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Virus spread simulation via contained particles in a box

Topic – 1

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Abstract - In this paper, the spread of a pandemic is simulated via a “particle in a box” style simulation. Several methods are investigated to reduce the spreading of the virus. These included: sheltering in place, social distancing, and reducing the transmission probability. Lastly the effects of having a virus which kills quickly was investigated to see if it was possible for a virus to burn itself out.

The defining event of the 2020 year is without a doubt going to be the covid-19 pandemic. The covid-19 pandemic was able to place nearly every first world country on lockdown or stay at home orders. For any given pandemic it can be useful to be able to make predictions about how effective a preventative safety measure can be. As stated in the article, ‘Why outbreaks like coronavirus spread exponentially and how to “flatten the curve”’: “Still, without any measures to slow it down, covid-19 will continue to spread exponentially for months. To understand why, it is instructive to simulate the spread of a fake disease through a population”. In this article a fake pandemic is simulate by placing randomly moving particles in a box, in this case the particles represent people. When a collision occurs, the virus is considered spread. The same style of simulation was used to test several safety measures to reduce the effects of the virus on the population.

A sample of a virus spreading via this system of is shown at 4-time steps. Blue, yellow, and green, represent vulnerable, infected, and recovered, respectively.

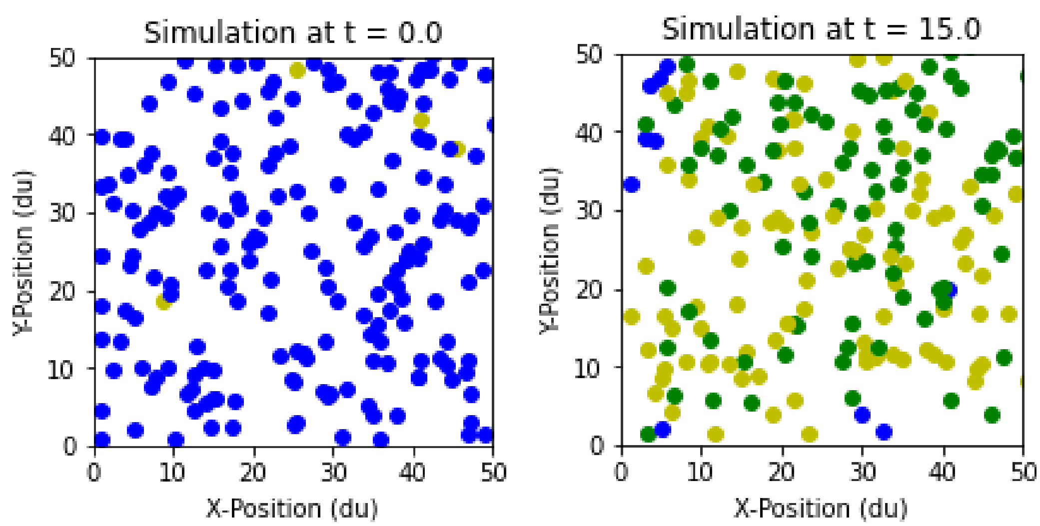
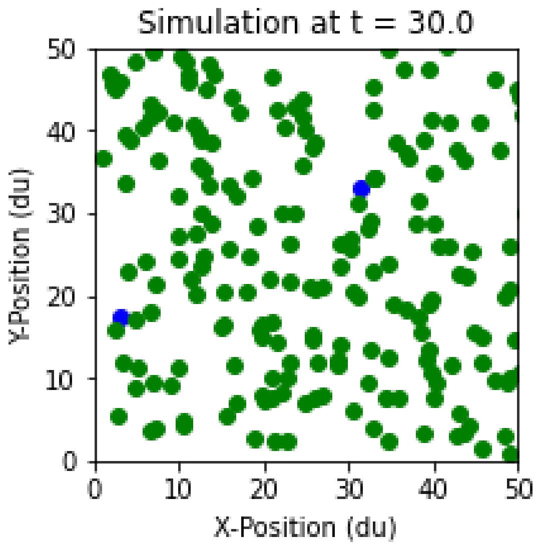


