EFFECT OF MIGRATION WITH HETEROGENEOUS PREVENTION MEASURES USING AN AGENT BASED MODEL

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Motivations and Inspirations:

◦ Effect of migration between states or cities.

◦ To see the effect of heterogeneity in cities and regions in terms of lockdown and hygiene habits.

The New York Times

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India's Coronavirus Lockdown Leaves Vast Numbers Stranded and Hungry

NEW DELHI — In one of the biggest migrations in India's modern history, hundreds of thousands of migrant laborers have begun long journeys on foot to get home, having been rendered homeless and jobless by Prime Minister Narendra Modi's nationwide lockdown to contain the spread of the coronavirus.

Some Research Questions:

- How the positioning and working hours of hubs (supermarket and essential services) be, to minimize the spread?
- To find the possibility of controlled migration.
- The effect of heterogeneity in size of families in the spread.

Some previously done work and what's new with our project?

- Qingchu Wu, Tarik Hadzibeganovic (2020), An individual-based modeling framework for infectious disease spreading in clustered complex networks.
- Yong Yang , Peter M Atkinson and Dick Ettema (2011), Analysis of CDC social control measures using an agent-based simulation of an influenza epidemic in a city.

What's new?

- Heterogeneity in measures across cities and;
- Presence of central locations and their effect on spread while migration is going on.

About the model and Overview

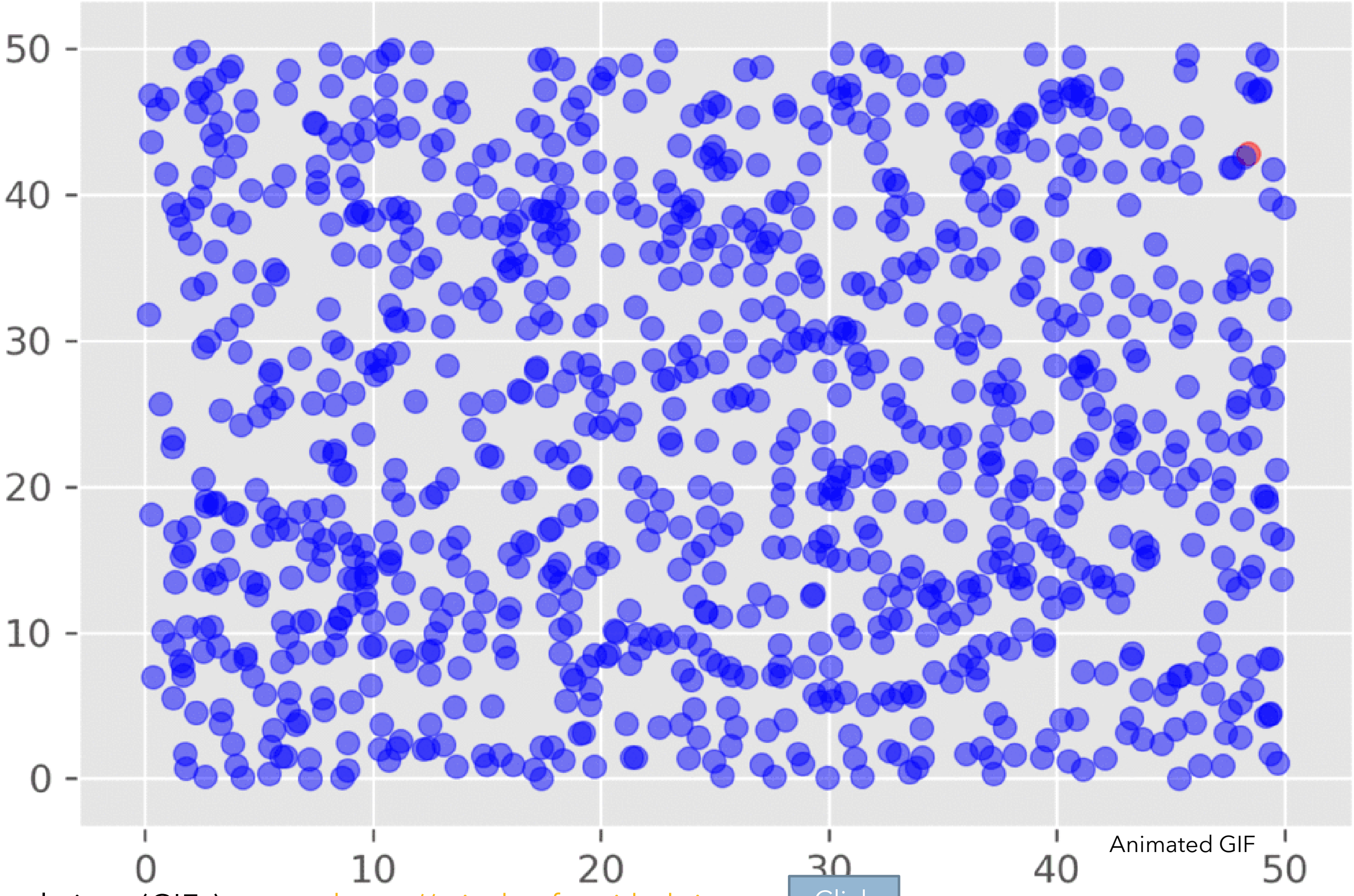
Agents are citizens of each city

Effect of having hubs and centers

Simulate travel and migration

RANDOM MOVEMENT OF AGENTS

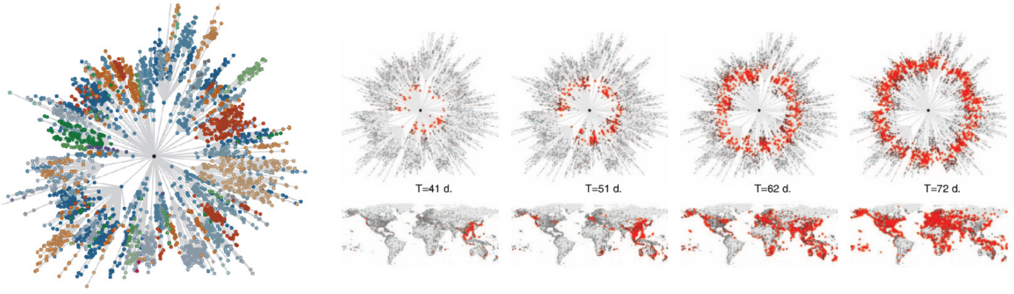
An Agent Based model

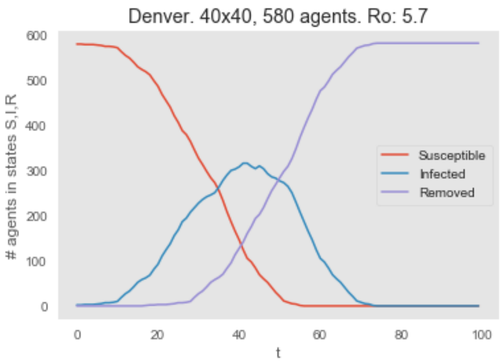


Animated GIF

Simulations (GIFs) are at : https://atiyabzafar.github.io => Click

Please go to the link for full understanding pdf cannot have animated gifs

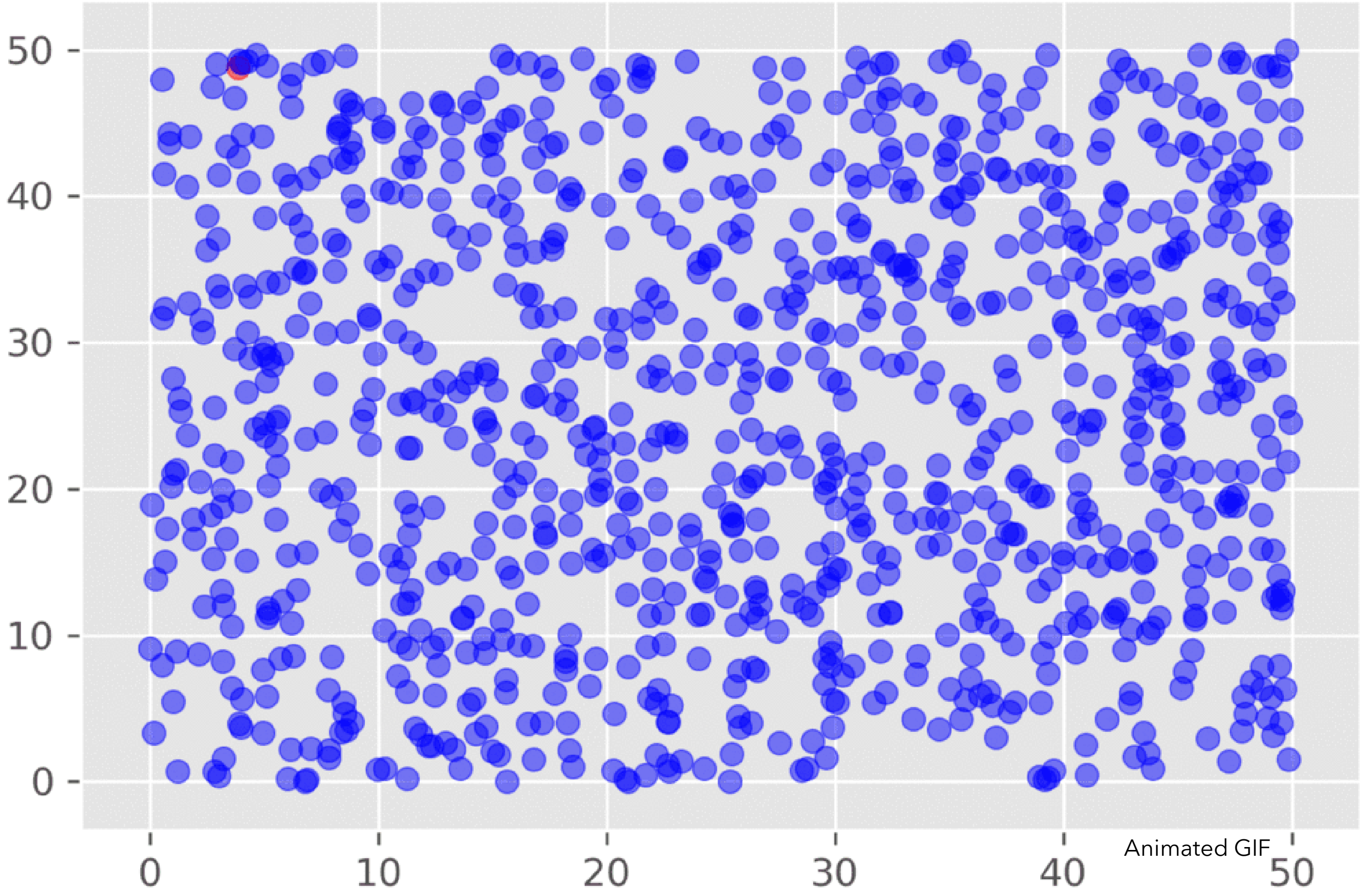




Brockmann, Dirk, and Dirk Helbing. "The hidden geometry of complex, network-driven contagion phenomena." science 342.6164 (2013): 1337-1342.

