantine policies are in effect, (7) Vaccination and Quarantine policies are in effect and (8) All policies are in effect.

The percentage of non-infected, infected and immune people will be measured against the ticks in all runs, then these data points will be averaged per tick and illustrated per preventative possibilities. The behavioral space used to collect will be set to a realistic population density of 800 in a 50x50 meter space, of which 1% are infected from the beginning, and if vaccination applies, then 80% of the population is immunized by such means. Data collection would automatically stop once the virus is not present anymore in the population. The goal of this data collection and the analysis is to answer the research question on how these early applied and consistent policies affect the spread of the virus and which is the most effective strategy.

7. Results

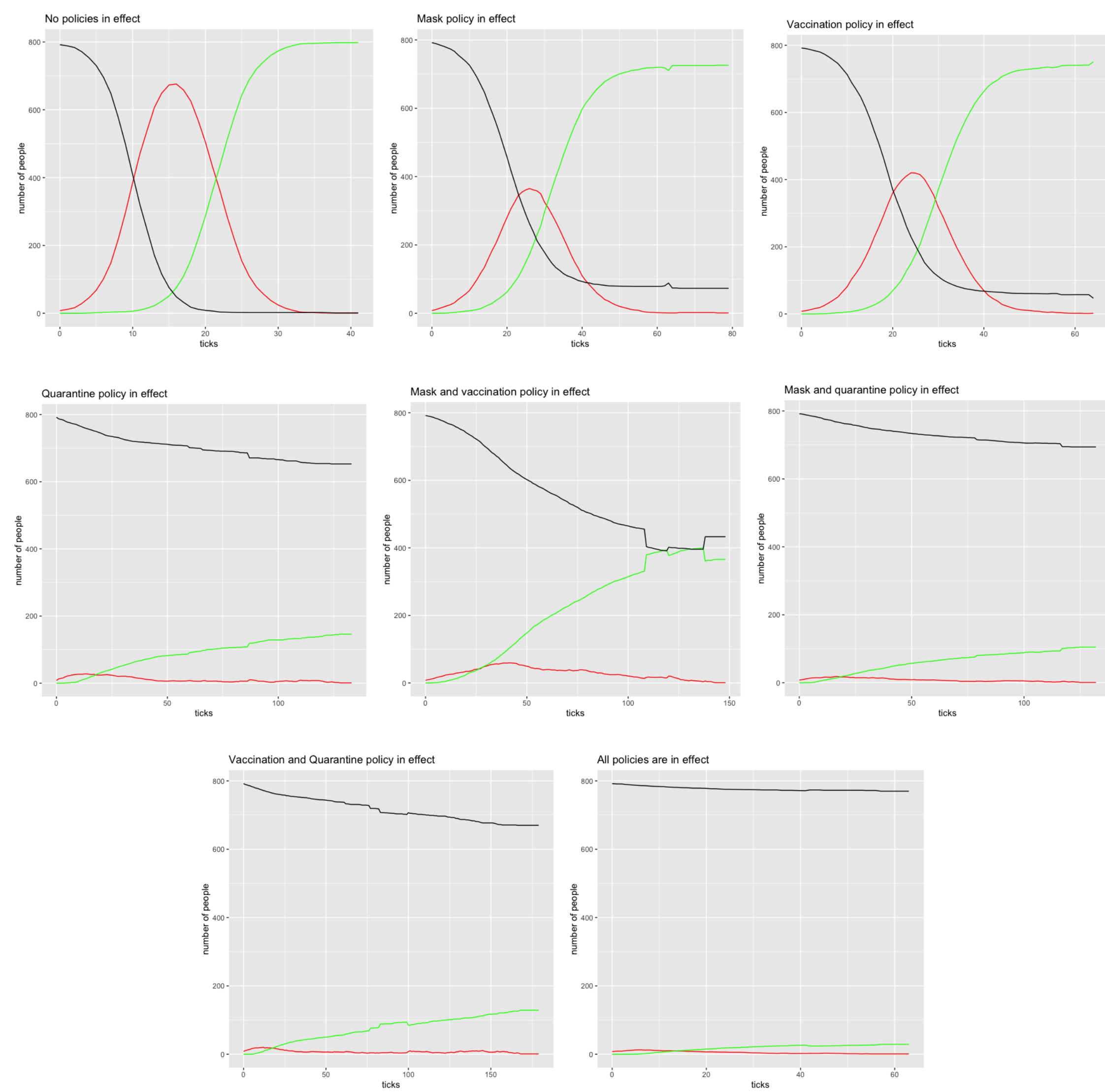


Fig. 1 until 8 - Experiment 1 until Experiment 8

Black line: Non-Infected, Red line: Infected, Green line: Recovered

The 8 graphs above indicate the results elaborating on the effect of the combination of different early applied strategies and their in the spread of the Covid-19 pandemic. As expected, the most effective measure was found to be the use of (8) all three policies together, with

SARS-CoV-2 infecting less than 10% of the population. Following, combining quarantine with vaccination (7) and the use of masks (6) resulted in a relatively flat infection line as well, with 12-15% of the population becoming infected. (4) Quarantine was the most effective solo measure, with only 20% of the population becoming infected when being enforced. Unexpectedly, quarantine outperformed the remaining combination measure, the (5) combination of vaccination and mask-wearing left 50% of the population non-infected. However, all measures including quarantine almost doubles the time it takes for the infections to back get to zero. On 6th and 7th place on effectiveness, the use of (3) vaccination and (3) mask-wearing respectively flatten the curve of infected people, leaving around 10-15% of the population non-infected. Lasly, as expected, when (1) no preventative strategies apply, the curve will be the sharpest, leaving no one non-infected.

8. Discussion

To further analyze the results and get statistical outcomes, a Factorial Repeated Measures Analysis of Variance (ANOVA) analysis will be conducted. The effectiveness of these policies will be measured against the number of ticks it takes for each combination to make the virus disappear from the population completely. This would test if there is a significant difference in means for different methods regarding how many ticks it takes for SARS-CoV-2 to disappear from the population completely. Therefore, the H_0: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7 = \mu_8$, meaning that all methods are equal in terms of variance, and H_a: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5 \neq \mu_6 \neq \mu_7 \neq \mu_8$, symbolizing that there is a significant difference in effectiveness. After conducting the test in R Studio, the following results are obtained:

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
options	1	483	483.1	0.368	0.548
residuals	38	49926	1213.8		

Since the p-value is greater than 0.05, we fail to reject the H_a stating that different methods have equal variances. Limitations of this model include not being able to analyze the full range of effectiveness, with infection curve sharpness and the percentage of population getting infected.

9. Conclusion

This research project aimed at simulation the spread of SARS-CoV-2 in NetLogo and conducts a study to find the most effective preventative single or combined measure out of mask-wearing, quarantine and vaccination based on the sharpness of the infection curve, the percentage of the population becoming infected and the days it takes for the virus to go distinct from the population. It was found that the most effective strategy was the combination of all measures, resulting in less than 10% of the population being infected. Quarantine was the most effective solo measure, only 20% became infected when enforced. The solo use of masks and vaccination was found to be less effective, with around 10-15% of the population remaining non-infected. Therefore, it is concluded that combining strategies is the most effective way of slowing down the spread of COVID-19. Future work could include reinfections in the model, to research multiple waves of infections, as well as researching how the inconsistency and late-introduction of measures affect the proceedings of the pandemic.

10. Self-reflection

During the course of Project Socially Aware Computing, I have gained much hands-on experience with multi-agent models, and now are confident working in the NetLogo environment. Although I was expecting another strongly theoretical course, I was surprised and delighted by the fact that during a controlled and helpful environment, I could work independently on a topic of my own choice, reaching my best. I plan to apply the gained knowledge during my Bachelor's project, which will be focused on a similar social issue. What I feel like I did well in this course besides good organization and planning, is the choice of the model itself. Working with a model that we all have recent and quite close experience with made the research a smoother process. If I were to have more time, I would extend the model to be a multiple wave SARS-CoV-2 model.

11. References

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