MIDDLE EAST TECHNICAL UNIVERSITY

A Stochastic Simulation of Coronavirus Spread

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1- Introduction

This project aims to create a computational framework for the outbreak conditions and prevention by simulation. In order to do that, four scenarios, each of them having discrete purposes, are going to be implemented. After these implementations, the project can shed light on preventing the spread of infection and develop some policies.

2- Assumptions

It is assumed that running the simulation a hundred times is enough to obtain statistical data accurately. Therefore, each scenario's simulation has been repeated a hundred times, and the data is gathered accordingly.

When the result of the multiplication of the vaccination rate and the number of healthy people equals not an integer value, it is assumed that the result will be rounded to the nearest smaller integer.

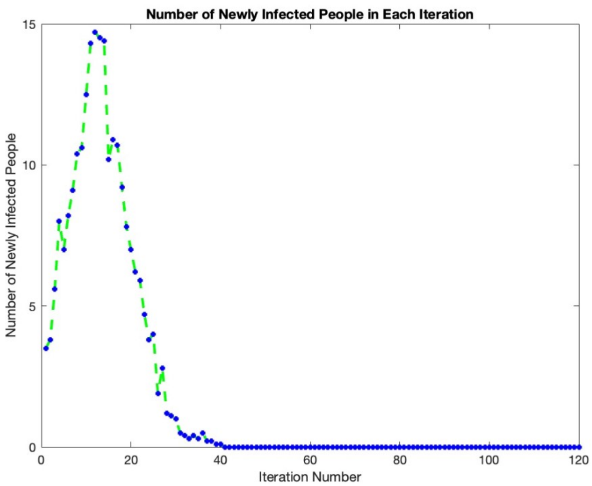
When the graphs are put in order of three, they correspond to Scenario II, Scenario III, and Scenario IV, respectively. In the same logic, when the graphs are put in a table of four, the order is,

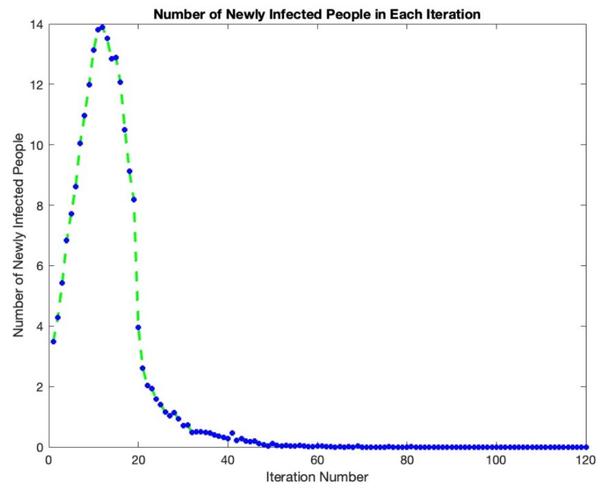
Scenario I	Scenario II
Scenario III	Scenario IV

