

Virus Spread in a Population: An Agent-Based Modeling Approach



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Acknowledgement

We would like to express our sincere gratitude to **Prof. Dr. Muhammad Aslam** for his valuable guidance, encouragement, and continuous support throughout the course of this project. His insightful feedback and expert suggestions played a crucial role in shaping the direction and quality of this work. We are also thankful to the **Department of Computer Science, University of Engineering and Technology Lahore**, for providing us with the academic environment and resources necessary to complete this project successfully. Special appreciation is extended to our peers for their constructive discussions and moral support during the development and testing of the Agent-Based Model using NetLogo. Finally, we would like to acknowledge our families for their constant encouragement, patience, and motivation, which greatly contributed to the successful completion of this project.

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Abstract

The spread of infectious diseases is a complex phenomenon driven by individual behavior, social interactions, and policy interventions. Traditional compartmental models often rely on simplifying assumptions such as homogeneous mixing, which limits their ability to capture realistic human dynamics. In this study, we develop an Agent-Based Model (ABM) using NetLogo to simulate virus spread within a population where individuals follow daily routines including work, shopping, and staying at home. Each individual is modeled as an autonomous agent whose local interactions give rise to emergent population-level outcomes. The model incorporates disease stages, probabilistic infection mechanisms, and government policy interventions such as curfews and interval-based work schedules. Simulation results demonstrate that increased human mobility accelerates virus transmission, while policy interventions effectively reduce the reproduction number (R_0) at the cost of economic productivity. The model serves as an experimental platform for understanding the trade-off between public health protection and economic activity.

Keywords: Agent-Based Modeling, Virus Spread, NetLogo, Epidemic Simulation, Policy Intervention, Emergence

1 Introduction

The rapid spread of infectious diseases poses significant challenges to public health systems and policymakers [1]. Understanding how individual behavior contributes to large-scale outbreaks is essential for designing effective interventions. Infectious diseases are caused by pathogenic microorganisms, such as bacteria, viruses, parasites or fungi; the diseases can be spread, directly or indirectly, from one person to another [2]. These diseases can be grouped in three categories: diseases which cause high levels of mortality; diseases which place on populations heavy burdens of disability; and diseases which owing to the rapid and unexpected nature of their spread can have serious global repercussions [3]. Classical epidemic models such as SIR and SEIR provide valuable insights but often assume uniform mixing of populations, ignoring spatial structure, daily routines, and behavioral variability.

Agent-Based Modeling (ABM) offers an alternative approach by simulating individuals as autonomous entities interacting locally within an environment [4]. Instead of imposing global equations, ABMs allow system-level patterns to emerge from simple agent-level rules. This approach is particularly suitable for modeling epidemics where human movement, social behavior, and policy compliance play a crucial role.

This project presents an Agent-Based Model developed in NetLogo [5] to simulate virus

spread in a population. The model focuses on how individual routines, disease characteristics, and government interventions collectively influence infection dynamics and economic outcomes. The purpose of the model is not to predict real-world case numbers but to explore scenarios and observe emergent behavior in a controlled simulation environment.

2 Agent-Based Modeling Background

Agent-Based Modeling is a computational modeling paradigm in which a system is represented as a collection of interacting agents operating within an environment. Each agent follows a set of rules that govern behavior, movement, and interaction. The overall behavior of the system emerges from these decentralized interactions rather than from top-down control.

In the context of epidemic modeling, ABM enables representation of heterogeneous individuals, explicit modeling of movement and contact patterns, inclusion of behavioral responses and policy measures, and observation of non-linear and emergent dynamics. These characteristics make ABM especially effective for studying infectious disease spread under varying behavioral and policy conditions.

Several studies have employed agent-based modeling (ABM) to analyze virus propagation under varying mobility and intervention scenarios. For instance, Das et al. [6] proposed a NetLogo-based epidemic model in which agents move across multiple locations via configurable routes, allowing independent lockdown of both routes and locations. The model incorporates key epidemiological states, including infection, recovery, and precautionary behavior, and enables probabilistic transmission influenced by agent immunity and preventive measures. Unlike traditional compartmental approaches, this framework emphasizes spatial mobility, localized interactions, and policy-driven constraints. Although the reported results primarily demonstrate model functionality rather than predictive accuracy, the study provides a flexible, open-source platform for educational use and for extending epidemic simulations with additional behavioral or policy-based mechanisms.

Additionally, Harweg et al. [7] utilized agent-based pedestrian simulations to evaluate the effectiveness of physical distancing as a non-pharmaceutical intervention during the COVID-19 pandemic. One such approach employed an adaptable social force-based agent model to simulate pedestrian movement in realistic public environments and quantify exposure times resulting from close contacts. The study analyzed the impact of varying population densities, interpersonal distances, and infection rates using statistical measures such as box-and-whisker plots. Simulation results indicated that maintaining low pedestrian density significantly reduces exposure duration, thereby supporting physical

distancing policies. These findings highlight the usefulness of agent-based simulations for assessing behavioral interventions aimed at mitigating infectious disease transmission.

