Infectious Disease Project

Jambaldorj Ochirpurev, Andrew Rippy

Introduction

In this project, we will study the COVID-19 and model the baseline predictions along with 4 different scenarios. The goal of our project is to find the most effective intervention and to analyze different interventions.

Model

We are creating a model where we are assuming:

- A relatively small, well-mixed population of people
- Interactions are at a consistent rate
- We have both asymptomatic and symptomatic populations, that both spread the disease

Our Mathematical model is given by:

S = Susceptible (general population)	$\frac{dS}{dt} = -\beta_a S(I_a + L)/n - \beta_s S I_s/n$
H = Health care workers	$\frac{dH}{dt} = -\beta_a H(I_a + L)/n - \beta_h H I_s/n$
L = Latent population	$\frac{dL}{dt} = \beta_a (S + H)(I_a + L)/n + \beta_s S I_s/n + \beta_a H I_s/n - \lambda L$
I_a = Infected, asymptomatic	$\frac{dI_a}{dt} = (1 - p)\lambda L - \gamma_a I_a$
I_s = Infected, symptomatic	$\frac{dI_s}{dt} = p\lambda L - \gamma_s I_s - \mu I_s$
R = Recovered	$\frac{dR}{dt} = \gamma_s I_s + \gamma_a I_a$

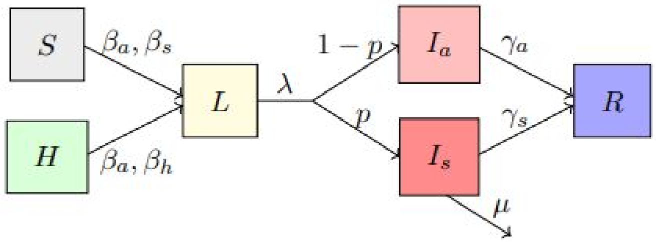


Figure 1: A visual representation of our disease model

Initial Conditions

Given the model above, we will be using the initial conditions below for our baseline model, for a total population of 1000.

$$S = 940,\ H = 50,\ L = 0,\ I_a = 10,\ I_s = 0,\ R = 0$$

And for our coefficients, for our baseline model for COVID-19, we will be using:

Coefficient value	description
$\lambda = 1/8 \text{ day}^{-1}$	8 day mean latency period between exposure and disease onset
$\gamma_a = 1/14 \text{ day}^{-1}$	14 day mean recovery period, asymptomatic cases
$\gamma_a = 1/35 \text{ day}^{-2}$	35 day mean recovery period, symptomatic cases
$p = 0.5$	Fraction of cases that are symptomatic
$\beta_a = 0.2 \text{ day}^{-1}$	Contact rate between S and $I_a + L$ and H and $I_a + L$
$\beta_s = 0.1 \text{ day}^{-1}$	Contact rate between S and I_s
$\beta_h = 0.5 \text{ day}^{-1}$	Contact rate between H and I_s

We are assuming the total daily death rate will depend on the resources available, ie, if there are many infected symptomatic people being treated, there are little resources available. Thus we have the piece wise function for the daily death rate:

$$\mu = \begin{cases} 0.001 & I_s \leq 50 \\ 0.002 & 50 \leq I_s \leq 100 \\ 0.004 & 100 \leq I_s \end{cases}$$

This represents a 0.1 % - 0.4 % chance of death each day, depending on how many infected people need help.

