# HIV Transmission Simulation Using NetLogo: The Role of ART and Behavioral Interventions

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***Abstract***

*Human immunodeficiency virus (HIV) remains a significant global health challenge, with gaps in treatment access and adherence hindering epidemic control. This study uses agent-based modeling (ABM) in NetLogo to simulate HIV transmission within a structured population, integrating behavioral, biological, and intervention factors. Our simulations show that antiretroviral therapy (ART) reduces new infections by lowering viral load and slows disease progression, resulting in a stabilized HIV-positive population compared to untreated scenarios. These findings align with clinical data on the benefits of rapid ART initiation. Additionally, the model explores how psychosocial interventions, inspired by art therapy, could improve ART adherence and retention. By enabling detailed scenario testing, this ABM framework offers a powerful tool for policymakers to optimize HIV prevention and treatment strategies. Future work will incorporate reinforcement learning to dynamically refine intervention approaches, further supporting data-driven public health decisions.*

## I. Introduction

Human immunodeficiency virus (HIV) remains a global health challenge, with over 75 million infections and 37 million people currently living with the virus (Deeks et al., 2015). Despite the effectiveness of antiretroviral therapy (ART), access and adherence remain uneven, particularly among vulnerable populations. In the Philippines, HIV cases are rising rapidly, primarily affecting female sex workers (FSWs), men who have sex with men (MSM), and people who inject drugs (PWID) (Restar et al., 2018). However, research has disproportionately focused on behavioral outcomes, leaving gaps in biomedical and structural factors. Molecular studies reveal overlapping viral strains across populations, suggesting interconnected transmission networks (Telan et al., 2013).

Agent-based modeling (ABM) offers a powerful tool for simulating HIV transmission dynamics. Platforms like NetLogo allow researchers to explore virus behavior across varying social and biological conditions. Prior work has applied NetLogo to epidemic spread (Lucatero, 2025), HIV immunodynamics (Ndifon, 2005), and general viral propagation under behavioral constraints (Das, 2021). Even outside biomedical domains, NetLogo has been used to simulate infection-like processes with statistical rigor (Alimboyong, 2021). Reinforcement learning has also been employed to optimize HIV elimination strategies, underscoring the role of dynamic, data-driven modeling in public health decision-making (Khatami & Gopalappa, 2021).

Beyond virology and policy, the lived experience of people with HIV involves psychological and emotional challenges. Art therapy has emerged as a complementary strategy for symptom relief, with Rao et al. (2008) demonstrating its effectiveness in improving physical symptoms. While rapid ART initiation improves clinical outcomes (Ford et al., 2018), emotional and social dimensions often remain unaddressed. Integrating art-based approaches alongside simulation-based modeling offers a more holistic perspective on HIV, supporting both behavioral insight and patient resilience.

This study uses NetLogo to simulate HIV transmission and treatment dynamics while also considering the role of psychosocial interventions such as art therapy. By combining computational modeling with human-centered care strategies, we aim to enhance understanding of HIV spread and identify multi-dimensional approaches to intervention and support.

## II. Methodology

This study employed **agent-based modeling (ABM)** in **NetLogo** to simulate HIV transmission dynamics within a structured population. The model incorporated individual behavioral, biological, and intervention-related factors, enabling comprehensive analysis of disease spread and control strategies.

### Model Design and Parameters

Agents represented individuals with varying risk behaviors—female sex workers (FSWs), men who have sex with men (MSM), people who inject drugs (PWID), and the general population—based on epidemiological data (Restar et al., 2018). Each agent was assigned attributes including HIV status, viral load, immune response dynamics (Ndifon, 2005), and ART adherence. Transmission probability per contact was adjusted according to condom use, viral load, and partner selection rules. The effects of ART were modeled to reduce infectivity and enhance immune function.

### Simulation Environment

The model operated in discrete time steps (days), during which agents dynamically interacted by forming or dissolving connections. Sexual partnerships and needle-sharing behaviors influenced transmission rates within the population.

### Interventions Simulated

Three key interventions were modeled:

- **Antiretroviral Therapy (ART):** Simulated following Ford et al. (2018) to assess the impact of rapid ART initiation on transmission dynamics.

- **Behavioral Interventions:** Modeled changes in condom use rates, partner exchange frequency, and ART adherence.

- **Psychosocial Interventions (Art Therapy Analogy):** Inspired by Rao et al. (2008), psychological support was simulated to improve ART adherence and health-seeking behaviors.

### Model Validation

The model's structure and outputs were cross-validated against frameworks and findings from Lucatero (2025), Das (2021), and Alimboyong (2021). Key metrics—HIV prevalence, incidence of new infections, and treatment uptake—were compared with epidemiological benchmarks. Sensitivity analyses were performed by varying critical parameters to assess model robustness.

### Software and Implementation

Simulations were executed using **NetLogo**, with the BehaviorSpace tool employed for batch runs and parameter sweeps. Output data were exported in CSV format for further statistical analysis.

## III. RESULTS AND DISCUSSION

### Result

The simulation results reveal distinct differences in HIV transmission dynamics under two scenarios: without antiretroviral therapy (ART) and with ART intervention.

