Scientific Report: SIR Epidemic Simulation

AI Coding Agent

2025-02-13

Introduction

1. Methods

We implemented a deterministic **Susceptible-Infected-Recovered (SIR)** epidemic model to simulate the spread of an infectious disease in a closed population.

The model dynamics are defined by the following system of ordinary differential equations (ODEs):

$$\begin{aligned} \frac{dS}{dt} &= -\frac{\beta SI}{N} \\ \frac{dI}{dt} &= \frac{\beta SI}{N} - \gamma I \\ \frac{dR}{dt} &= \gamma I \end{aligned}$$

Parameters: * **Total Population (N):** 1000 * **Initial Infected (I_0):** 1 * **Transmission Rate (β):** 0.3 (Baseline) * **Recovery Rate (γ):** 0.1 * **Duration:** 160 days

The system was solved numerically using `scipy.integrate.odeint`. The implementation was modularized into configuration, modeling, simulation, and visualization components.

2. Results

Baseline Simulation ($\beta = 0.3$)

The simulation revealed a classic epidemic wave (Figure 1): * **Peak Infection:** 300.78 individuals (~30% of the population). * **Time to Peak:** Day 38.24. * **Final Recovered:** 940.52 individuals (94% attack rate).

The epidemic ended due to the depletion of the susceptible pool (herd immunity), rather than total infection of the population.

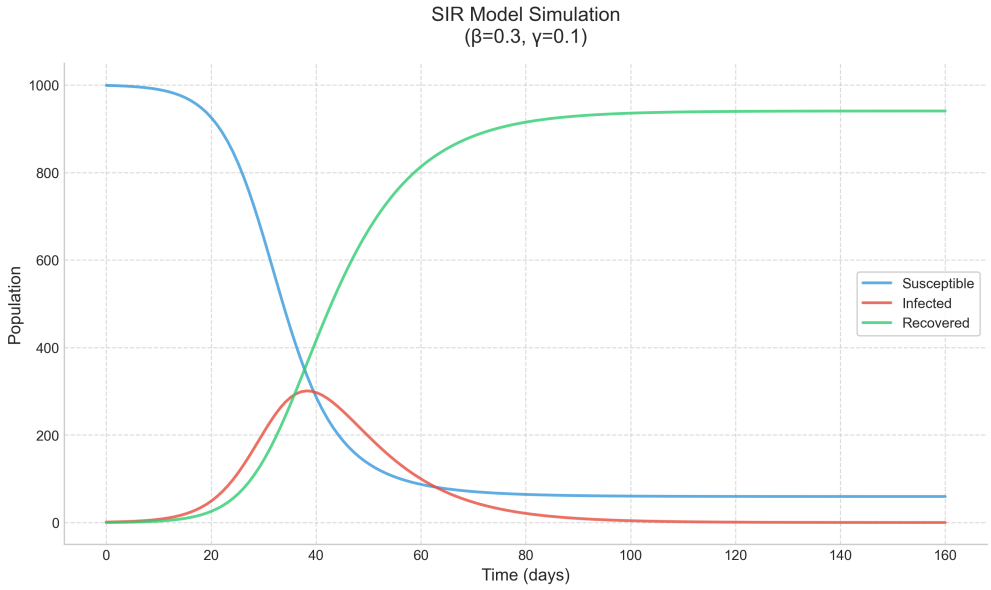

Figure 1: Baseline SIR simulation showing dynamics of Susceptible (Blue), Infected (Red), and Recovered (Green) populations over time.

Sensitivity Analysis

We investigated the impact of varying the transmission rate β from 0.1 to 0.5 (Figure 2): * **Non-linear Impact:** Increasing β resulted in a super-linear increase in peak infection count. * **Acceleration:** Higher β values caused the epidemic to peak significantly earlier (exponential decay in time-to-peak). * **Threshold Behavior:** At lower β values (closer to $\gamma = 0.1$), the outbreak was significantly suppressed, demonstrating the critical nature of the basic reproduction number ($R_0 = \beta/\gamma$).

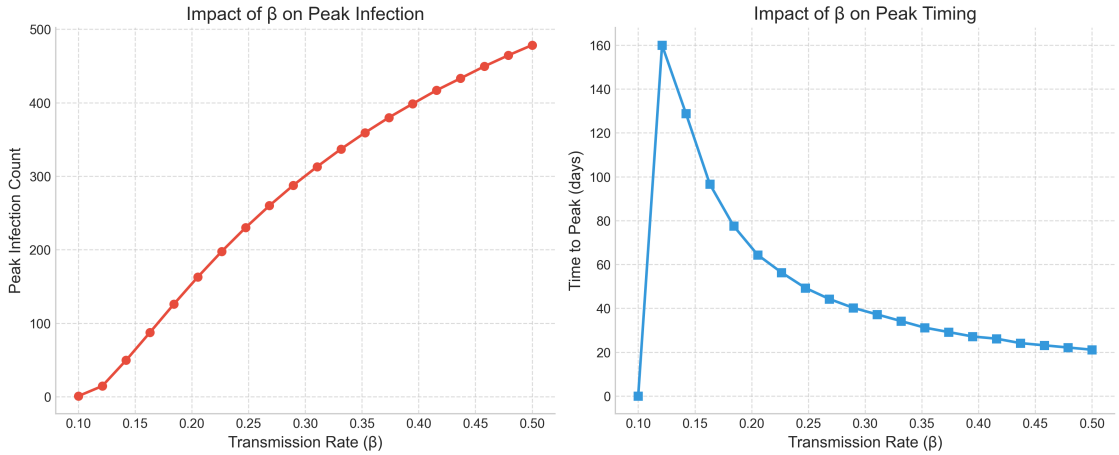

Figure 2: Sensitivity analysis of transmission rate (β). Left panel: Peak infection count vs β. Right panel: Time to peak vs β.

3. Validation

The codebase underwent a structured review process: 1. **Code Review:** Addressed hardcoded values, improved type safety, and enforced modular separation of concerns. 2. **Reproduction:** The refactored simulation was verified to produce **identical** numerical results to the initial prototype, checking peak values and timing. 3. **Visualization:** Automated tests generated plots for both the time-series dynamics and parameter sensitivity, confirming the qualitative behavior matches theoretical expectations.