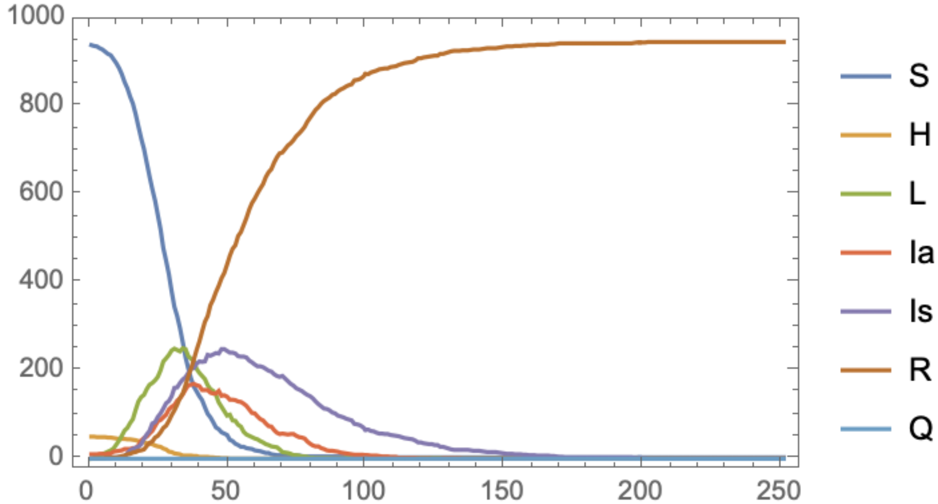


Figure 2: Baseline Model

Different Scenarios

Scenario 1: Varying Contact Rate

- The contact rate will be not constant and will be defined by the Piece-wise Function.
- For the first few weeks, contact rate will be 1; then the contact rate will be gradually decreased for the next 5 weeks. After that, the contact rate will increase and will reach 1 again.

Scenario 2: Strict Social Distancing

- The contact rate value will be 0.3 in this scenario

Scenario 3: Quarantining

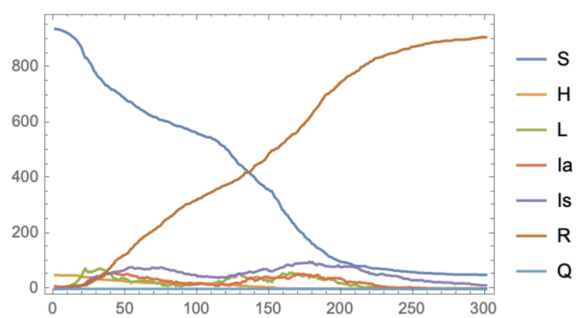
- Test people every day and quarantine every symptomatic people, and people in the quarantine cannot spread the virus

Scenario 4: Mass Testings

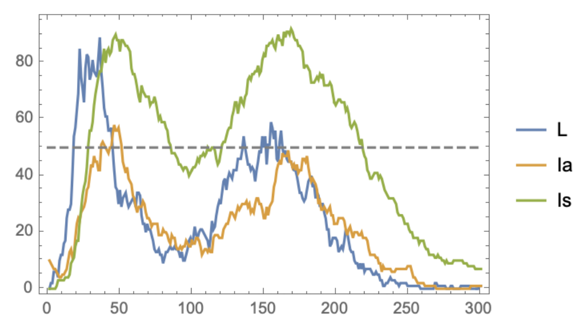
- Test every person every day, and detects asymptomatic people with 95% probability
- If a person is asymptomatic and is tested positive, they will spread the virus like the symptomatic people

Result

The result of the first scenario can be seen from the Figure 3.



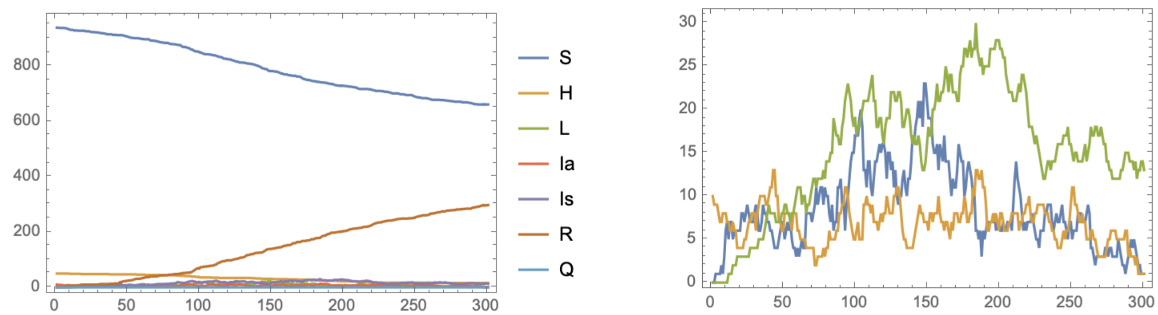
(a) Varying Contact Rate.



(b) Varying Contact Rate.

Figure 3: Varying Contact Rate Scenario.

