Epidemic Models and Decision Support for Vaccine Distribution and Essential Medical Supplies

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Introduction

- Endemic
- Epidemic
- Pandemic

Figure 1: Disease Outbreak [shorturl.at/fnqS6]

- What is Compartmental Disease Modeling?
- SIR, SEIR, etc.

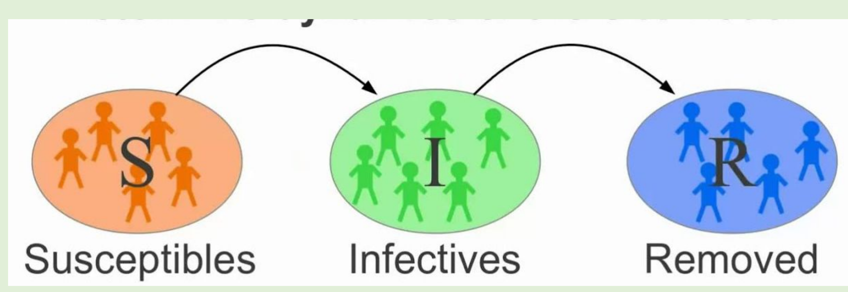

Figure 2: SIR Model [shorturl.at/kmuMZ]

Basic SIR Model

- Mathematical modeling is an appropriate way to analyze any epidemic outbreak in a region.
- Kermack and McKendrick (1927) first introduced the ordinary differential equation (ODE) for an epidemic outbreak.
- The following ordinary differential equations represent the population dynamics from one compartment to other compartments during an epidemic.

$$\frac{dS}{dt} = -\beta SI \ \ldots\ldots (1)$$

$$\frac{dI}{dt} = \beta SI - \gamma I \ldots (2)$$

$$\frac{dR}{dt} = \gamma I \ldots\ldots\ldots (3)$$

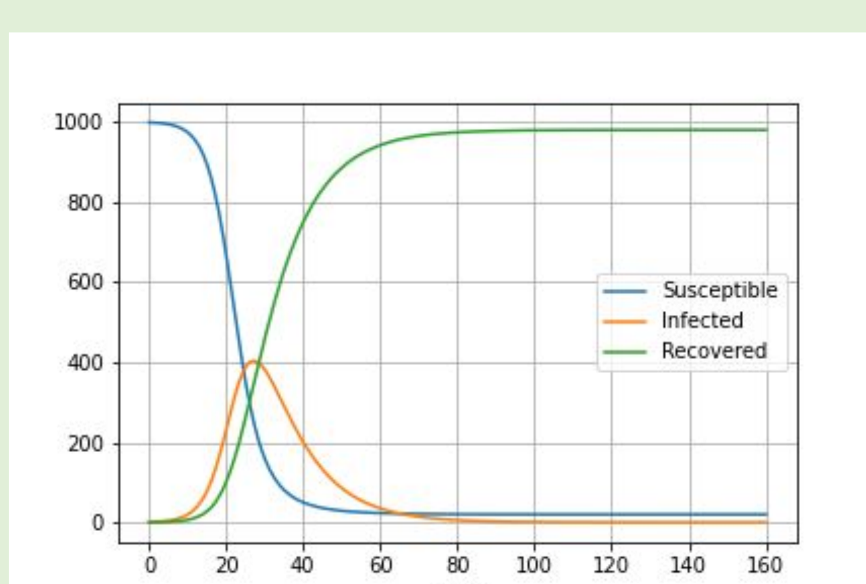

Figure 3: SIR Model

Results

- We have simulated the model using the *odient* library in python programming language for t = 50 days, considering all the model parameters and population values.
- Below figure represent the comparison of susceptible, infected, and recovered population when considering with vaccination and without vaccination.

