Model of Pandemic Progression

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Abstract

This report presents a system dynamics model to analyze pandemic situation. This Model help us to understand population dynamics, healthcare system responses, vaccination strategies, and economic impacts during a pandemic. We specially focused on understanding epidemic wave patterns and evaluating strategies for simulation-based analysis.

1 Problem Statement

The COVID-19 pandemic has highlighted the critical requirement for robust modeling tools which is used to understand and manage the infectious disease outbreaks. To Predict how diseases spread is still a difficult task. It is require to accurate the models that consider different group of peoples and their behaviors. Another major challenge is to manage healthcare systems. We also require to carefully test that prevention strategies work best.

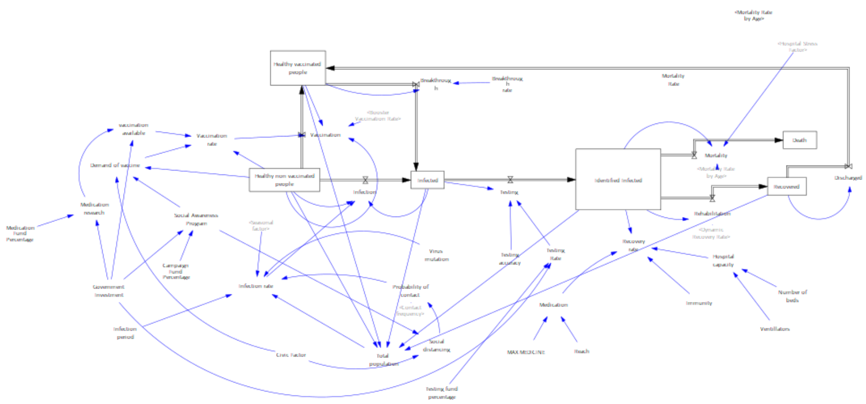

Figure 1: Overview of the pandemic model showing key components and their interactions

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2 Introduction

Understanding pandemic dynamics is crucial for effective public health response. Our system dynamics model captures the complex interactions between disease transmission, healthcare capacity constraints. Disease transmission dynamics are modeled across six distinct population compartments, providing detailed insights into how the virus moves through different groups. . Further, it also considers the economic and social impacts of the disease itself and various control measures via medication , vaccination and social awareness . Behavioral aspects, including public compliance with health measures and the effects of pandemic fatigue, are integrated into the model to provide realistic predictions.

3 Model Structure

The model consists of several key components that interact with each other to determine pandemic outcomes:

1. **Population Segments**:
   - Healthy vaccinated people.

- Healthy non-vaccinated people.
- Infected individuals.
- Recovered individuals.
- Deceased individuals.

2. **Infection and Recovery Rates**:

    - **Breakthrough Infection Rate**: Some vaccinated individuals still get infected.

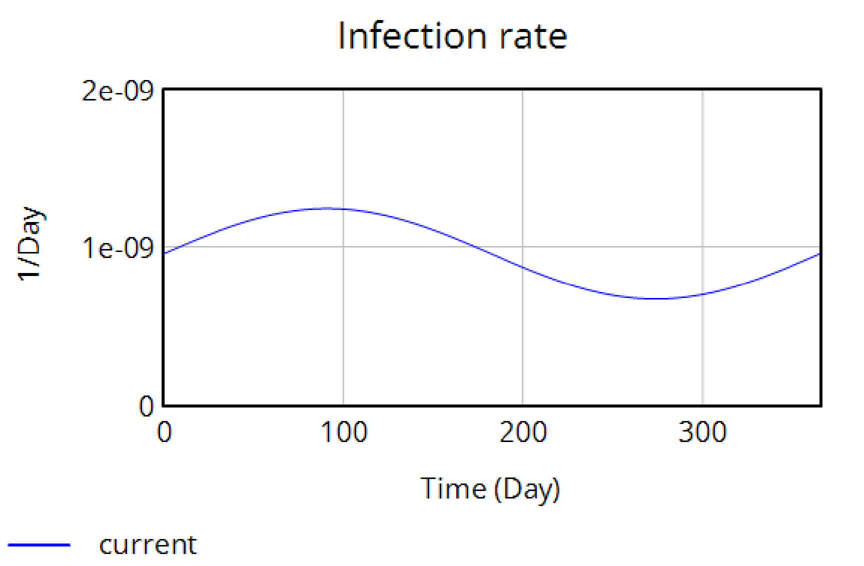

Figure 2: Key feedback loops in the pandemic model, showing how different components interact to create system behavior

    - **Mortality Rate**: Determines how many infected individuals succumb to the disease.
    - **Recovery Rate**: Defines how quickly infected individuals recover and possibly gain immunity.

