

Agent-based models of non-pharmaceutical interventions for epidemic control

Robert Brian Milligan and Supervised by Julian Garcia Gallego & Buser Say

7 July 2022

Abstract

Currently there is much interest in modelling diseases to understanding ways governments, workplaces and other decisions makers may seek to control the spread of COVID-19. Many various computational models of disease spread exist and this paper builds upon an network agent based model and changes the ways in which agents can comply or not comply with various actions. Both non-strategic and strategic methods of agent compliance were looked into and it was found that the lower the reproduction rate of the disease the better any type of non-pharmaceutical intervention was, with high R_0 values the best results were found when benefit for compliance related to the number of agents one was in contact with, and with lower R_0 values the best results were found when the benefit for compliance related to looking at the number of agents one was in contact with that was either symptomatic, hospitalised, fatality or in quarantine.

Contents

1	Introduction	3
2	Description of Model	3
2.1	Using networks to model contacts	4
2.2	Description of Model Parameters	6
2.3	Description of Compliance In the Model	7
3	Childcare Model and Benchmark Tests	7
4	Non-Strategic Model	10
5	Strategic Model	10
6	Results	11
7	Analysis of Testing Compliance	15

8 Discussion	16
9 Conclusion	16
A Appendix Section	17

1 Introduction

Mathematical and computational models are important in preparing policies to deal with pandemics. These models typically do not incorporate behaviour or if they do, do so in simple ways such as compartmental models that incorporate "aggregate states" this was implemented as having 6 different behavioural scenarios which would change based on the time of the simulation or having a certain threshold of positive test, positive cases or deaths per day [1]

This paper investigates the modification of an existing model disease spread produced by Ryan McGee and used a part of various peer reviewed research articles [4] [5]. I have looked at applying the model to the situation of COVID-19 in childcare and involves creating both a non strategic and strategic behavioural models. The Behaviour relates to compliance to various actions the agent can choose to do such as doing an additional COVID rapid antigen test if they have symptoms of the virus. The non strategic model looks at giving agents a fixed cost of complying with requested actions with a reward based on a mix of local situations such as if they are in close contact with an agent who is in isolation and a global situation such as the percentage of the group that reported a positive test within the last 2 weeks. The strategic model looks at agents where they know how all other agents will act and use this information to decide if it in their interest to comply.

Add a few more paragraphs: go slowly.

The rest of this paper is organised as follows. Section 2 describes the basic model, Section....

2 Description of Model

The model that is modified in this paper is an Agent Based Model (ABM). This ABM is one where agents can belong to one and only one compartment representing their state.

Agents progress through states with the only sink node being Recovered and Fatality the states of Susceptible, Exposed, Pre-Infectious, Infectious-Asymptomatic, Infectious-Symptomatic, Hospitalised, Fatality and Recovered exist. All these except Hospitalised and Fatality can have agents in a mirror state where they are also isolated, meaning they cannot acquire the disease or spread it to any other agents in the network.

Once an agent catches the disease they move along the stages of the disease until they are a fatality or recovered, at any point they have the ability to move across to the mirror isolation state.

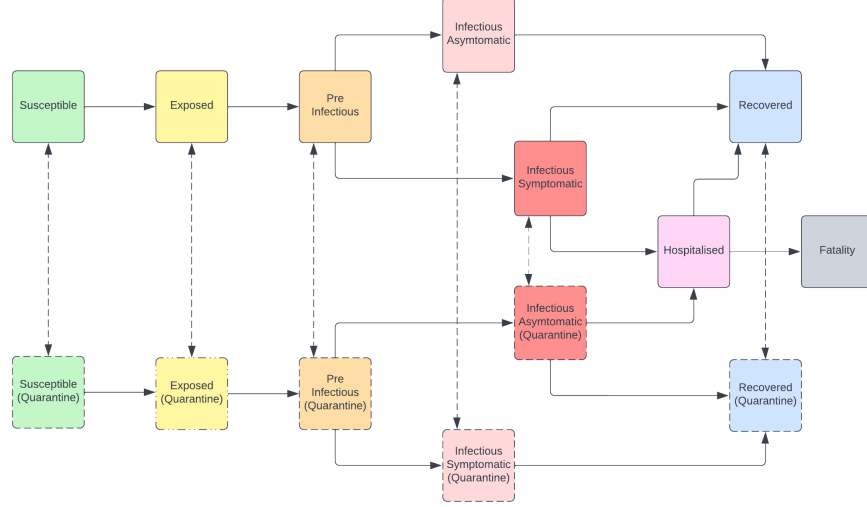


Figure 1: a diagram of the existing model of seirplus [3]

2.1 Using networks to model contacts

The version of the model we use considers a simple network, one which uses a one single connected network designed to simulate a workplace.

