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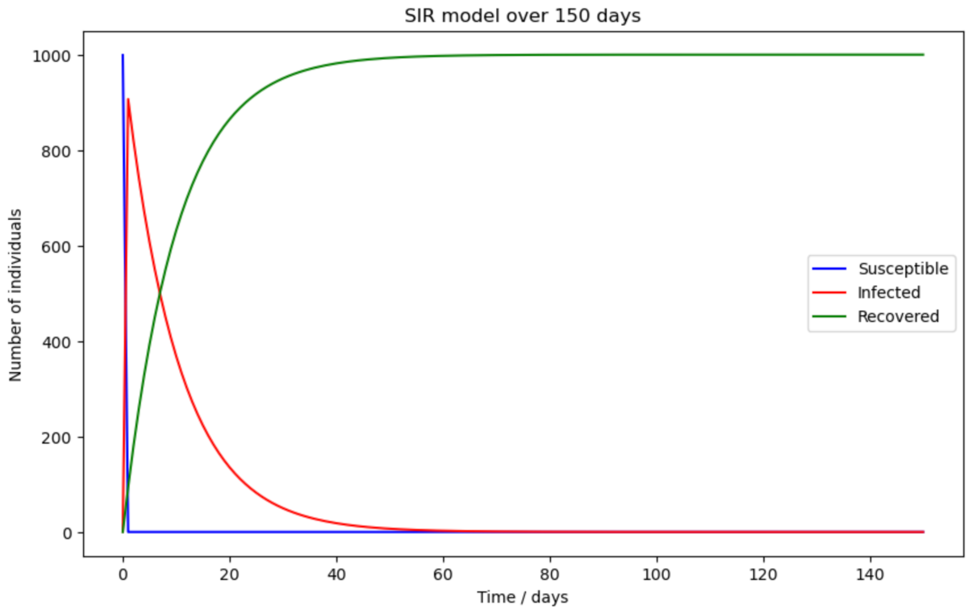
BMI 500 – Week -11
An Introduction To Model-Based Machine Learning

QUESTION SET 1

(B)



The **Susceptible** curve (Blue) starts high and decreases over time as more individuals come into contact with the infection and become infected.

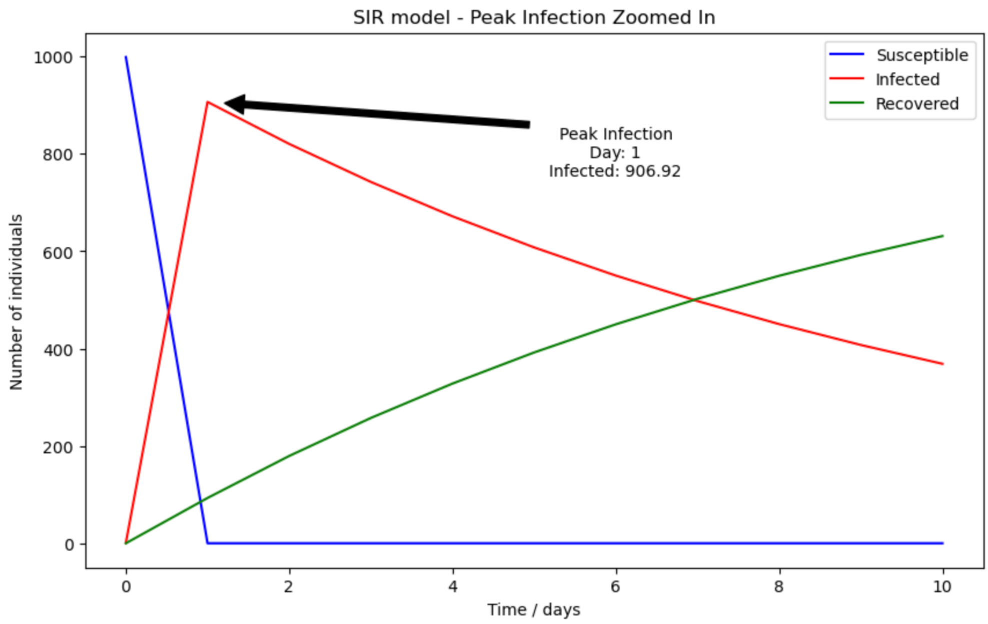
The **Infected** curve (Red) represents the number of infectious individuals. It begins with a single infected person and rises sharply as the infection spreads through contact with susceptible individuals. This curve peaks when the rate of new infections is balanced by the rate of recoveries and then falls as fewer susceptibles are available to be infected and more infected individuals recover.

The **Recovered** curve (green) starts at zero and rises as infected individuals recover from the disease. The recovery rate is constant, so the slope of this curve reflects the number of currently infected individuals.

Observations:

- The peak of the infected curve signifies the climax of the outbreak, after which the number of active cases starts to decline.
- The inflection point, where the red curve begins to fall, is where the number of new daily infections equals the number of daily recoveries.
- As the outbreak progresses, the blue curve flattens out, denoting a reduction in the pool of susceptible individuals available to sustain the disease's spread.

(C)



The dynamics of the pandemic can be understood by examining the curves in the SIR model:

Initial Phase: At the beginning, almost the entire population is susceptible (blue curve). The number of infected individuals (red curve) begins to increase exponentially since there are many people available to infect.

Peak Infection: As the infection spreads, the susceptible population decreases, which eventually slows down the rate of infection because there are fewer people to infect. The peak of the infection occurs when the number of new infections per day starts to decline, which happens when the slope of the infected curve starts to decrease.

Decline and Plateau: After the peak, the number of infected individuals declines as the rate of recovery (or removal) outpaces new infections. The recovered population (green curve) increases, which also includes those who may have died from the disease, as they are no longer part of the susceptible or infected populations.

