Dynamic Interactions in Epidemic Modeling: An Interactive SEIR Model

Introduction

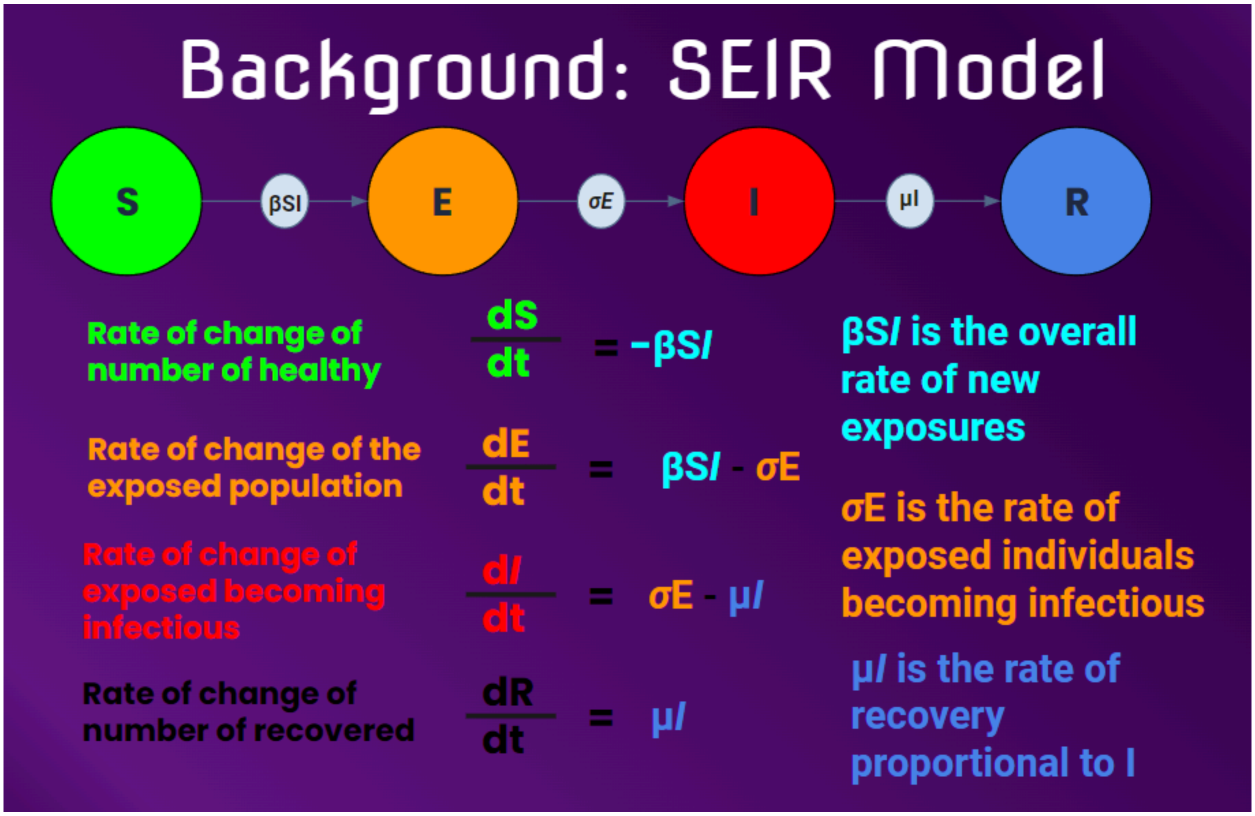
Motivation: Understanding the dynamics of infectious disease spread is essential for students and industry professionals in epidemiology and public health. However, traditional teaching methods may rely on static models that do not fully convey the dynamic and complex nature of epidemics. An interactive SEIR model provides a hands-on learning experience, allowing users to experiment with various epidemic parameters and observe the outcomes in real-time.

Problem Statement: Current educational tools for teaching epidemiology are often limited by their inability to dynamically demonstrate the impact of varying public health interventions and disease characteristics on epidemic outcomes. This limit hinders the understanding and engagement needed for effective learning. The interactive SEIR model addresses this by providing a real-time simulation environment. This tool allows learners to manipulate variables such as transmission rate, transition rate, recovery rate, and population size.

Related Work and Background

Existing Research: As stated by foundational epidemiology research the SEIR model is a fundamental tool in epidemiology, used to understand the spread of infectious diseases through populations. It divides the population into four compartments: Susceptible(S), Exposed(E), Infectious(I), Recovered(R). Individuals in the Susceptible category are healthy but can contract the disease. Once exposed to the disease, they move to the Exposed category where they are infected but not yet infectious. After a period, which reflects the incubation period of the disease, exposed individuals become infectious and are categorized under Infectious. Finally, after the infection period, individuals recover and move into the Recovered category, where they are assumed to have immunity.