Random Movement for agents

- In our model agents move randomly
- Each agent can either be
  - Susceptible (Blue Dot)
  - Infected (Red Dots)
  - Removed/Recovered (Green)
- Each infected agent can infect the susceptible neighbours if there exists an S-I link in the corresponding graph within a proximity radius.



Animated GIF

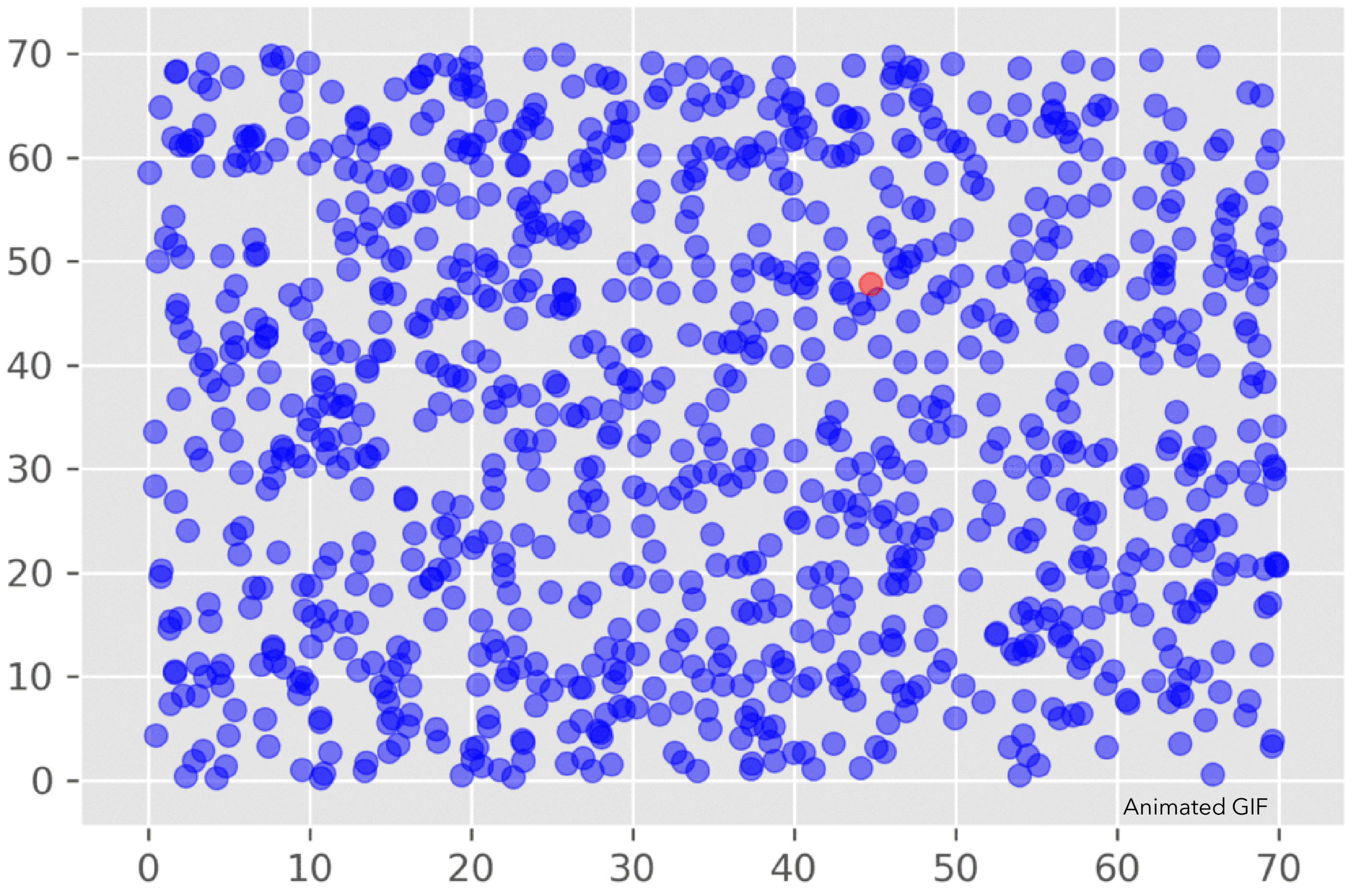
Effect of Migration

We studied the effect of Migration across the cities. In the next simulation we sampled 4 cities and initially had one agent infected in each city, we randomly choose a fixed number of people from the city and allow them to migrate from one city to another. The following simulations are the result:

We see

- Faster spreading

Simulations (GIFs) are at : https://atiyabzafar.github.io => Click



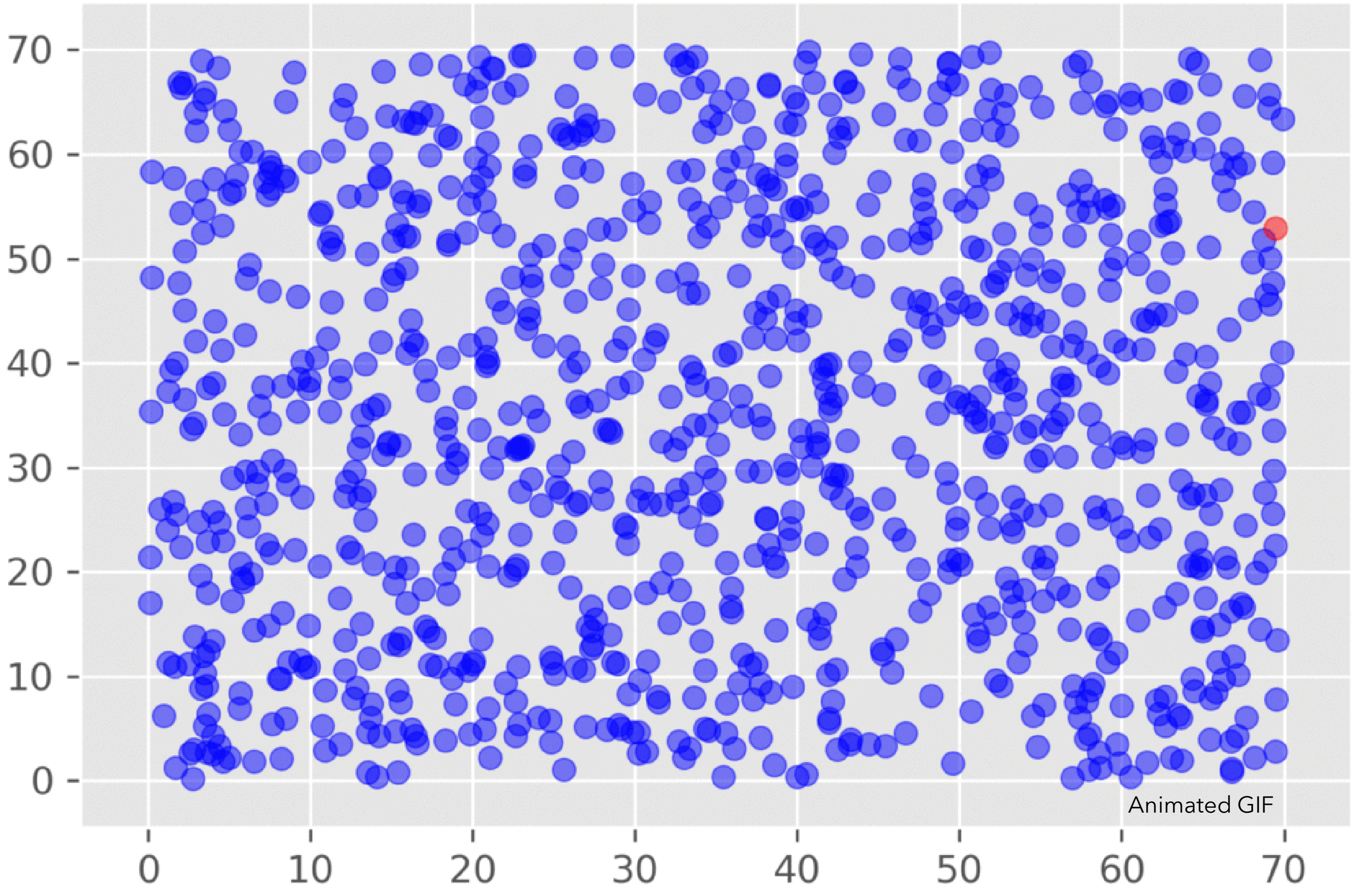
Effect of Migration

- Faster spreading
- More hotspots appear

More hotspots appeaing across the city (not just one where the infection started)

