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Modelling the UK Governments Response to COVID-19

1. Introduction

As of March 2020 the world is responding to the global crisis that is COVID-19, an infectious disease caused by the virus SARS-CoV-2. [1] The disease, first identified in December 2019, has gone on to infect at least over a million people as of the 3rd April - the true value is likely much higher as countries are mainly testing those that have severe symptoms. [2] The disease can cause a variety of symptoms but most common are a fever, cough and shortness of breath. [1] This global pandemic will be recorded as one of the deadliest viruses in recent human history.

My project involves attempting to simulate the effects of this pandemic on the United Kingdom. It is be based on the well known SIR model with additional augmentations. The augmentations developed build on real world knowledge, more info on this is available in the description of methods. The model will be programmed with the ability to easily change the parameters of the model in order to simulate the response that each parameter has on the overall state of the population. The main benefit to making these simulations is to inform policy makers on the impact of potential interventions. Simulations can show the impact to the number of infected, the peak of that infection and deaths. Theses will be key in making sure hospitals are not overrun.

1.1 Related Work

'A contribution to the mathematical theory of epidemics' [3]

This is the first paper in which the first compartmental model was formalised in 1927. They were the first to use these models in order to predict the number of infected and duration of the epidemic.

'Statistics based predictions of coronavirus 2019-nCoV spreading in mainland China' [4]

This paper uses an analytical version of the SIR model in order to predict the future infections. The work I produce will be different because I will use a graph using real data instead of a mathematical formulae. Additionally I am not predicting the future state but seeing the impact of measures to slow coronavirus spreading.

2. Description of Methods

In this section I will discuss the changes I will make over the standard SIR model, to improve the simulation for the current situation we are seeing with COVID-19.

2.1 Augmentations

There are several possible augmentations I have made to the model in order to better simulate the pandemic in the UK. They are listed below:

2.1.1 Recovery - Death

The SIR model does not include deaths in its modelling. This is perhaps the most important output we are interested in. I will add a separate state in which a person who is infected can move to either a recovered or deceased state.

2.1.2 Isolation

The United Kingdom government announced on the 13th March that anyone who was experiencing symptoms of the virus should stay home for at least seven days. [5] I will implement this in my model by allowing someone in an infected state that is showing symptoms to move to a quarantined state.

2.1.3 Asymptomatic

Whilst data on the number of asymptomatic carries is still unclear, they do exist. The CDC estimates them to be around 25% of the total amount of the infected. Additionally they have said it is still possible to spread the virus even if someone is asymptomatic. [6]

The asymptomatic augmentation is to model these people that will have the virus but will not go into self-isolation because of a lack of information. One idea to reduce this is to increase testing for those most likely to contract the virus.

2.1.4 Lockdown

The Prime Minister announced on the 24th March that the country will go into lockdown. The rules that were introduced are outlined below.

"People may only leave home to exercise once a day, travel to and from work when it is 'absolutely necessary', shop for essential items and fulfil any medical or care needs. Shops selling non-essential goods have been told to shut and gatherings in public of more than two people who do not live together will be prohibited."[7]

In my model I have simulated this by adding the ability to reduce the infection rate for a specified period of time.

2.1.5 Graph Based

Traditionally the SIR model is done either analytically or by using the number of people currently in a state to decide on the rate of change. The model I have developed uses a graph in order to simulate the different relationships people have within a community. The graph data I am using is from SNAP, the Stanford Network Analysis Project. [8] This is a general purpose network analysis and graph mining library. The dataset I have chosen to use is connections between Facebook users of around 4000 people, with almost 90000 connections between them.

2.2 The Algorithm

In my modified simulation there are 6 states:

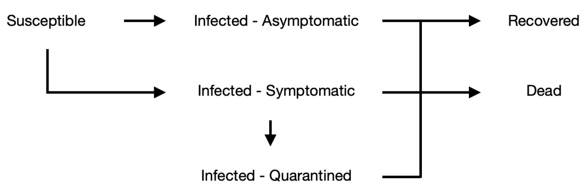
1. Susceptible
2. Infected - Symptomatic
3. Infected - Asymptomatic
4. Infected - Quarantined
5. Recovered
6. Dead

To start the model a certain number of people are picked at random and put into an infected state. The algorithm then starts a loop where every iteration is a time step in days.