Mathematically, the transitions between these states are typically represented by differential equations, governed by parameters such as: Beta (β) the transmission rate, which affects how quickly the disease spreads from infectious to susceptible individuals, Sigma (σ) represents the transition rate or the rate at which individuals become infectious, inversely related to the incubation period, Mu (μ) is the recovery rate indicating how quickly infectious individuals recover and gain immunity. These parameters are crucial as they dictate the dynamics of the disease spread, this influences the model's predictions on outbreak progression and eventual control.



Background Information: This report requires an understanding of differential equations, population dynamics, and statistics. These concepts are integral to the design of the SEIR model and the interpretation of its results. This provides a structured framework to analyze the impact of various health interventions. The model incorporates real-time data input capabilities, enhancing its utility in responding to changing conditions during an epidemic.

Methods

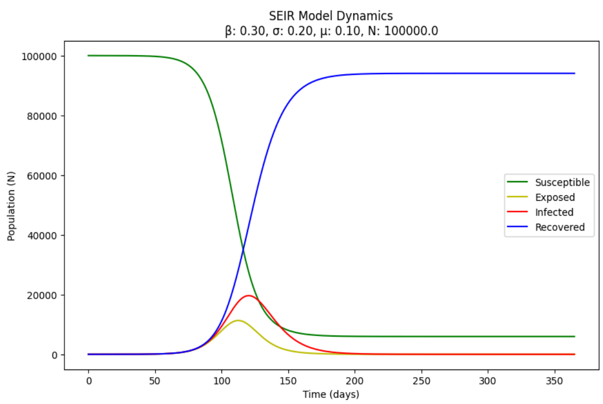
Approach: This model utilizes a simulated environment developed in Python, incorporating the SEIR model to analyze the dynamics of infectious disease within a population. Key to this approach is the interactive nature of the simulation, which allows users to manipulate variables such as the transmission rate (β), the transition rate (σ), the recovery rate (μ), and the population size (N). Using two functions one for the data generation of the model where the rate of change for each compartment is calculated and the other function will plot this data.

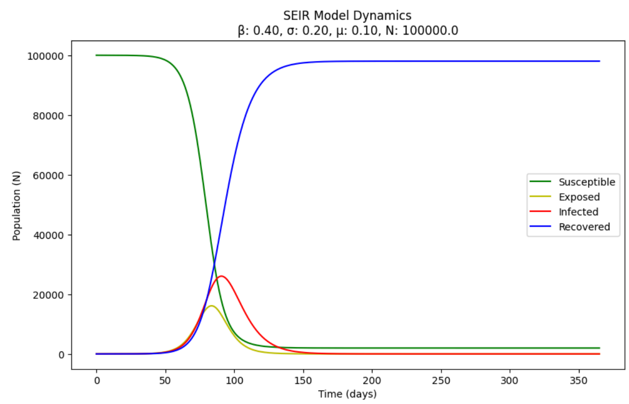
Evaluation and Results

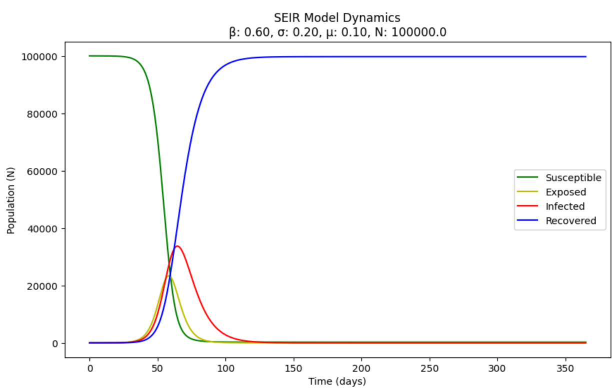
Procedure: The evaluation process involved running multiple simulations with the SEIR model, each adjusting key parameters as mentioned before. The model was set to simulate the spread of an infectious disease over 365 days, with the initial conditions set for the number of susceptible, exposed, infectious, and recovered individuals. Scenarios were used to test different outcomes in the model, high transmission scenario with high β and standard σ and μ, high latency scenario where β is standard with decreased σ, high recovery scenario where β and σ are standard with increased μ.