The effect of *Seeding* the infection

Simulations (GIFs) are at : https://atiyabzafar.github.io => Click

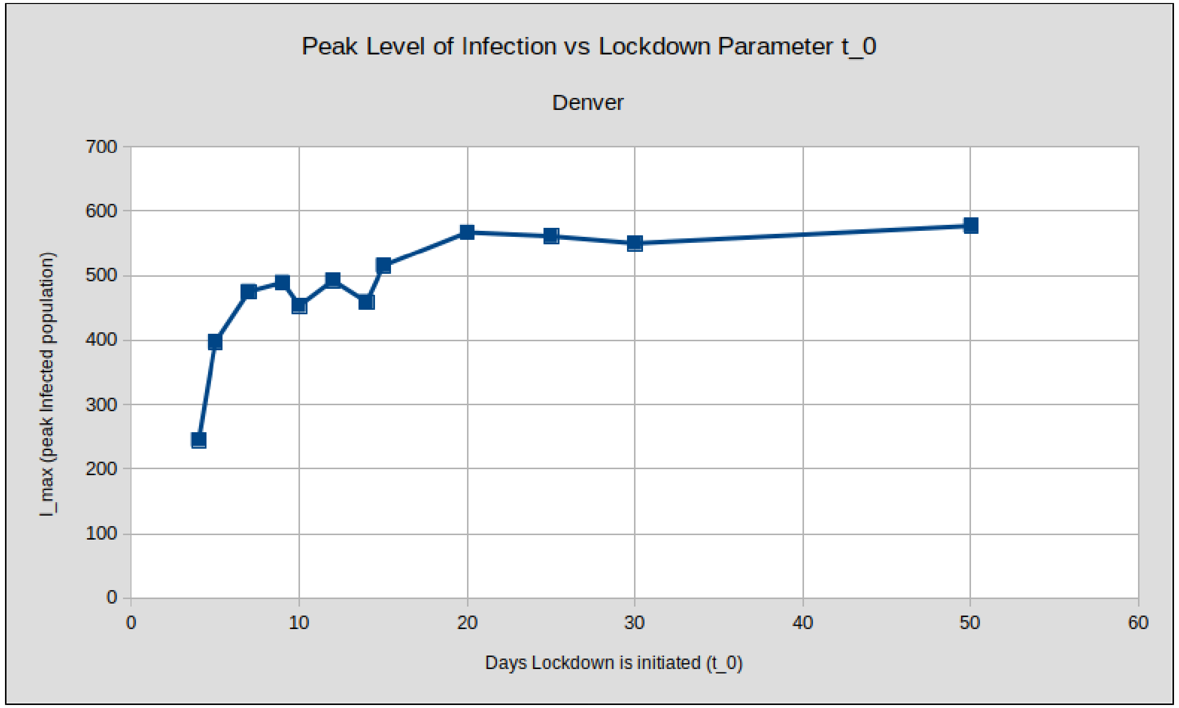


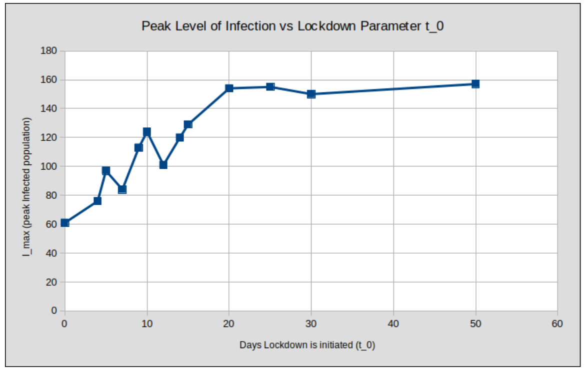
Effect of Migration

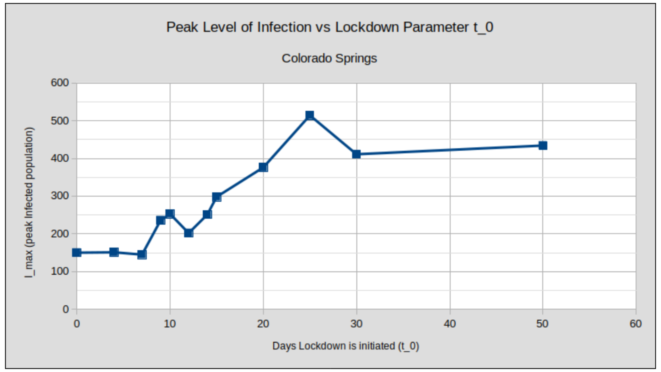
- Faster spreading
- More hotspots appear
- Quickly covers the whole city

The infection spans the city quickly, hastening the process of infection at an alarming rate.

Simulations (GIFs) are at : https://atiyabzafar.github.io => Click



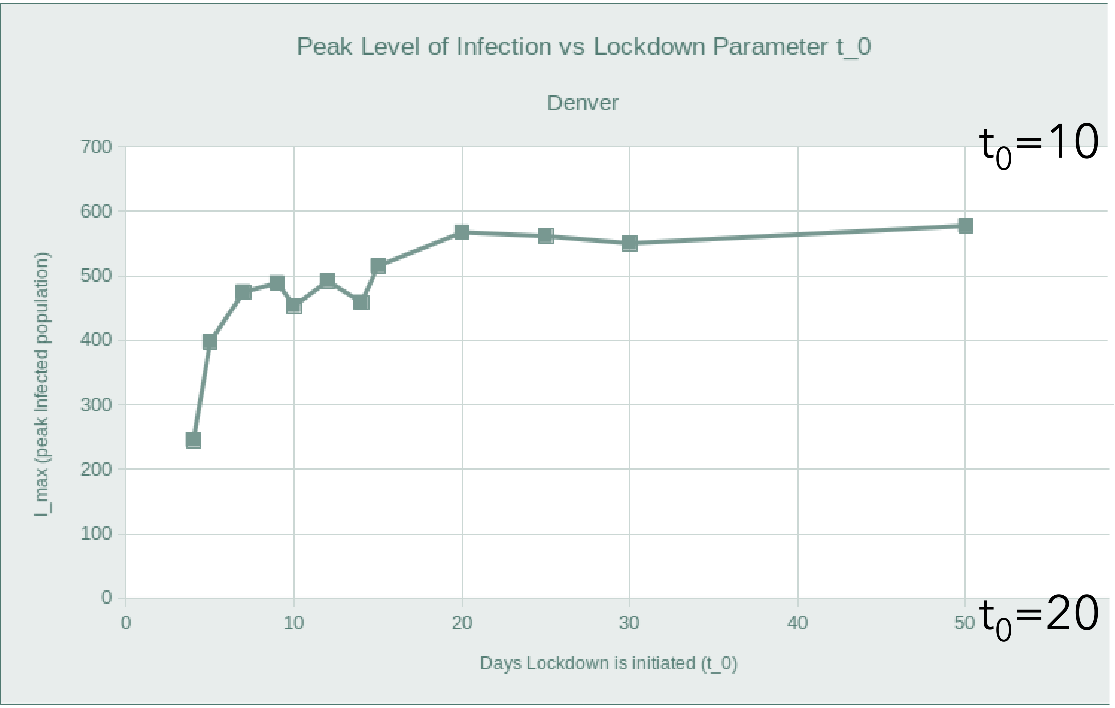


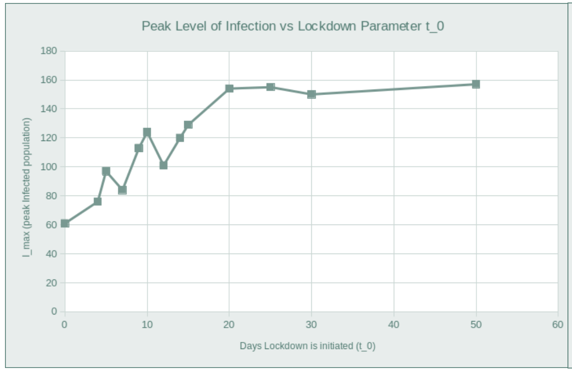


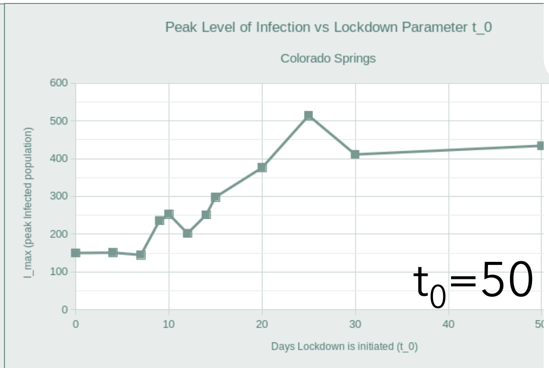
Effect of Inter-city lockdown at different time

- We define t_0 as the time at which Lockdown commences. i.e. Migration is stopped.
- You can think of this as the time when government decides to close state/city borders to stop the spread.
- Y-axis: Peak infected Imax
- If the lockdown is late
- The peak increases untill the whole poulation is infected.

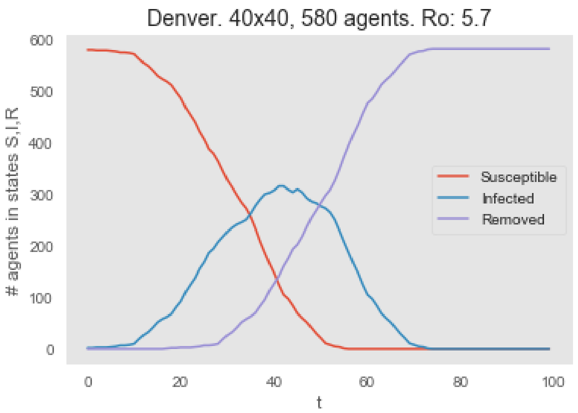
Note : These runs should be taken with a grain of salt since our model is completely stochastic and if time would have permitted, we would have run the simulation for N times and taken average.



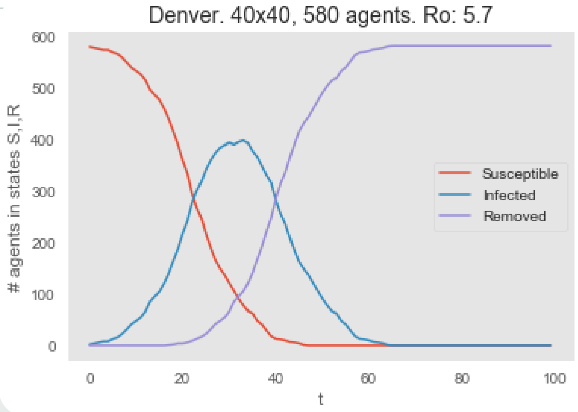




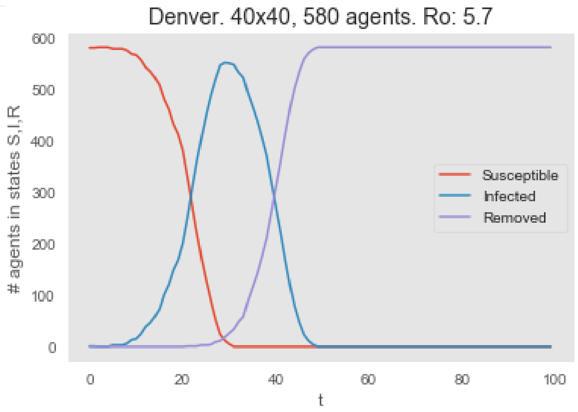
t_0=10



t_0=20



t_0=50



Effect of Inter-city lockdown at different time

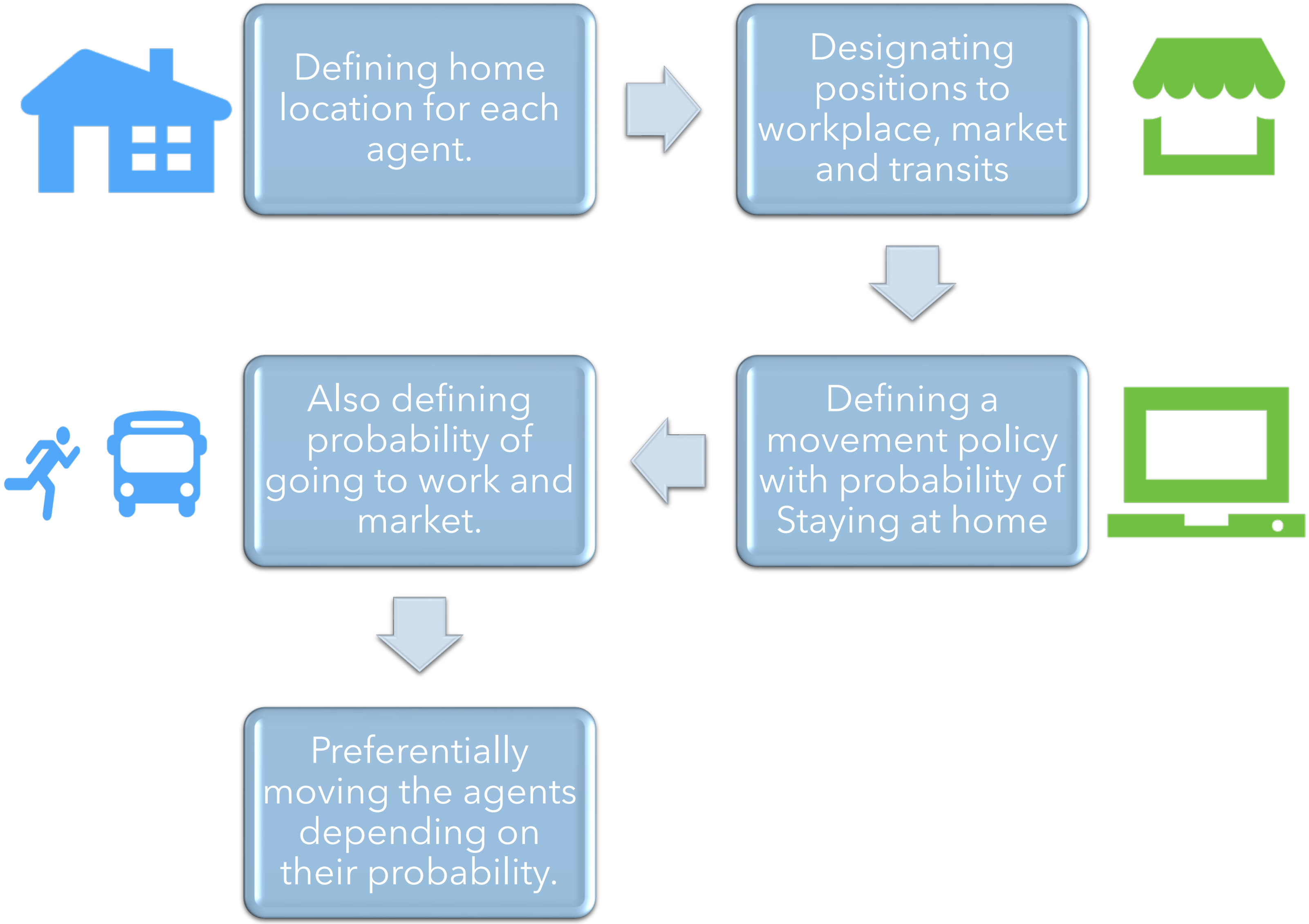
We see that if the lockdown is commenced too late into the infection.