Moreover, Pangallo et al. [8] employed large-scale, data-driven agent-based models to examine the coupled dynamics of epidemic spread and economic activity during the COVID-19 pandemic. One notable study developed a granular ABM of the New York metropolitan area, integrating detailed socioeconomic attributes, multilayer contact networks, and mobility-informed interactions to simulate both epidemiological and economic outcomes. The model explicitly captured behavioral responses through a “fear of infection” mechanism that reduced consumption and mobility, demonstrating that spontaneous behavioral change can produce trade-offs comparable to mandated non-pharmaceutical interventions. Simulation results highlighted unequal impacts across income groups, with low-income, customer-facing workers experiencing the strongest health–economy trade-offs. This work underscores the importance of incorporating behavioral adaptation and socioeconomic heterogeneity into epidemic ABMs for policy-relevant analysis.

3 Model Description

3.1 Simulation Platform

The model is implemented using NetLogo (version 6.1.1 or compatible), a multi-agent programmable modeling environment widely used for simulating complex systems.

3.2 Agents

Agents (turtles) represent individuals in the population. Each agent has attributes that define health status, disease stage, daily activity schedule, movement behavior, and economic contribution. Agents operate autonomously and make decisions based on predefined rules. Figure 1 illustrates the complete overview of agents and their interactions within the environment.

3.3 Environment

The environment (patches) represents a simplified city layout consisting of residential areas (homes), workplaces, and shops. Agents move between these locations based on time-dependent routines.

3.4 Time Representation

Simulation time advances in discrete steps called ticks. Each tick represents one hour of real-world time, allowing daily routines and curfews to be modeled explicitly.

4 Agent Behavior and Daily Routines

Each agent follows a daily routine that includes leaving home during wake-up hours, traveling to work for a specified number of hours, visiting shops for shopping activities, returning home, and remaining indoors during curfew hours.

The duration and timing of these activities are controlled by user-defined parameters. These routines directly influence the frequency and duration of interactions between agents, which in turn affects virus transmission. Human movement is therefore a primary driver of infection dynamics in the model.

5 Disease Modeling

5.1 Disease Stages

Once infected, an agent progresses through fixed disease stages: incubation stage, contagious stage, and symptomatic stage. The duration of each stage is defined by fixed parameters and remains constant throughout the simulation.

5.2 Infection Mechanism

Virus transmission occurs through local interactions only. When a healthy agent comes into close proximity with an infected agent, infection may occur based on probabilistic rules such as probability of infection, probability of being contagious, and probability of remaining active despite symptoms. There is no global infection rule; all transmission emerges from individual interactions.

6 Policy Intervention Module

The model includes mechanisms to simulate government interventions, such as curfew enforcement restricting movement during certain hours and interval-based work policies