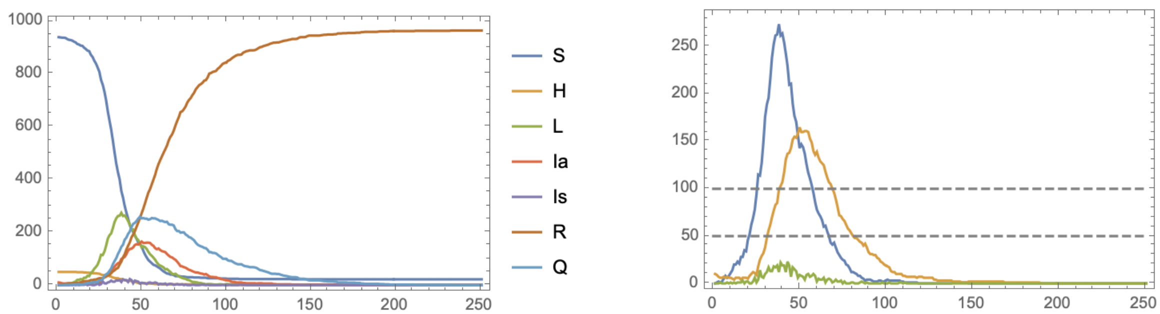
The result of Scenario 2 can be seen from the Figure 4.



(a) Social Distancing. (b) Social Distancing.

Figure 4: Social Distancing.

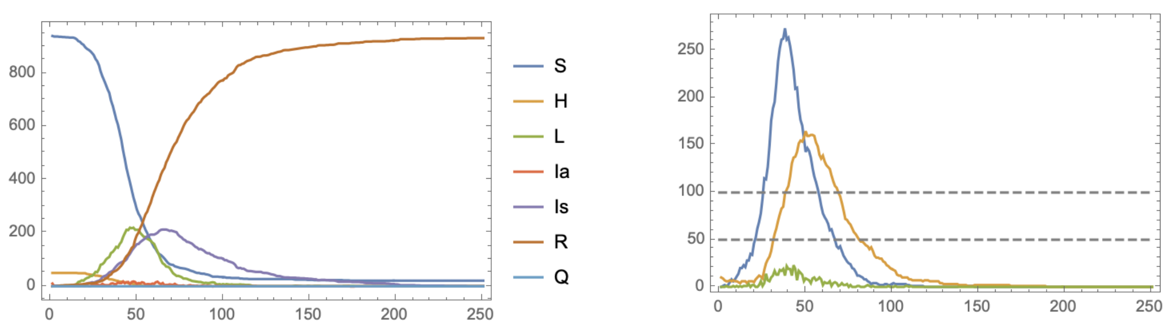
The result of Scenario 3 can be seen from the Figure 5.



(a) Quarantining. (b) Quarantining.

Figure 5: Quarantining.

The result of Scenario 4 can be seen form the Figure 6.



(a) Mass Testing. (b) Mass Testing.

Figure 6: Mass Testing.

The figure 7 shows the the number of fatality vs. contact rates when the contact rate goes from 0 to 1.

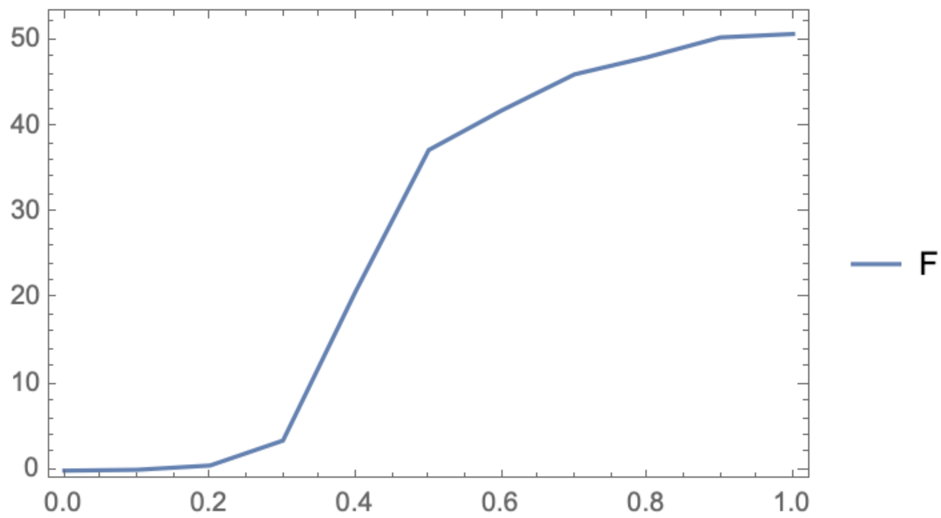


Figure 7: The number of fatalities vs contact rate

The Table 1. shows the number of fatalities and total number of COVID-19 cases for the all the scenarios.