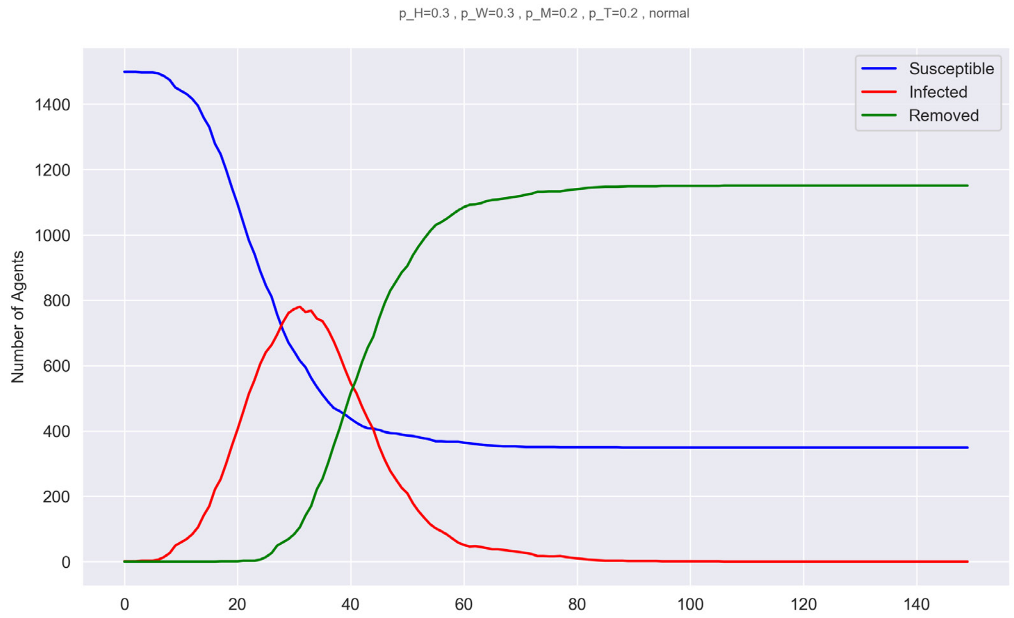
- The peak rises and it puts pressure on our healthcare facilities and available critical care beds in the city.
- It is thus critical in our toy model that the lockdown must start head on.

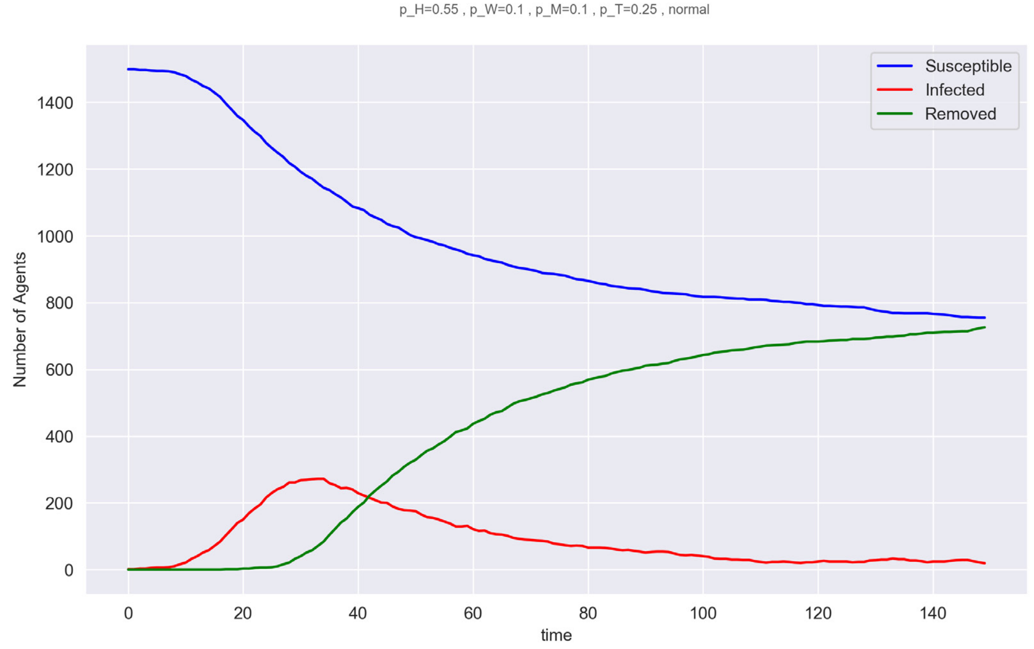
PREFERENTIAL MOVEMENT AND SOCIAL DISTANCING

More Realistic Model with Hubs like Markets and workplaces

Preferential Movement model

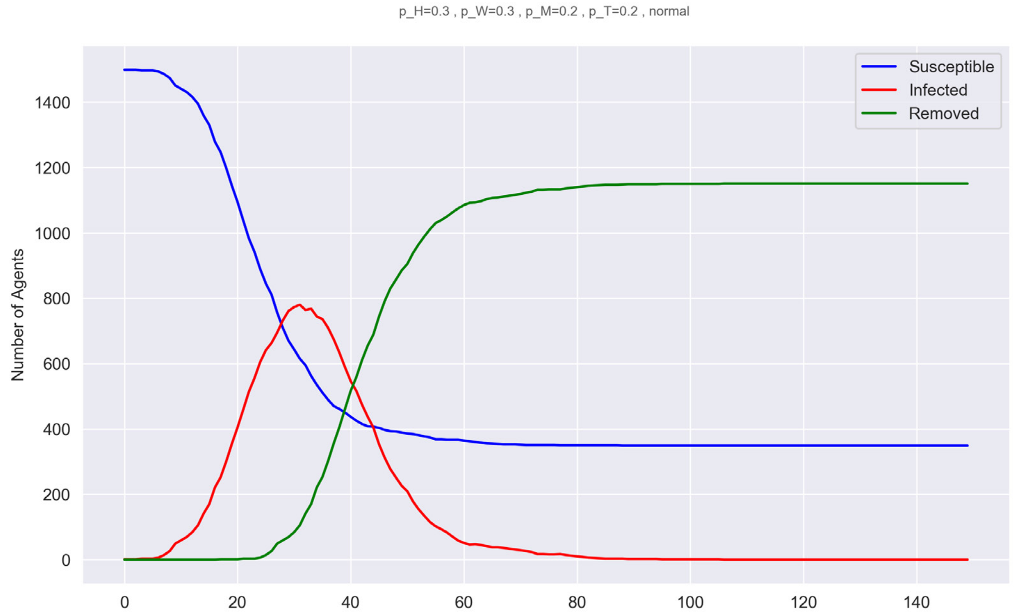






Using Preferential Return Model

- Cities have central locations
- Agents are assigned specific central locations based on their starting points
- Agents visit central locations with certain probability