Within this time step the following happens, those in state 1 have the chance to become infected. This is decided by counting incoming edges that are from infected members of the population however excluding those that are in quarantine. Once the number of edges is found, random numbers and the rate of infection decides whether an individual becomes infected, thereby moving out of state 1. The next decision is whether the person will show symptoms or not. This is chosen using the symptom rate. Therefore a person can move from state 1 to either state 2 or 3.

To model people self isolating individuals in state 2, have a chance to move to a quarantined state where no further infection originating from them is possible. The decision is based on the quarantine rate.

All individuals that are infected have a probability to move to the remaining two states, recovered or dead. The chance of moving to those states is based on the recovery rate and death rate.



3. Discussion about Experiments

In the following sections I will discuss the results from the experiments performed with the model using different parameters. The most important aspects of these simulations I will focus on are the number of total infected, the peak infected, that is the percentage of the population that are infected at one time, a large number here would put extraordinary pressure on the health services and cause deaths to increase further than needed.

3.1 SIR Model

The first model is a baseline with no additional measures. This will allow us to compare potential interventions. The results of this simulation showed that over 92% of people were infected with only 7.7% remaining virus free. The initial peak was very high at around 46%. Deaths were also high at 0.97%.

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Final values:

Remaining Susceptible: 7.77%
Total Infected: 92.23%
Peak Infected: 46.47%
Total Deaths: 0.97%
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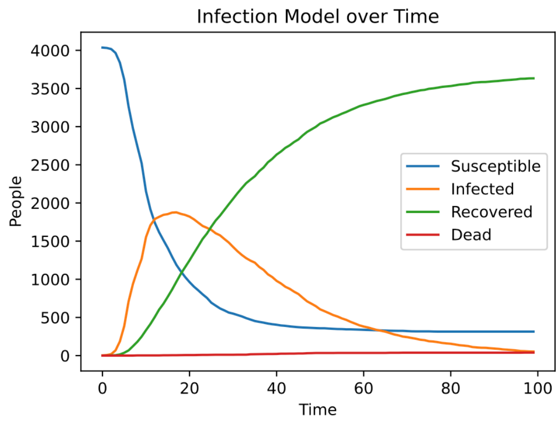

3.2 Social Distancing

Social distancing is reducing you physical contact from other people. To simulate this I simply reduced the rate of infection from 0.02 to 0.01. These simple measures significantly improved the outcome of this pandemic. Only 70% of people were infected, and there was a peak infection rate of 32%, deaths were also lowered to 0.79%. This reduction is not enough to stop the overburdening of the health system however it is a significant step in the right direction.

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Final values:

Remaining Susceptible: 29.88%
Total Infected: 70.12%
Peak Infected: 31.94%
Total Deaths: 0.79%
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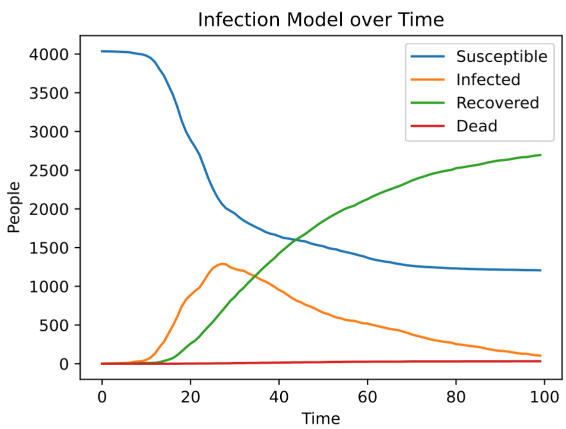

3.3 Self Isolation

To simulate this I set the quarantine rate to 0.3. The reason this is not 1 is because even before having symptoms the virus can still be spread. Additionally not everyone will conform to the quarantine. The result this had on the virus was significant. There was a large reduction in the total infected at only 47% however the initial peak was quite similar at 31%. Total deaths were significantly reduced at 0.37%. This measure is successful in reducing the number of infected however the peak is still high and unsustainable.