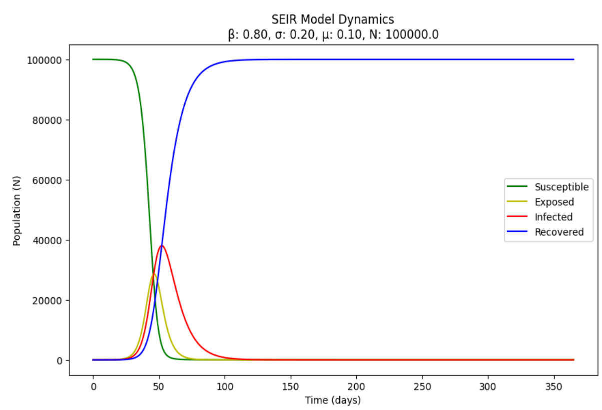
Results: The scenario findings highlight how changes in key epidemiological parameters can drastically alter the trajectory of an epidemic.

High transmission scenario:



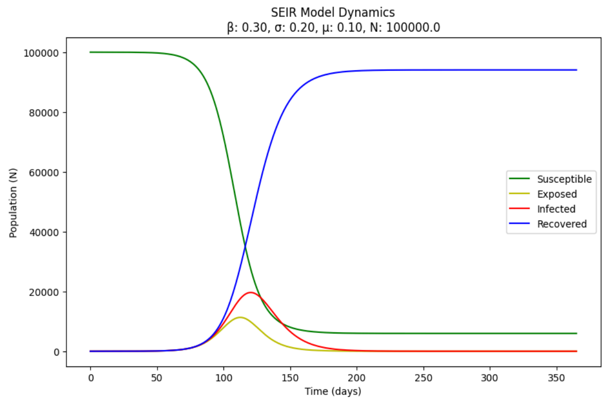


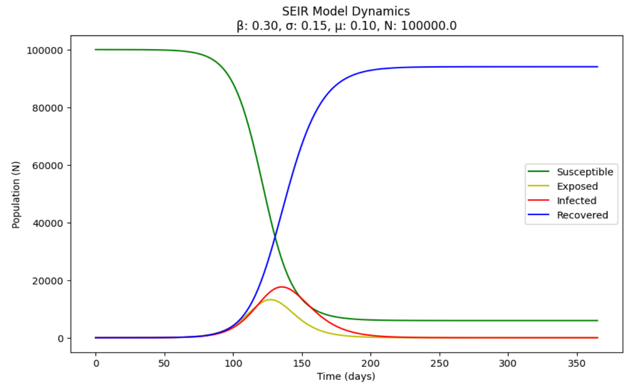


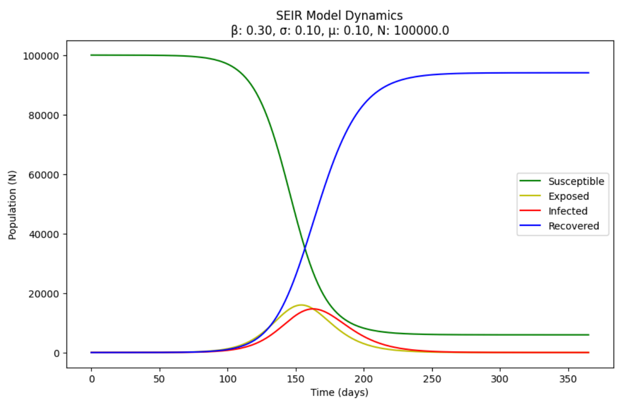


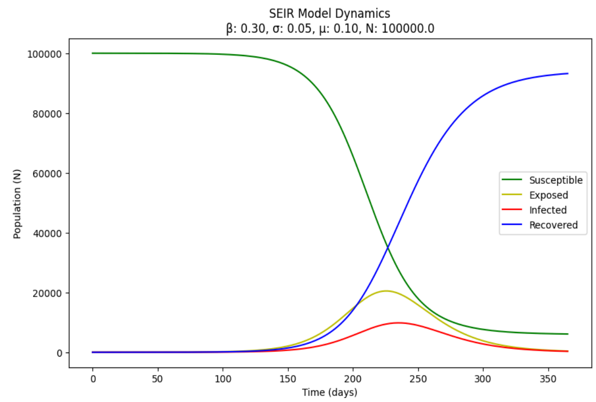
- This scenario resulted in rapid spread with a high peak infection rate, the higher the transmission rate (β) got the quicker the outbreak occurred and most individuals got infected and recovered. This shows students how important the impact of transmission rates are on epidemic severity.