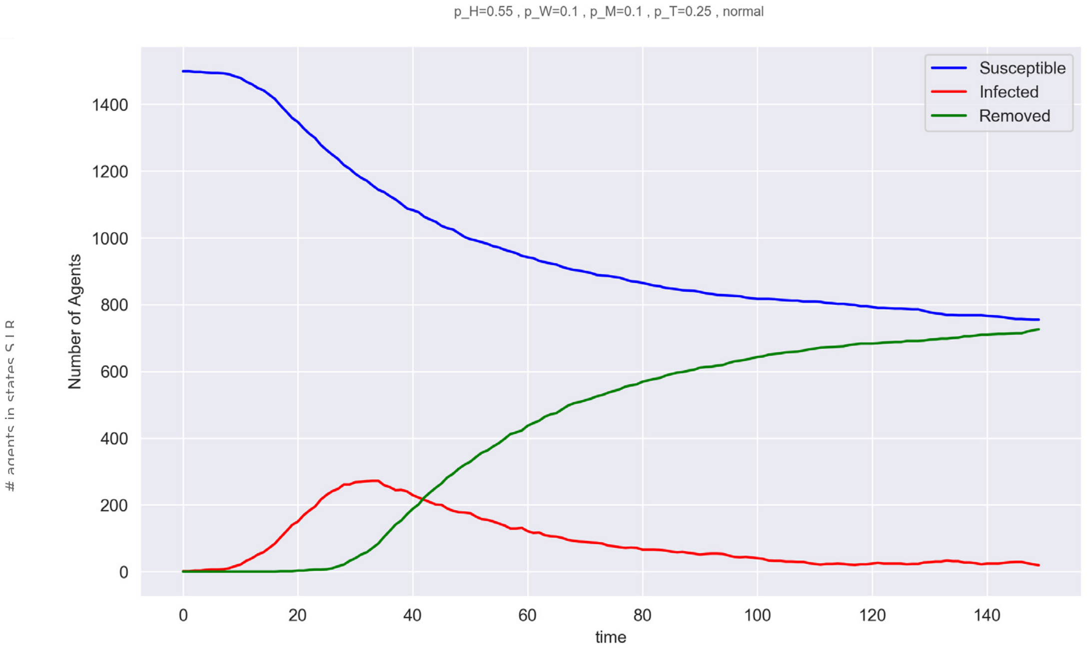


Probability of Agents staying at home : 0.3

Probability of Agents to go to work: 0.3

Probability of Agents staying at home : 0.55

Probability of Agents to go to work: 0.1



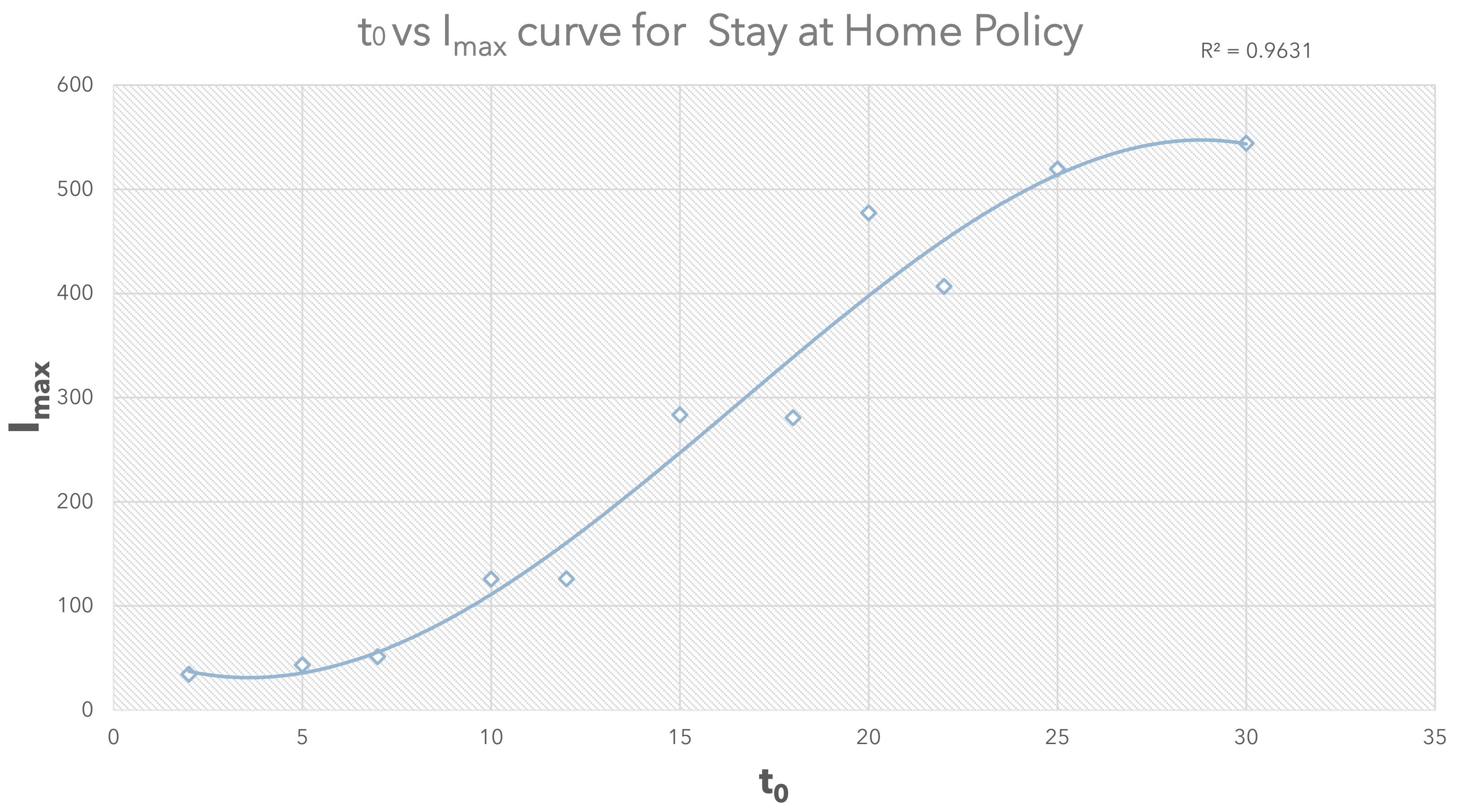
The peak decreases

Using Preferential Return Model

- Cities have central locations
- Agents are assigned specific central locations based on their starting points
- Agents visit central locations with certain probability

Work from Home Works

ANALYSING DIFFERENT KINDS OF LOCKDOWNS



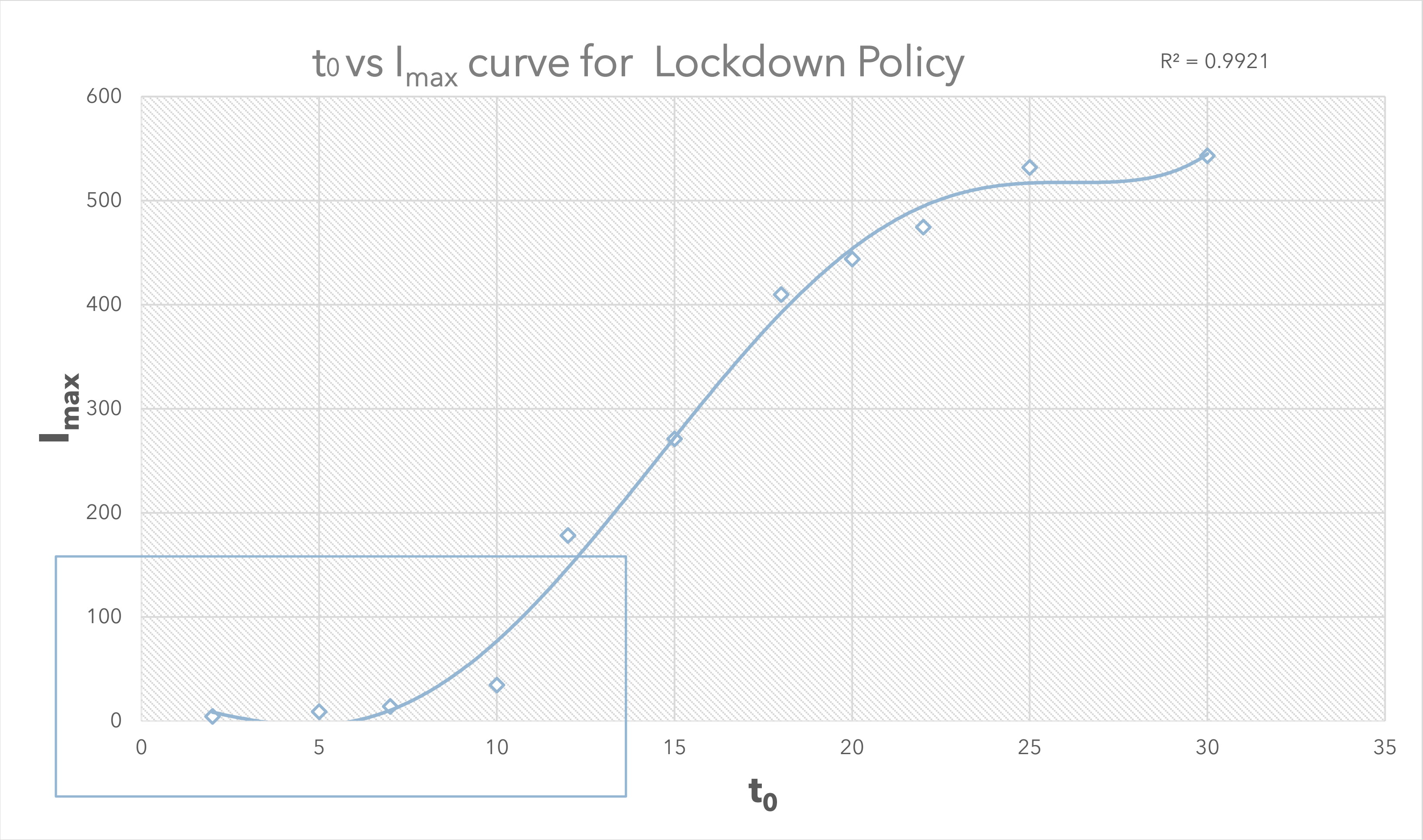
Movement Policy 1: Stay at home

Stay At Home: Probabilities : 'home': 0.9, 'work': 0.00, 'market': 0.05, 'transit': 0.05

- For large value of t_0, the epidemic peak is found to be large.
- If the stay at home policy is commenced early on we end up with less people infected

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects
- We again define t_0 to be the time at which lockdown commences.
- Higher the peak for Imax, more pressure is applied on the healthcare system
- The plot shows trend for Imax vs t_0 , Each value of t_0 is average for 10 runs. To remove the effect of Stochasticity of the model.



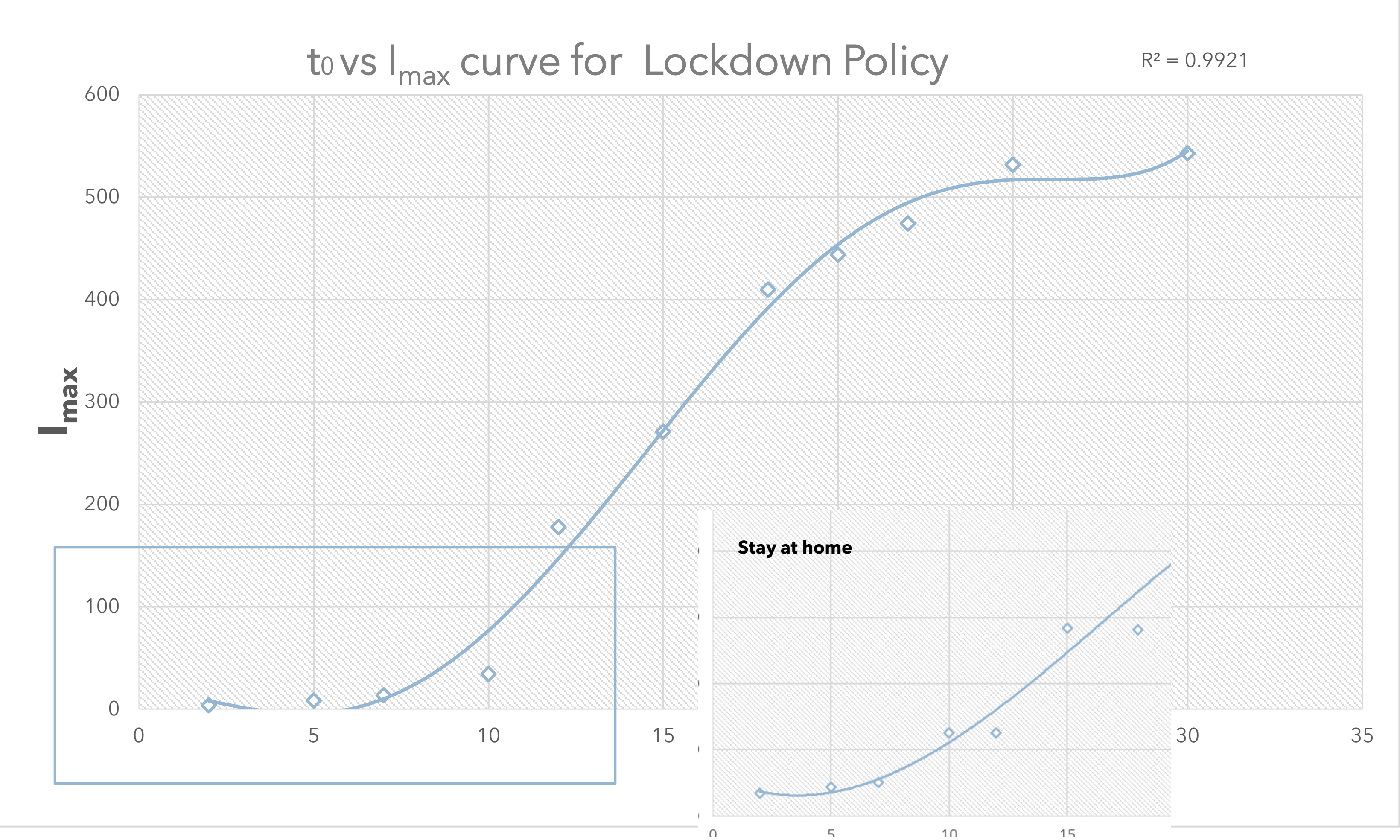
Movement Policy 2: Stay at home

Lockdown: Probabilities :: 'home': 0.95, 'work': 0.00, 'market': 0.04, 'transit': 0.01