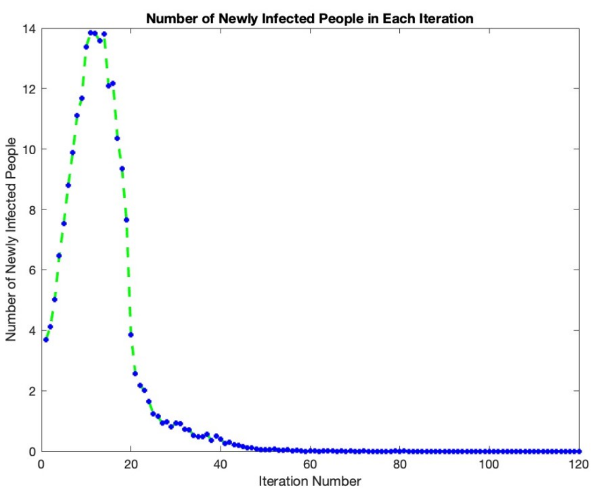
3- Reporting

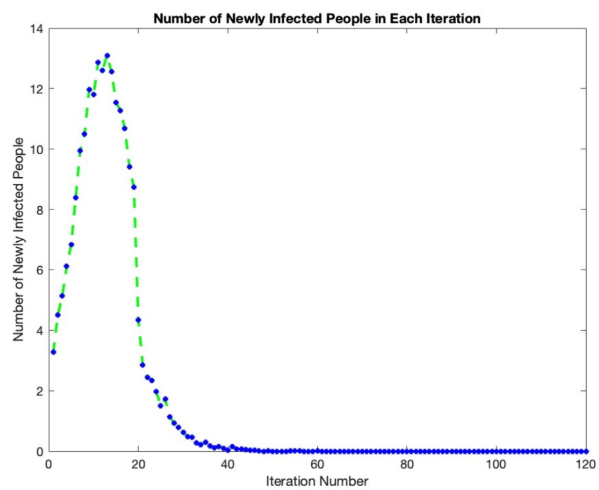
3.1 PART - 1

3.1.1 Number of Newly Infected People in Each Iteration



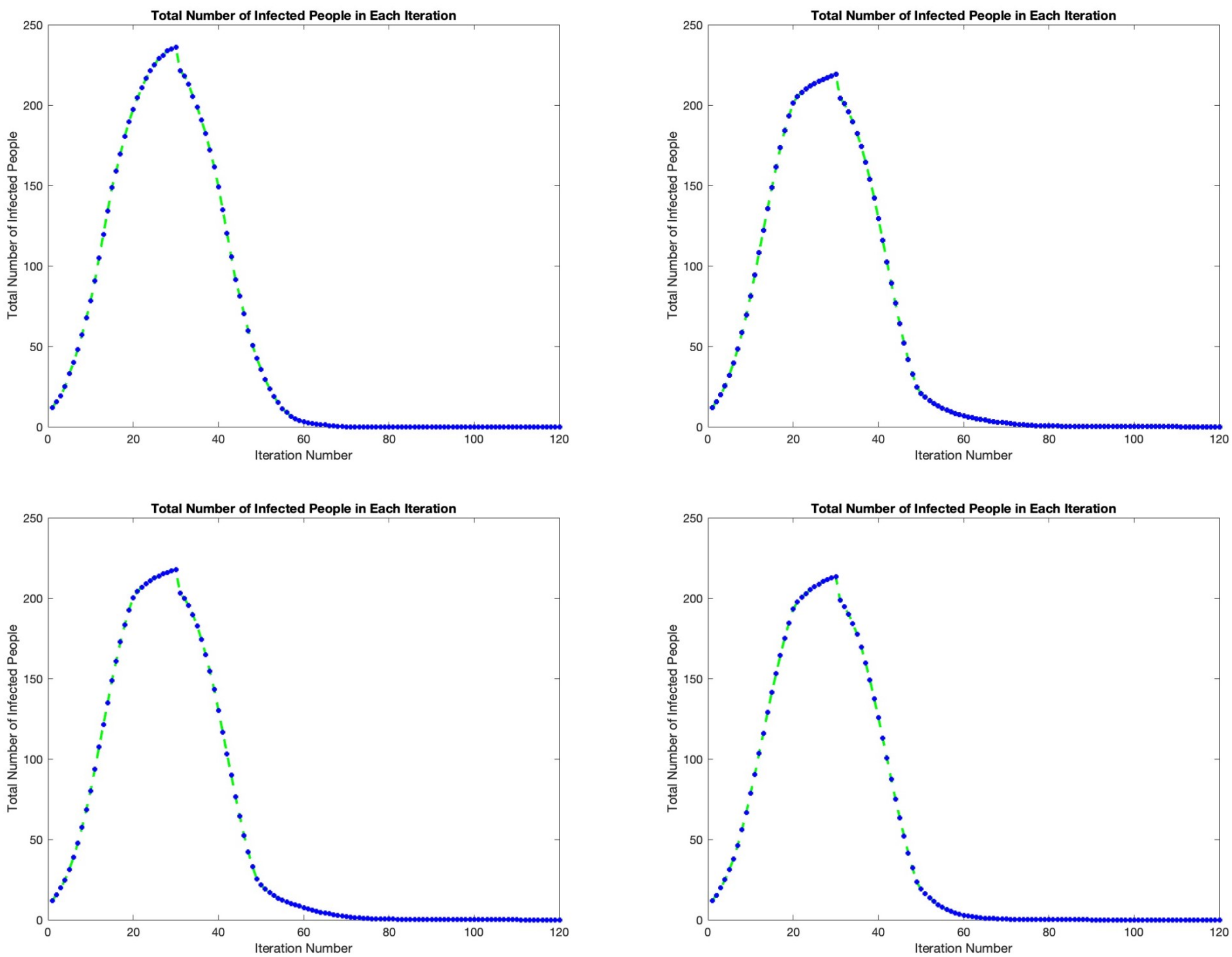






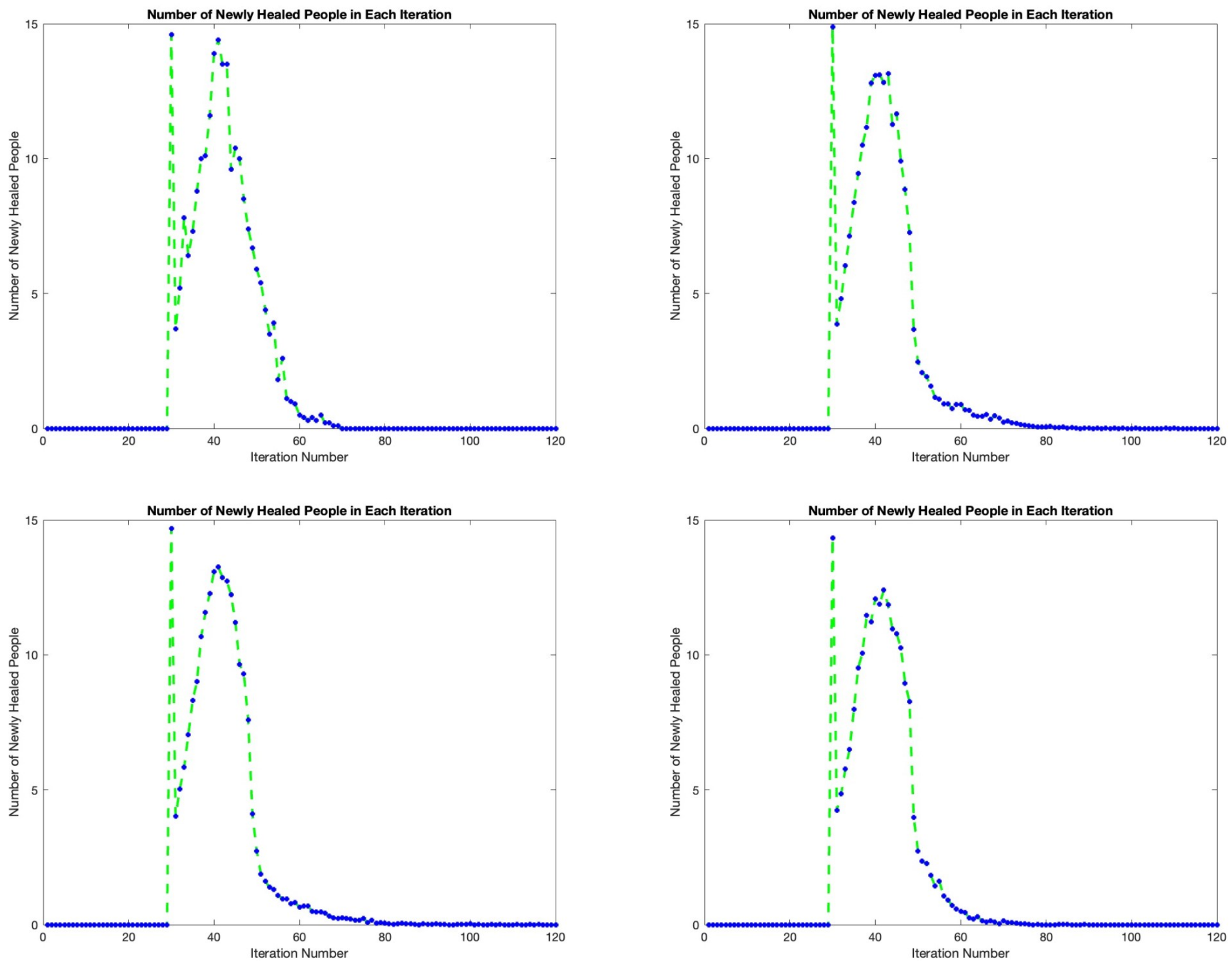
The first graph includes an isolation case, whereas the second graph includes the one vaccination policy. In the comparison of these graphs, it can be seen that the isolation effect is important, but the vaccination effect contributes to the prevention of infection after the 20th iteration. That is, after the 20th iteration, the vaccination effect has more impact than the isolation policy. However, before the 20th iteration, the infection spreads more easily in the case of vaccination without isolation. Adding an isolation policy to vaccination reduces the number of newly infected people overall. In a total of four graphs, it can be observed that the last case, consisting of double vaccination and isolation, dramatically reduces the propagation of infection.

3.1.2 Total Number of Infected People in the System in Each Iteration



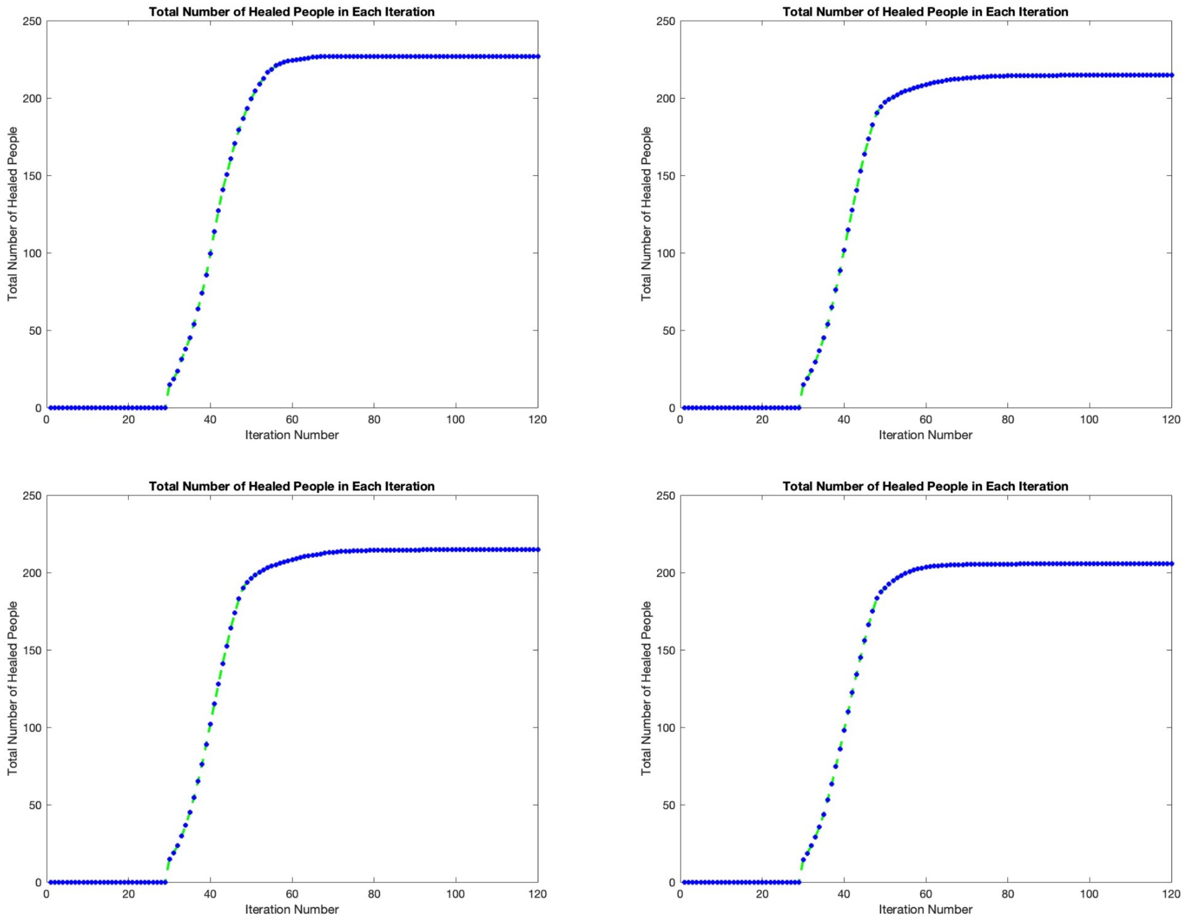
Vaccination policy has a considerable impact after the 20th iteration, especially in the iterations where a significant proportion of the population is vaccinated. On the other hand, isolation has an effect on all iterations, but not that much compared to vaccination policy. Adding isolation to vaccination has, of course, a more positive impact in terms of reducing the prevention. In addition, the case consisting of isolation and double vaccination is the best way to stop the spreading of the infection.

3.1.3 Number of Newly Healed People in Each Iteration



Because as isolation policy and vaccination policy are being added to the case, the number of infected people is getting smaller. Therefore, in that case, the number of newly healed people tends to drop, as is observed in the graphs.