Figure 1.1, 1.2



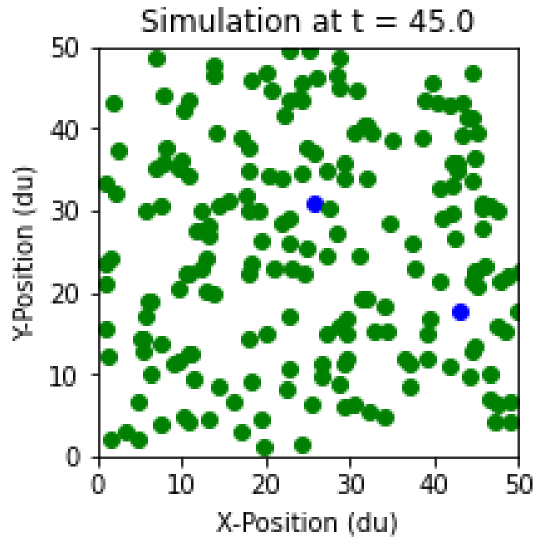


Figure 1.3, 1.4

Two critical values were monitored. The peak number of cases, and the time in which it takes to achieve that peak. Both these values are expected to be related, that is if the peak occurs sooner it should also be smaller. The number that the peak infection reaches is a critical value to ensure there is enough resources. The time it takes to reach the peak is also an important value. This is because it can help gauge how long safety measures should be taken.

There are several safety measures that will be investigated which can be taken during a pandemic. These include, sheltering in place, social distancing, and reducing transmission probability via various barriers (masks, face shields, dividers, etc.…). For these simulations, each method was tested individually. Meaning that when studying the effects of a single safety measures the others were not taken. No safety measure was taken for the control simulation. For any safety measure to be considered effective the goal is to minimize the number infected, control over when the peak occurs is not too useful but is useful when determining resource allocation.

The default parameters for the control (and in figures 1.1-1.4) was to use 200 particles, they moved at a rate of 2 distance units (du) per time unit(tu). At t = 0 a total of 5 individuals are infected, no one is sheltered, the transmission probability is 100%. The radius of each particle was set to 1du. The recovery time (That is the time to no longer be contagious) is 10tu. The simulations were run for 45tu, this provided plenty of time for all simulations to achieve their peak and nearly go to 0 infected. The results of the control group were as follows:

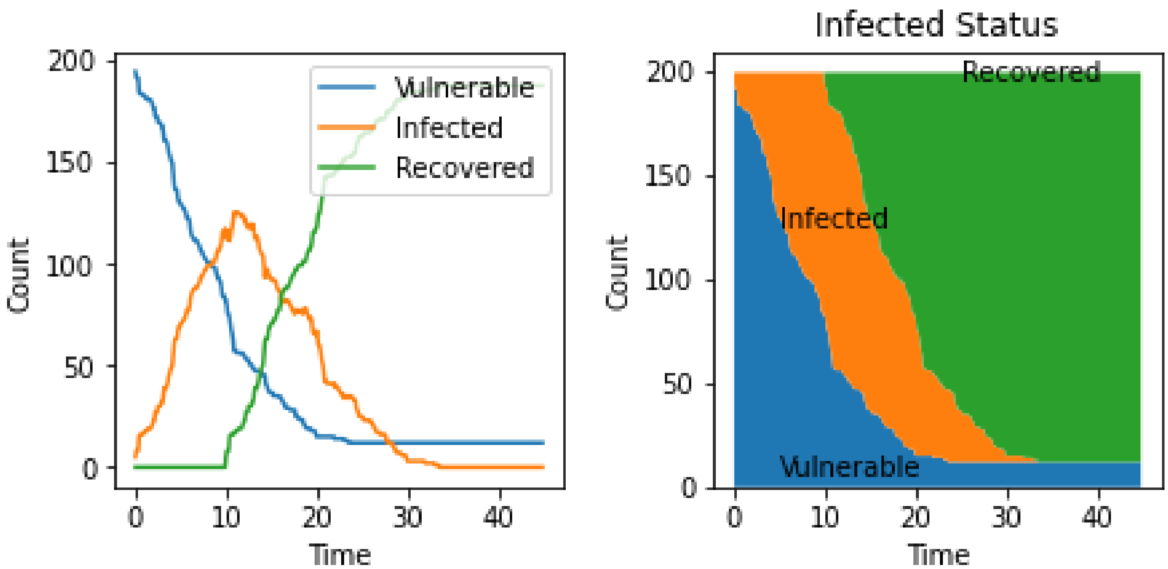


Figure 2.1, 2.2

Peak Infections: 125 at time 10

Total Infections: 187

As seen this virus highly infectious, even more so then COVID-19. For our virus, the peak infection was over 5/8th of the population, and all but 13 individuals were infected at some point in time. As this is the control this is to be expected as it should be the worst-case scenario.

The first safety measure tested was sheltering in place. This was done by locking the position of some particles to where it initially spawned. With less particles moving it should be expected to see a reduction in the peak infection value. It is important to note that for these simulation the initial 5 infected individuals were chosen to be not sheltering.

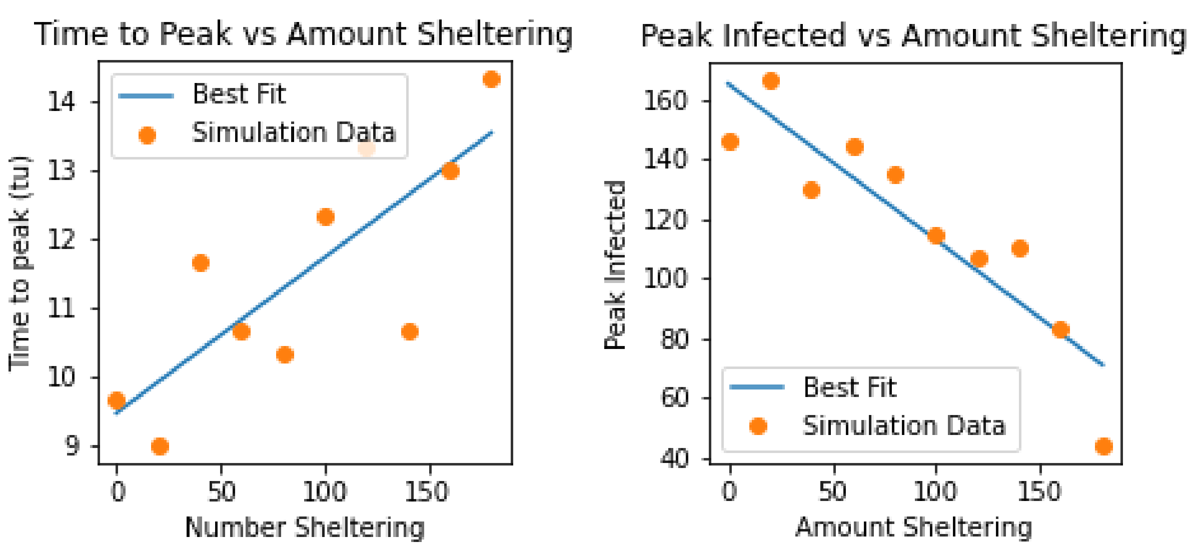
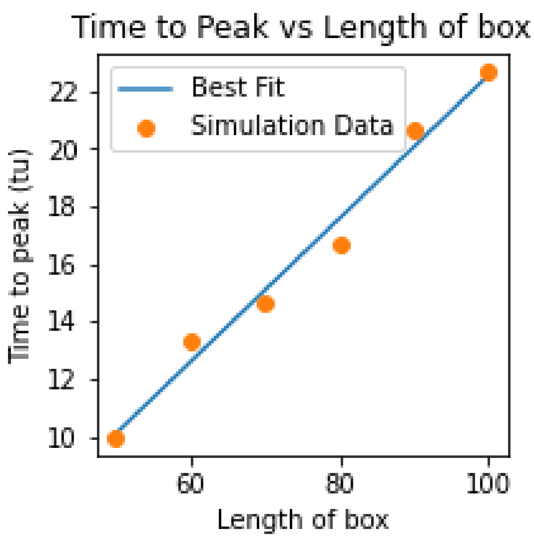