We make the lockdown slightly stricter, making sure more agents stay at home by not allowing them to use transit . Looks same, but it's the initial window we must zoom into to analyse actual difference. (Next slide)

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for Imax, more pressure is applied on the healthcare system



Lockdown: Probabilities :: 'home': 0.95, 'work': 0.00, 'market': 0.04, 'transit': 0.01

If we look at the cases when lockdown commences in early stages.
When we use lockdown policy compared to stay at home policy (Slightly more strict restrictions) , the peak value decreases by a factor of >~3
(t_0=10, I_{max}(Stay at home) =124, I_{max}(Lockdown)=35)

Studying Types of Lockdown Measures

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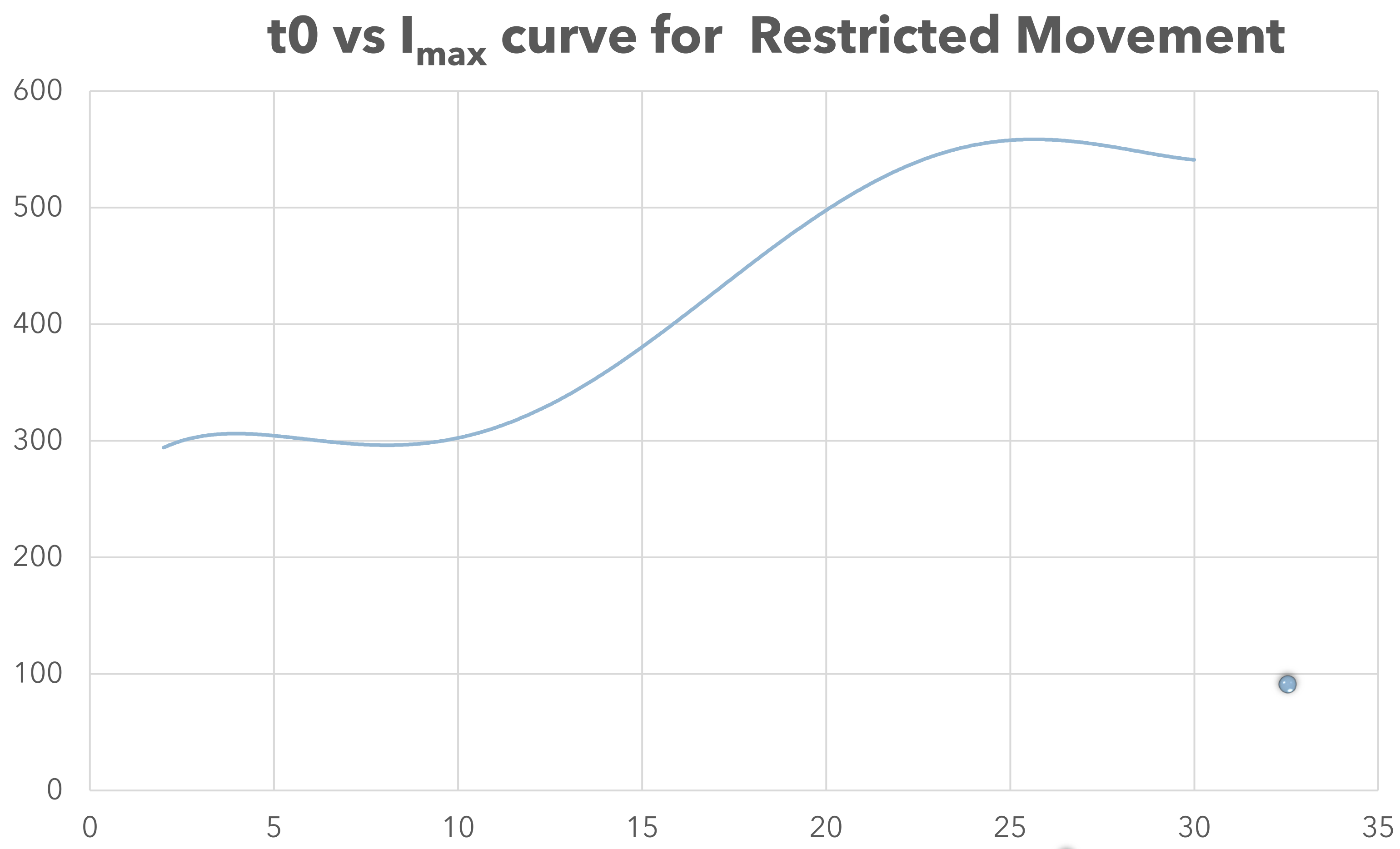


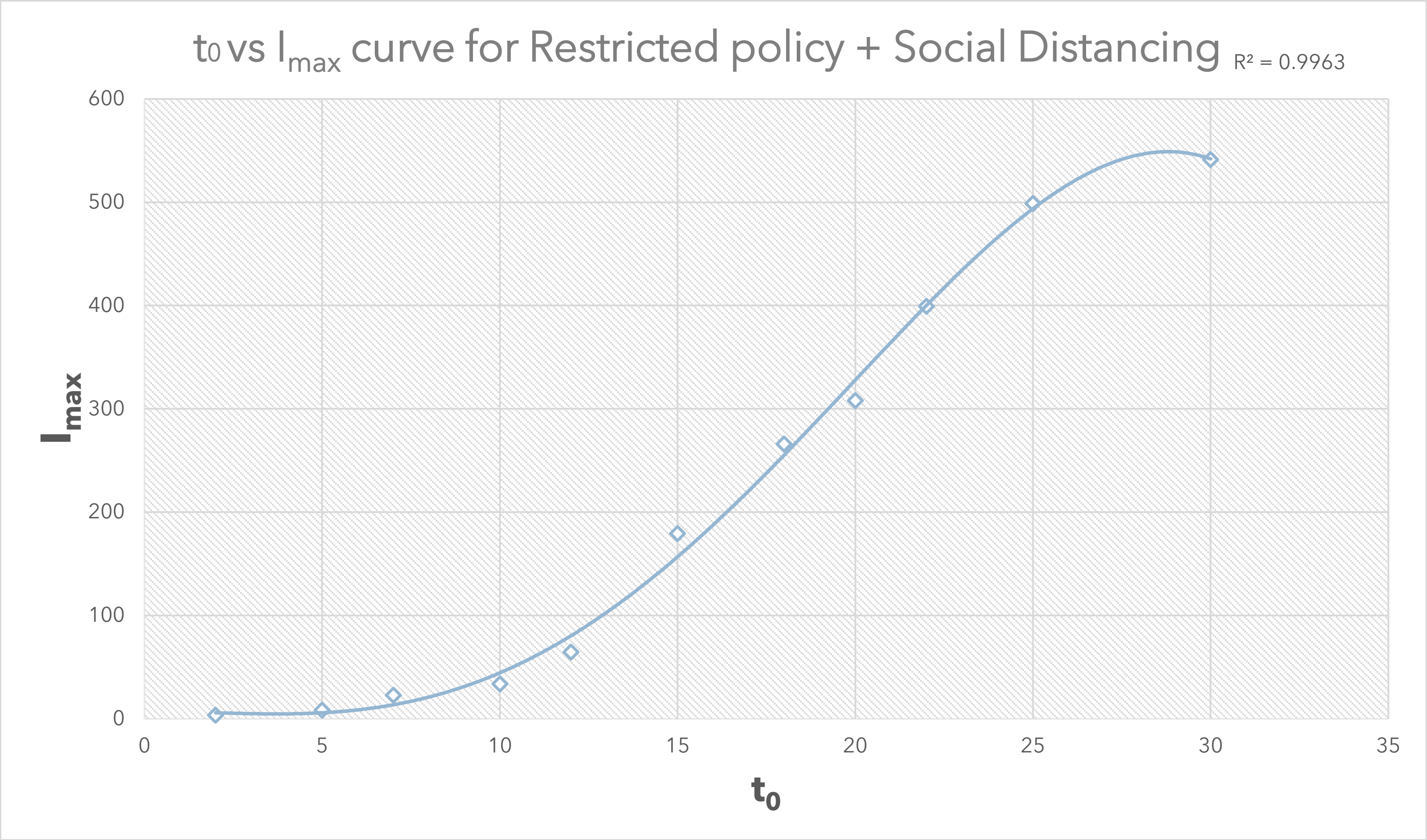
Movement Policy 3: Restricted (More relaxed)

Restricted : Probabilities : 'home': 0.75, 'work': 0.05, 'market': 0.1, 'transit': 0.1

No Matter what Lockdown restriction (strict or lax) you follow if the lockdown is instigated late then it's bad news.

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for Imax, more pressure is applied on the healthcare system



Restricted : Probabilities : 'home': 0.75, 'work': 0.05, 'market': 0.1, 'transit': 0.1

Simulating Social Distancing by decreasing Proximity Radius

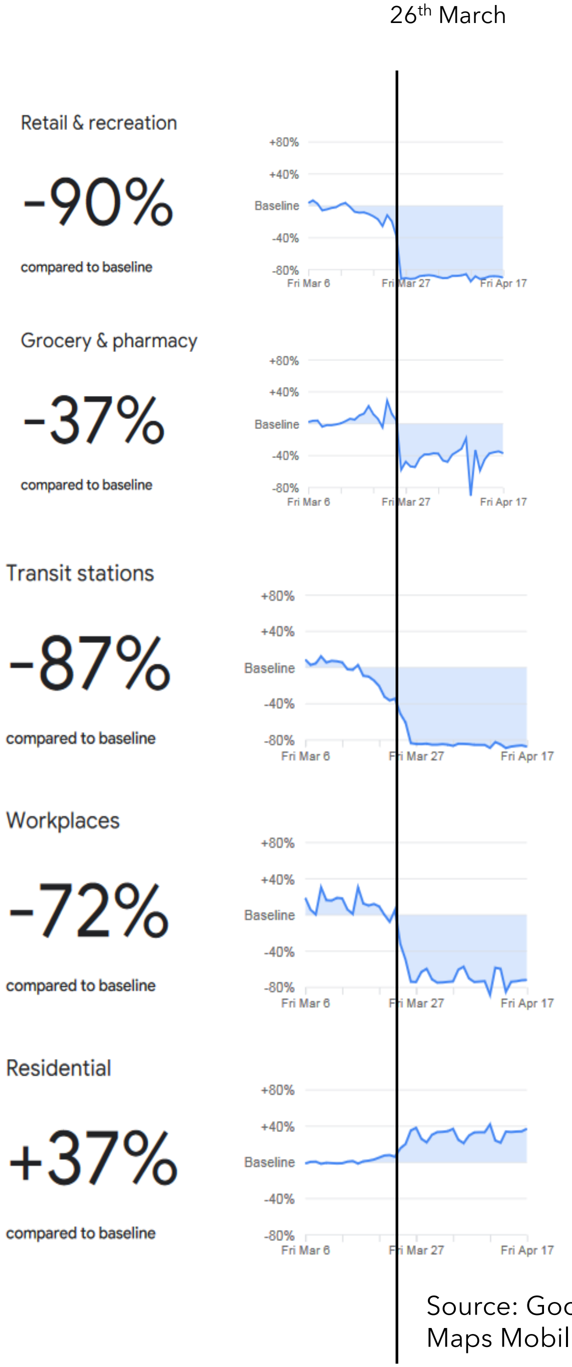
A City with good hygiene habit and who is following Social Distancing well, does not need very strict lockdown as can be seen from this simulation.