3.1.4 Total Number of Healed People in Each Iteration

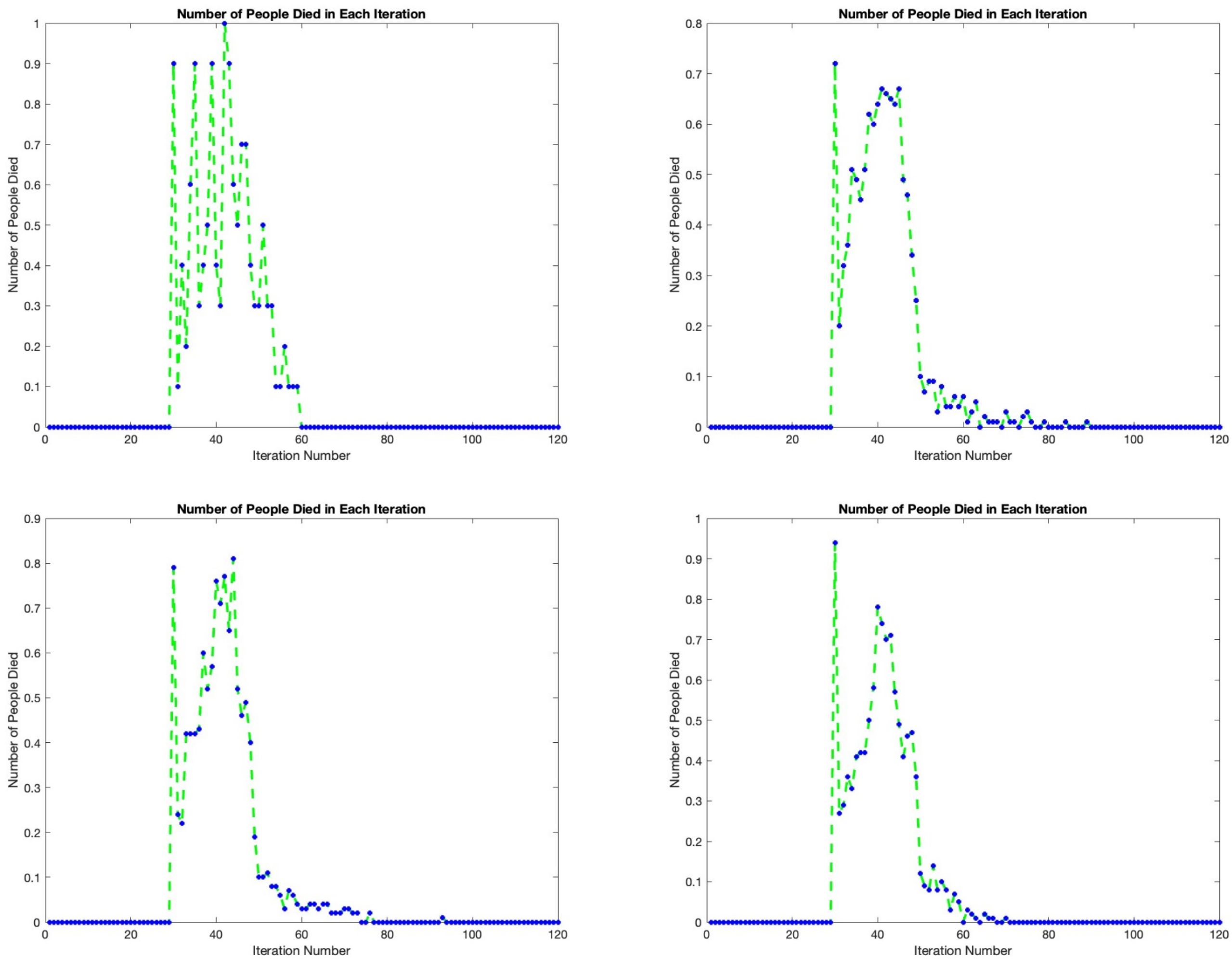


The graphs show the total number of healed people in each iteration. As seen in the graphs, the number of healed people is highest in Scenario I and lowest in Scenario IV since the number of infected people is also highest and lowest in these scenarios respectively. The reason for this situation is that in Scenario I, vaccination is not implemented. However, in Scenario IV, there exists double vaccination.

The difference between Scenario II and Scenario III is that Scenario III involves the isolation condition. Scenario III has lower y-axis values, which indicates the effect of only the isolation condition.

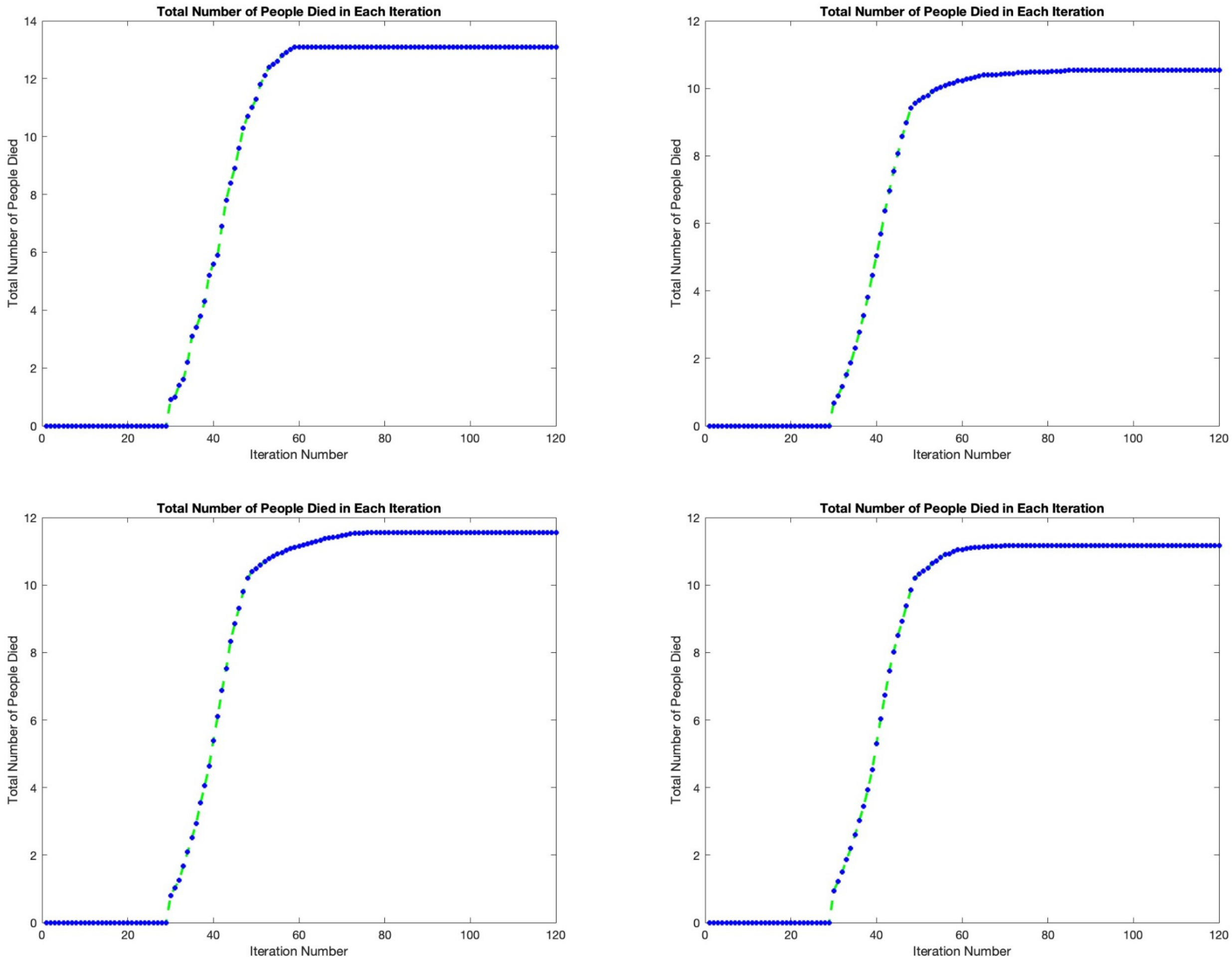
Comparing all graphs together, the positive effect of vaccination and isolation can be observed.

3.1.5 Number of People Died in Each Iteration

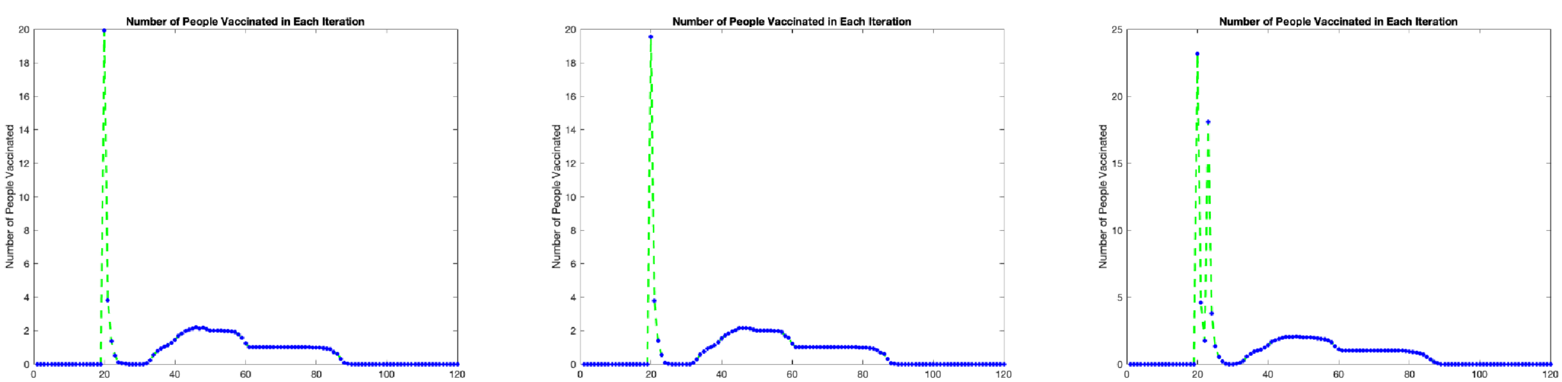


Through Scenarios I to IV, the number of people died in each iteration decreases because of vaccination and isolation factors. Also, as seen on the Scenario I graph, in contrast to others, there are more peaks. The vaccination factor decreases the number of peaks in these graphs.