Figure 3.1, 3.2

As seen in figure 3.1 there does appear to be a relationship between the number of individuals sheltering and the time that the peak takes to occur. The relationship does appear be weak, however this is likely due to the limits of the simulation. In general, it is expected that because less infected are moving it should take longer to infect more people. Thus, our best fit equation of y = 0.02x + 9.45, is appropriate. As seen in figure 3.2 the peak number infected and the amount sheltering are also related. A linear relationship can fit the data with the form of y = -0.52x +165.16. This clearly shows sheltering in place is an effective method to reduce the peak number of individuals infected. As the slope is negative it shows that an increase in the number of people sheltering leads to a decrease in the peak infection amount. This is what is expected from an effective safety measure.

The next safety measure that was investigated was social distancing. To do this the area of the box was increased. This was done by increasing the side length. Due to this it is important to remember that a doubling of the side length is a quadrupling of the area.



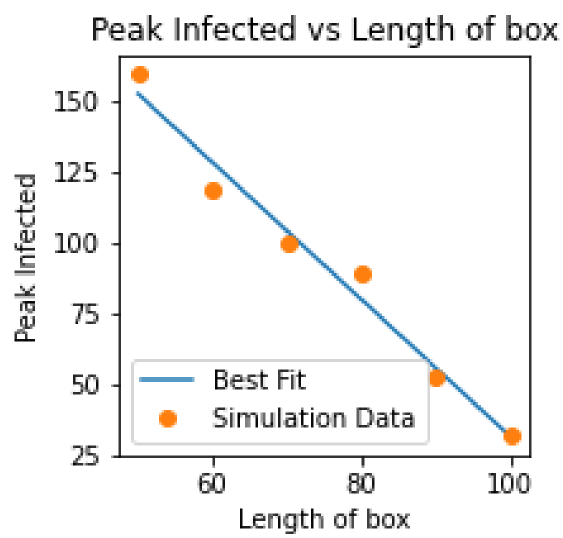


Figure 4.1, 4.2

Figure 4.1 shows that there is a strong relationship between the length of the box and the time to peak. All simulation data lands near the best bit. The equation for which is: y = 0.25x + -2.38. This result is as expected. With an increase in the spacing between individuals it will take longer for the virus to spread. Like Figure 4.1, 4.2 also has a strong relationship. Figure 4.2 shows the relationship between the length of the box and the peak infected value. The equation for the best fit line is y = -2.43x + 274.14. As with sheltering we expect to see a negative slope which has been obtained. This means that increasing the area and thus proving more space between individuals does reduce the transmission of the virus.

The last safety measure tested was the use of physical barriers. These would include masks, face shields, or other physical barriers that reduce the probability of transmission. To do this instead of any contact meaning transmission, there was only a chance of transmission.