These large networks are made up of a number of cohorts which are loosely connected and each of these cohorts can have a number of subgroups which are highly connected.

The network is set up before the simulation begins and is different every time and does not change throughout the simulations run.

Agents are arranged in a network as nodes and are connected by edges representing which other nodes are their close contacts. 80% of disease spread is through the close contact edges and 20% is spread randomly.

Each day agents will be asked to do a test if their day has come up on a surveillance testing schedule, they show symptoms or have been contacted that they are a close contact. However there is a compliance value to them following through with the requested action

During the day agents can spread the contagion to each other and can progress through the stages of the disease if they have it. They additionally have the choice to participate in contact tracing.

Agents will also be asked to isolate for one of six reasons. They or a group member develop a symptomatic case, returns a positive test or is told they are a close contact through using contact tracing. Again there is a compliance value to decide if they follow through with the requested action

These systems can effectively be disabled by overriding the compliance for them to be a large negative number, for example compliance with contact tracing

can be set to -10 to disable the use of that system and this done to limit the model to a smaller number of variables which compliance can affect.

The model has a variety of limitations including

- Having all agents always test on the same day, thus if semiweekly is chosen, all agents will be asked to test on Monday and Thursday
- the network itself is unchanging, however this is not necessarily bad as it removes a variable that may change results

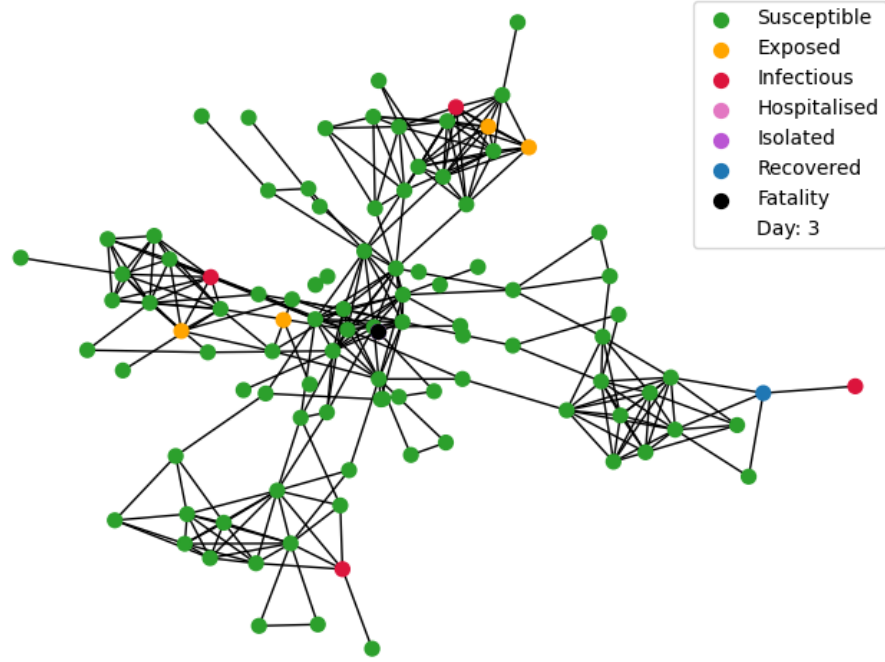


Figure 2: An Example Netowrk

Example of the network of 100 agents To simulate the childcare scenario they are split into 5 groups of about 20 agents each with high connectivity inside the group and low connectivity between the groups The agents current state is shown by the nodes colour and the edges are that agents close contacts which the disease can spread easiest though the population

2.2 Description of Model Parameters

The Current Modifications of the model relate to allowing 10 of the Model Parameters that relate to Compliance to be dynamically updated each day dependent on a given rule. The 5 most relevent of these being.