3.1.6 Total Number of People Died in Each Iteration



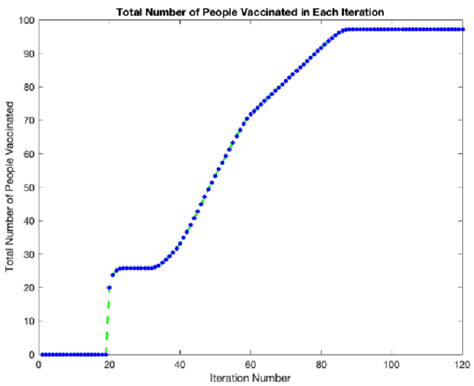
The fact explained above can also be seen in the cumulative graphs of the number of people died. This again emphasizes the effect of the vaccination factor.

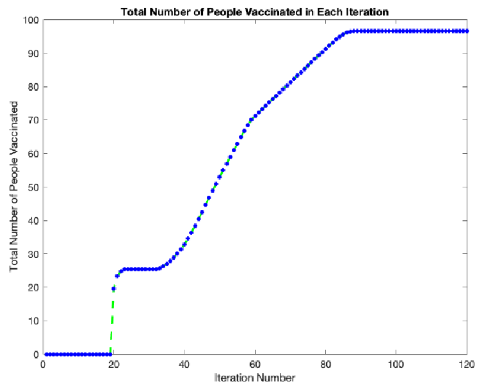


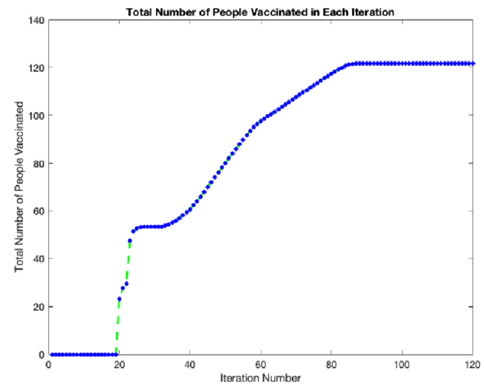
3.1.7 Number of People Vaccinated in Each Iteration

In Scenarios II and III, only one vaccination policy is valid. However, in Scenario IV, second vaccination is also possible. Therefore, the number of people vaccinated in each iteration is highest in Scenario IV, among these scenarios.

3.1.8 Total Number of People Vaccinated in Each Iteration

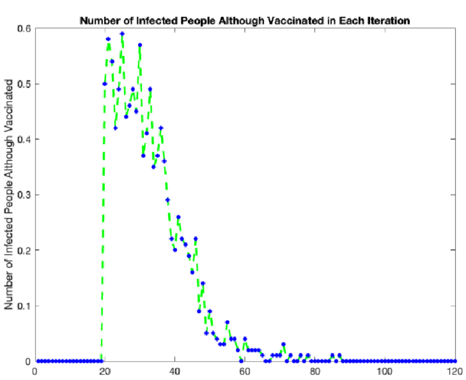


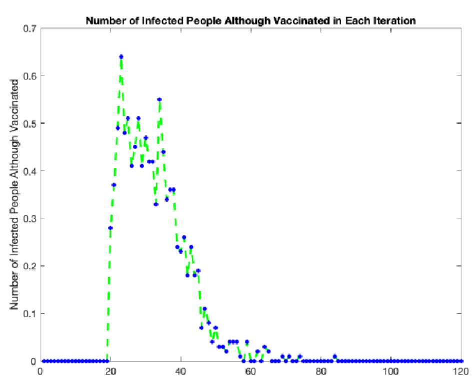


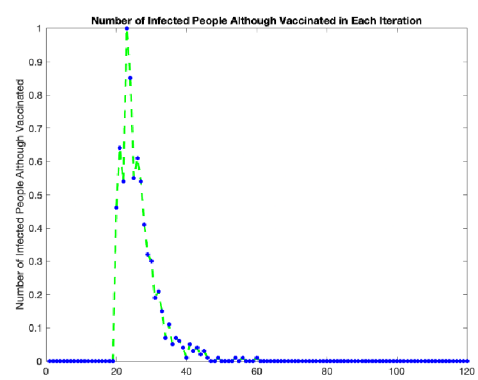


This is the cumulative vaccinated people data of 2.1.7. As mentioned above, Scenario IV has the highest total number of people vaccinated because of a possible second vaccination case.

3.1.9 Number of Infected People Although Vaccinated in Each Iteration



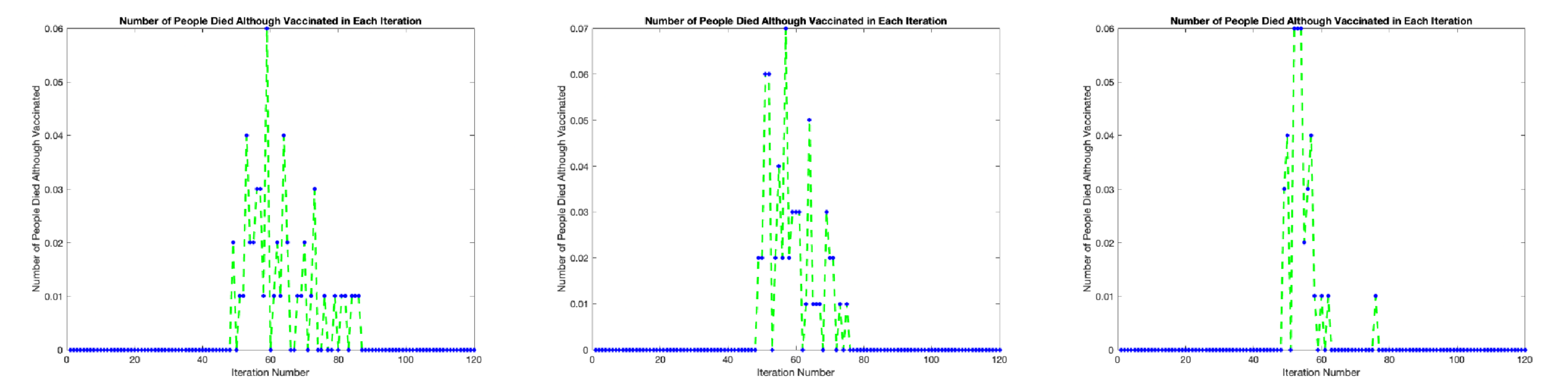




In Scenario IV, if the one vaccinated person does not get the second vaccination, the being infected probability is getting higher compared to Scenario II and III. However, mostly because they get second vaccination, the number of infected people although vaccinated is smaller overall.

Since there is an isolation policy difference between Scenario II and III, scenario III's corresponding data is smaller. That is, in general, the number of infected people although vaccinated is highest in Scenario II.

3.1.10 Number of People Died Although Vaccinated in Each Iteration



As seen on the graphs, the number of dead people and infected people although they got vaccinated is low and gets even lower through scenarios with the effect of isolation.