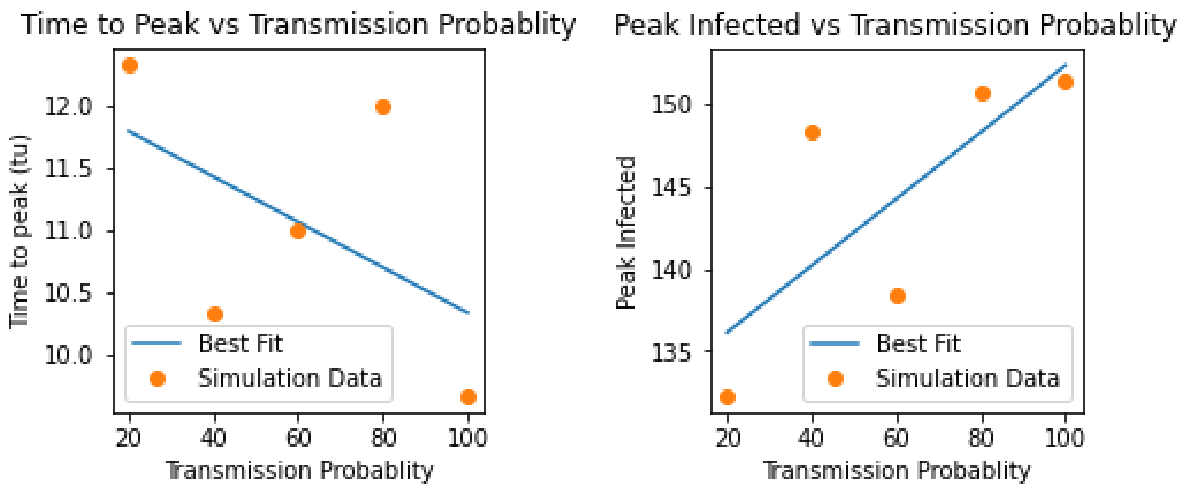


Figure 5.1, 5.2

Figure 5.1 shows that, surprisingly, there is not a strong correlation between time to peak and transmission probability. The best fit line is y = -0.02x +12.17. Seeing that the slope of this equation is nearly zero, it can be assumed that due to the randomness of the simulation, a different run could result in a positive slope. Despite the failure of figure 5.1, figure 5.2 does provide useful information.

Figure 5.2 shows that as the transmission probability increases the peak number infected also increases. The equation or this best fit line is y = 0.20x+ 132.10. This is as expected as it means that as the transmission probability increases so does the peak number of infected individuals.

Result summary:

Method	**Time to Peak (time units)**	**Max infections reached**
Sheltering in place	y = 0.02 x + 9.45	y = -0.52 x + 165.16
Social Distancing	y = 0.25 x + -2.38	y = -2.43 x + 274.14
Transmission Probability	y = -0.02 x + 12.17	y = 0.20 x + 132.10

From the three methods all proved effective when trying to lower the maximum number of infected reached. However, it is important to note that one method proved to be far more effective then the rest. The most effective method was social distancing. With a slope value of -2.43, increasing the side of the box by just 1 reduced the total max infections by 2.43. This is far greater than the 0.52 that the max is reduced by when an individual shelters in place. Social distancing is also the only method that had a strong correlation between how much it was preformed and when the time to peak was reached. For social distancing each, 4 individuals sheltering would result in an increase of 1 unit of time for the time to peak.

It is now clear that safety measures can be effective at reducing he transmission of a virus during a pandemic. However, this is not the only way pandemics come to an end. It is very possible for a pandemic to burn itself out and naturally come to an end. By introducing death to the simulation this can easily be seen. To add death to the simulation, a set chance of death was used, this was then multiplied by the recovery time to have a chance of death every timestep.

This means a person can catch the virus and may die before spreading it. When a person dies, they are removed immediately from the box. For the control group a value of 10% was used for the chance of death.