- What proportion of agents take a test immediately as a result of having symptoms
- What proportion of agents will do surveillance
- What proportion of agents will isolate given they have a symptomatic case
- What proportion of agents will isolate given a positive result from a test
- What proportion of agents in a group isolate given one of them has a positive result from a test

A simple model might only use a few of these compliance parameters such as and is how the parameters work in the base model

Symtomatic Testing Rate Compliance	50%
Surveillance Testing Rate Compliance	50%
Isolation from Positive Test Compliance	100%

2.3 Description of Compliance In the Model

Compliance can be set a variety of ways in the modified model but in this paper 3 are used

- The default setting where agents are given an initial value for compliance and is unchanging e.g. 50% are set to comply and will always do so
- The non strategic model where agents are given an initial compliance and can become more compliant depending on the network situation , their local situation or a mix
- The strategic model where agents utilise knowledge of the amount of agents in the network who will comply to make a decision to comply or not

3 Childcare Model and Benchmark Tests

- Parameter justification
- test false negative rate 0.36 [6]
- R0 mean of Omicron is 9.5, delta is 5.4 [2]
- base compliance for behaviour is set at levels of 0.5 and 1, to represent 50% of agents and all agents complying
- 100 agents in model split into 5 groups with high interconnectedness within the group and low connections between groups
- compliance increases for 2 actions, symptomatic test and regular interval surveillance tests
- The cost of compliance is fixed and there is a reward based on if connecting agents are isolated, hospitalised or a fatality
- from looking at early results since only 2-3 tests a week there is a delay and the higher the r0 the fewer chances they can have to change their mind about compliance

- the R_0 of 9.5 or 5.4 may be too high as it assumes children spread the disease at the same rate as the general population as well as all disease spread occurring in childcare which it probably is not. Therefore 2 other R_0 cases of 3 and 2 are used as they may more accurately capture a real world scenario where not all transmission is through the 1 childcare setting

