**Final Project – Disease Propagation Modeling (C++) Write-up**

**Unless indicated, the data shown below is based on my C++ disease propagation model with the following parameters:**

* **Population size = 40,000 people**
* **Infection period (total sick day) = 5 days**
* **Maximum daily interaction for each infected person = up to 40 people (this is randomly set to a number from 0 to 5 at each step of the model for each infected person)**
* **Probability of infection from an interaction = 10%**
* **Number of vaccinated individuals on Day 1 = 0 people**

**Summary:**

**I created my model following the guides from Chapter 51 of our class textbook (Dr. Victor Eijkhout’s *Introduction to Scientific Programming in C++/FORTRAN2003*). A class Person was created to represent a person in the population.**

**The class Person can have 4 main states represented by integers: -2 (vaccinated), -1 (recovered), 0 (susceptible), and positive integers (sick, also corresponding on the amount of day the Person is sick until recovered). There is a method that infects the person and a method that updates the person’s state on the next day if they are sick.**

**A class Population was generated to contain a vector of a group of Person. Within the class Population, there is a method that randomly infects a Person inside the vector and provides update on the next day. Within the Update() method, each sick Person meets with some random Person in the vector, the encounters that may go up to the maximum daily interaction assigned. The spread of the infection occurs only when sick Person comes in contact with a susceptible Person and the susceptible person is unlucky (random number < probability of infection).**

**In the main program, I created a loop that monitors the class Population every day (infinite step) starting from Population with a patient zero and exiting when there are no longer a sick Person in the vector. The program gives a printout to variables such as daily transmissions, the number of days the infection is present in the Population, and the number of Persons protected from the infection (herd immunity). These data are saved to a csv file and imported to Google Collab’s Python3 for further analysis using packages like Pandas and Matplotlib.**

**Other modifications were made to the model to see the impact of social distancing, vaccination, and asymptomatic Persons on the disease propagation.**

**Link to Google Collab:**

<https://colab.research.google.com/drive/1qVe4JE0hK9CtSyBf8tYjRhZRlmgLQlqj?authuser=1#scrollTo=d1dHSAxgfFIH>

**Note: Make sure the csv files in this folder are uploaded before running Python3**

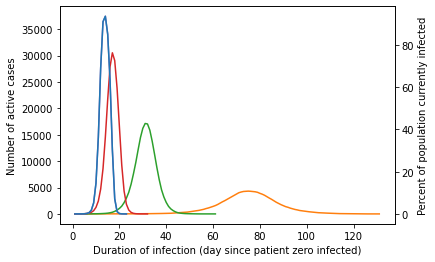
**A picture containing chart

Description automatically generatedGeneral plot of transmission**

**Figure 1. Total number of active cases throughout the duration of the life of an infection (daily maximum interaction = 40 people)**

**This is an example of a plot showing the total number of active cases of infection throughout its course in the population of 40,000 people. Here, the maximum daily interaction was set to be up to 40 people. The number of active cases exhibits a normal distribution (bell-shaped curve). No vaccination was given to the population, and everyone was infected in the end. The plot shows that the number of cases the disease being short-lived, dying out 23 days after the first person was infected. The number of daily cases peaked at Day 14 during which 37,464 people (93.7% of the population) was sick.**

**Effect of maximum daily interaction on disease propagation (social distancing)**



Max Interaction = 40

Max Interaction = 20

Max Interaction = 10

Max Interaction = 5

**Figure 2.** T**otal number of active cases throughout the duration of an infection life with varying daily maximum interactions (5, 10, 20, 40)**

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Description automatically generated**Figure 3.** The duration of an infection in the population at varying maximum daily interactions (from 0 to 40).

**Figure 4.** Total transmission of a disease throughout the whole life of infection at varying maximum daily interactions (from 0 to 40).