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Final values:

Remaining Susceptible: 52.93%
Total Infected: 47.07%
Peak Infected: 31.12%
Total Deaths: 0.37%
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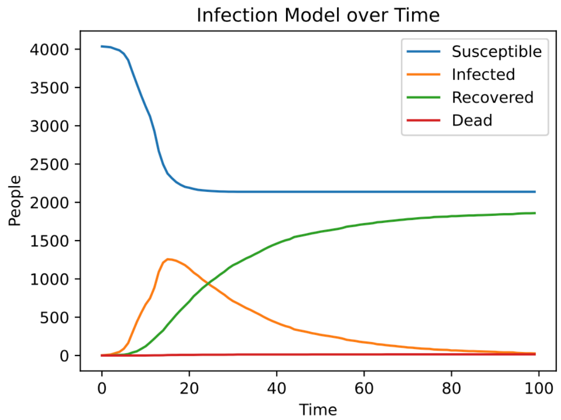

3.4 Testing

This simulation uses the value of rS which has been reduced to 0.75, meaning 25% of the population are asymptomatic. This had the effect of reducing the effect quarantining has on the population as a whole. The total infected was 67% whilst peak moderately increase to 36%. Deaths were at 0.64%. What this shows is the need for testing. The more of these asymptomatic cases that can be found the better the outcome will be.

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Final values:

Remaining Susceptible: 32.51%
Total Infected: 67.49%
Peak Infected: 35.55%
Total Deaths: 0.64%
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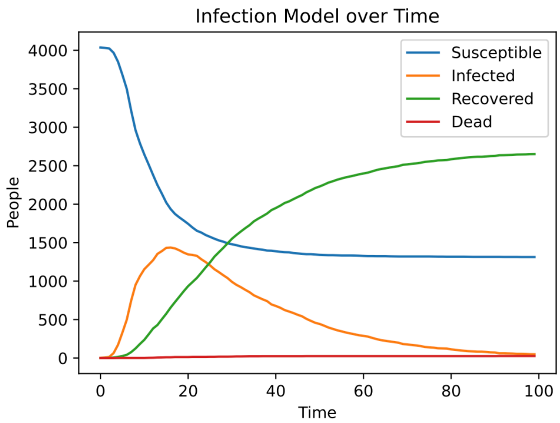

3.5 Lockdown

In order to simulate lockdown I first set the parameters to initiate a lockdown 7 days into the simulation and end 30 days into the simulation. The reduce infection rate, rI, was set to 0.005. The results from this were quite poor, in total 85% of people were infected however the peak was reduced to a lower value of 30%, the best so far. Deaths were only slightly below the baseline value at 0.89%. Looking at the graph shows the cause of this, whilst the number of infections slows after introducing the lockdown after the 30th day there is a significant rise as another peak forms.

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Final values:

Remaining Susceptible: 14.71%
Total Infected: 85.29%
Peak Infected: 30.35%
Total Deaths: 0.89%
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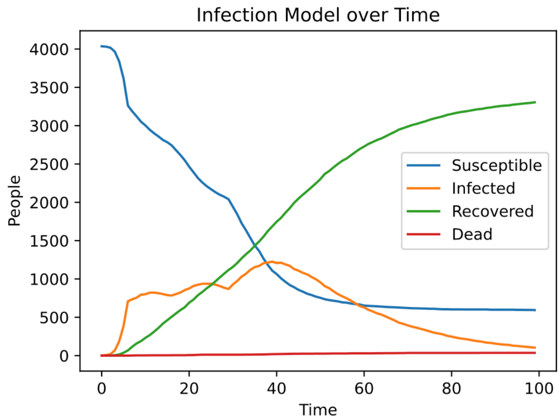

To counter this I attempted to increase the duration of the lockdown, instead of ending on the 30th day I set the parameter to the 60th day. The results showed that total infected was still high at 79%, peak infected was significantly lower than all other experiments at only 23%. Although the percentage of deaths still remained high at 0.82%. The graph showed there was a sustained level of people in the infected state that was very slowly decreasing. These experiments show that whilst lockdown is not effective in reducing the number of people that will eventually contract the virus it does very well in slowing down the infection rate and therefore keeping hospitals from becoming overburdened.