The benchmark model is associated with one single large peak of disease spread

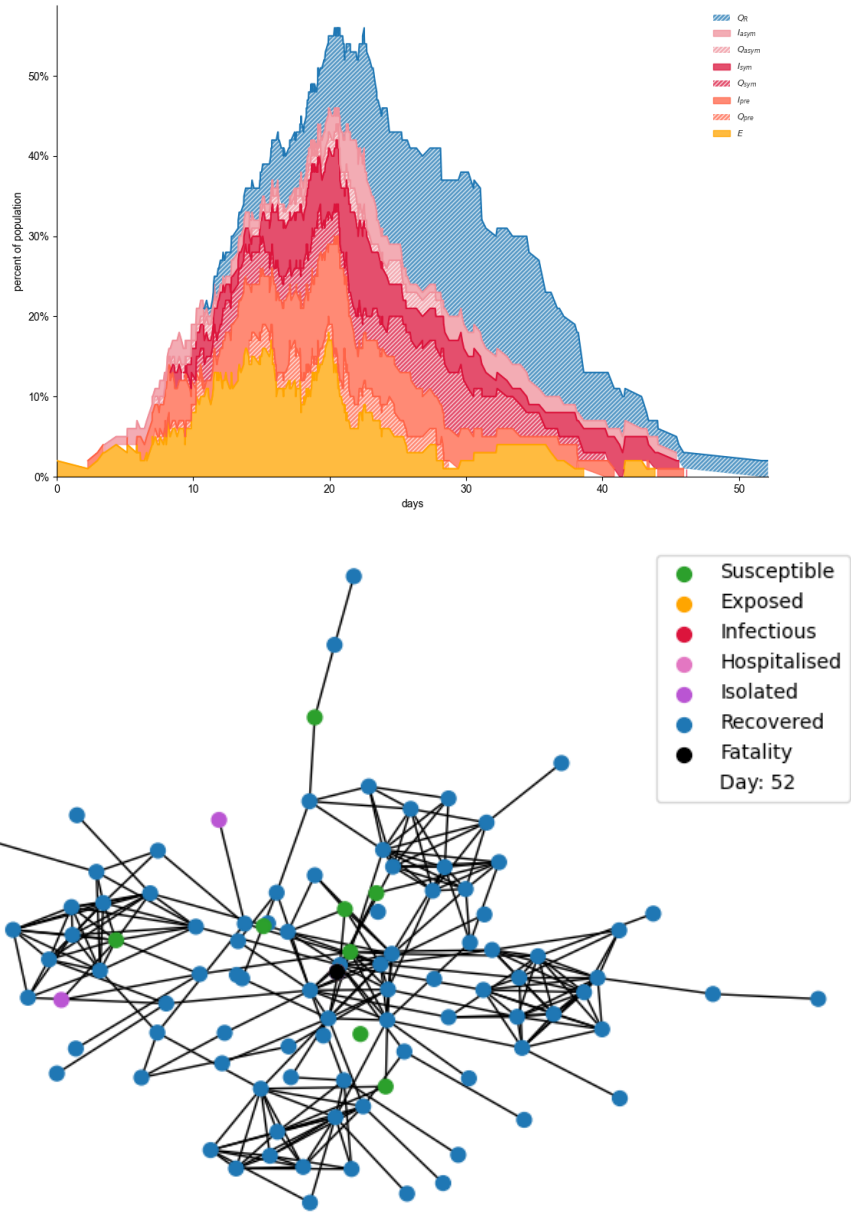


Figure 3: Benchmark Run with Unchanging Compliance at 50% for regular twice weekly surveillance testing and testing if symptomatic with the resulting final network. 92 of the 100 agents received the infection

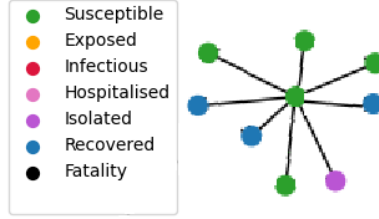


Figure 4: An Example Simplified Network

4 Non-Strategic Model

We have a fixed cost of compliance to an action and varying factors that can raise it. A mix of global and local behavioural factors can be added to make an agent more compliant. In the current build these are the known positive cases in the network in the past 14 days. The proportion of contact agents (those which share an edge) which are a fatality, hospitalised or in isolation. These values are taken away from the base cost and if the result is lower from a specified value the agent will be compliant to that action, otherwise they are not

For a simple example we have a situation for this central agent

Symtomatic Testing Rate Compliance	50%
Surveillance Testing Rate Compliance	50%
This agent's base aptitude	uniformly distributed (-0.1,0.1)
Base Cost of Compliance	0.5

$$\text{Compliance} = 0.5 - (5 * 1/10) - (4*0.02) + 0.3 = 0.22$$

In this case the agent is compliant it will test if they develop a symptomatic case immediately and will do surveillance testing as the compliance is now less than the threshold of 0.5 if the neighbouring agent that entered hospital returns a positive test, our agent will enter isolation if a positive test is returned the reward for agents can be based on a mix of both a local and global network situation as in the example runs

Of the 10 possible compliance parameters built into the existing mode, 3 are used these which are:

- immediately testing if the agent has a symptomatic case
- using regular surveillance testing
- isolating if a positive test is returned - set to always be true

5 Strategic Model

The view of benefit and cost can be grouped into 3 categories. There is a level at which people will not contribute as they find the act pointless as they know

near no agents will comply

- 1. Global Situation of the model e.g. changes over time but is identical across all agents e.g. number of active cases or rate of change in spread rate, could place 2 infections in first week and compare each week to the last week, rate of change week on week $[0,0,0,0,0,2]$ if the next week 4 cases are spread, the rate would be 2
- 2. Structural Layout of the model, identical over time but varies between each agents e.g. number of close contacts or number of agents one can reach in 1 step, or could be 2 steps, the more agents one is in contact with the greater the benefit
- 3. Structural Situation of the model, changes over time and varies for each agent e.g. number of close contacts in a particular state or group of states like hospitalised, fatality, isolated etc, if a close contact is in one of those states the benefit to compliance is greater

6 Results

In this model two choices of compliance are considered, If an agent is compliant they will perform semi-weekly surveillance testing in addition to testing whenever they develop a symptomatic case of the disease, If they are not compliant they will do neither of these actions.

There are 5 models compared these are Baseline 50% compliance, this is where each agent when generated has a 50% chance to always or to never comply.

Baseline 100% compliance, this is where each agent when generated has a 100% chance to always comply.

for the non-strategic model, initially a value is generated for what threshold of compliance they will have and when it is past that set value they become compliant and if it moves back they no longer are. For example the base attitude for an agent might be 0.5, if on a given day the benefit exceeds that they become compliant and less than that, no longer compliant.