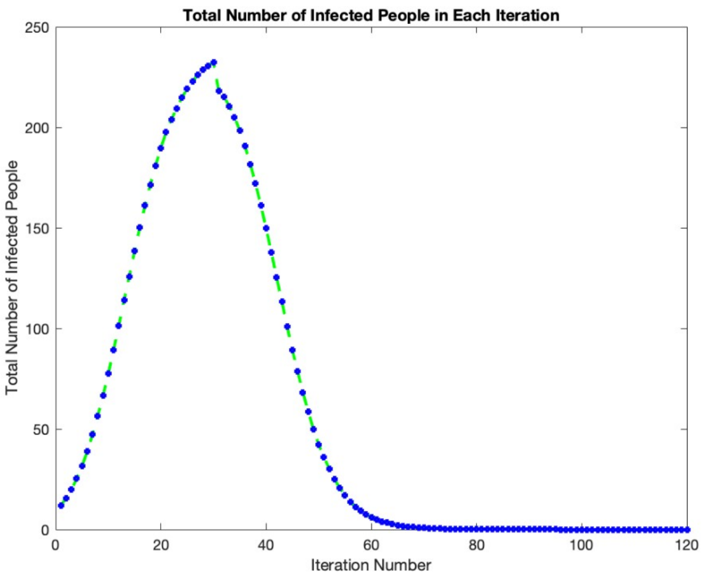
3.2 PART - 2

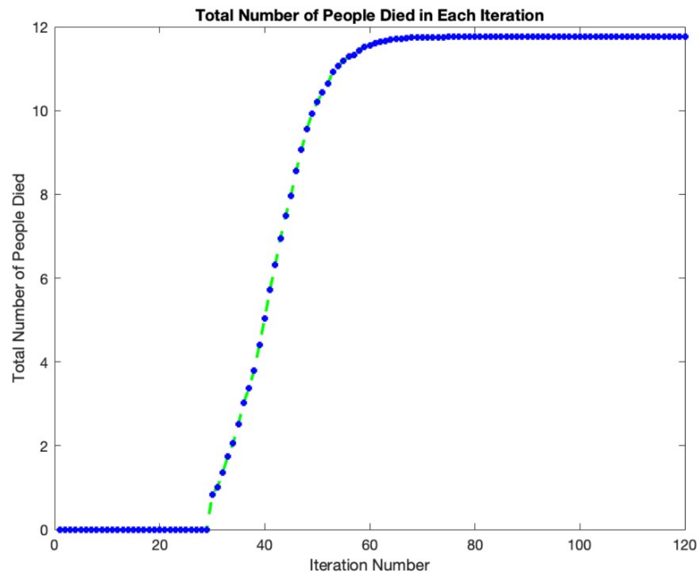
PART 3.2.1

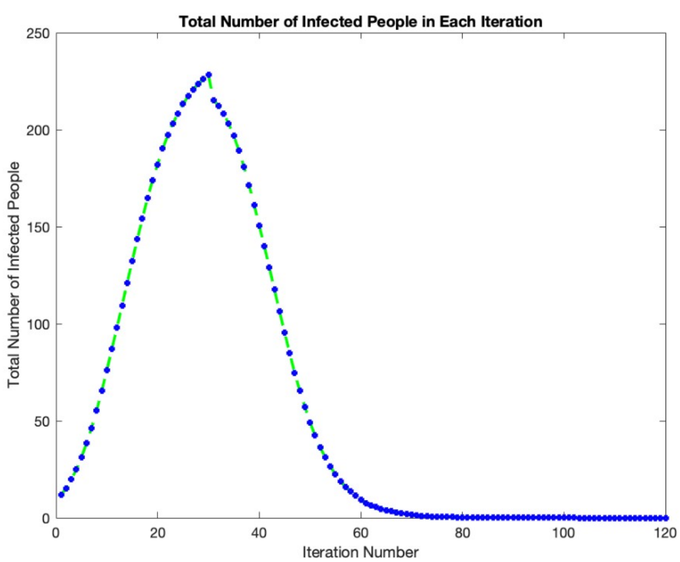
Under only the isolation policy implemented, the impact of isolation probability on the total number of infected and dead people in the system through the iterations is asked.

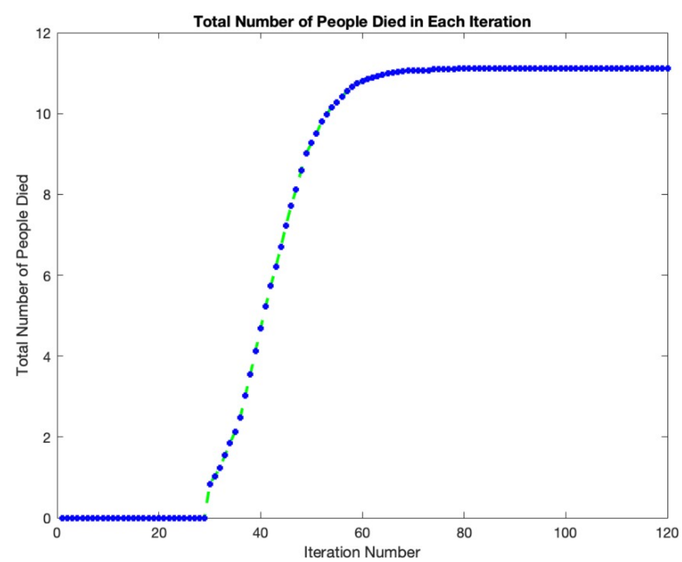
The case where only the isolation policy is implemented is Scenario I. Thus, the isolation probability is changed accordingly with three different alternatives in order to observe its actual impact on the total number of infected people and dead people in the system through iterations. In order to do that observation, the data where isolation probability is equal to 0, 0.5, and 1 are gathered separately.

Isolation Probability = 0

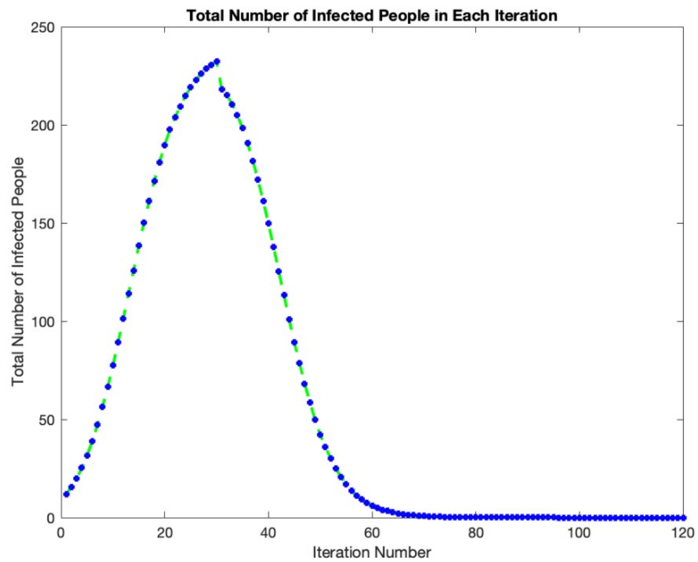


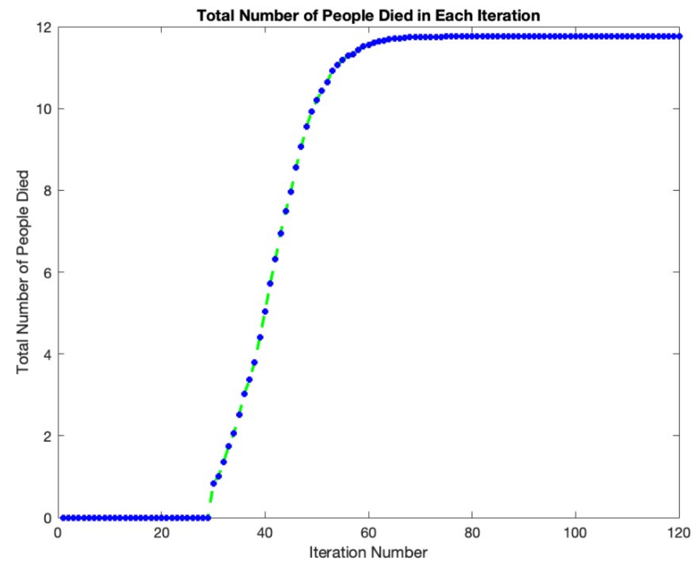






Isolation Probability = 0.5





Isolation Probability = 1

Observing the “Total Number of Infected People in Each Iteration” graphs for the three cases, it can be argued that there exists no significant difference between the graphs. However, it may also be emphasized that the graphs’ peak points are not equal; that is, when the isolation probability is larger, the peak points’ corresponding y-axis values are lower.

The other mark is that the “Total Number of People Died in Each Iteration” graphs for the three cases might be interpreted more easily since the difference can be seen more clearly. When comparing the 0 and 1 isolation probability graphs, the consecutive peak points in the range of y-axis values between 10-12 are precisely close to 12 in the case of 0 isolation probability. In contrast, the other graph’s values are around 11 in the case of 1 isolation probability.

However, this interpretation can not be constructed easily in the cases where isolation probabilities are 0 and 0.5 & 0.5 and 1. The other statistics that can be compared are the slopes of graphs between the 30th and the 60th iterations. While the isolation probability is getting smaller, the slope of the graphs in the corresponding interval is getting steeper.

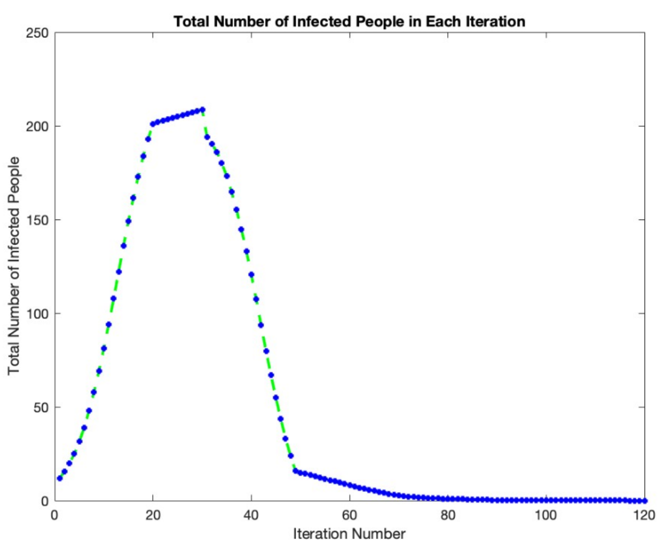
PART 3.2.2

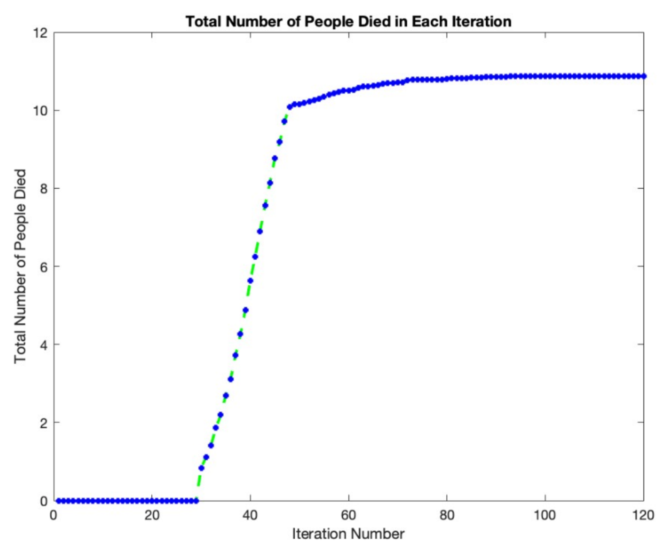
-Under only the vaccination policy, the impact of the vaccination rate on the total number of infected and dead people in the system is asked.