Studying Types of Lockdown Measures

- We define Different kinds levels of lockdown
- And look at their effects on Healthcare pressure
- Higher the peak for Imax, more pressure is applied on the healthcare system

Alert Level	Risk Assessment
Level 4 – Lockdown Likely the disease is not contained	• Community transmission is occurring. • Widespread outbreaks and new clusters.
Level 3 – Restrict High risk the disease is not contained	• Community transmission might be happening. • New clusters may emerge but can be controlled through testing and contact tracing.
Level 2 – Reduce The disease is contained, but the risk of community transmission remains	• Household transmission could be occurring. • Single or isolated cluster outbreaks.
Level 1 – Prepare The disease is contained in New Zealand	• COVID-19 is uncontrolled overseas. • Isolated household transmission could be occurring in New Zealand.

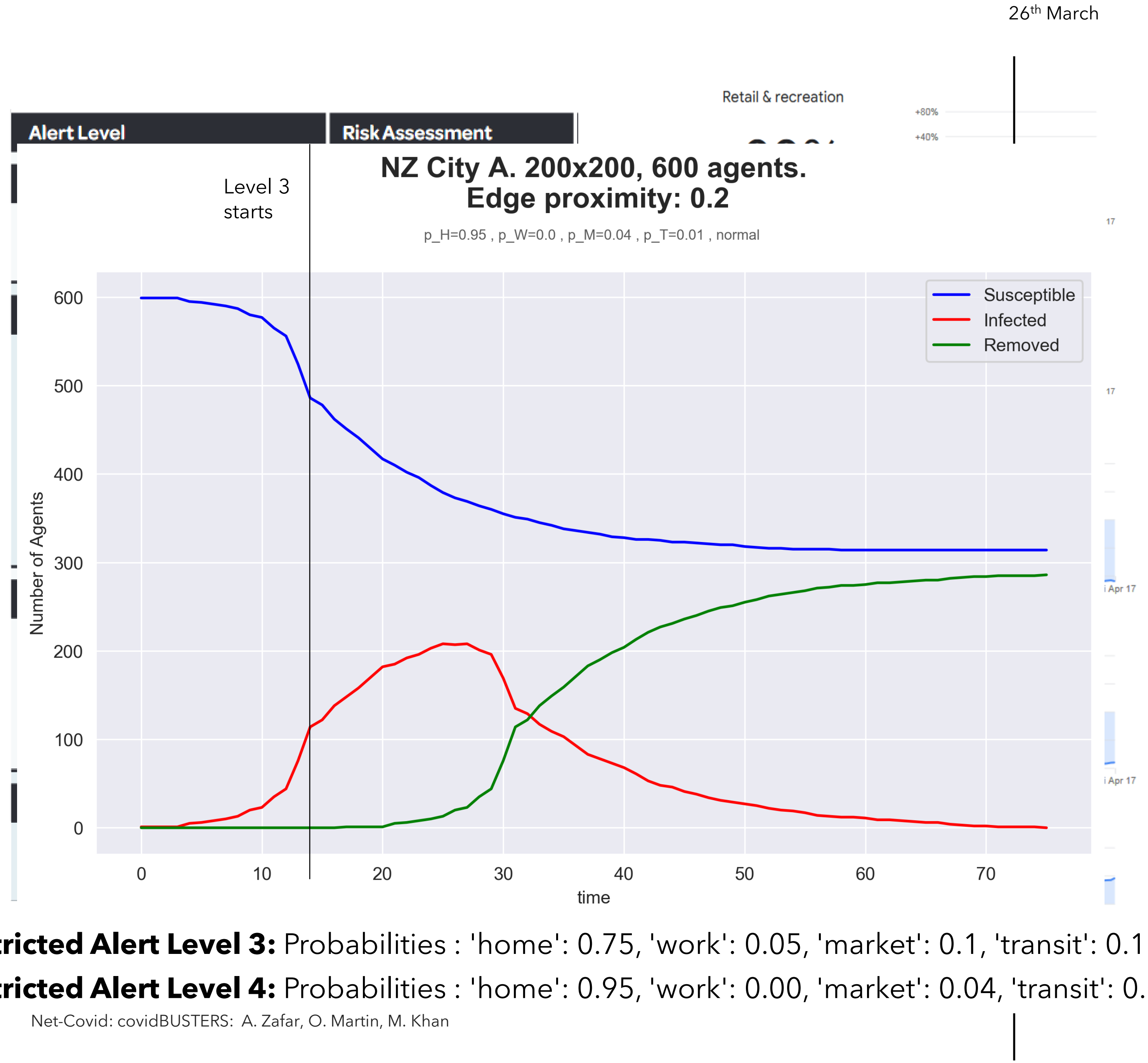
Source: https://covid19.govt.nz/alert-system/covid-19-alert-system



Source: Google Maps Mobility

Case Study New Zealand

- Prime Minister of New Zealand Ardern said there was no widespread community transmission now in New Zealand and "we have won that battle".
- They used a 4 level Alert system
- Effective from 26th March Alert level 3
- And from 28th Level 4



Restricted Alert Level 3: Probabilities : 'home': 0.75, 'work': 0.05, 'market': 0.1, 'transit': 0.1

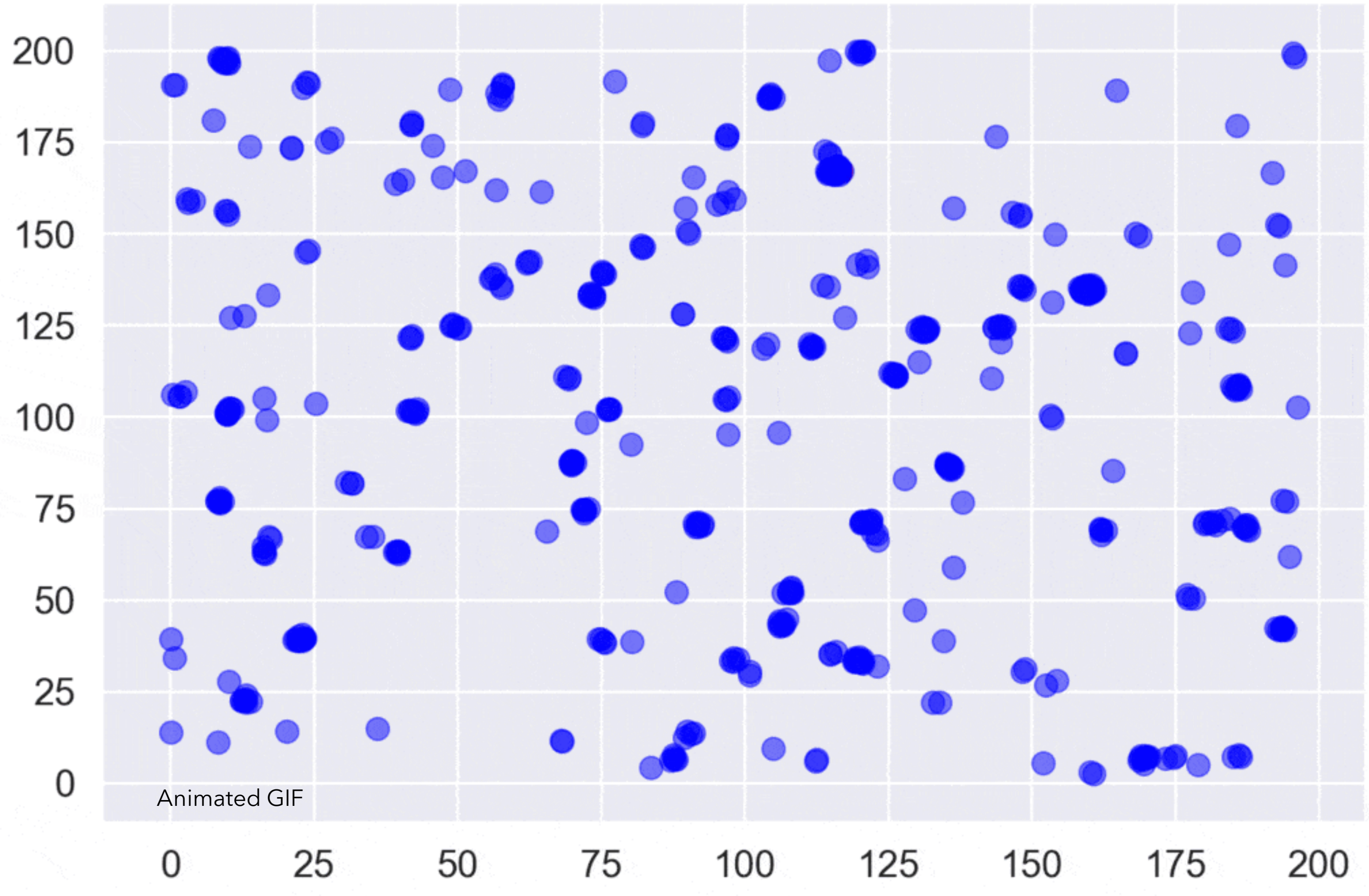
Restricted Alert Level 4: Probabilities : 'home': 0.95, 'work': 0.00, 'market': 0.04, 'transit': 0.01

Case Study New Zealand

- They used a 4 level Alert system
- Effective from 26th March Alert level 3
- And from 28th Level 4
- We select movement policy using the mobility data provided by google to consider the change in the probabilities.
- Multi Level lockdown system is more effective in our model as well.
- Even after running the simulation multiple times we find a considerable amount of susceptible population remains susceptible.
- Peak arrives in ~10 days as seen in the data as well.