Non-Strategic Minimum 50% , this is where each day the compliance value for an agent is updated and changes based on a combination of the global known positive test cases recorded in the network within the last 14 days as well as the proportion of close contacts of an agent that are either symptomatic, a fatality, hospitalised or in isolation.

For the strategic model a curve is created to model a game theory dilemma on wherever or not the agent should comply given they know the reward for compliance and what every other agent will do, depending on the benefit the likelihood of any one agent complying can vary from 0, to 60-99

Strategic Community Size, this is where the benefit to compliance is based on the number of close contacts the agent has. This is a case where the curve is different for each agent but unchanging over time. Strategic Local State, this is where the benefit to compliance is based on the number of close contacts that

are either in a state of symptomatic, a fatality, hospitalised or in isolation. This is a case where the curve is different for each agent and unchanging over time. Strategic Global State, this is where the benefit to compliance is based on the number of agents in the network that are either in a state of symptomatic, a fatality, hospitalised or in isolation. This is a case where the curve is the same for each agent but changes over time.

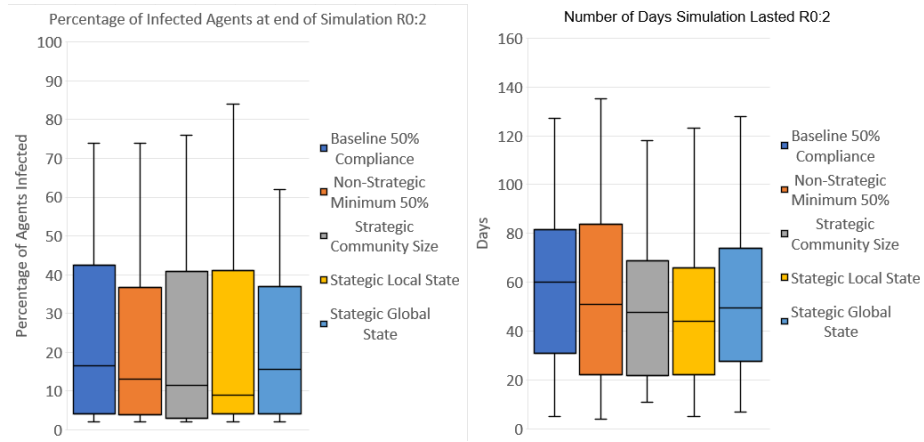


Figure 5: Test Results over R0 of 2

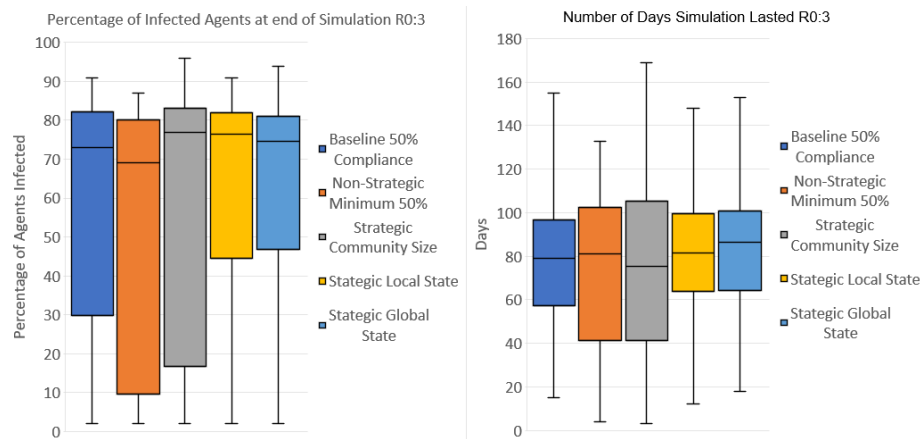


Figure 6: Test Results over R0 of 3

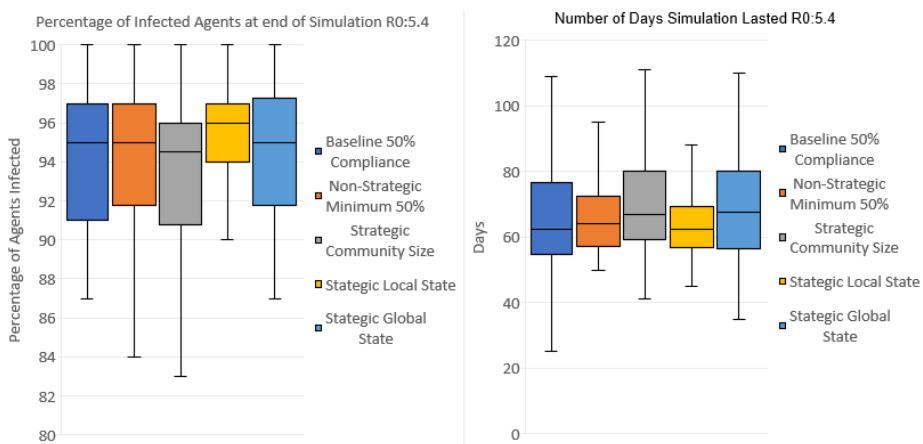


Figure 7: Test Results over R0 of 5.4

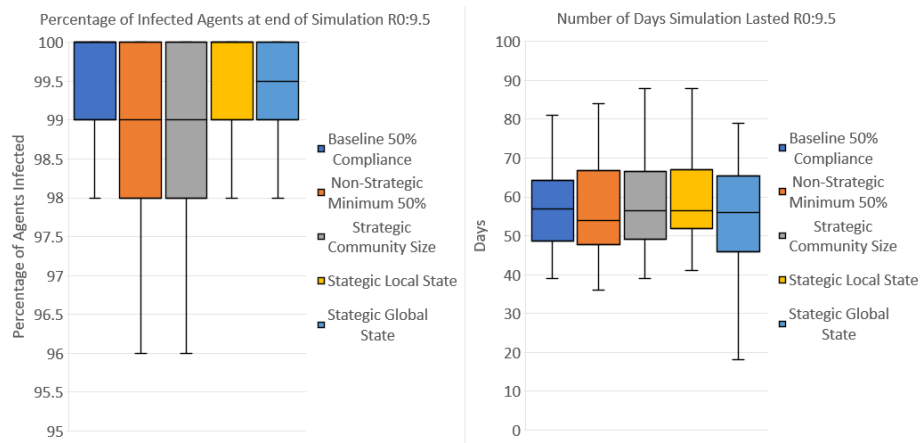


