Investigating the Effect of Herd Immunity Through Simulation

Shraddha Mahesh Thanki (12300457)
Supervisor: Prof. Dr. Christoph Schober
Subject: Programming Lab for HPC/QC
University: Deggendorf Institute of Technology

May 30, 2024

Abstract

Herd immunity's impacts are investigated in this research using a C++ simulation model. Our objective is to model the transmission of a disease at different vaccination rates within a community in order to get better insight into how vaccination achieves herd immunity. We next compare the simulation findings with theoretical forecasts to evaluate the accuracy and reliability of the results.

1 Introduction and Objectives

This project's primary objectives are to examine the consequences of herd immunity and reproduce the transmission of a disease across a community. We intend to compare our results with theoretical predictions to find the vaccination rate required to produce herd immunity through performing these simulations.

2 Background Information: Herd Immunity

Herd immunity occurs when a large proportion of a community develops immune to a disease, either through vaccination or past illnesses, hence giving indirect protection to others who are not immune. The fundamental reproduction number, R_0, determines how many individuals an infected person will propagate the disease to. This figure is determined by a variety of factors, including the disease's transmissibility, the length of infectiousness, and the frequency of contact between patients.

In our simple SIR-simulation, R_0 can be calculated by:

$$R_0 = D \cdot \beta \cdot C$$

where D is the duration of the disease, β is the transmissibility, and C is the number of contacts.

In the simulation model defined above, $C = 6$. A disease with $\beta = 0.1$ and $D = 5$ would give $R_0 = 5 \cdot 0.1 \cdot 6 = 3$. According to Figure 1, the herd immunity threshold should be about 60%.

3 Methodology

The C++ simulation simulates illness transmission through a population by specifically modeling each person. The simulation includes important factors such as infection duration, illness transmissibility, and immunization rate.

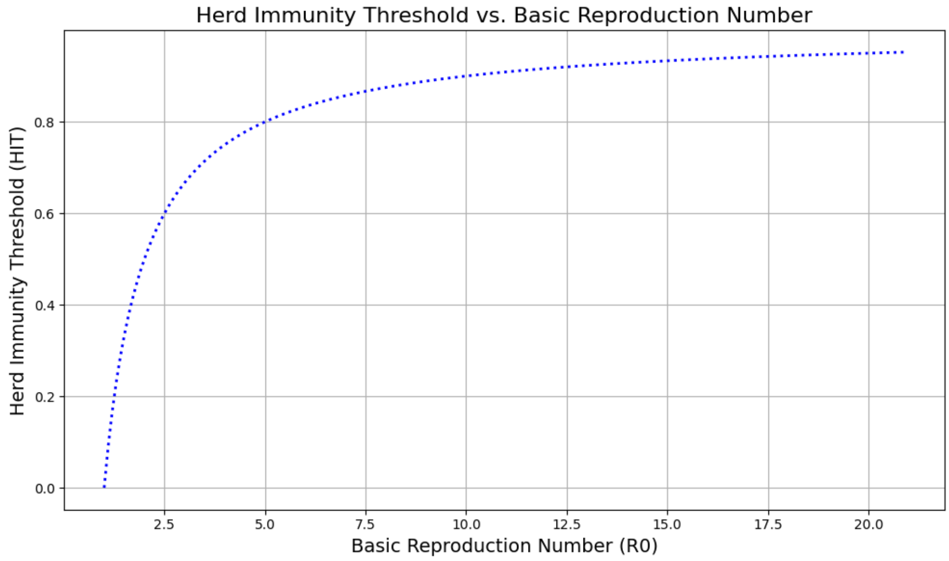

Figure 1: Herd Immunity Threshold vs. Basic Reproduction Number

3.1 Model Parameters

- Duration of infection (D): 3 days
- Transmissibility (β): 0.4
- Number of contacts per day (C): 6
- Population size: 15,000
- Vaccination rates: 0% to 100% in steps of 10%

3.2 Simulation Steps

The simulation begins with one infected individual. Every day, this person interacts with six randomly selected members of the public. If a vulnerable individual comes into touch with an infectious person, they have a 40% chance of becoming infected. Vaccinated people are immune. The simulation runs until no infected persons remain.

4 Results

4.1 Recovered Individuals vs. Vaccination Rate

The first set of results examines the number of recovered individuals at the end of the simulation for different vaccination rates.

4.2 Disease Progression for 50% Vaccination Rate

The second set of results examines the progression of the disease over time for a 50% vaccination rate.