In order to do that analysis, The graphs are sketched for three cases in the Scenario II where,

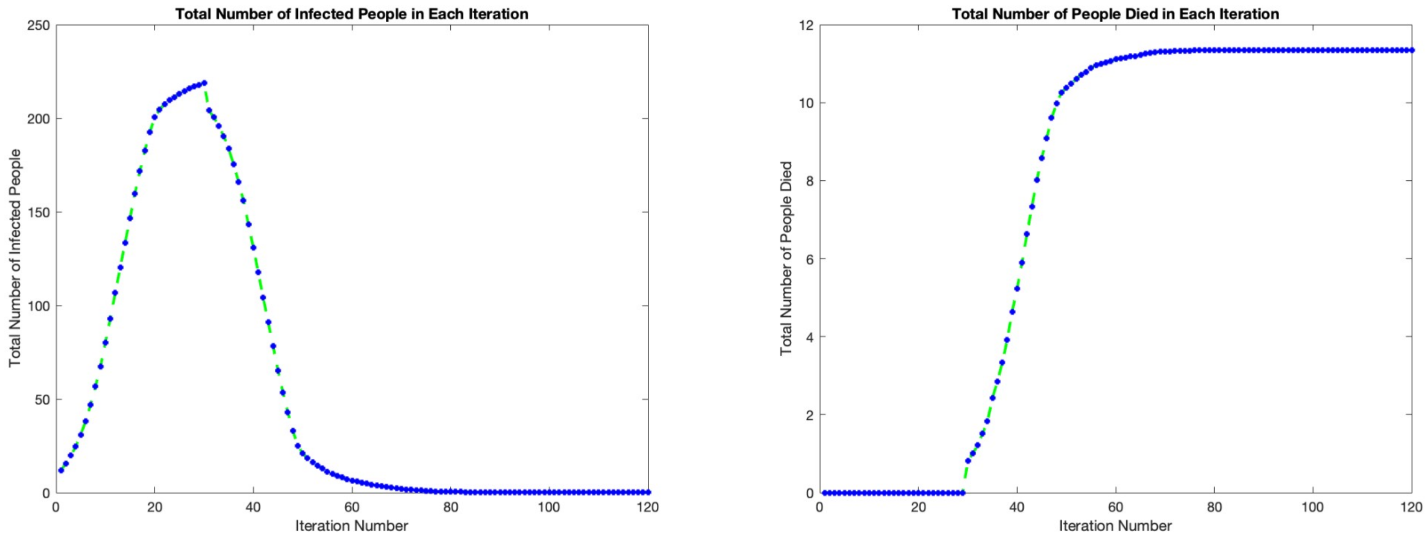
$$Vaccination\ Rate\ 1 = \frac{1}{1 \times (iterationNum - 19)}$$
$$Vaccination\ Rate\ 2 = \frac{1}{2 \times (iterationNum - 19)}$$
$$Vaccination\ Rate\ 3 = \frac{1}{4 \times (iterationNum - 19)}$$

The current vaccination rate in Scenario 2 was the second one. The first vaccination rate corresponds to the case in which the current vaccination rate doubles. Moreover, the third vaccination rate corresponds to the case in which the current vaccination rate falls in half.

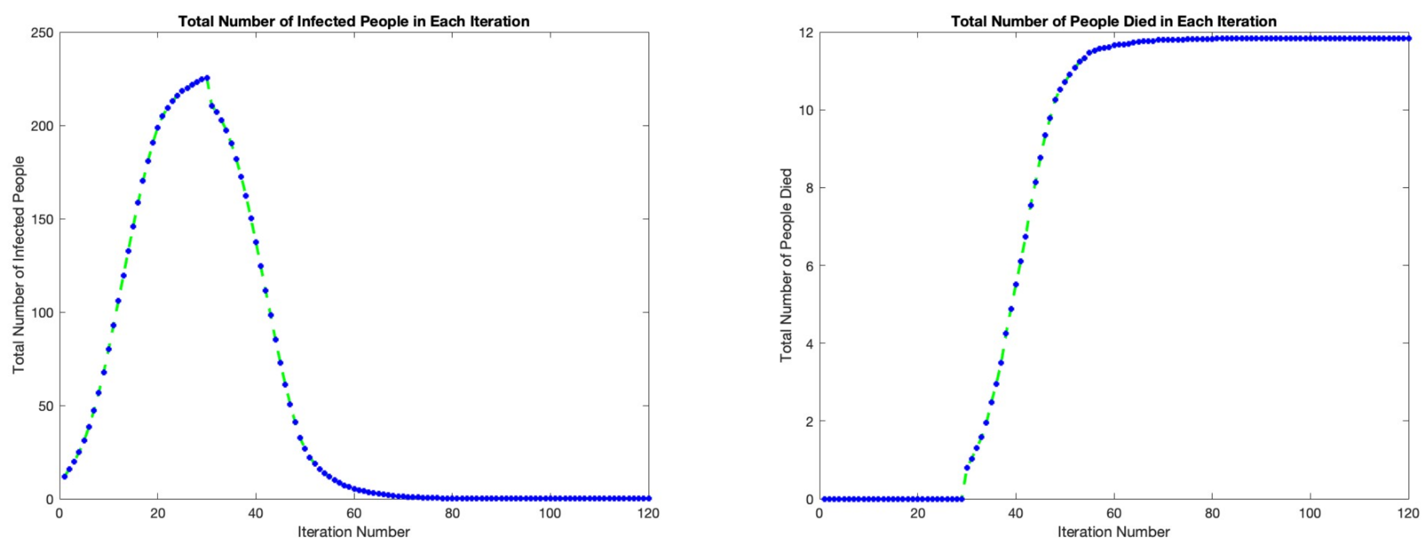




Vaccination Rate 1



Vaccination Rate 2



Vaccination Rate 3

Looking at the "Total Number of Infected People in Each Iteration" graphs, the comment that the vaccination rate affects peak points of the total number of infected people can be made. When the vaccination rate doubles, the peak number of total infected people is around 200-210. When the default vaccination rate is valid, the corresponding values are around 210-220. Also, when the vaccination rate falls in half, the corresponding values are around 230. Therefore, an increase in the vaccination rate reduces the total number of infected people slightly after the 20th iteration, where the vaccination starts. That is, in order to prevent infection, vaccination rates can be increased.

Observing the “Total Number of People Died in Each Iteration” graphs, It can clearly be said that the vaccination rate reduces the total number of people died. When the rate doubles, the total number of people died is around 10-11; when the current rate is valid, the value is around 11-11.5. In the last rate case, where the rate cuts in half, the value is nearly 12. That is, the total number of people died sticks in the range of 10-12 in a rule that the lower the vaccination rate, the more convergence to 12 the value of the total number of people died.

PART 3.2.3

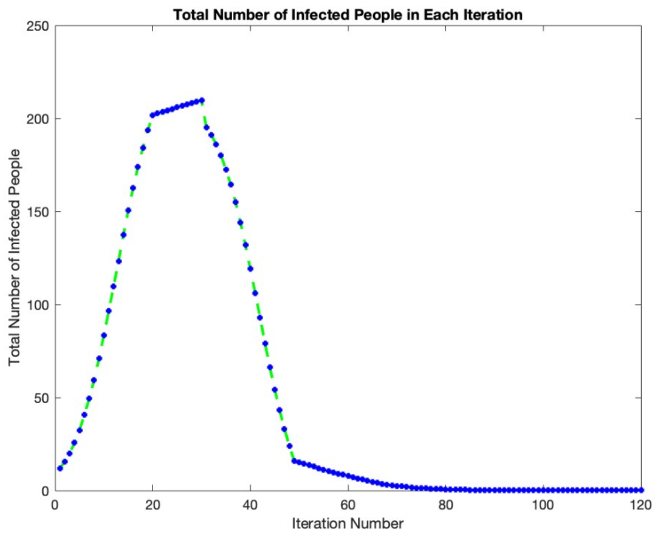
- Under the policy of isolation and vaccination together, the impact of different vaccination rates for a given isolation probability on the total number of infected and dead people in the system is asked.