Figure 8: Test Results over R0 of 9.5

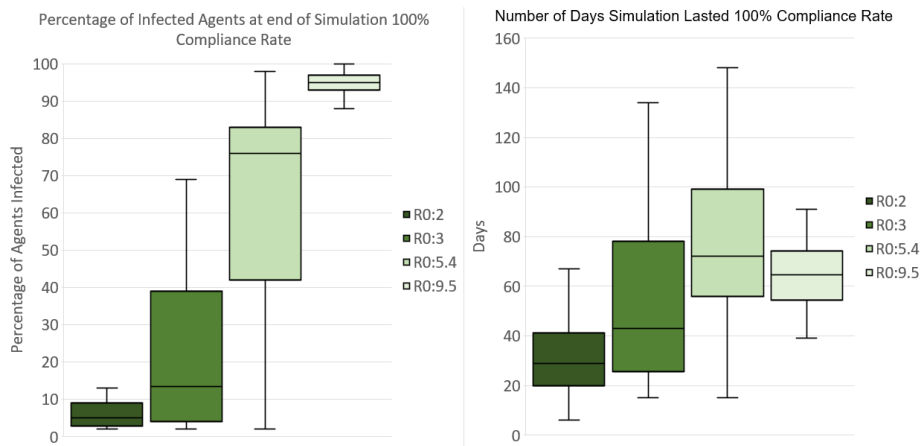


Figure 9: Test Results over all R0 values at 100% Compliance

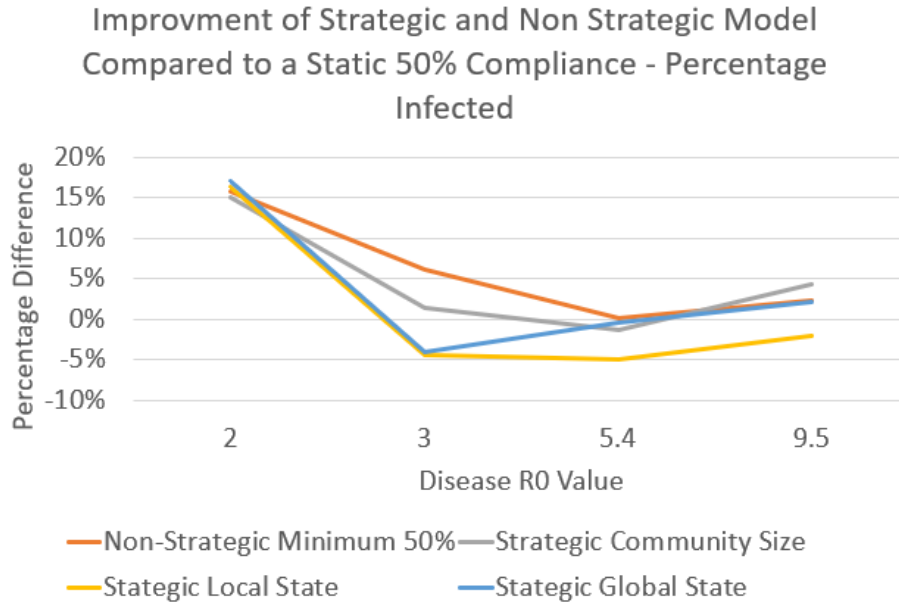


Figure 10: Test Results Comparing the Results of R0 values

7 Analysis of Testing Compliance

To evaluate the result of the model we take the average of these two values over many runs

- What percentage of the population caught the contagion?
- How many days did it take for the outbreak to stop with 0 actual active cases?

We can analyse compliance by comparing the effect varying levels have on the length a contagion actively spreads and what proportion of the population becomes infected. Firstly a baseline can be set to explore the parameter space, then further tests done to see the effect having compliance change as a result of the current known spread of the contagion in the network.

Over 4 different R0 virus base reproduction rate was the model run with, over the different R0 levels the reduction in total cases reduced from a -2% improvement with an R0 of 9.5 to a 28% improvement with an R0 of 2. This is probably due to one of the aspects the model relating to the 14 day known positive cases recorded. With a low R0 in the system there are more chances for agents to test themselves before they pass on the disease and these reported cases incentivise even more agents to do symptomatic and surveillance testing. With extremely high R0 numbers it is observed that the non-strategic behavioural model has little effect on the total number infected. Across all cases it can be