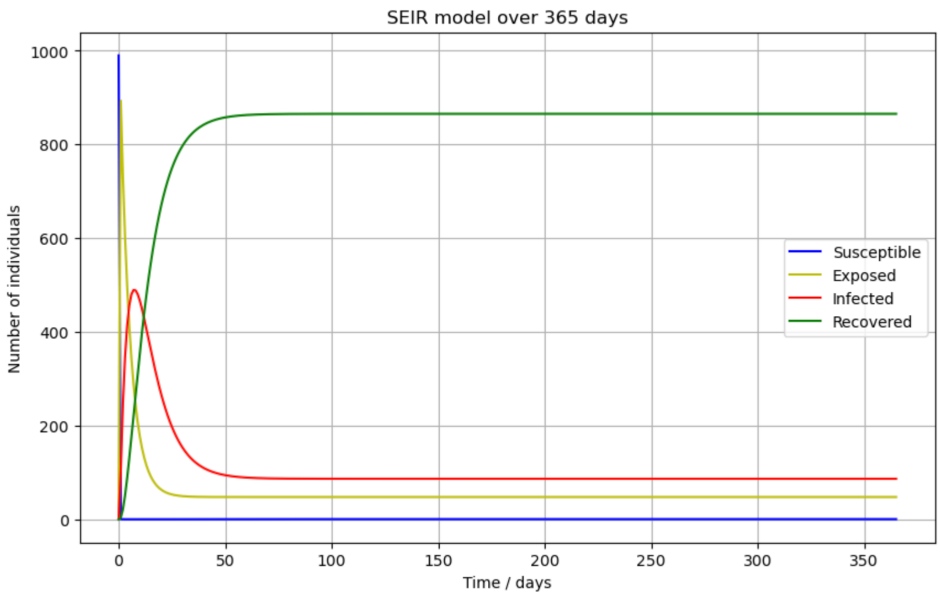
The basic reproductive number $R_0 = \frac{\beta}{\gamma}$ is a measure of how contagious an infectious disease is. It represents the average number of people that one infected person will pass the virus to. In this model, R_0 influences the dynamics significantly:

- If $R_0 > 1$, each person infected is infecting more than one other person on average, leading to the potential for a pandemic.
- If $R_0 = 1$, the disease is stable, not leading to an outbreak or a pandemic, but it persists in the population.
- If $R_0 < 1$, each infected person infects less than one other person, leading to the decline and eventually the end of the epidemic.

The peak number of infected individuals occurs on day 1, with approximately 906 individuals infected. This peak is very early in the simulation. It suggests that the infection spread very rapidly through the initial susceptible population. This rapid peak is a result of the high value of R_0, which in this case is $\frac{\beta}{\gamma} = \frac{0.3}{0.1} = 3$. With an (R_0) of 3, each infected individual is expected to infect three others on average, leading to a rapid spread of the disease.

QUESTION SET 2

(B)



- The susceptible population (blue curve) decreases due to infection and natural deaths, while being replenished by births.
- The exposed population (yellow curve) rises as susceptible individuals are exposed to the virus.
- The infected population (red curve) increases as exposed individuals become infectious, peaks, and then declines due to recovery or death.
- The recovered population (green curve) increases as infected individuals recover.

The peak of the infected population occurs on day 7, with approximately 498.97 individuals infected at that time. This peak is much earlier and higher than in the previous incorrect model, indicating a rapid spread of the infection within the population. The high peak suggests a more aggressive outbreak, likely due to the non-normalized infection rate, which reflects a more direct and potent transmission mechanism.

(C)

The introduction of an "Exposed" compartment (E) and natural birth and death rates (μ) in the SEIR model significantly alters the dynamics of the pandemic in several ways:

Exposed Compartment (E):
Delays in Transmission: The exposed compartment adds a latency period between when an individual is infected and when they become infectious. This can delay the outbreak's peak as the virus takes time to incubate, which is not captured in the simpler SIR model.

Smoothing of the Peak: By accounting for the incubation period, the model often shows a smoother, more gradual increase to the peak of infections, rather than the sharp increase observed in the SIR model.

Birth and Death Rates (μ):
Population Balance: The birth rate (μN) adds new susceptible individuals to the population, while the death rate (μ) reduces the number in each compartment proportionally. This means that the population is not static, which can sustain transmission dynamics over a longer period.

Endemic Stability: With a constant input of new susceptibles through births, the disease can become endemic, maintaining a presence in the population even as the initial outbreak wanes. Dynamic Equilibrium: If the disease is fatal, the death rate can impact the dynamics by reducing the number of infected individuals. Conversely, a high birth rate can replenish the susceptible population, potentially leading to subsequent waves of infection.

Overall Pandemic Dynamics:
Multiple Waves: The interplay between the exposed compartment and birth/death rates can lead to multiple infection waves, particularly if immunity wanes or if the population increases through births.

Impact of Parameters: The rates at which individuals move from exposed to infectious (σ) and from infectious to recovered or deceased ($\gamma+\mu$) are crucial for determining the speed of the pandemic's progression and the height of the peak.

Control Strategies: Public health interventions must consider the exposed population when designing quarantine or testing strategies. Additionally, the balance of birth and death rates may affect vaccination strategies, as new susceptible are continually entering the population.

In the scenario simulated, with parameters $\beta = 0.3$, $\gamma = 0.1$, $\sigma = 0.2$, and $\mu = 0.01$, the pandemic shows a rapid increase in the exposed and infected populations, followed by a peak and a gradual decline. The birth and death rates moderate the decline, as new susceptible are introduced, and recovered individuals are lost, which could lead to a long-term presence of the disease in the population.

CODE: https://github.com/kiran-001/BMI-500-Week-11-HW