QUARANTINING INFECTED TO QUARANTINE CENTERS

We define Quarantine Center for the city that's outside the city



$$Q.rate = \frac{Positive\ detected\ (reprorted)\ cases}{Total\ infected}$$

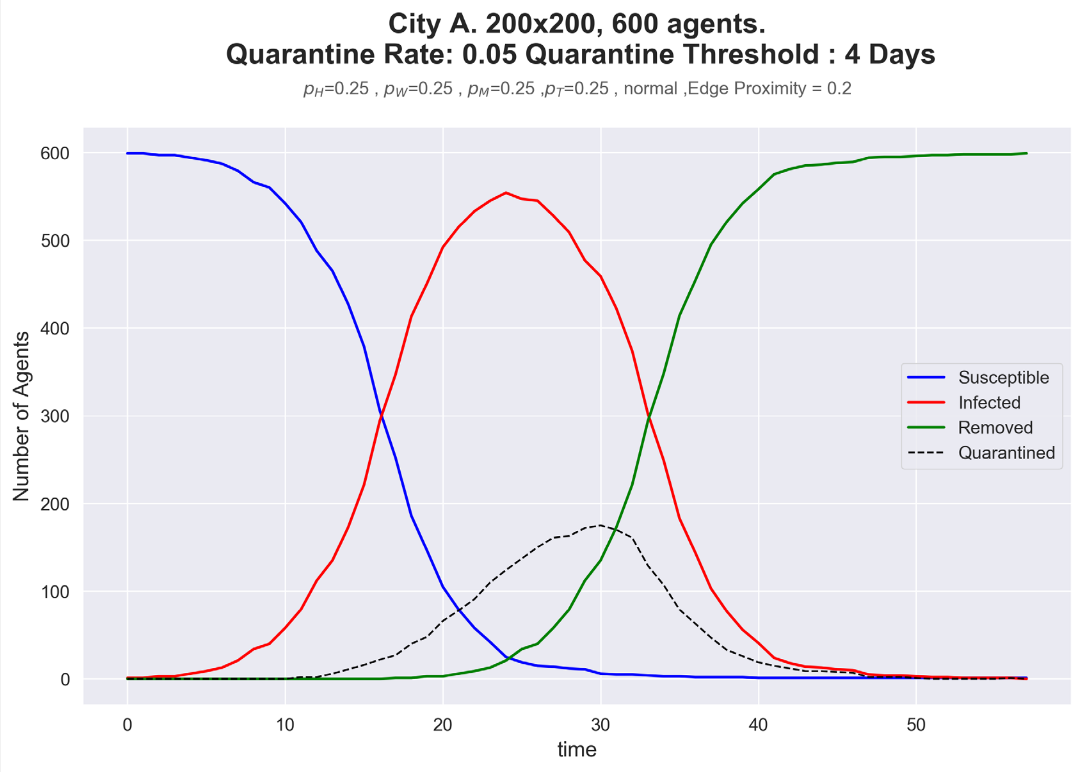
Quarantine

- We make a quarantine center outside the city so that we can send the infected patients that are reported to the centers.
- We define a quarantine threshold as the number of days an infected individual is reported
- Also define a quarantine Rate that is the ratio of infected individuals that are reported and thus send to quarantine.

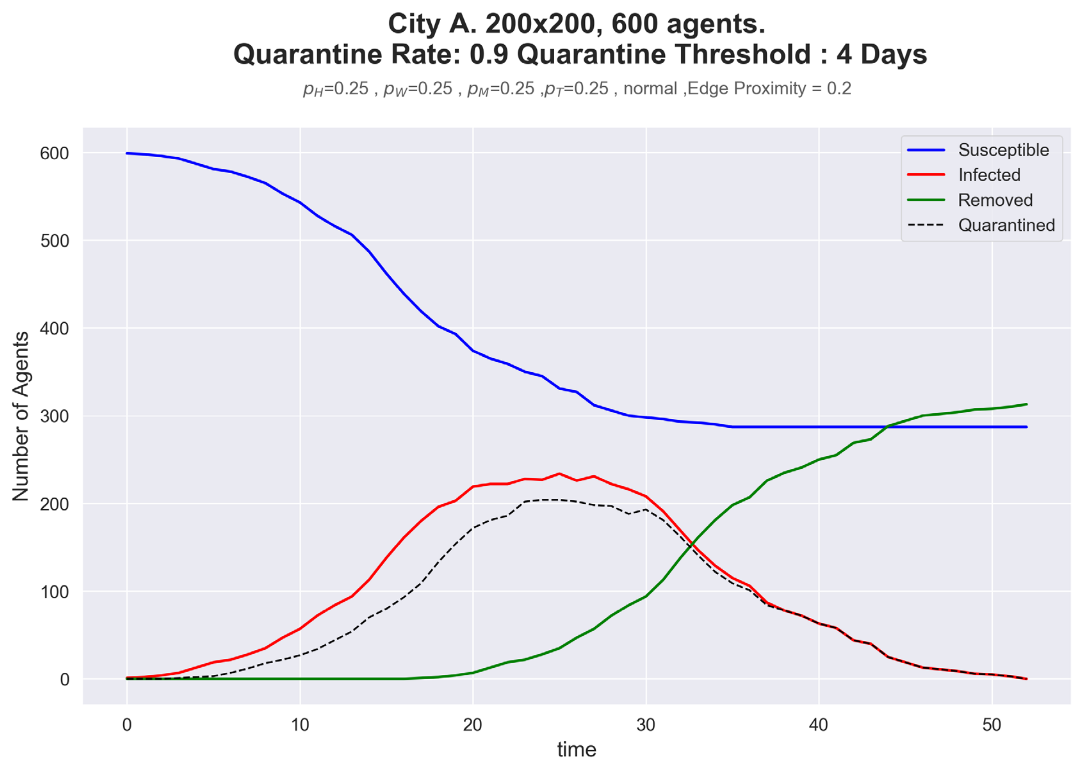
Simulations (Gif) are at : https://atiyabzafar.github.io => Click

In the following two cases we see different rates of quarantine happening. We have even movement policy, so there is no lockdown in place.
When the Q. *Rate is low (left)* most cases are not detected positive and thus the *infection spreads over all city*.
When the Q. *Rate is large* most of the infected population is quarantined after 4 days (Q. Threshold), the peak is shallower and *half of population is left Susceptible*.

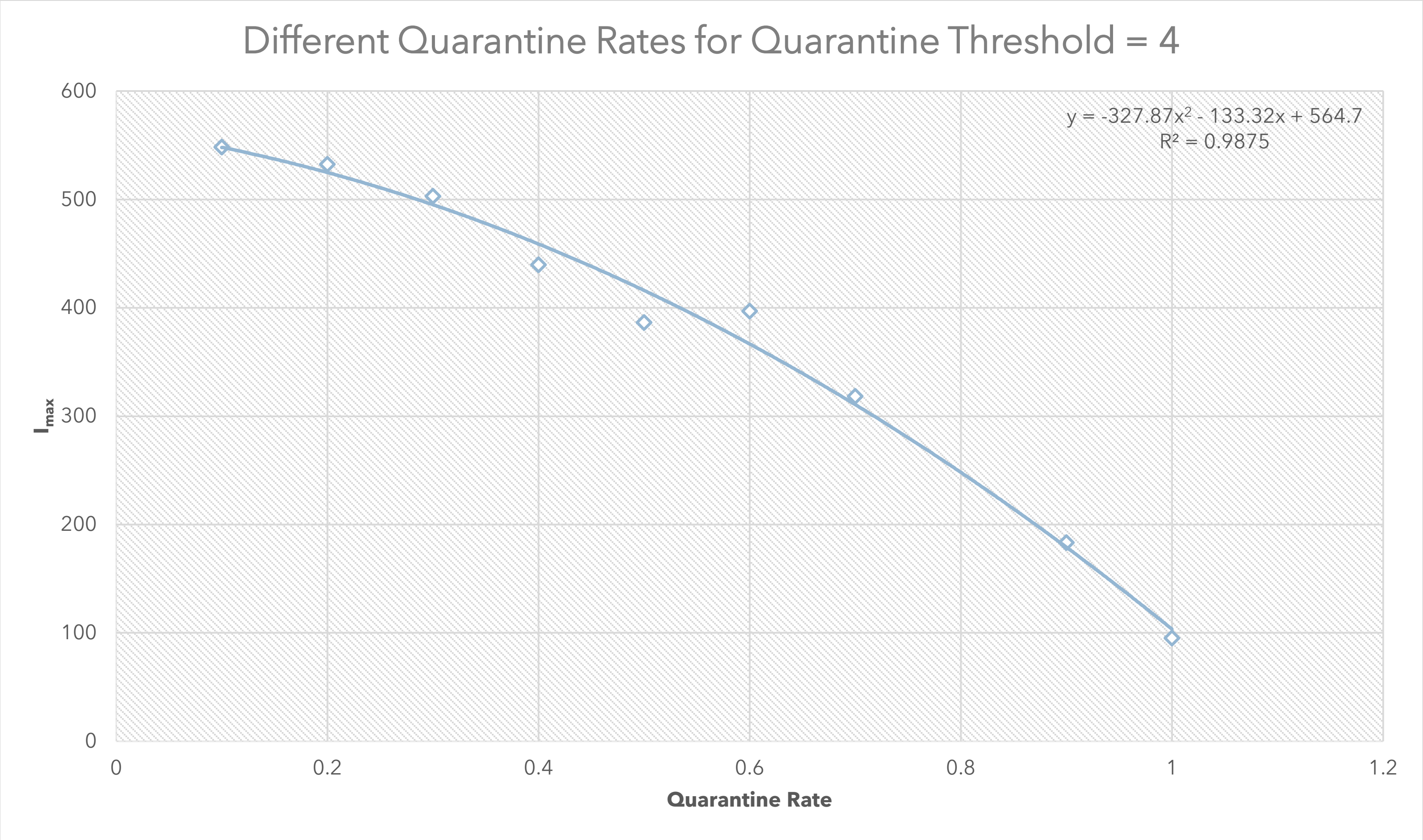
Q. Rate = 0.05



Q. Rate = 0.9



Note: Quarantining everyone quickly would lead to a very broad peak, but it leads to problem of herd immunity. If a significant part of population is left unexposed it might not lead to immunity at large scale and we then must think of better ways of achieving the same.



Because of the way we have defined our Quarantine Rate, if a test kit is not working optimally. (As we have seen in real life)[1] . The Q. Rate would go down and more infected people will be allowed to move around and infect.
The drastic effect of "*false negatives*" comes into picture when we look at our model and real data[1].

1. https://www.healthline.com/health-news/false-negatives-covid19-tests-symptoms-assume-you-have-illness

The peak decreases as higher ratio is quarantined

- As my quarantine rate increases the peak infected population goes down which shows the more people we quarantine the better we can control the spread of covid19.
- As WHO general director remarked on March 16th: *"Test, Test, Test"*
- This graph shows the importance of testing. The more tests we do, the more positive cases we can quarantine and the better we can control the epidemic in our model.
- Testing and isolation works wonders.

Future Plans

- Figure out a way to optimize choices of which market to stay open. Location study from the apartments/housings to make sure infection is minimized
- Incorporate inter-city migration with the city lockdown rules and preferential movement.
- ~~Physical Isolation/Quarantine of Infected Population and their effect.~~
- ~~Exploring more effects of social distancing as we have defined social distancing parameter already.~~
- Incorporate heterogeneous families in the cities.