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Final values:

Remaining Susceptible: 20.92%
Total Infected: 79.08%
Peak Infected: 23.22%
Total Deaths: 0.82%
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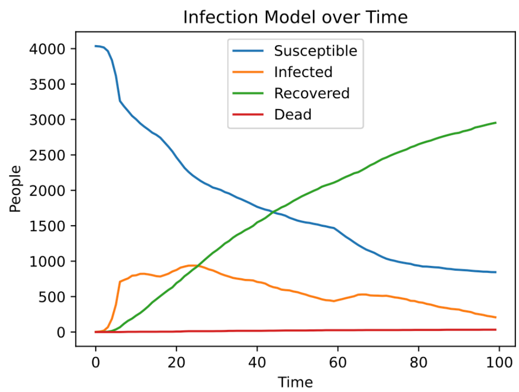

3.6 Combination

The final experiment I performed was based on a combination of all aforementioned measures. This was by far the most effective solution. The total infected remained very low at 33%, peak infected was at a maximum of 10% and total deaths were at 0.25%. Looking at the graph shows that the number of infections stayed fairly constant apart from after day 105 were there was a small spike. The benefit of the relatively flat infection line is that services will not be surprised by a sudden uptick in infections.

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Final values:

Remaining Susceptible: 67.15%
Total Infected: 32.85%
Peak Infected: 9.98%
Total Deaths: 0.25%
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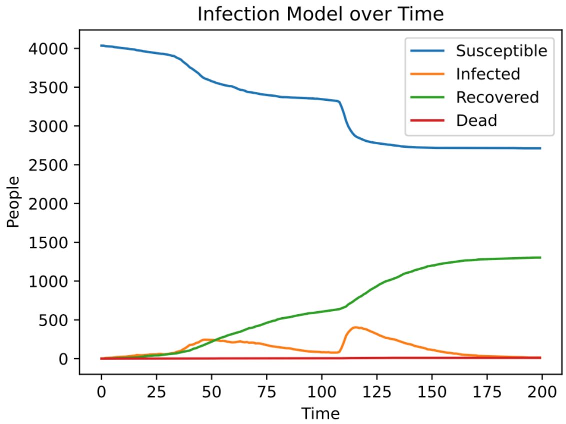

4. Conclusion

This project has shown the effects of various precautionary measures the government has taken over the course of this pandemic. Whilst the values of these results should not be closely monitored because the starting parameters have only been chosen with limited knowledge and many differing variables. The effect that these measures may have is useful to see in order to measure how effective the rules will be in order to combat the pandemic.

There are several conclusions that can be made from the results. In order to reduce the number of deaths the most effective route is to encourage self-isolation, though this alone will not reduce the peak of infections enough. The effect of the self-isolation can be improved by greater testing in order to catch those who may be asymptomatic. Finally to lower the peak a lockdown is a good method, however it will need to be implemented for some time otherwise a delayed peak may occur. The government will need to use all these measures as they all have a somewhat positive effect.

If I were to suggest improvements I would increase the size of the data used. In this case I was not able to find a bigger sample size but in doing so it would better represent the UK population as a whole. I could then try and model the deaths numbers that the UK is seeing now, which would be impossible currently because the population size is too small to properly represent it.

References

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[6] "CDC Director On Models For The Months To Come: 'This Virus Is Going To Be With Us'", *Npr*, 2020. [Online]. Available: https://www.npr.org/sections/health-shots/2020/03/31/824155179/cdc-director-on-models-for-the-months-to-come-this-virus-is-going-to-be-with-us. [Accessed: 20- Apr- 2020].

[7] "Strict new curbs on life in UK announced by PM", *BBC News*, 2020. [Online]. Available: https://www.bbc.co.uk/news/uk-52012432. [Accessed: 20- Apr- 2020].

[8] "SNAP: Network datasets: Social circles", *SNAP*, 2020. [Online]. Available: https://snap.stanford.edu/data/ego-Facebook.html. [Accessed: 20- Apr- 2020].