3. **Public Awareness and Compliance**:

    - Awareness campaigns influence vaccination demand.
    - Compliance with health measures affects infection rates.

4. **Government Intervention**:

    - Funds allocated to pandemic response.
    - Investment in public awareness campaigns.

- Policies affecting social behavior and health measures

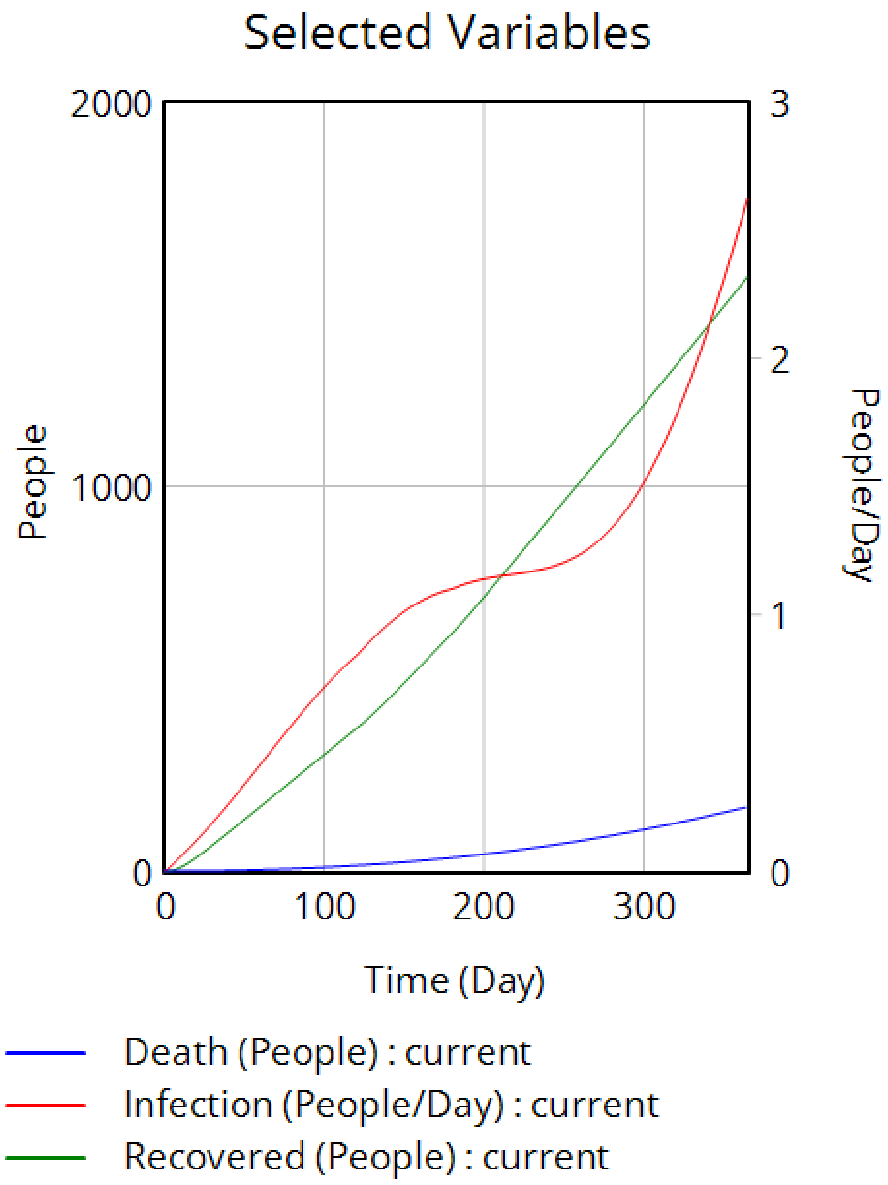

Figure 3: Comparison data

4 Modelling

4.1 Disease Spread

Our model simulates how diseases spread by accounting for several key factors. It tracks how often people come into contact with each other, including changes in social behavior due to rules like lockdowns or mask mandates. The model also includes seasonal effects, since diseases can spread differently depending on the time of year due to weather and human activity. Social distancing measures are factored in as well, reducing contact rates—but their impact depends on how strictly people follow them. Finally, the model considers population density, since crowded areas (like cities) tend to have faster disease spread than less populated ones. By combining these elements, the model helps predict how outbreaks may grow or slow under different conditions.