	The number of fatalities	Total # of COVID-19 cases
Baseline Predictions:	51.5	991.75
Scenario 1: Varying Contact Rate	29.61	925.15
Scenario 2: Social Distancing	7.5	451.9
Scenario 3: Quarantining	16.02	976.73
Scenario 4: Mass Testing	50.25	981.82

Table 1: The number of fatalities and the total number of cases

Analysis

Baseline

The baseline model gives us a scenario in which there is a quick spike in cases, nearly every susceptible person quickly gets infected, and then slowly the majority of people recover, and the disease dies out. Clearly, this is not the best case scenario, as the large spike in cases overwhelms the ability for hospitals to effectively take care of the infected, quadrupling the daily death rate, and resulting in 51 deaths, and everyone getting infected. So, *doing nothing is bad. We need to intervene..*

Scenario 1: Varying Contact Rate

Here, we slightly modify the baseline model to include a varying contact rate. What this equates to is social distancing, with 0 being strict no contact distancing, and 1 being no distancing at all. What happens here is a scenario that seems to be closely mimicking the United States. For the first few weeks, the virus spreads with complete contact from person to person (rate = 1), causing a spike in cases. People begin to see things on the news, and contact rate falls, but there is still a decent amount of contact between people (rate =0.5) for two weeks. The government then is slow to respond, but responds with strict social distancing guidelines, closing non-essential businesses, in house orders, etc, and the contact rate drops quite low, with only essential contact between people (rate = .2). This lasts for 55 days, at which point the curve seems to be flattening, and social distancing guidelines let up. People are hesitant at first (rate = 0.4) for the first 20 days, but then go back to semi-normal contact (rate = 0.7) for 40 days after, and then resume completely normal contact after this (rate = 1). The results are worrying. Perhaps the let up on social distancing may have been too soon, as a second spike in cases appears, the remaining sick people become infected, are treated, and the virus dies out. Ultimately, everyone still gets the virus, but the hospitals are not overwhelmed, so fewer people die (only 30), as opposed to the 51 in the baseline.

Scenario 2: Social Distancing

Here, we limit the contact rate to 0.3 the entire time. With moderately strict social distancing, only allowing for essential contact, (groceries, health care workers), it can be seen that the virus has a small peak, but quickly dies out since it cannot come into contact with many new hosts, and the infected either die or recover. This results in only 7 deaths, which is significantly fewer deaths than the aforementioned scenarios, and the total infected is *over half* the previous, with only 450 people in total getting infected.

Scenario 3: Quarantining

Here, every time somebody exhibits symptoms, they are moved to a strict quarantine, which has zero contact with the rest of the population. However, the caveat is here is *exhibits symptoms*. Asymptomatic people still keep the virus transmissible, and despite removing visibly sick people from the population, there is only a small impact on the speed of infection, and the height of the infection peak. Everyone ultimately gets the virus. However, due to the slightly lower peak, hospitals do not get overwhelmed as fast, and the deaths are much lower than the baseline(Only 16).

Scenario 4: Mass Testing

Here, we essentially remove the asymptomatic component, and we know the status of every person. This lowers the infectivity of the disease as people do not unknowingly transmit the disease to others. However, just knowing your status, without other guidelines, doesn't change much from the baseline. Deaths and total infected remain the same as the baseline. However, when paired with a quarantine, this could completely kill off the virus very quickly, as you can eliminate the asymptomatic carriers from transmitting.

Conclusion

In conclusion, based on the scenarios we have tested, the best possible course of action would be moderately strict to strict social distancing, with contact rates of .3 or lower, as seen in Figure 7. Across the board, it results in the least people infected, and the least people dead. However, as seen in scenario 1, if we do not adhere to the social distancing for long enough, the disease will flare up once again, and there will be a second wave, essentially making all the work of the initial social distance in vain. So, in conclusion, wait out the quarantine, don't jump the gun, or all of the past 8 weeks are in vain.