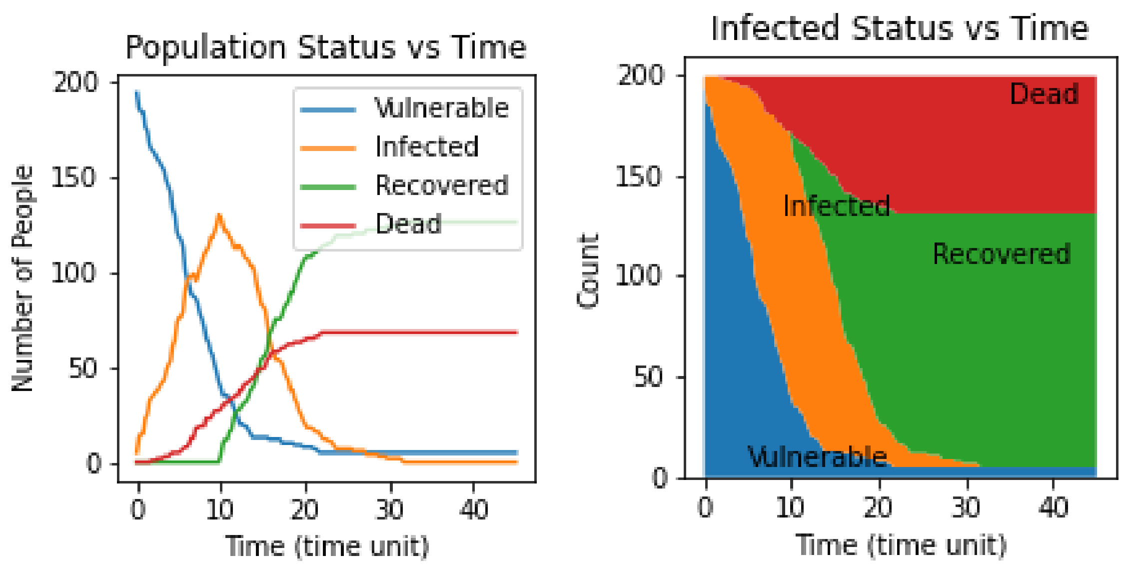


Figure 6.1, 6.2

Statistic	Control without Death	Control with Death
Starting Infection	5	5
Peak Infections	125 at time 10	130 at time 9
Total infected	187	194
Deaths	0	68

As seen when compared to the control the only substantial difference is the deaths. It can also b e interesting to see the effects of a virus that is extremely deadly and has a higher chance of dea th. Varying the chance of death between 0 and 100 results in the following results:

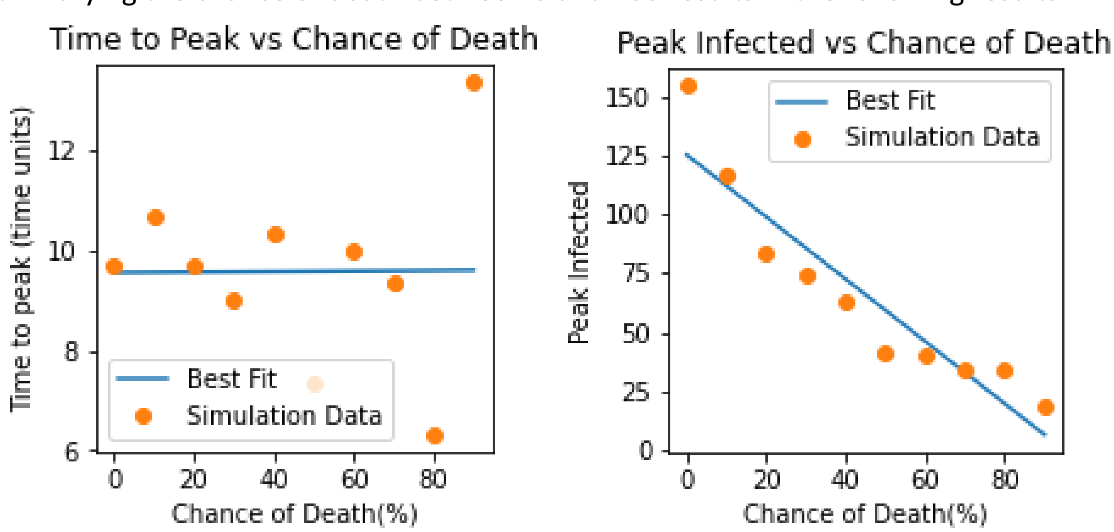


Figure 7.1, 7.2

As seen by Figure 7.1, the time to peak and chance of death are not very well correlated. The best fit equation is y = 0.00x + 9.54. This is not a surprising result given the limitation of the simulation, as there is no incubation period. However, figure 7.2 shows there is a clear correlation between peak infected and the chance of death. The best fit equation of y = -1.32x + 133.9. With a negative slope it is then known that if a disease has a higher chance of death, it will have a lower peak infected value. This is because peak infected does not include those who had already died.

As demonstrated the ability to model a pandemic can provide useful information. Using a partic le in a box style simulation it was shown that all three methods: sheltering in place, social distan cing, and reduction of transmission probability via physical barrier, all proved to be effective saf ety measures. Furthermore, the simulation was also able to demonstrate that a virus which has a high chance of death will not show a high peak infection number. To better the simulation and provide more accurate results an incubation period should be added. This would allow a virus to spread before the person infected dies. Furthermore, developing a system in which those who a re sick do shelter in place can also increase the accuracy of the simulation. Despite these limits simulating a pandemic via particles in a box is an effective way to determine how effective, if at all, a safety measure may be.

Works Cited

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