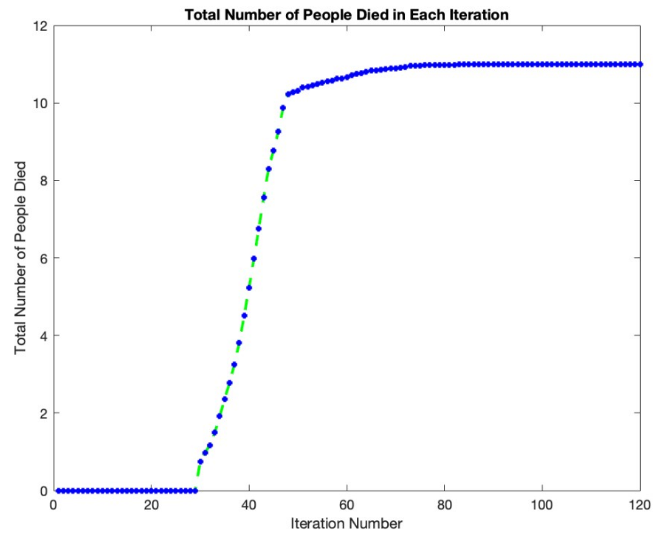
To make that analysis, Three different vaccination rates are going to be implemented in Scenario III. By doing so, the impact of different vaccination rates can be observed.

$$
\begin{aligned}
Vaccination\ Rate\ 1 &= \frac{1}{1 \times (iterationNum - 19)} \\
Vaccination\ Rate\ 2 &= \frac{1}{2 \times (iterationNum - 19)} \\
Vaccination\ Rate\ 3 &= \frac{1}{4 \times (iterationNum - 19)}
\end{aligned}
$$

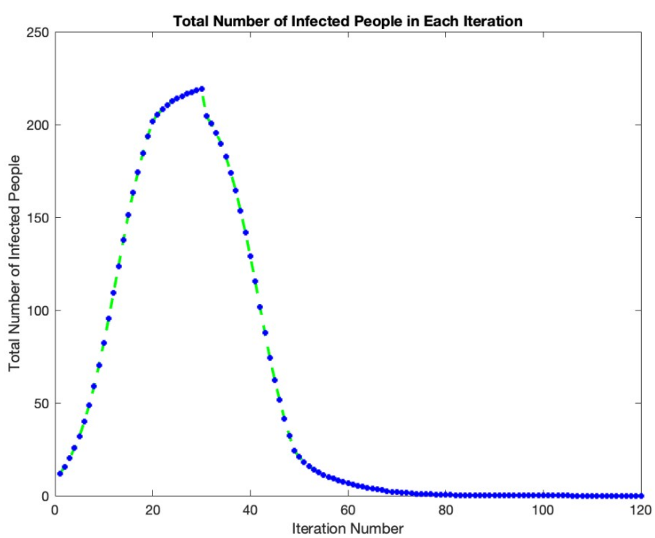
The current vaccination rate in Scenario 3 was the second one. The first vaccination rate corresponds to the case in which the current vaccination rate doubles. Moreover, the third vaccination rate corresponds to the case in which the current vaccination rate falls in half.

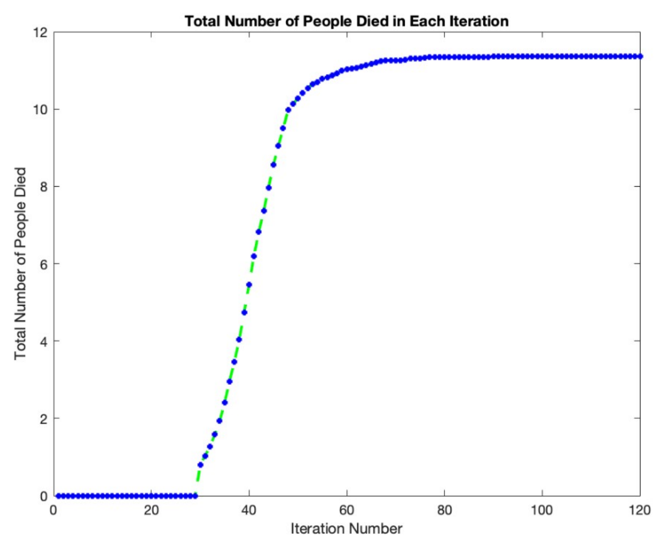
Vaccination Rate 1



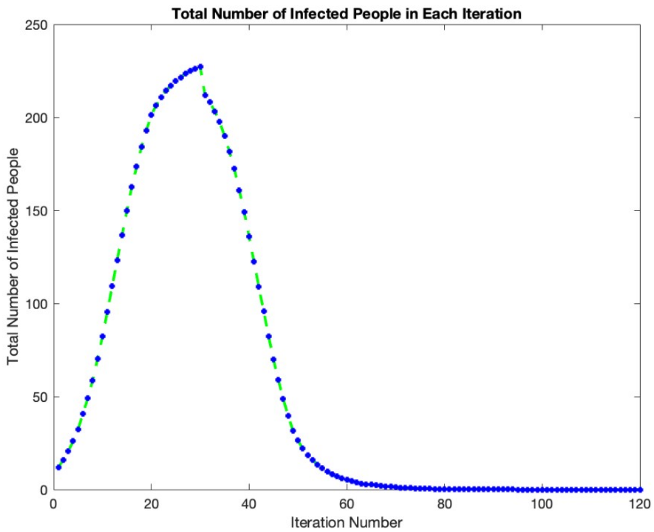


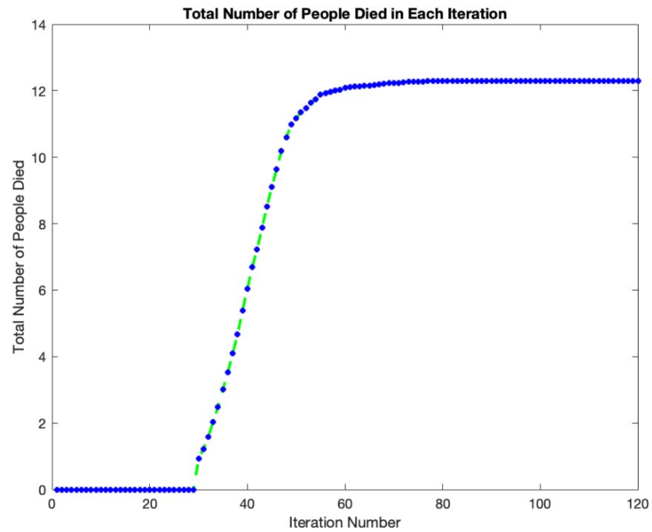
Vaccination Rate 2





Vaccination Rate 3



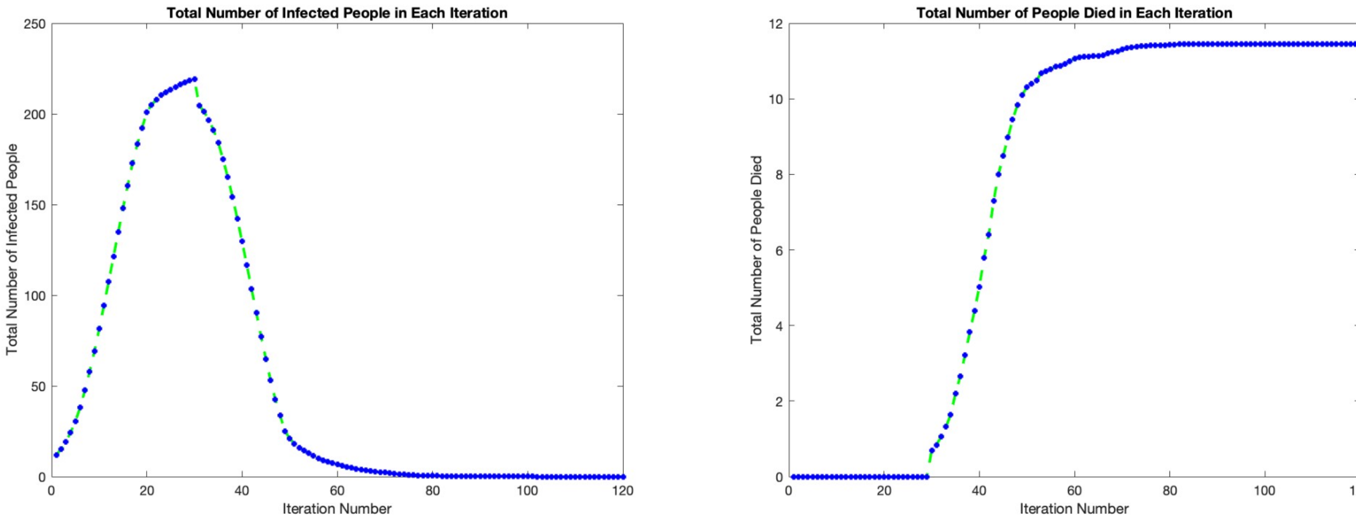


Making a comparison between the graphs "Total Number of Infected People in Each Iteration", it can be seen that when the vaccination rate increases, the total number of infected people decreases slightly after the 20th iteration where the vaccination starts. In the same perspective, the total number of people died decreases slightly after vaccination of the people is achieved substantially. In numerical observation, when vaccination rate 1 is valid, the total number of people died is around 10-10.5. Also, when rate 2 is valid, that value extends to nearly 11. Lastly, when rate 3 is valid, the value is around 12. This impact of vaccination should be regarded as important because these increases correspond to at least 8%, which is a critical value when considering people's lifetime.