High latency scenario:



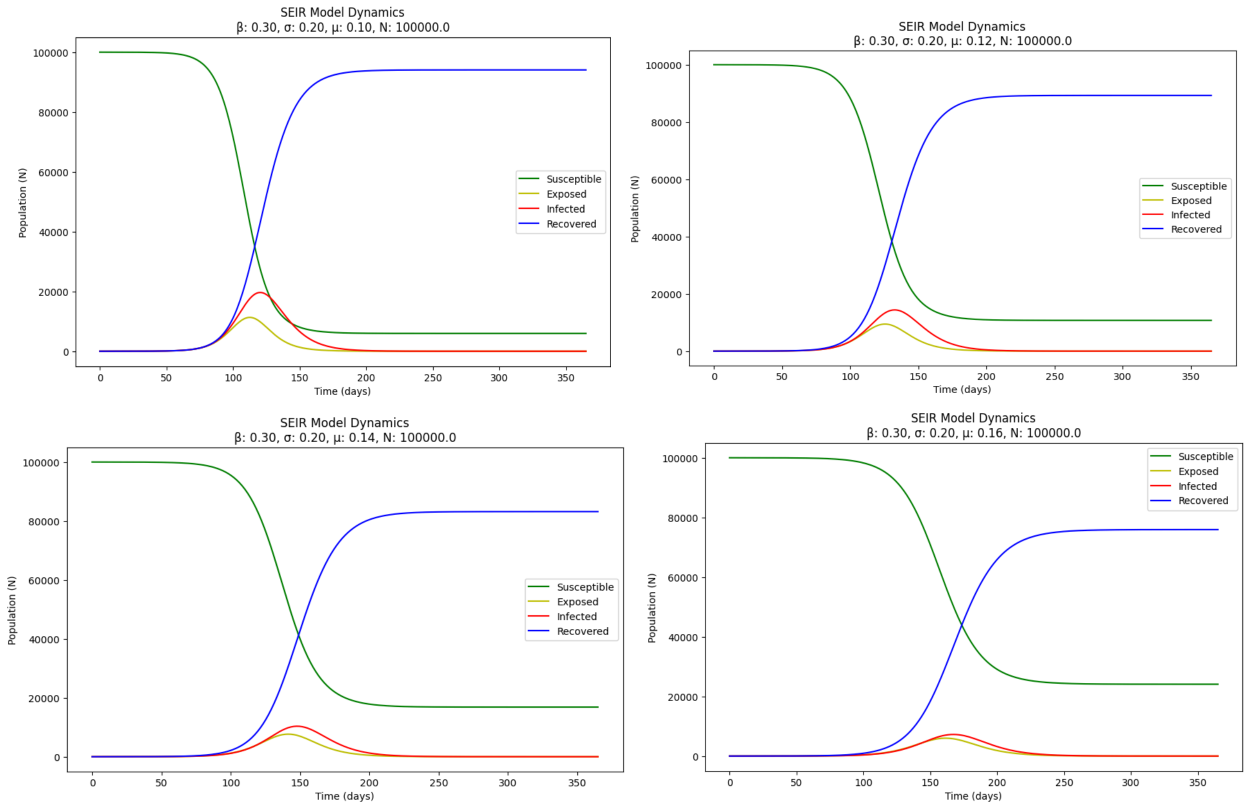






- With a lower transition rate (σ) the outbreak's severity is lowered and the outbreak will happen later on in the simulation. This flattens the curve, reducing the peak infection rate but this extends the epidemic’s duration. This could be used by students to study the effectiveness of policies such as social distancing and masking as they lower the transition rate (σ).

High Recovery Scenario:



- Increased recovery rate (μ) significantly shortened the duration of the epidemic and reduced total infections, underscoring the importance of effective treatment and recovery strategies.

Conclusion and Future Work

Contributions: This report showcases the significant role that dynamic modeling plays in understanding and managing infectious diseases. By using an interactive SEIR model, this report demonstrates the complex dynamics of disease transmission and recovery within a population. The findings in this report contribute to the field of epidemiology by providing learners with a hands-on tool that can simulate different scenarios based on variable disease parameters. This interactive approach allows both researchers and policy makers to visualize the potential impact of public health interventions and better prepare for and manage outbreaks.

Future Directions: The arena of infectious disease modeling offers many opportunities for further expansion. Future work could expand this SEIR model by incorporating additional layers of complexity, such as age-structured populations, spatial dynamics, or stochastic elements to better mimic our material world. Also, extending the model could provide deeper insights into effective disease control measures. Further research could also adapt the interactive model for educational purposes, enhancing its utility in academic settings to train future epidemiologists.

Feedback: After this presentation we were given feedback on how I could improve upon the motivations and problem statement. The presentation could have had more background knowledge added to it for better audience understanding. The slides had a bit more text than needed so cutting down on text and having flash cards up could improve upon this. More preparation and practice of the presentation would have resulted in a more effective performance.

References

Thomas, Robin. "How Do Mathematicians Model Infectious Disease Outbreaks?" *YouTube*, Oxford, 8 Apr. 2020, www.youtube.com/watch?v=m6Hr69JH_wA&t=1452s.