The effect of social distancing on disease propagation can be modeled by adjusting the number of interactions each person is allowed to have each day (the daily maximum interaction). As shown on Figure 2, social distancing leads to a lower number of active cases of infection any time during the infection life. As the number of interactions between people in the population increases, we see that the maximum number of active cases increases. The population with the daily interaction of 40 is inundated with over 90% of the population being infected in a single day (Day 14)! Here, there could be complications and other factors like accelerated death rates as the hospital is overwhelmed with many sick patients. The population with the maximum daily interaction number of 5 people peaks at a later day on the number of active cases. Social distancing leads to a longer infection lifetime (see Figure 3), but lower number of active cases overall (shorter but wider bell curves).

Figure 3 and Figure 4 show that if the maximum daily interaction is less than 5 people, the infection lifetime and the total number of disease transmission are minimal. This may not be practical in a real setting where interactions may not be avoidable. Here, it seems that a sweet spot (where the number of total transmission and interaction are low) might be at the interactions of a small group of 5-6 people. Any interactions higher than that (if every sick person interacts more than 5-6 people) could result in a catastrophic number of total transmissions.

Chart, scatter chart

Description automatically generated**The effect of vaccination on disease propagation (herd Immunity)**

**Figure 5.** The number of days the infection is active in the population as a result of Day 1 vaccination.

Herd immunity (people who did not receive the vaccine but were never sick) can be observed in the model by varying the fraction of the population vaccinated on Day 1. In earlier simulations, at higher maximum daily interactions, almost 100% of the population was infected at one point during the infection lifetime. We only saw herd immunity with extreme social distancing. However, with a fraction of the population being vaccinated, herd immunity can be observed even when the maximum interaction is 40.

In Figures 5-7, the percent of the population vaccinated on Day 1 was varied to observe its effect on the infection duration, total transmission, and herd immunity (keeping maximum daily interaction at 40 people). Figure 6 shows that the number of people protected from the infection increases almost linearly up to 80% vaccinated population. Above 80% vaccinations, probably by some chances, the total transmission remains at 1 (patient zero), as shown on Figure 7. What is interesting is vaccination has the same effect on the infection lifetime as social distancing. Figure 5 shows that the infection remains in the population longer with increasing vaccination, (up until no propagation when vaccination is greater than 80% of the population).

Chart

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**Figure 6.** The number of people who were protected from the infection (did not receive vaccination; herd immunity) as a result of vaccination on Day 1.

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**Figure 7.** Total transmission throughout the infection life as a result of vaccination on Day 1.

**The effect of asymptomatic population on disease propagation (varied interaction)**

Please note that this results in this section are very preliminary.

The effect of asymptomatic population on disease propagation can be modeled by varying the number of daily interactions within the infected individuals. The idea is based on the observation that infected people who are asymptomatic would behave more recklessly than infected people with shown symptoms. Here, I modeled asymptomatic condition by assigning a special status in the class Person that indicates if the person is asymptomatic or not. For COVID-19, 20% is the probability of asymptomatic conditions (80% the infected shows symptoms; the other 20% shows no symptoms). I also added another complexity of an onset date when symptoms show up for sick individuals. All the infected people are asymptomatic up until Day 5 of their infection (a relatively reasonable number for COVID-19).

Those that are infected but are asymptomatic (before Day 5 OR at any day during the infection period) will interact with the same number of people as an uninfected person (I set this to be equal to the maximum daily interaction = 10). Those who are infected and have symptoms present will have a limited number of daily interactions (I used limited daily interaction = 5 for this study).

I varied the fraction of those who are asymptomatic when infected and see its effect on the infection duration and total transmission. I observed that, using the conditions I have listed, I saw no correlations asymptomatic fraction and the disease duration or the total transmission. Further study needs to be done to observe asymptomatic status. Suggestions include adjusting the numbers of maximum and limited daily interactions and the number of people vaccinated.

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**Figure 8.** Life of an infection as a result of different interaction behavior caused by the people who are sick but asymptomatic.

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**Figure 9.** Total transmission throughout the infection life as a result of different interaction behavior caused by the people who are sick but asymptomatic.