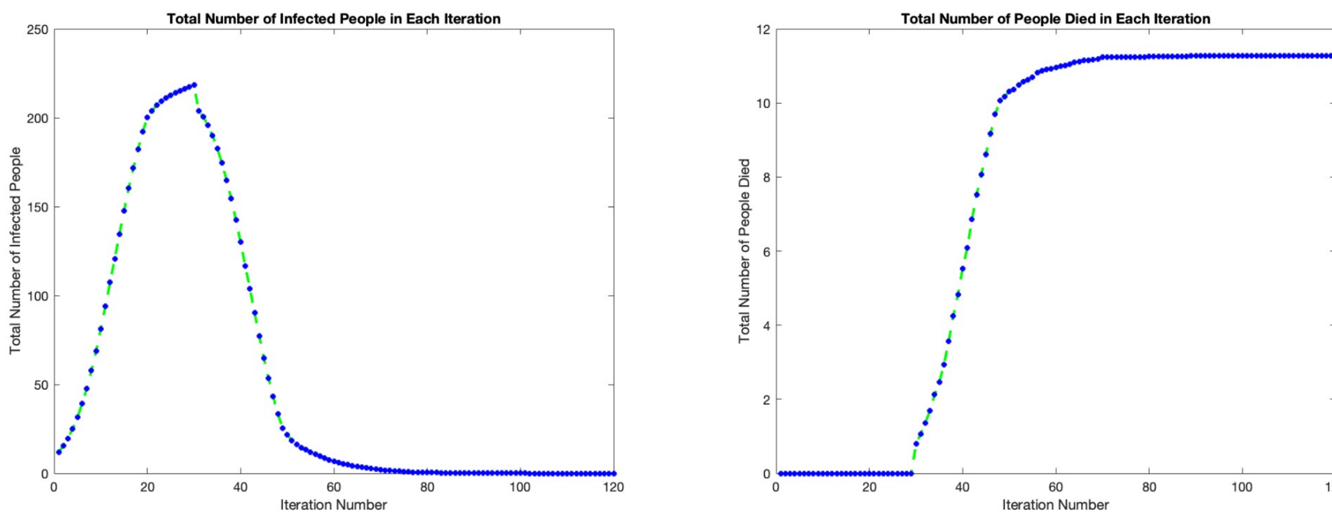
PART 3.2.4

-Under the policy of isolation and vaccination, the impact of different isolation rates for a given vaccination rate on the total number of infected and dead people in the system is asked.

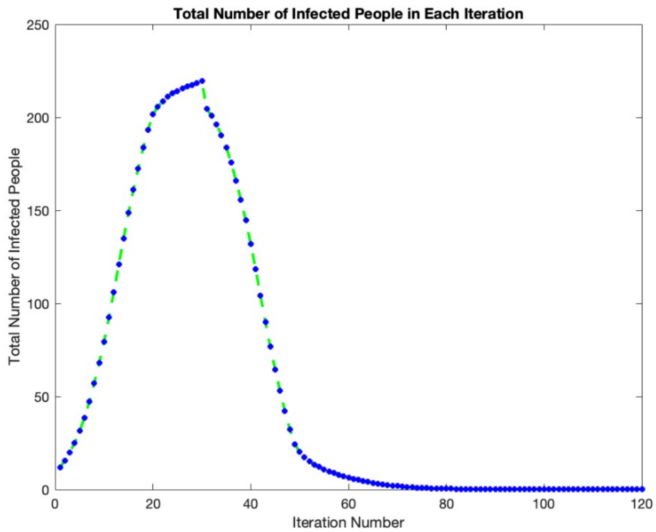
For this analysis, different isolation probabilities (0 & 0.5 & 1) will be implemented for Scenario III.

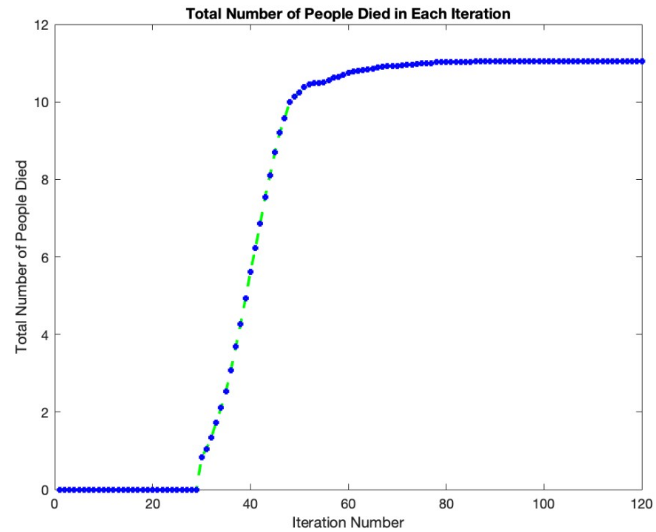


Isolation Probability = 0



Isolation Probability = 0.5





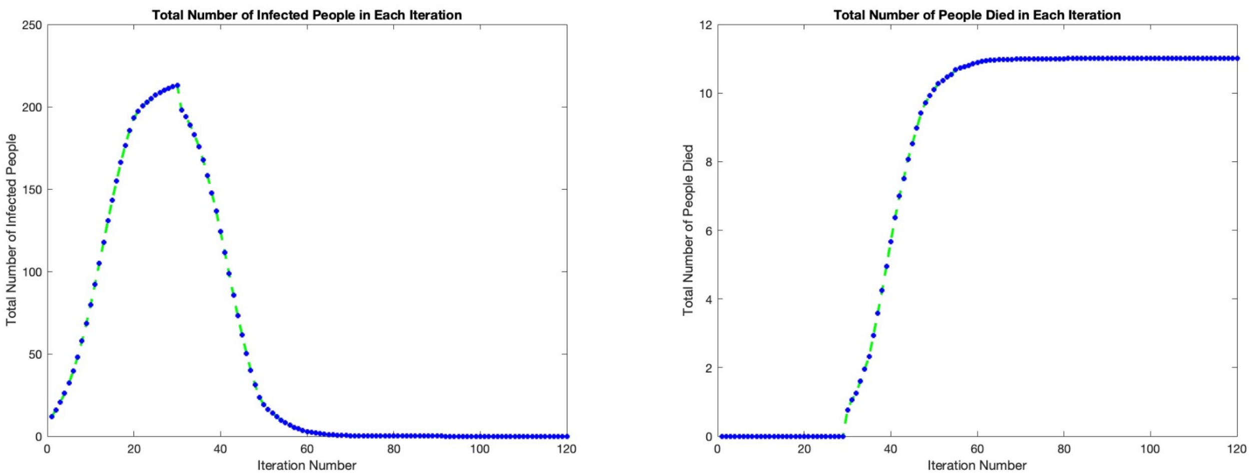
Isolation Probability = 1

Comparing the "Total Number of Infected People in Each Iteration" graphs, it can be interpreted that when the isolation probability increases, total number of infected people in each iteration decreases. However, the difference cannot be seen easily on the graphs because the difference is minimal. Also, in the comparison of the "Total Number of People Died in Each Iteration" graphs, the isolation probability increase affects the total number of people died in the inverse relationship, that is, the higher the isolation probability, the lower the total number of people died. From a numerical perspective, when isolation probability is 0, the total number of people died reaches nearly 12, and when isolation probability is 1, the total number of people died drops to nearly 11.

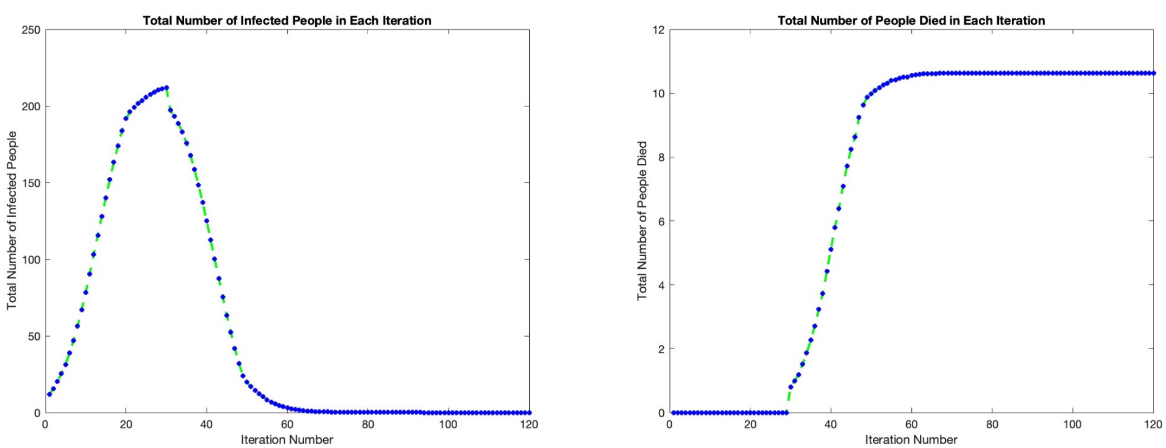
PART 3.2.5

-Under the double vaccination scenario, given the isolation probability as in Scenario I, the impact of different rates of second vaccination on the total number of infected and dead people in the system through the iterations is asked.

In order to analyze that impact, two cases where the second vaccination rate is equal to 0 and 1 are going to be implemented in Scenario IV.



Second Vaccination Rate = 0



Second Vaccination Rate = 1

In the graphs of "Total Number of Infected People in Each Iteration", it can be observed that second vaccination reduces the total number of infected people but with minimal differences. Also, in the graphs of "Total Number of People Died in Each Iteration", it can be seen that the second vaccination causes a decrease in the total number of people who died. In terms of the numerical data, this difference can be seen when the second vaccination rate is equal to zero, the total number of people died reaches around 11, whereas the total number of people died goes to nearly 10-10.5 when the rate is equal to 1. These situations can denote that the difference between the two cases is very little.

4- Conclusion

With the use of the given parameters, the effects of isolation, vaccination, and double vaccination are investigated and modeled against virus spread in order to have a better understanding of the coronavirus outbreak with four different scenarios.

Overall, by using the computational framework created, it is observed that having both isolation and vaccination factors helps reduce the number of dead and infected people in the simulation.