5 Discussion

The results of the simulation suggest that when vaccination rates rise, the number of recovered persons falls, indicating fewer illnesses. This pattern is consistent with the theoretical assump-

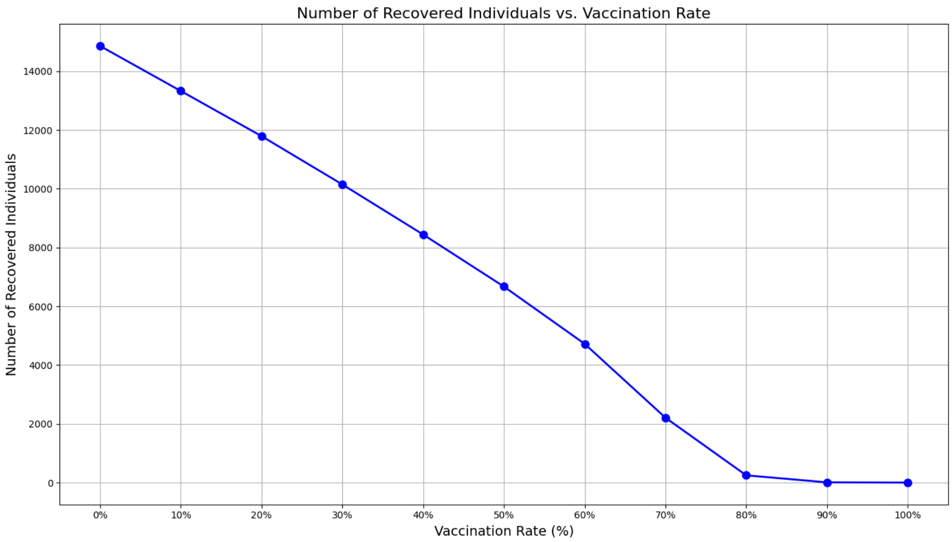

Figure 2: Number of Recovered Individuals vs. Vaccination Rate

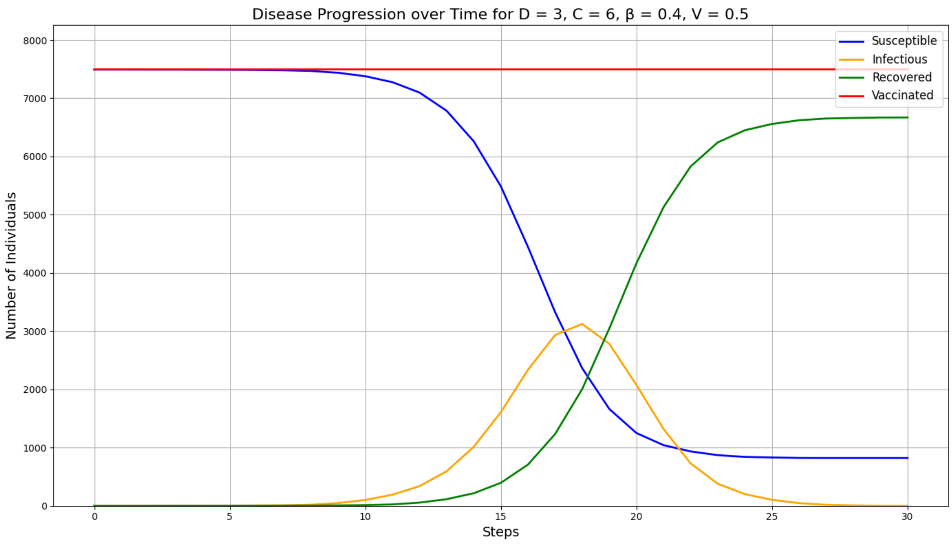

Figure 3: Disease Progression over Time for 50% Vaccination Rate

tions of herd immunity. For example, with a 50% vaccination rate, persons at risk decline and recovered ones grow, highlighting vaccination's efficacy in disease prevention.

When comparing the simulated herd immunity threshold with the theoretical threshold (Figure 1), results show that the simulation correctly captures the disease dynamics. However, slight variations may arise because of random variation in the simulation.

6 Conclusion

This study highlights the crucial role of vaccination in achieving herd immunity. The simulation results confirm that higher vaccination rates lead to fewer infections and quicker disease extinction. These findings highlight the critical role of vaccination programs in controlling infectious diseases.

7 References

- Summer Term 2024, Prof. Dr. Christoph Schober (christoph.schober@th-deg.de), Programming Lab for HPC/QC, “StA”.