### HIV Transmission Without ART

Figure 1 illustrates a clear upward trend in the number of HIV-positive individuals over time, with a corresponding sharp decline in the healthy population. This pattern demonstrates the unchecked spread of the virus in the absence of treatment, leading to increased infection rates and progressive immune system deterioration. The continuous rise signals a potentially exponential outbreak if no interventions are applied.

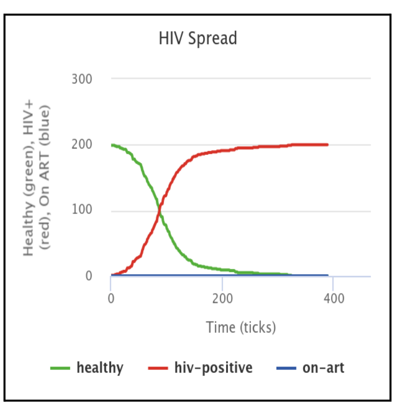


**Figure 1:** HIV transmission over time without ART

### HIV Transmission With ART

In contrast, Figure 2 reveals a substantially lower number of HIV-positive individuals when antiretroviral therapy is introduced. The blue curve represents the population receiving ART, which contributes to slowing disease progression by reducing viral load and infectiousness. This results in fewer new infections and a higher retention of healthy individuals over time, reflecting ART's effectiveness in controlling the epidemic.

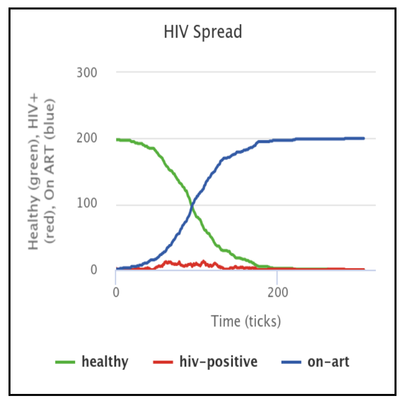


***Figure 2:*** *HIV transmission over time with ART.*

### Key Observations

- **Reduced Infection Rates:** ART effectively lowers HIV transmission by decreasing viral load, reducing the probability of infecting others.
- **Higher Retention of Healthy Individuals:** The ART scenario maintains a larger healthy population compared to the untreated case.
- **Stabilized HIV Population:** The growth curve of HIV-positive

individuals under ART is less steep and approaches a plateau, indicating controlled epidemic progression rather than unchecked exponential growth.

**Discussion**

The simulation outcomes strongly support the well-established importance of antiretroviral therapy (ART) in managing the HIV epidemic. Consistent with Ford et al. (2018), our model demonstrates that rapid initiation of ART substantially reduces new infections and improves overall survival by slowing viral transmission and preserving the healthy population.

In addition, the work of Khatami and Gopalappa (2021), who applied reinforcement learning to optimize ART coverage, aligns with our findings—highlighting the value of data-driven, adaptive strategies for effective epidemic control. Our simulation further underscores that strategic deployment of ART can stabilize HIV prevalence and potentially reverse epidemic growth.

These results emphasize the necessity of integrating timely ART interventions within comprehensive HIV control programs. By modeling both behavioral and biological factors, this approach provides a flexible platform for testing public health policies and optimizing resource allocation.

Looking ahead, the model could be enhanced by incorporating psychosocial interventions inspired by Rao et al. (2008), such as art therapy analogs to improve ART adherence and retention. Integrating these dimensions would offer a more holistic perspective on HIV management, bridging the biological, behavioral, and psychosocial aspects critical to successful treatment outcomes.

## IV. CONCLUSION AND RECOMMENDATION

This study utilized agent-based modeling in NetLogo to simulate HIV transmission dynamics and evaluate the impact of antiretroviral therapy (ART) within a structured population. The results demonstrate that ART significantly reduces HIV transmission, slows disease progression, and helps maintain a larger healthy population. These findings align with empirical evidence, reinforcing the critical role of rapid ART initiation in controlling the HIV epidemic.

Moreover, the study highlights the importance of integrating psychosocial support strategies, such as art therapy-inspired interventions, to improve adherence and retention in care. Incorporating biological, behavioral, and psychosocial factors into simulation models provides a comprehensive framework for evaluating and optimizing HIV prevention and treatment programs.

**Recommendations** for future research and public health practice include:

- **Expanding the simulation model to include psychosocial interventions:** To better capture how support services enhance ART adherence and patient well-being, improving long-term outcomes.

- **Applying reinforcement learning techniques:** To dynamically optimize intervention strategies based on real-time data, ensuring more effective resource allocation and adaptive responses to epidemic changes.

- **Testing combined intervention scenarios:** To identify the most efficient mix of biomedical, behavioral, and psychosocial approaches that maximize epidemic control while considering limited resources.

- **Improving data collection on vulnerable populations:** To refine model accuracy and tailor interventions effectively by capturing detailed epidemiological and behavioral information.

In conclusion, this study underscores that timely and widespread ART deployment remains indispensable for global HIV control. Complementing ART with targeted psychosocial and behavioral interventions, supported by advanced modeling techniques, can substantially enhance the effectiveness of HIV response efforts worldwide.

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