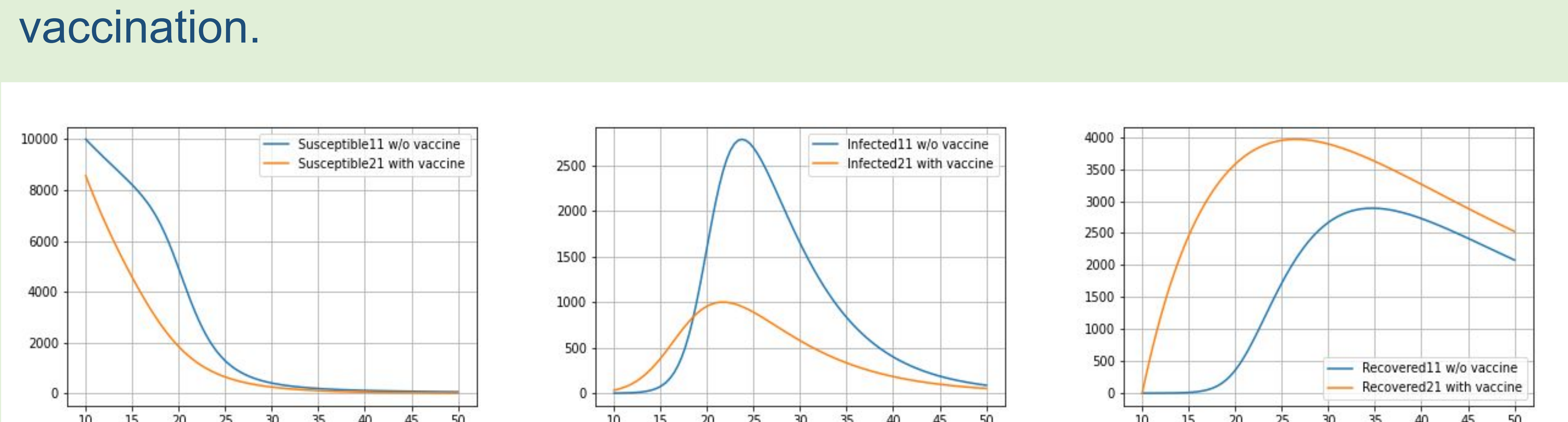

Figure 4: Comparison Diagram

Assumption

- We have considered that in a single region i = 1, there are two priority groups j = 2, high priority and low priority groups, respectively, for vaccines.
- We have taken model parameter values such as the natural death rate (alpha), natural birth rate (mu), disease transmission rate (beta), and recovery rate (gamma) from the literature Shamsi et al.(2021).
- Also, we have assumed the total population number (N) (not the real number) for both priority groups.
- Then, we assumed the initial number of infected(I) and recovered (R) populations for both priority groups. And using the following relationship, we are able to calculate the number of susceptible (S) population value N = S + I + R.
- The value of the proportion of susceptible individuals at session i who are vaccinated at time t (ui) has been taken from the literature Shamsi et al.(2021).

Model Description

- In this presentation, we intend to present a set of differential equations before and after vaccination that has been taken from the literature, Shamsi et al.(2021).

- Following are the ODE before vaccination:

$0 \le t \le \tau_{start}$

$$\frac{dS_i}{dt} = \mu_i - \alpha_i S_i - \beta_i S_i I_i \ \ldots\ldots(4)$$

$$\frac{dI_i}{dt} = \beta_i S_i I_i - \alpha_i I_i - \gamma_i I_i \ \ldots\ldots(5)$$

$$\frac{dR_i}{dt} = \gamma_i I_i - \alpha_i R_i \ \ldots\ldots\ldots\ldots(6)$$

$S_i(0) > 0$, $I_i(0) > 0$ and $R_i(0) \ge 0$

- Following are the ODE after vaccination:

$\tau_{start} \le t \le T_{end}$

$$\frac{d\hat{S}_i}{dt} = \mu_i - \alpha_i \hat{S}_i - \beta_i \hat{S}_i \hat{I}_i - u_i \hat{S}_i \ \ldots\ldots\ldots(7)$$

$$\frac{d\hat{I}_i}{dt} = \beta_i \hat{S}_i \hat{I}_i - \alpha_i \hat{I}_i - \gamma_i \hat{I}_i \ \ldots\ldots\ldots\ldots(8)$$

$$\frac{d\hat{R}_i}{dt} = \gamma_i \hat{I}_i - \alpha_i \hat{R}_i + u_i \hat{S}_i \ \ldots\ldots\ldots\ldots(9)$$

$\hat{S}_i(0) > 0$, $\hat{I}_i(0) > 0$ and $\hat{R}_i(0) \ge 0$

Conclusion and Future Research Direction

- We can observe from the above graph the number of susceptible populations decreases rapidly when we consider the vaccination factor.
- Similarly, the infected population decreases, and the recovered population increase rapidly.
- In the future, we can extend this work in different directions.
- Using the SIR data obtained from the simulation, we can design the market. This means we can choose the vaccine suppliers.
- Also, we can solve a vehicle routing problem for the efficient distribution of vaccines.

Reference

- Kermack, W. O., and McKendrick, A. G. (1927). A contribution to the mathematical theory of epidemics. Proceedings of the royal society of london. Series A, Containing papers of a mathematical and physical character, 115(772), 700-721.
- Shamsi Gamchi, N., Torabi, S. A., and Jolai, F. (2021). A novel vehicle routing problem for vaccine distribution using SIR epidemic model. OR Spectrum, 43(1), 155-188.