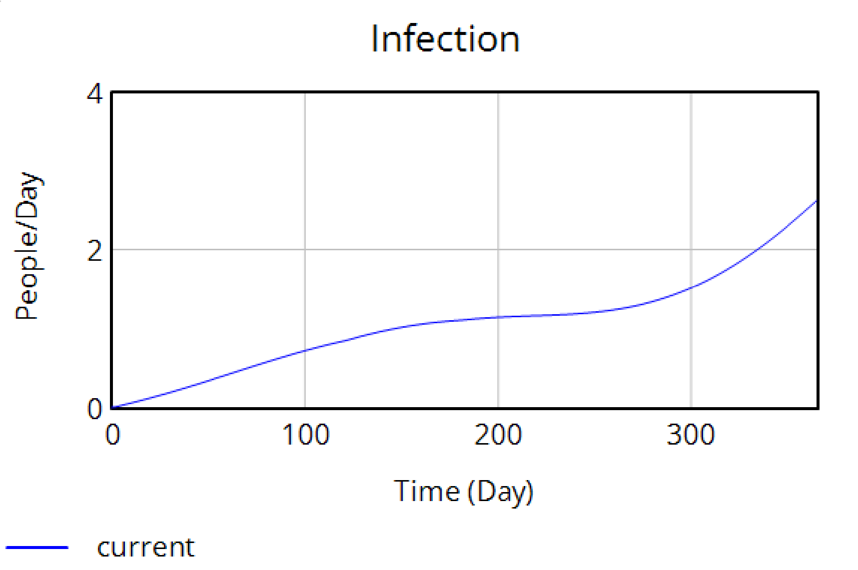

Figure 4: Simulation results showing disease spread patterns

4.2 Healthcare Response

Our model treats the healthcare system as a network of connected parts that adapt to changing demands. The number of available hospital beds—both regular and ICU—limits how many patients can be treated, with adjustments made based on how severe cases are. We also track medical staff availability, including the impact of exhaustion and extra help during peak outbreaks. Treatment methods are included as factors that influence how well patients recover and how resources are used. The system prioritizes where to allocate resources (like beds, staff, and equipment) by balancing what patients need most with what the healthcare system can actually provide.

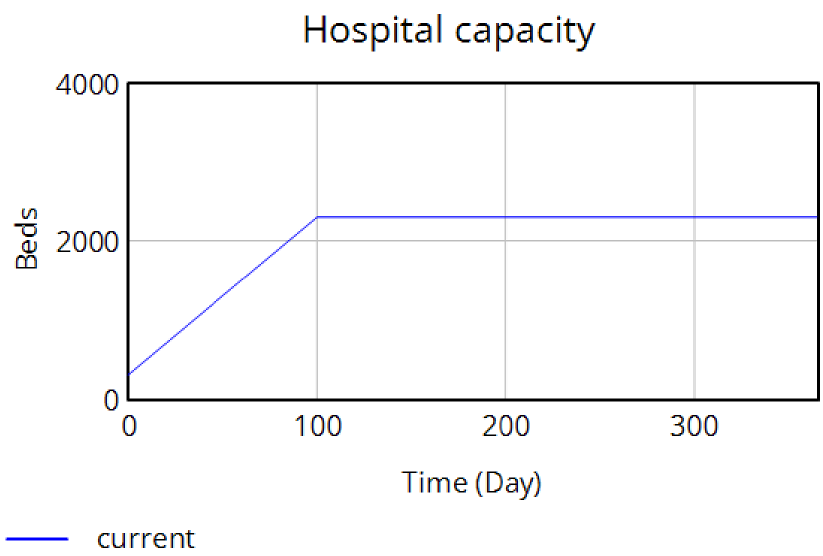

Figure 5: Healthcare system capacity and utilization

5 Disease Dynamics

5.1 Disease Spread

Disease spreading and infection rate depends upon the characterstics of the virus spread. The covid 19 has a high spreading rate than the mortality rate which was making the pandemic situation