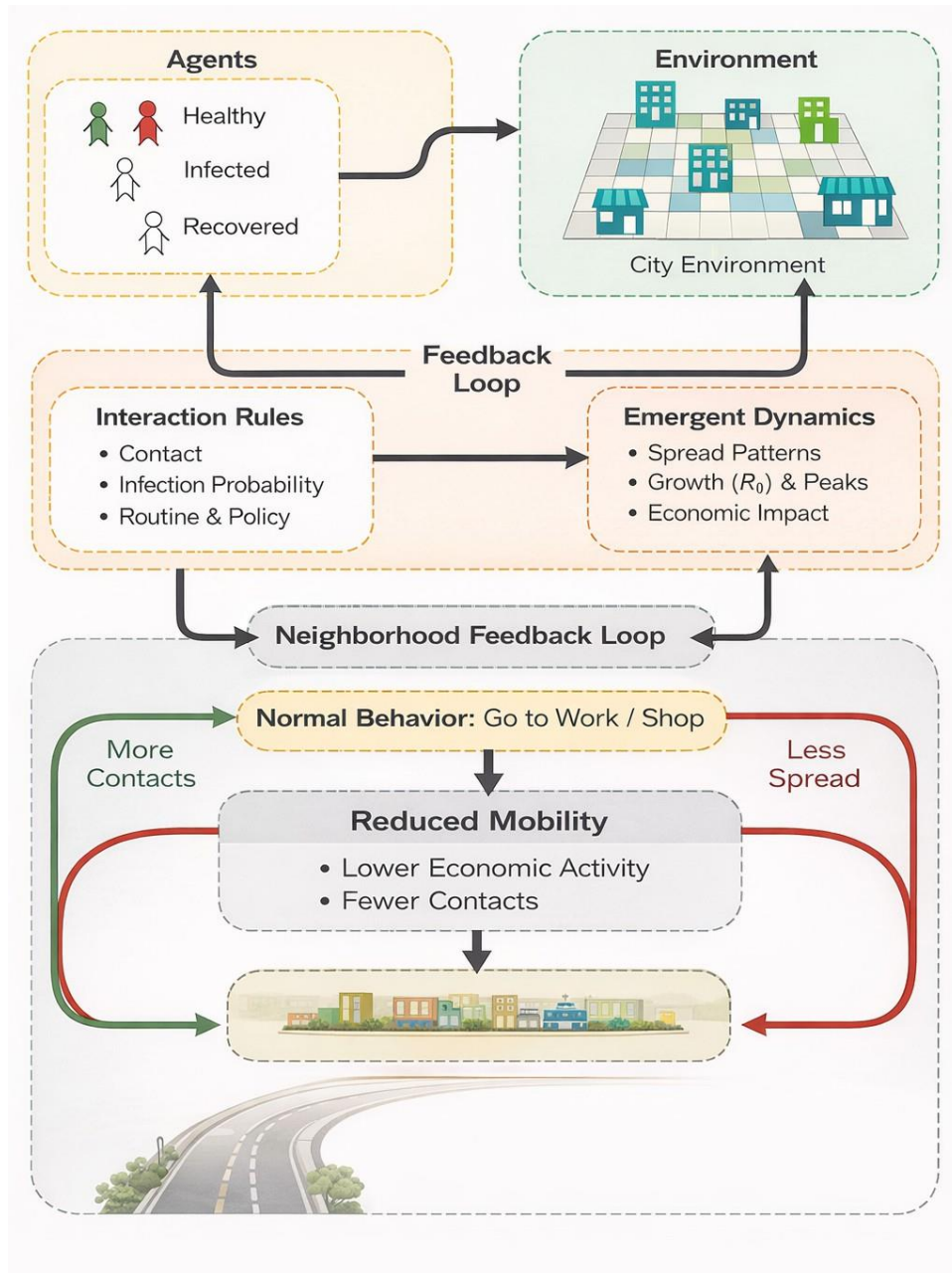


Figure 1: Architecture of the agent-based epidemic model showing autonomous agents interacting within a shared environment, incorporating movement, contact-based infection spread, and adaptive behavioral responses that influence epidemic dynamics

that divide work hours among groups. These policies aim to reduce crowding and interaction frequency. While effective in lowering virus transmission, they also reduce economic activity, enabling the study of policy trade-offs.

7 Economic Modeling

Economic activity in the model is linked to agent movement and participation in work and shopping. Key economic indicators include gross economic productivity and shop-level economic activity. Agents contribute to the economy when they engage in work or shopping activities. Policy restrictions reduce movement, which in turn lowers economic output.

8 Simulation Outputs

The model provides real-time graphical outputs, including distribution of agents across disease stages, number of agents traveling outside their homes, reproduction number (R_0), and economic performance indicators. These outputs allow observation of how changes in behavior and policy affect both health and economic outcomes over time.

9 Results and Observations

Simulation experiments reveal several consistent patterns. Increased human mobility leads to faster virus spread, higher compliance with curfews reduces infection rates, movement by symptomatic agents significantly worsens outbreaks, and policy interventions successfully reduce R_0 . However, strict policies result in reduced economic productivity. These results highlight the non-linear and emergent nature of epidemic dynamics.

10 Discussion

The model demonstrates that virus spread is not solely a biological phenomenon but a socio-behavioral one. Individual decisions regarding movement and activity collectively shape population-level outcomes. Policy interventions introduce a clear trade-off between controlling infection and sustaining economic activity. While the model simplifies real-world conditions, it effectively captures qualitative dynamics and provides valuable insights into epidemic behavior.

11 Limitations

The model has several limitations, including a simplified city layout, fixed disease stage durations, lack of age or risk stratification, and absence of vaccination or immunity loss mechanisms. These limitations are intentional to maintain model clarity and focus on behavioral dynamics.

12 Conclusion

This project presents an Agent-Based Model for simulating virus spread in a population using NetLogo. By modeling individuals as autonomous agents with daily routines and probabilistic infection behavior, the model captures emergent epidemic dynamics driven by local interactions. Simulation results demonstrate the effectiveness of policy interventions in reducing virus spread while highlighting the associated economic costs. The model serves as a powerful educational tool for understanding complex systems and the trade-offs inherent in pandemic management.

13 Future Work

Future extensions could include vaccination strategies, multiple virus variants, age-based or risk-based agent differentiation, and calibration using real epidemiological data. Such enhancements would improve realism and policy relevance.

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