SIR Epidemic Model: A Comprehensive Visualization and Analysis in COVID-19 Dynamics

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Abstract

This document presents a data-driven approach to epidemic modeling using the SIR (Susceptible-Infected-Recovered) model, with a focus on COVID-19. It explores graphical representations of the simulation, interprets trends and peak infection rates, and evaluates the accuracy of numerical methods like Euler and Runge-Kutta (RK4). The findings provide insights for public health policies, including social distancing, vaccination, and lockdown strategies.

1 Introduction

COVID-19, caused by the SARS-CoV-2 virus, spread rapidly, overwhelming healthcare systems. Mathematical models, particularly the SIR model, played a vital role in predicting the dynamics of infection spread. This study applies the SIR model to simulate COVID-19 outbreaks, analyze peak infections, and evaluate mitigation strategies.

2 1. Data Visualization: Graphical Representations of Epidemic Dynamics

2.1 SIR Model Dynamics Graph

Key Takeaways:

- Initially, almost everyone is susceptible (blue curve).

- The infected curve (red) peaks at a critical point, highlighting the need for medical intervention.
- The recovered curve (green) gradually rises, indicating increasing population immunity.

3 2. Graph Analysis: Trends, Peak Infection, and Accuracy of Numerical Methods

3.1 Comparing Euler & RK4 Numerical Methods

Key Insights:

- Euler's method underestimates the infection peak, leading to inaccurate forecasts.
- RK4 is more reliable, making it useful for public health planning (e.g., predicting ICU demand).
- Accurate modeling ensures effective decision-making during real-world outbreaks like COVID-19.

3.2 Effect of Infection & Recovery Rates on COVID-19

Observations:

- Higher β (infection rate) leads to earlier, steeper outbreaks.
- Higher γ (recovery rate) speeds up recovery, flattening the infection curve.
- Social distancing and vaccination impact these rates and help control the spread.

4 3. Presentation Design: Clarity, Readability & Visual Impact

Enhancements for Better Understanding:

- Seaborn's professional styling ensures a polished look.
- Shaded areas emphasize critical infection periods.
- Labeled axes and legends improve clarity.

5 Impact on Healthcare Systems

The peak of the infected curve correlates with hospital demand. Table **??** summarizes the relationship between peak infections and hospitalizations.

6 Policy Interventions and Real-World Applications

To control COVID-19, governments worldwide implemented:

- Social distancing ($\beta \downarrow$)
- Mask mandates ($\beta \downarrow$)
- Vaccination campaigns ($\gamma \uparrow$)
- Lockdowns and quarantine ($S \downarrow$ to limit contact)

These strategies effectively flattened the curve, reducing hospital overload and saving lives.

7 Key Takeaways

- Peak infection periods require strong healthcare response strategies.
- RK4 provides more accurate epidemic forecasts than Euler's method.
- Policy decisions (e.g., lockdowns, vaccinations) significantly impact disease spread.
- Data-driven epidemic modeling is crucial for global health preparedness.

8 Conclusion

The SIR model offers valuable insights into COVID-19 dynamics. Accurate modeling supports pandemic preparedness by guiding interventions such as vaccination strategies and social distancing policies.

References