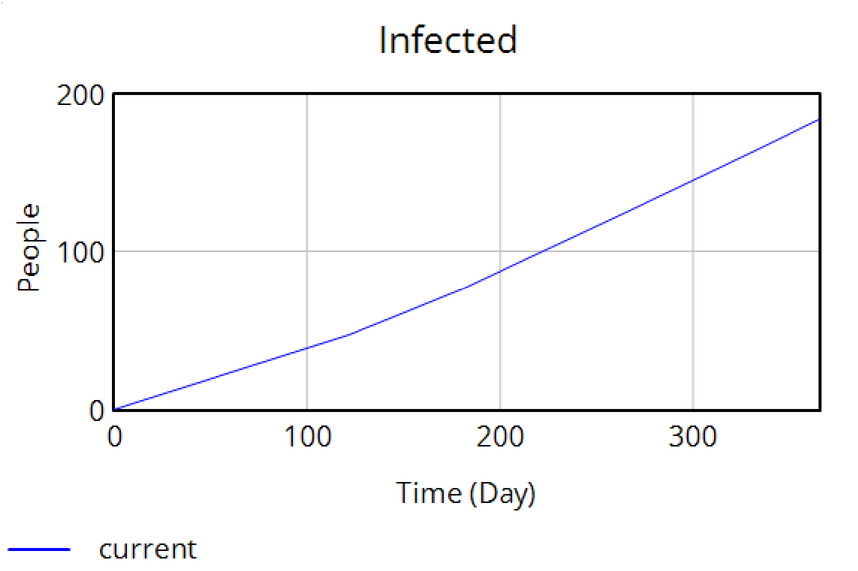

Figure 6: Visualization of the infection process showing how R0 changes over time in response to interventions and immunity

5.2 Disease Spread and Mortality

Hospital bed capacity serves as a primary constraint, with dynamic allocation between standard and intensive care units based on case severity. Healthcare is affected by the resources available like no of beds and ICU wards. It also is limited to the medication availability and supply

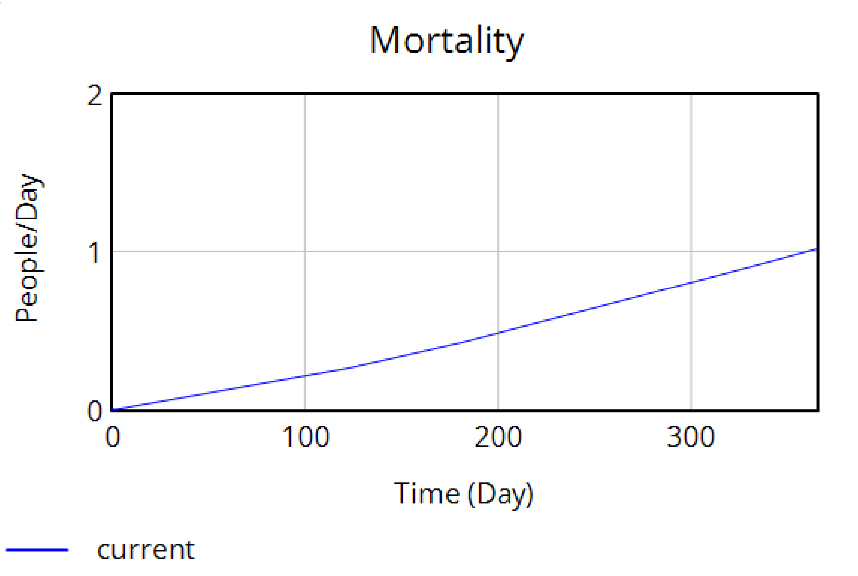

Figure 7: Mortality patterns

6 Conclusion

The model establishes an integrated framework for examining pandemic progression dynamics. It enables policy scenario evaluation to assess impacts on population health indicators. Through simulation of alternative intervention strategies, the framework supports evidence-based decision-making to: (1) mitigate transmission rates, (2) decrease fatality incidence, and (3) optimize vaccine allocation efficiency.