seen that the amount of time the simulation runs for is tied with how many agents get infected. Both the static values of compliance and non-strategic behavioural model follow this trend.

8 Discussion

9 Conclusion

A Appendix Section

Removed parameter section

- TRACING_COMPLIANCE_RATE (what proportion of agents comply with contact tracing)
- ISOLATION_COMPLIANCE_RATE_POSITIVE_CONTACT (what proportion of agents isolate given they are a close contact)
- TESTING_COMPLIANCE_RATE_TRACED (what proportion of agents take a test immediately as a result of being informed they are a close contact)
- ISOLATION_COMPLIANCE_RATE_SYMPOMATIC_GROUPMATE (what proportion of agents will isolate given one of their group mates has a symptomatic case)
- ISOLATION_COMPLIANCE_RATE_POSITIVE_CONTACT_GROUPMATE (what proportion of agents in a group isolate given one of them is a close contact)

References

- [1] Alexander Karaivanov. A social network model of covid-19. *PLOS ONE*, 15(10), 2020.
- [2] Ying Liu and Joacim Rocklöv. The effective reproductive number of the omicron variant of sars-cov-2 is several times relative to delta. *Journal of Travel Medicine*, 29(3), 2022.
- [3] Ryan McGee. seirplus, Jan 2021.
- [4] Ryan S. McGee, Julian R. Homburger, Hannah E. Williams, Carl T. Bergstrom, and Alicia Y. Zhou. Model-driven mitigation measures for re-opening schools during the covid-19 pandemic. *Proceedings of the National Academy of Sciences*, 118, Jul 2021.
- [5] Ryan S. McGee, Julian R. Homburger, Hannah E. Williams, Carl T. Bergstrom, and Alicia Y. Zhou. Proactive covid-19 testing in a partially vaccinated population. Aug 2021.
- [6] Thea van de Mortel. Closed centres, anxious parents and infected kids: What’s the plan for childcare during omicron?, Feb 2022.