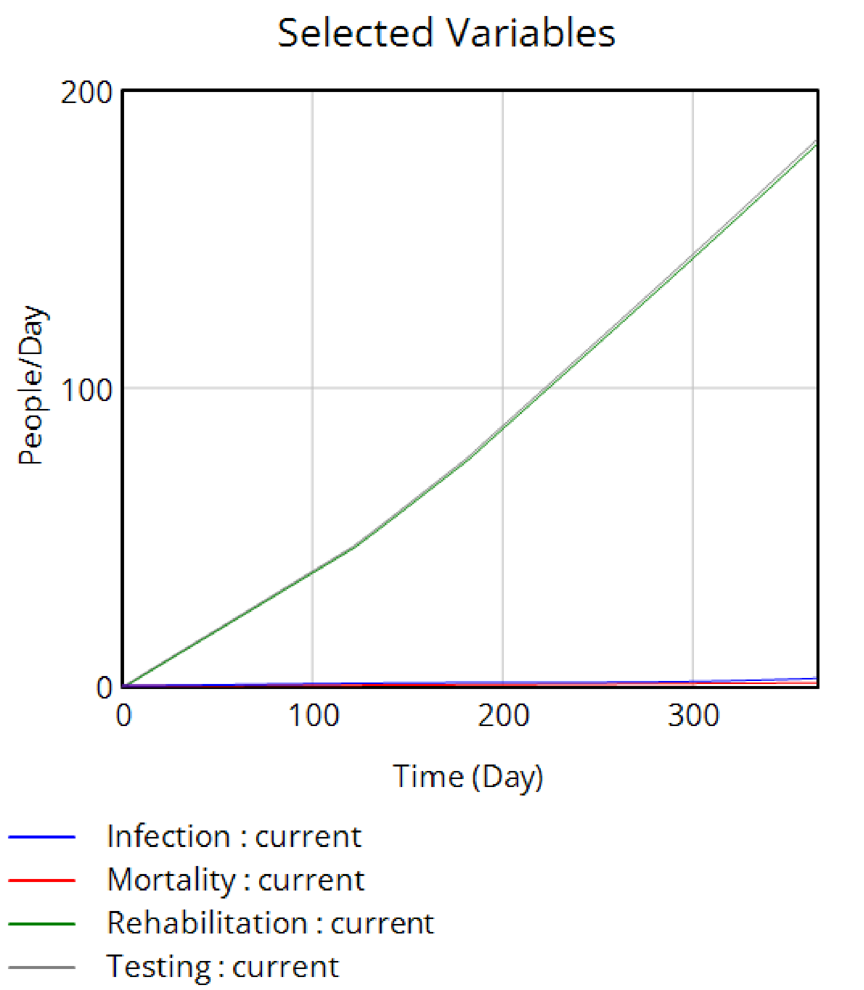

Figure 8: Comparison of different intervention strategies and their effects on pandemic outcomes including , deaths, and rehabiliation.

7 Updates in new submission

7.1 Parameter Calibration and Debugging

The model implementation required careful calibration of numerous parameters and stock-flow relationships. Initial debugging focused on ensuring mathematical consistency and proper unit conversion across all equations. We analyzed the various scenarios and situation to carefully identify the pattern between various entities.

7.2 Stock-Flow Adjustments

Critical adjustments were made to several stock-flow relationships to successful simulate the behaviour of the vensim model. The currect relationship is crucial for the model to correctly exhibit the behaviour of the model and produce the expected and reasonable graphs .

7.3 Behavioral Analysis

Graph generation and analysis revealed several key behavioral patterns: The model successfully reproduced characteristic epidemic waves which was expected. We worked to simulate and identify the behaviour of the graphs to identify the bugs and the issues.

7.4 Model Validation

The debugging process included validation, verification against real-world data:

- Comparison of predicted vs. observed stock flow curves
- Validation of healthcare system utilization patterns
- Assessment of vaccination program effectiveness
- Verification of economic impact predictions